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Airport Solar Photovoltaic Concentrator Project

Phase I - Final Report

(June 1, 1978 to February 28, 1979)

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And

Motorola Government Electronics Division

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APPENDIX 1A
STATEMENT OF WORK
INVERTER EQUIPMENT, PHASE I

STATEMENT-OF-WORK COVERING THE INVERTER MANUFACTURER'S
ENGINEERING EFFORT UNDER PHASE I

1.0 INTRODUCTION

The following Statement-of-Work describes the engineering work needed to adapt present UPS inverter designs to the specific job of converting the DC energy from a large, photovoltaic, concentrator type, solar-collector to the AC energy required by normal 60Hz AC equipment. This power conditioning equipment is to be part of a moderate sized (approximately 500kW) solar power plant being designed for experimental use at the Phoenix, Arizona Airport. Arizona Public Service (APS) is the prime contractor with the United States Department of Energy (DOE) for this demonstration solar power plant. Motorola as a sub-contractor to APS is responsible for the system design and component design and development.

The development program will consist of three phases; Phase I is the engineering study of the entire system and will include a major part of the design effort on individual parts of the system; Phase II is the fabrication, installation and test of the required hardware; and Phase III is operation of the complete power plant to obtain operating data. Phase I of the effort is now underway and is scheduled to be completed in February of 1979.

2.0 THE USE OF UNINTERRUPTIBLE POWER SUPPLY (UPS) COMPONENTS

In order to reduce the necessary design and development effort it is planned to utilize to the fullest extent possible existing hardware that has been designed for UPS systems. However, in several respects the requirements for the solar power system

differ from the requirements for a standard UPS. This makes it necessary to carry out a small amount of engineering work to accomplish the design changes necessary to adapt the UPS to the solar power plant application.

The areas requiring special attention and possible design modification are: (1) The power control system, (2) Electromagnetic interference from the inverter, (3) Operation of the inverter with a wide range of input voltage, (4) Special requirements for the solid state switching circuits, and the associated switch gear and (5) Inverter cooling.

3.0 TENTATIVE SPECIFICATION OF POWER CONDITIONING EQUIPMENT

In order to define the equipment desired Motorola has prepared a tentative specification (Dwg No. 12-P04443L Rev. B) which reflects the present requirements as they are now visualized. This specification is to be used as a guide in the performance of the engineering tasks outlined in paragraph 4.0.

The details of this specification should not be considered to be fixed. However, any appreciable deviations should be discussed with Motorola as the need arises so that the plans can progress together. As a minimum 3 coordination meetings are planned during the course of the development effort; one to be held at Motorola in Phoenix and 2 at the inverter manufacturers plant.

4.0 SPECIFIC ENGINEERING TASKS

4.1 POWER CONTROL SYSTEMS (TASK #1)

In order to effectively utilize the solar, photovoltaic, collector it is necessary to operate the solar collector in such a way that the maximum power is obtained. This can be done by

controlling the voltage and power at the inverter input to properly "match" the solar collector.

The basic design of the control system to do this will be Motorola's responsibility. However, the inverter manufacturer must specify the desired control signals and review and approve the overall design of the peak-power control system. An analysis of the dynamics of the power control loop should be made to determine the stability of the control system.

In addition the system controls for operation in the "load-following" mode must include a method of monitoring the power being used by the dedicated load even when this power is coming from the utility. Consequently a means of monitoring power at the input to the dedicated load must be designed into the special solid-state switch.

Due to the demonstration nature of the solar power plant it is also necessary to monitor the power at the inverter output. A "power out" reading at this point in the system must be supplied for the master control and data acquisition system.

In summary Task #1 includes:

- (a) A review of Motorola's design of the peak power tracking system. This includes the specification of any interface signals and an analysis of the stability of the control loop.
- (b) The design of power monitoring circuits to be used at the input to the dedicated load and the output of the inverter.
- (c) The output of this task will be an engineering report covering the design of the inverter control system that must operate in conjunction with the peak-power tracker and the design of the special power monitoring circuits.

4.2 ELECTROMAGNETIC INTERFERENCE EVALUATION AND CONTROL (TASK #2)

Due to the use of this power conditioning equipment at an operating airport it is essential that the electromagnetic interference (EMI) be held to a low level to prevent interference with any of the many radio services in the area. We believe that the permissible EMI levels can be above the levels permitted by MIL-STD-461; however, a careful investigation is necessary before these levels can be set.

Motorola will be responsible for setting the standards to be met and evaluating existing inverter equipment similar to that planned for the airport installation. If serious problems are found it will be the inverter manufacturer's responsibility to reduce the EMI to acceptable levels.

In summary Task #2 includes:

(a) Technical assistance to enable Motorola personnel to evaluate the EMI from a typical inverter at the manufacturer's plant. (b) The design modifications necessary to reduce the EMI if the levels found in step (a) are too high. (c) The output of this task will be a report covering the design modifications to reduce EMI. If no reduction is needed no report is required.

4.3 MISCELLANEOUS INVERTER DESIGN MODIFICATIONS (TASK #3)

It will be necessary to operate the inverter over a wide range of input voltage from a source having a high internal impedance. This will probably require a large bank of input capacitors and possibly improved voltage control circuits.

The power conditioning equipment must operate in parallel with a utility power grid and this operation must be unattended. This will require an extensive review and possibly some redesign of the fail-safe and automatic features of the equipment.

In summary Task #3 includes:

(a) The finalization of the inverter input voltage characteristics (both nominal and the operating range). An analysis of the factors that effect the allowable operating range of the input voltage shall be included in order to permit a cost trade-off to be made between inverter complexity and the cost of voltage control at the array. The actual choice of the operating voltage range and the possible addition of array voltage control is a joint task of Motorola and the inverter manufacturer.

(b) A review of fail-safe and automatic features of the equipment to show how the inverter can operate unattended.

(c) An engineering report covering the analysis of operating voltage range and the principal modifications that are planned to enable the standard UPS equipment to function properly in this application.

4.4 DESIGN OF THE SPECIAL SWITCHGEAR (TASK #4)

The switchgear necessary to protect the inverter when operating in parallel with the utility and to provide unfailing back-up of the solar power plant when operating in the load following mode is believed to be somewhat different from the standard UPS switchgear. Consequently a certain amount of specially designed switchgear may be required.

The purpose of this task is to design the special switchgear, including the solid-state "back-up" switch described in the specification, that is required. Consideration must be given to the physical separation (approximately 4500 feet) between the inverter and the fast-acting solid-state switch.

The output of this task is part of Task #6 (see paragraph 4.6).

4.5 INVERTER COOLING (TASK #5)

A trade-off must be made by Motorola and APS between inverter cost and the cost of airconditioning equipment for the inverter building. In order to permit this trade-off to be made an estimate of the cost impact of cooling the inverter with outside air as opposed to "room air" is needed.

The output of Task #5 is a report covering the cost increase of cooling the inverter with air ducted in from the outside instead of the usual "room air". Pertinent engineering information such as the CfM of air required will be included in this report.

4.6 SPECIFICATIONS (TASK #6)

One of the principal outputs from Phase I of the development program is a detailed specification of the equipment required for the solar power plant. Task #6 is the preparation of detailed specifications for the two items discussed above (the inverter and the solid state switch).

The output of Task #6 is a complete specification, including the overall physical package, of the inverter and the solid-state switch.

4.7 COST AND SCHEDULE ESTIMATE (TASK #7)

Another required output from Phase I of the development program is a detailed cost and schedule estimate of Phase II of the program.

The purpose of this task is to cover the effort of preparing a detailed estimate of the cost and schedule of Phase II. The output is a detailed estimate of the cost delivery, installation, and check-out of the hardware for Phase II.

5.0 DELIVERY SCHEDULE

The Task 1 report is due December 1. However, a target date of November 10 is set for completion of most of the engineering effort and agreement on the suitability of the approach taken by Motorola for the peak power controller.

The technical assistance to enable Motorola to evaluate EMI from a typical large inverter will be required in October or November. If a report on design modification is necessary under Task 2 this is due on January 1, 1979.

The complete Task 3 report is due December 15. However, the analysis of the factors determining the allowable range of input voltage should be complete by November 1 in order to enable Motorola to study the cost trade-off between inverter complexity and array complexity.

The engineering effort under Task 4 is expected to occur throughout the program and the complete specification is due near the end of the program (under Task #6). However, an early determination of the approximate physical size and weight of the

solid-state "back-up" switch is necessary since this influences the plans for installations at the Airport Terminal Building. A preliminary estimate of the size and weight of the outdoor installation of this switch is due on September 15.

The report under Task 5 covering inverter cooling with outside air is due November 1. Early delivery of this information is necessary to enable the overall cost trade-off to be made and to allow APS to design the airconditioning equipment for the facilities building.

The specifications required under Task 6 are due January 12 for incorporation into the Phase II technical proposal.

The cost and schedule estimate of Task 7 is due on February 2, 1979. Motorola will furnish detailed instructions as to what is to be included in this estimate no later than January 12, 1979.

APPENDIX 1B
SPECIFICATION - INVERTER EQUIPMENT

REVISIONS

REV	DESCRIPTION	DATE	APPROVED
A	UPDATE	7/27/78	
B	MORE FLEXIBLE SWGR. OUTDOOR INSTALLATION	8/10/78	
C	SH.5 - MECH. SWITCH AT LOAD ELIMINATED SH.7 - TYPING ERROR SH.11 & 12 - MODIFIED TABLE I SH.13 - TYPING ERROR	10/25/78	
D	COMPLETE REVISION (ALL PAGE NUMBERS CHANGED)		

[illegible]

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1.0 SCOPE

The scope of this document is to establish minimum requirements for a power conditioning system to be used in a medium-sized solar photovoltaic concentrator system. It shall include reference documents, equipment specifications, and a discussion of basic system operation.

2.0 REFERENCE DOCUMENT

MIL-STD-461A Electromagnetic Interference
Characteristics Requirements for
Equipment, Notice 6, 3 July 1973

MOTOROLA DOCUMENT

00-P04447L Control Plan for Generated Interference
from the Airport Solar Photovoltaic
Concentrator Project

3.0 REQUIREMENTS

3.1 DESCRIPTION OF DESIRED EQUIPMENT

3.1.1 Purpose

The purpose of the power conditioning equipment is to transform the DC energy generated by a large photovoltaic concentrator type, solar array to a standard usable form of AC power. This solar energy recovery system is to be installed at Sky Harbor International Airport in Phoenix, Arizona, and is to be funded by the U.S. Department of Energy (DOE) as an experimental demonstration of a moderate-sized, photovoltaic, solar energy recovery system. The Arizona Public Service Co. (APS) will be the prime contractor and system operator for this experimental system. The basic purpose

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of the project is to obtain experimental data on the actual cost of electrical energy delivered from a moderate-sized photovoltaic collector. The project is named the Airport Solar Photovoltaic Concentrator Project (ASPCP).

3.1.2 System Size and Important Features

The power output of the power conditioning system is 500 kW maximum under optimum operating conditions. Features that are believed to be of primary importance to this demonstration installation are:

(1) Efficiency

Since this is a demonstration installation, it is particularly important to realize the maximum energy return. This will be appreciably effected by the efficiency of the power conditioning equipment. If the efficiency requested in the electrical specification can be improved appreciably by design improvements, these improvements should be planned and the specification upgraded to the improved values.

(2) System Flexibility

It is desired that the system installed be flexible enough to permit it to be operated in several different modes. This will make it possible to obtain actual experimental data to evaluate the energy recovery possibilities in different types of operation.

To provide the maximum flexibility, it is necessary for power conditioning equipment to operate in parallel with the utility

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power grid and on a stand alone basis.

(3) System Reliability

Since this is to be a demonstration installation it will have high "visibility" and must operate reliably. There will be a large number of visitors interested in observing the system in operation. The large percentage of sunlight available in the Central Arizona area makes this feature even more important.

(4) Automation

In order to minimize the cost of the electrical energy delivered to the load, it is essential that this solar power plant be fully automated. It must operate unattended from sunrise to sunset and through days with intermittent cloud cover.

3.1.3 The Use Of Uninterruptible Power Supply (UPS) Components

It is anticipated that all of the principal elements of the power conditioning equipment can be drawn from existing UPS equipment. In some cases, additional development may be necessary, and in some cases, the UPS components can be used without changes. The principal differences between this equipment and standard UPS equipment are:

- (1) The DC input voltage from the solar array will vary over a wide range and the source impedance is high.
- (2) The AC output must operate in parallel with the utility power grid probably most of the time.
- (3) The AC voltage regulation need not be as good as normally required for UPS installation.

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- (4) When operating in parallel with the AC power grid, the output impedance of the UPS can be higher than normal since power surges can be furnished by the power grid.
- (5) The UPS input rectification and battery charging circuitry will not be required since input power from the array is DC and no battery storage is anticipated for the ASPCP.
- (6) Computer control of the inverter system will require special interfacing.
- (7) Logic internal to the inverter may require modification to become compatible with the system requirements.
- (8) The generation of EMI will be a main concern due to the possibility of interference with communication equipment at the airport.

3.2 SYSTEM CONFIGURATION

3.3 PRINCIPAL ELEMENTS OF THE SYSTEM

Figure 1 shows the overall electrical system configuration now planned for the ASPCP. This system includes the following principal elements: (1) A "field" of 59 steerable solar arrays, each one capable of supplying a peak power of 9.6 kW, (2) A three-phase inverter package providing an output of 480 V (line to line) at 60 Hz, (3) A Master Control Unit (MCU) capable of controlling maximum power or load following operation, commanding the inverter to start-up or shutdown, sensing the status of and controlling the

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entire system, and attempting to restart after a fault has taken the solar power-conditioning system off line, (4) A 12.5 kV transmission line (underground cable) and two 750 KVA transformers to carry the power from the array site to the load building, (5) An auxiliary switch package to provide the necessary load and utility interface switching as well as to provide load power sense and undervoltage sense signals, and (6) The dedicated load at the airport.

3.4 MODES OF OPERATION

3.4.1 "Maximum Power" Operation

In the Maximum Power mode of operation the ASPCP is in parallel with the utility grid and both CB2 and CB8 in the auxiliary switch package (Figure 1) are closed (the solid state switch S1 is deactivated). The inverters are sequenced through a start-up procedure and are finally put on line by closing CB3. Load sharing between the utility grid and the Solar Power Conditioning System is accomplished by the internal inverter logic circuits which control both phase and amplitude of the inverter output. In this mode of operation, a maximum power algorithm generated in the MCU is used to control the loading of the array to provide close to the maximum power available from the array by matching the inverter load to the array power. This maximum power is determined by the solar insolation (radiation intensity from the sun) and the ambient temperature of the array. Note that in this mode of operation, all power surges can be absorbed by the utility power grid. The power

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Figure 1 ASPCP DETAILED
SYSTEM BLOCK
DIAGRAM 1 of 3

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FIGURE 1 ASPCP DETAILED SYSTEM
BLOCK DIAGRAM. 2 of 3

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REV C
SHEET 11

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grid has sufficient capacity so that the transient caused by switching the ASPCP on or off at full capacity is not serious; however, a "power walk-in" of several seconds to reach full load should always be provided on inverter start-up. In addition, the inverter logic control should attempt to match load power when switching from maximum power to load following operation to reduce transients.

3.4.2 "Load Following" Operation

In the "dedicated load" or "load following" mode of operation, CB2, CB8 and the solid-state switch (S1) are normally open. In this condition, the load is supplied entirely from the inverter which is not connected to the power grid. The maximum load on the ASPCP system will be approximately 300 kW. In this mode of operation, the standard method of inverter voltage control is used to stabilize the inverter output voltage and the array will always operate at less than its maximum power output. (This makes the load rating of 300 kW maximum necessary). In this mode of operation, the MCU will determine the proper time to switch to the load following mode. This will be done by comparing the load power demand with the array maximum power available. Switch-over is initiated only if the available power exceeds the load demand and the load following mode has been enabled.

In this mode of operation, the solid-state switch (S1) in the auxiliary switch package is necessary to permit instantaneous transfer of the load to the utility power grid when the array

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power can no longer satisfy the demand of the load. This provides utility back-up to the solar power system and makes it possible to supply the load without interruptions.

Change over from "maximum power" to "load following" operation may involve the manual operation of circuit breakers and the visual detection of system status or it may be accomplished automatically by the MCU computer.

3.5 SYSTEM CONTROL

3.5.1 Overview of System

All circuit breakers are motor-operated for remote control by the MCU and in some cases by the inverter logic. The MCU completely controls the entire electrical system except for some basic logic internal to the inverter. This internal logic will be used to protect the inverter by sounding an alarm and possibly initiating inverter shutdown when an unwanted condition exists. Inverter logic controls the internal operation of the inverter to the point where the MCU signals the inverter to start-up, shutdown, operate in voltage control, operate in phase control with the phase being controlled by the MCU, reset an alarm or alarms that have been triggered by a fault, and try to restart the system after a fault has occurred. The MCU will bring the system up through a start-up computer sequence, bring the system down through a shutdown computer sequence, set up operating conditions for maximum power and load following modes, determine which mode of operation to be in, sense status of the entire system, and attempt to reset and restart

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the system once after an unwanted condition has caused partial or total shutdown. The overriding directive is to provide uninterruptible power to the load. Therefore, the status and control of S1, CB2 and CB8 are of prime concern.

3.5.2 Inverter

The inverter must respond to signals from the MCU to 1) change phase angle to control power, 2) change between phase and voltage control, 3) reset all alarms, and 4) turn on or off. In addition, the inverter must regulate its output voltage with respect to a 3 phase, 480 VAC, 60 Hz load voltage signal line, and its output frequency with respect to a 3 phase, 480 VAC, 60 Hz utility feeder line. The inverter must also supply the MCU with alarm status signals, a signal that the inverter output voltage is within specification, and that the output frequency is in sync with the utility. A reverse power monitor at the inverter output should protect the inverter system by opening CB3.

Inverter alarms will be provided to the MCU and should include the following:

1. Cooling fan failure
2. DC ground fault
3. DC overvoltage
4. DC undervoltage
5. AC overvoltage
6. AC undervoltage
7. AC overload

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DRAWN					
ISSUED		SCALE	1B-15	SHEET	15

8. Inverter fuse failure

9. Inverter overtemp

Inverter logic is capable of sensing all of the above conditions and triggering an alarm. In addition to triggering an alarm, conditions 3, 4, 5, 8, and 9, using inverter logic, will shutdown the inverter by opening the inverter output and input breakers and turning the inverter off. The AC undervoltage is adjustable (0% to -50%) and should be set wider (typically -20%) than the system AC undervoltage level (typically -9%).

Inverter logic must be available to detect sudden, rapid decreases of array voltage (due to clouds) in either mode of operation and to decrease inverter phase (power) accordingly, limited only by the inverter losses. In the load following mode, the MCU will revert to the maximum power mode when the array power will no longer support the dedicated load. The system will remain in the maximum power mode when array power returns.

The inverter must also have the logic to match load power before changing from maximum power to the load following mode under normal operating conditions. This is required to reduce switching transients. An analog signal indicating load power will be provided to the inverter logic circuits.

Inverter input and output filtering schemes are required to meet the EMI requirements of MIL-STD-461A for radiation and conduction levels. The "Motorola Control Plan For Generated Interference From The ASPCP" DRAWING No. 00-P04447L shows that the EMI levels

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DRAWN		SCALE		18-16	SHEET 16
ISSUED					

of radiation and conduction per MIL-STD-461A must be met with the exception that the conduction level requirements can be relaxed 10 dB. The inverter input must be filtered to prevent EMI radiation levels from the solar array greater than specified per MIL-STD-461A.

Prior to closing CB3 during start-up, the MCU will maintain the inverter output power at a minimum level (30-40 kW) to supply the inverter losses. In order to reduce transients, the inverter power will be increased to maximum power after CB3 is closed. The inverter logic must instantly put the inverters in phase control upon sensing closure of CB2 and CB8 to protect the inverters from possible utility feedback.

3.5.3 Inverter Switchgear

The inverter switchgear must include 1) a motor-controlled circuit breaker in each inverter input (CB4 and CB6) capable of handling 650 A DC maximum, 2) a motor-controlled circuit breaker in each inverter output (CB5 and CB7) capable of handling 460 A AC maximum, 3) a motor-controlled AC circuit breaker (CB3) tying the inverter load bus to the line transformer, capable of handling 1000 A AC maximum, and 4) the necessary logic for normal UPS operation of the inverter. This logic shall also be capable of the following:

1. Opening the inverter output breaker (CB5 or CB7) and turning the inverter off prior to an inverter input circuit breaker (CB4 or CB6) tripping due to a fault.

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DRAWN					
ISSUED		SCALE	1/8-17	SHEET 17	

2. Allowing CB5 or CB7 to close only when each inverter output voltage is at 480 VAC within specification.
3. Allowing CB5 and CB7 to close only when the inverter outputs are both matched voltage/voltage and phase/phase.
4. Allowing CB3 to close only when the inverter load bus is at 480 VAC within specification, and the frequency is in sync with the utility.
5. Signalling S1, CB2, CB8 to close when any combination of CB3, CB5, CB7 opens abnormally.
6. Providing alarms to the MCU for 1) system AC overvoltage, 2) system AC undervoltage, and 3) system AC overload.

Signals indicating the status of CB3, CB4, CB5, CB6, and CB7 must be available to the MCU. The inverter switchgear circuit breakers (CB3 thru CB7) must also respond to control signals from the MCU.

3.5.4 Auxiliary Switchgear

The Auxiliary Switchgear (Figure 1) shall be comprised of a motor-controlled circuit breaker (CB2) capable of handling 460 A AC in parallel with a solid state switch (S1) capable of handling the peak starting current for a 125 HP induction motor for at least 12 cycles until a circuit breaker can close in parallel. Another motor-controlled AC circuit breaker (CB8) with 460 A AC capability is paralleled with the series arrangement of SW3, SW4,

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DRAWN					
ISSUED		SCALE	1B-18	SHEET	18

and S1/CB2. S1, CB2, and CB8 will have separate control lines for independent operation, but shall normally operate simultaneously.

An undervoltage sensor will signal the MCU and S1 when the load voltage dips below some predetermined level for a period of time. A load power sensor will provide an analog signal to the MCU for control and data acquisition purposes and to the inverter for control purposes.

Three manual knifeblade switches (SW3, SW4, SW5) are required to isolate CB2 and S1 from the load, the utility, and the ASPCP system. SW3 and SW4 will have the same current and voltage requirements as CB2. SW5 must be able to handle 920 A AC.

Signals indicating the status of S1, CB2 and CB8 must be available to the MCU. S1, CB2, CB8 must be capable of being closed by the MCU as well as by the inverter if CB3 opens.

3.6 INTERFACES

Motorola plans to purchase two parts of the system shown in Figure 1. These are: (1) The inverter package (two 375 KVA inverters and inverter switchgear) and (2) The auxiliary switchgear.

3.6.1 Inverter

The inverter interfaces include the DC power input, start and stop control signals, maximum power control signals, an operating mode signal, alarm reset control signals, alarm status signals, inverter signals indicating that the output has reached 480 VAC within specification and that the output circuit breaker (CB5 or CB7) can be closed, a 3 phase, 480 VAC, 60 Hz utility sync

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DRAWN		SCALE		18-19	SHEET 10
ISSUED					

line, and a 3 phase, 480 VAC, 60 Hz load voltage regulation line.. The characteristics of the DC input from the array are detailed in Tables I and II. The DC power input consists of a positive and a negative line with a worst case voltage range from 359 VDC to 670 VDC. Starting and stopping the inverters is accomplished with relays paralleled with pushbuttons on the inverter control panel that momentarily close for at least 0.5 seconds. Maximum power control signals will be supplied on two lines with steady state DC voltage levels of either 12 VDC or ground. Both lines high (12 VDC) commands the inverter to increase phase, both lines low (ground) commands the inverter to decrease phase, and one line high and one line low commands the inverter to hold phase (power) constant. The operating mode signal is a one-line, steady state DC voltage signal that is either 12 VDC or ground. The alarm reset control is a relay in parallel with a pushbutton that will close for at least 0.5 second. Alarm status is brought out using an optical coupler in parallel with a lamp on the inverter instrument panel (one for each of the nine alarms per inverter and the three system alarms). The status of all alarms will be utilized by the MCU as well as displayed on the manual/automatic control and display panel (MACDP). The inverter signal indicating to close the circuit breaker in the inverter output will be a single line, steady-state DC signal, 12 VDC or ground (ground when the output circuit breaker can be closed).. All relays will be located within the inverter cabinet and will^{BE} provided by the inverter manufacturer. All optical couplers will be located at the MACDP

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DRAWN	SCALE	1B-20	SHEET 20	
ISSUED				

interface and will be provided by Motorola.

3.6.2 Inverter Switchgear

The inverter switchgear interface includes control and status of circuit breakers status CB3 thru CB7, reset of system alarms, load power monitor signal, an interlock system between CB4 and CB5 (CB6 and CB7), and an interlock system between CB2/CB8 and CB3/CB5/CB7. Control of the five circuit breakers (CB3 thru CB7) is accomplished with relays in parallel with manual pushbuttons that momentarily close for 0.5 seconds or more. The status of each circuit breaker will be accomplished by auxiliary contacts on the breaker and will require 3 lines/breaker. The status of the three system alarms will be made available by using an optical coupler across each system alarm indicator light. An analog load power signal capable of sourcing 1 mA will be available for the inverter switchgear logic to match the load power. An interlock system between CB3/CB5/CB7 and CB2/CB8/S1 will close CB2, CB8, S1 before CB3 or CB5 or CB7 opens due to a fault or hardware failure. The inverter switchgear manufacturer shall supply this interlocking function. Again, all relays are located within the switchgear enclosure and supplied by the manufacturer. All optical couplers will be located at the MACDP interface and will be provided by Motorola.

3.6.3 The Auxiliary Switchgear

The auxiliary switchgear operates at 480 VAC with conventional 3 ϕ interfaces to the power system, the ASPCP system, and the dedicated load. The other interface circuits include a

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ISSUED		SCALE	1B-21	SHEET	21

3 phase, 480 VAC, 60 Hz utility sync line, a 3 phase, 480 VAC, 60 Hz load voltage regulation line, an undervoltage signal line, a load power sense line, and S1, CB2 and CB8 control and status signals. The utility sync line and load voltage regulation line include fuses. The load undervoltage monitor is a steady state signal that can be either 24 VDC or ground.

The load power sense line is proportional to the power at the load and will source 1 mA at full load power. Independent control of S1, CB2, and CB8 will be accomplished using separate on and off signal lines and individual relays in parallel with each breaker motor (one line for "open" and another for "close"). The relays will close momentarily for at least 0.5 seconds. The status of S1, CB2 and CB8, here again, will be indicated by utilizing a set of auxiliary contacts. All relays will be located within a weatherproof auxiliary switchgear cabinet.

3.7 MACHINE SPECIFICATIONS

3.7.1 Inverter and Inverter Switchgear

3.7.1.1 Electrical Specifications

3.7.1.1.1 Rating

The KVA rating must be sufficient to satisfy the worst-case conditions specified by Tables I and II at a P.F. from 1.0 to 0.8, lag.

3.7.1.1.2 Input DC Voltage

465 V nominal (see Tables I and II for range of voltage).

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DRAWN					
ISSUED		SCALE	1B-22	SHEET	22

3.7.1.1.3 Input Current

The array is current limited (short-circuit current is about 130% of "maximum power" current) and consequently capacitor storage must be included to provide the current pulses required by the inverter.

3.7.1.1.4 Output Voltage

480 V (line to line), 3 ϕ , (4 wire system). Phase voltages must be independently adjustable.

3.7.1.1.5 Voltage Regulation

In "load following" mode, +5 to -7.5% (no-load to full-load). In "max power" operation, the output voltage is determined by the utility grid voltage. This must be considered to vary by $\pm 10\%$.

3.7.1.1.6 Intentional Signal Harmonic Content

5% maximum (total harmonic content), 3% maximum (any single harmonic).

3.7.1.1.7 Frequency Range

It must be possible to synchronize with the power system at a frequency of 60 ± 0.8 Hz. The inverter must always operate in synchronism with the utility grid. If the power grid fails, the inverter must shut down.

3.7.1.1.8 Overload Rating

The inverter must be capable of operating with a 125% overload for 15 minutes. Current limiting shall occur at 150% of nominal and the inverter shall be capable of operating at the current limit for 30 seconds.

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DRAWN	SCALE	1B-23	SHEET 3	
ISSUED				

3.7.1.1.9 Efficiency

The full-load efficiency, as measured from the DC input of the inverter to the AC output of the inverter, shall be 92% or higher. The efficiency at 25% of full-load shall be 82% or higher

3.7.1.1.10 Over-Temperature Protection

Temperature sensors shall be provided to automatically turn the inverter off if operating temperatures exceed the maximum allowable limits.

3.7.1.1.11 Power "Walk-In"

When first brought onto the line in the "maximum power" mode of operation, the load taken by the inverter shall be increased gradually under the control of the maximum power tracker for a period as long as 30 seconds. When brought onto the line in the "load following" mode of operation, the inverter will first be paralleled with the utility at a low power level. Its power output will then be gradually increased under the control of the maximum power tracker and when the inverter power is greater than the dedicated load demand, with the inverter power approximately matching the dedicated load power, the auxiliary switchgear will be opened and the inverter alone will supply the dedicated load.

3.7.1.1.12 Inverter Switchgear

The inverter switchgear shall include input and output circuit breakers for each inverter suitable for interfacing with the solar system and with the utility, and providing adequate

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DRAWN	SCALE	1B-24	SHEET 24	
ISSUED				

TABLE I Estimated Range of Inverter Input Voltage, Current and Power for Various Environmental and Operating Conditions when using Motorola Solar Cells.

MAXIMUM POWER OPERATION

Solar Insolation (kW/m ²)	Ambient Temperature (°C)	Array Voltage (Vdc)	Array Current (Adc)	Inverter Input Power (kW)
1.0	30	478	1244	595
1.0	50	433	1241	539
0.9	5	543	1110	604
0.9	10	511	1156	592
0.5	50	474	638	303
0.5	5	559	650	364

LOAD FOLLOWING OPERATION

Solar Insolation (kW/m ²)	Ambient Temperature (°C)	Array Voltage (Vdc)	Array Current (Adc)	Inverter Input Power (kW)
1.0	30	578	553	320
1.0	30	621	0	0
0.9	5	670	0	0
0.9	5	630	507	320
1.0	50	535	597	320
0.6	50	520	614	320
0.9	5	647	309	200
0.6	50	594	0	0

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DRAWN		SCALE		18-25	SHEET 25
ISSUED					

TABLE II Estimated Range of Inverter Input Voltage, Current and Power for Various Environmental and Operating Conditions when using OCLI Solar Cells.

MAXIMUM POWER OPERATION

Solar Insolation (kW/m ²)	Ambient Temperature (°C)	Array Voltage (Vdc)	Array Current (Adc)	Inverter Input Power (kW)
1.0	30	391	1151	450
1.0	50	359	1121	403
0.9	5	444	1077	479
0.9	10	443	1044	464
0.5	50	426	549	234
0.5	5	511	563	288

LOAD FOLLOWING OPERATION

Solar Insolation (kW/m ²)	Ambient Temperature (°C)	Array Voltage (Vdc)	Array Current (Adc)	Inverter Input Power (kW)
1.0	30	503	634	320
1.0	30	588	0	0
0.9	5	642	0	0
0.9	5	565	565	320
1.0	50	453	706	320
0.6	50	412	666	320
0.9	5	599	333	200
0.6	50	568	0	0

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DRAWN		ISSUED	SCALE	1B-26	
				SHEET 26	

protection for the inverter. The circuit breakers (shown in Figure 1) must be sufficiently rated to handle the worst-case conditions specified in Tables I and II at a P.F. from 1.0 to 0.8 lag. Logic circuits for normal UPS operation and logic circuits for photovoltaic system control, as described in Section 3.5, will be mounted within the switchgear.

3.7.1.2 Physical Arrangement

The inverter package shall consist of two inverter cabinets and one inverter switchgear cabinet. Each inverter cabinet shall be a maximum of 92 inches high (85 inches without the cooling fans) and 38 inches deep. Each inverter shall be composed of two 5 foot side-by-side cabinets making the total width 10 feet/inverter. The inverter switchgear shall also be less than 85 inches high and 38 inches deep. It shall be composed of two cabinets totaling 8 foot in width.

The weight of each inverter shall be approximately 7000 lbs and that of the switchgear approximately 3000 lbs.

3.7.2 Auxiliary Switchgear

3.7.2.1 Usage and Physical Arrangement

The auxiliary switchgear of Figure 1 is to provide the capability of operating the system in the load following mode. This switchgear must be located near the load building (approximately 5200 feet from the inverter) and it is to be designed for outdoor installation. It must also be installed on a 6 x 8 foot concrete pad where a 2 x 6 foot area on one side is reserved for electrical conduit lead-ins.

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DRAWN				
ISSUED	SCALE	1B-27	SHEET 7	

The solid-state switch (S1), which is used when changing from the load following mode to the maximum power mode, must be capable of closing very rapidly to supply power to the load when the array can no longer support the load. The auxiliary switchgear shall include circuits that sense the amplitude of the voltage at the load. When this voltage falls below a predetermined "minimum" level, the solid-state switch will automatically revert to the closed condition resulting in parallel operation of the utility and the inverter. When this happens, a signal must be sent to the MCU indicating that the desired load following mode is not possible due to low output voltage. After switchback to the parallel mode of operation, an automatic sequence of operations initiated by an operator must be set in motion to again place the system in the load following mode. Large transient loads which might be caused by the starting of motors will be accomodated by automatic switchback to the parallel mode of operation when the inverter alone cannot maintain the proper line voltage.

Motorized circuit breakers (CB2 and CB8) are to be used in parallel with the solid-state switch (S1) in order to reduce system power losses when the system is in the parallel mode. A mechanical means of disconnecting the entire auxiliary switch from the inverter, the utility, and the load shall be provided using SW3, SW4, and SW5 as shown in Figure 1.

3.7.2.2 Electrical Specifications

- a. Voltage Rating 480V, 3 ϕ , 60 Hz, (4 wire system)

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DRAWN				
ISSUED	SCALE	13-28	SHEET 28	

- b. Efficiency (Solid-State Switch) 99% or greater at full load.
- c. Overload Rating 125% for 15 minutes.
- d. Automatic Back-up Capability The auxiliary switchgear must sense voltage across the dedicated load and if this falls below a preselected level, the solid-state switch must close to provide back-up power from the utility. The transient and overload capability of the solid-state switch must be adequate to provide the starting current for a 125 Hp induction motor (approximately 900 A for at least 0.25 second).
- e. Transfer Characteristics 100 microseconds or less.
- f. Power Monitoring The Auxiliary Switchgear will include the equipment necessary to provide a load power demand reading for the MCU and the inverter control circuits.
- g. Inside Air Temperature The ambient air temperature inside the auxiliary switchgear cabinet will range from 0°C to +52°C.

3.7.3 Automatic Operation

The Master Control Unit (MCU) will generate the commands

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DRAWN		SCALE		1B-29	SHEET 20
ISSUED					

for automatic operation of the system. The MCU will provide input signals to the inverter, and the inverter shall contain the necessary control circuits to automatically start-up, shut-down, or change output power.

Additional inverter control circuits may be included as deemed necessary by the inverter manufacturer to protect the inverter from damage.

3.7.4 Manual Operation

The inverter, inverter switchgear, and auxiliary switchgear shall be capable of manual operation as well as automatic operation.

3.7.5 Environmental Requirements

3.7.5.1 Operating Temperature

In order to make a logical trade-off between air-conditioning cost and inverter cost two alternate cooling methods are being considered.

a. Alternate Number 1

In this approach to inverter cooling, outside air is to be ducted to the air intake, passed through the machine, and exhausted outside the inverter building. Motorola will supply the duct work external to the inverter. The cooling air temperature will vary from a minimum of 2°C to a maximum of 52°C. The air temperature in the inverter room will vary between 18°C minimum and 30°C maximum.

b. Alternate Number 2

In this approach to inverter cooling, room air is used

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ISSUED		SCALE	1B-30	SHEET	30

in the normal fashion. The minimum cooling air temperature will be 18°C and the maximum cooling air temperature will be 32°C.

3.7.5.2 Electromagnetic Interference

Due to operation in an area relatively close to sensitive radio receiving equipment it is essential that the spurious signal output of the power converter be held to a minimum.

Motorola will set up the EMI requirements and make measurements to determine the EMI levels from a standard inverter. The permissible radiation and conduction levels will be per MIL-STD-461A (except that conducted level requirements be relaxed 10 dB) and as described in Motorola specification "Control Plan for Generated Interference from the ASPCP", Drawing No. 00-P04447L.

3.7.6 Instruments and Indicators

3.7.6.1 Instruments (See Figures 2 and 3)

The following instruments shall be provided as part of the Inverter Package:

- a. Inverter Input Voltage (DC)
- b. Inverter Input Current (DC)
- c. Inverter Output Voltage (Line-to-Line)
(Selector Switch for Phases)
- d. Inverter Output Current (Line-to-Line)
(Selector Switch for Phases)
- e. Inverter Frequency

The following instruments shall be provided as part of the Inverter Switchgear Package:

- a. AC Voltage (Line-to-Line)
(Selector Switch for Phases)

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DRAWN		SCALE		1/3 - 3 /	SHEET 31
ISSUED					

- b. AC Current (Line-to-Line)
(Selector Switch for Phases)

3.7.6.2 Indicators (See Figures 2 and 3)

The following indicators shall be provided as part of the Inverter Package:

- a. Status of Nine Inverter Alarms -

Cooling Fan Failure

DC Ground Fault

DC Overvoltage

DC Undervoltage

AC Overvoltage

AC Undervoltage

AC Overload

Inverter Fuse Failure

Inverter Overtemperature

- b. Mode of Operation (Max Power or Load Following)

- c. Status of Contactor in Inverter Input Inrush Current
Limiter Circuit.

The following indicators shall be provided as part of the Inverter Switchgear Package:

- a. Status of Three System Alarms -

AC Overvoltage

AC Undervoltage

AC Overload

- b. Status of all Circuit Breakers Within the Switchgear
Enclosure.

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DRAWN					
ISSUED		SCALE	1B-32	SHEET	32

FIGURE 2
INVERTER CONTROL PANEL

- INDICATOR ONLY
- ILLUMINATED CONTROL

32
(REF)

○ INDICATOR ONLY

○ ILLUMINATED CONTROL

TYPICAL SYSTEM CONTROL PANEL

FIGURE 3

4.0 QUALITY ASSURANCE PROVISIONS

4.1 QUALIFICATION

Qualification is not required, however, the supplier shall provide data or other evidence acceptable to Motorola that the equipment will be capable of operation without degradation in the environments peculiar to the geographic location of end use. Outdoor temperatures and heavy precipitation should be particularly addressed.

4.2 ACCEPTANCE INSPECTION AND TESTING

The supplier is responsible for all inspections and testing performed both at the point of manufacture and at the installation site. Motorola shall have the right to participate in all inspections and tests performed at the supplier's facility and the installation site.

4.2.1 Inspection and Test Plans

The supplier shall prepare and submit to Motorola for approval a formal inspection and test plan identifying the points in manufacture (and/or installation) where the inspections and tests are to take place. This plan may take the form of a flow chart.

4.2.2 Visual Inspection Criteria

The supplier shall provide to Motorola for approval a copy of the visual/mechanical accept/reject criteria proposed for use on this program. It shall address itself, but not be limited to, type and adequacy of connections, torquing requirements where

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DRAWN		SCALE		18-35	SHEET 35
ISSUED					

applicable, contamination, (flux residue, corrosion, foreign material, etc.) and safety provisions.

4.2.3 Acceptance Testing Procedures

The supplier shall prepare and submit to Motorola for approval, factory and installation site acceptance test procedures. These procedures shall include a list of test equipment to be used and should indicate manufacturer, model number, and accuracy.

4.2.4 Acceptance Test Data Sheets

Acceptance test data sheets shall be prepared. These sheets should list tests by paragraph number of the test procedure and provide space for actual recorded data and the specification limits. The test data document may be a part of the test procedure or a separate document. The test data document must be supplied with the test procedure for Motorola approval prior to use.

4.3 TEST EQUIPMENT, TYPE AND CALIBRATION

Wherever feasible, test equipment used in the performance of acceptance tests shall have an accuracy equal to or better than ten times the applicable parameter tolerance. Calibration of equipment utilized for acceptance testing shall be in current calibration, and have evidence of certification from an accredited laboratory whose standards have traceability to the National Bureau of Standards.

4.4 NOTIFICATION OF ACCEPTANCE INSPECTIONS AND TESTS

Pursuant to paragraph 4.2 herein, Motorola is to be notified a minimum of three working days in advance of all

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ISSUED		SCALE	18-36	SHEET	36

Acceptance inspections and tests.

4.5 DATA

Two copies of all inspection history and test data shall accompany delivery of the end product.

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REV

SCALE

18-37

SHEET

37

APPENDIX 1C
DESCRIPTION OF INVERTER OPERATION

2750 WEST LOMITA BOULEVARD

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TORRANCE, CALIFORNIA 90501

(213) 325-5040 TELEX 67-7228

1 March 1979

Motorola, Incorporated
Government Electronics Division
8201 East McDowell Road
Post Office Box 1417
Scottsdale, Arizona 85252

Gentlemen:

In context with the Task I requirement, this write-up presents the basic control scheme of the power inverters as they are used in Teledyne Inet's UPS systems and further the modified control scheme for operating the inverters in parallel with the utility is also discussed.

The overall system as discussed in the other parts of the project, has two 375 KVA inverters operating in parallel through inverter switchgear with the switchgear control logic but each inverter functions independently.

The attached Figures 1 and 2 indicate how the output voltage is developed and controlled. The quasi generator part of the control circuit synthesizes the basic 60 Hz rectangular waveform. This in turn controls the switching of power SCRs in the inverter bridge.

In effect the available DC power is applied to the primary side of the output transformer in the rectangular wave shape in both directions. After going through the power filters on the secondary side of the output transformer (not shown in the figures) 60 Hz sine wave voltage is made available to the load.

The magnitude of the output sine wave is controlled by changing the pulse width of rectangular wave generated by the quasi generator. For regulating the output voltage, continuous feedback is applied into the quasi generator by the voltage regulator.

The crystal generator block in Figure 1 develops the high frequency reference which is used to generate 60 Hz waveform. Generally the inverter output waveform is maintained in a certain phase relationship to the utility voltage and for that purpose a phase reference is fed into the crystal generator part of the circuit.

The current limit block shown in Figure 1 is for protective reason. In case of an excessive current flow sensed on the output of the inverter bridge, a fast control action is applied to narrow the width of quasi generator waveform. Thus, reducing power flow into the fault.

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1 March 1979
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In Figure 3, the proposed control scheme shows the modifications for running the inverter output either in load following mode or parallel mode.

In load following mode of operation, the inverter would operate essentially the same way as described in Figure 1. As long as the load demand does not exceed the available DC power, and the DC voltage remains within the limits, the inverter will function regulating the output voltage with variation of load power.

In the parallel mode of operation, the load will be fed jointly by the inverter and the utility grid. The excess power from the inverter will be available to the grid. The main assumption is that when the utility grid is connected to the load, the inverters have no control over the voltage. The only control for delivering power is to advance the phase of the internal voltage of the inverter (derived through Fundamental Filter) with respect to the utility voltage.

The variation of power flow from inverter and the effect of different parameters will be demonstrated in a separate write-up.

The parallel mode phase lead control block in Figure 3, continuously receives signal from the peak power (or max power) tracking control in conjunction with the solar array, such that the inverter output power has to be decreased or increased. As explained earlier, this would require adjusting the phase lead of the inverter with respect to the utility.

The outcome of the parallel mode control block is adjusted phase ref, which through quasi generator will make the phase lead of inverter vary and thus change its power output.

To start the system or to shut it down, the inverters will be operated in parallel with the utility. Before shut down, each inverter output will be powered down from 250 KW to about 20 KW before opening the inverter output circuit breakers. Thus there will be the least amount of transient.

In the case of sudden cloud over of the solar array which may collapse the DC bus voltage suddenly, it is planned to effect the phase lead to limit the power output.

In going from parallel mode of operation to load following mode of operation, there would have to be certain amount of delay controlled by the mode transition delay block shown in Figure 3. The idea is to match the output of inverter with the power drawn by the load and then open the circuit breaker from the utility side.

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Scottsdale, Arizona 85252

1 March 1979
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The effectiveness of the current limit and voltage regulation controls would be scaled differently during the parallel mode of operation and thus those signals are routed through so called mode adjustment block.

In general, the modifications per Figure 3 are such that the basic configuration of the inverter design is not altered. None of the additional controls require particularly fast response (faster than 10 cycles) and thus no stability problem is anticipated.

This write-up merely outlines the proposed control scheme. It is believed that detail design work will be followed in Phase II of the project.

Very truly yours,

N. Sharma

N. Sharma
Project Engineer

NS:jrm

Attachments

cc: Bob Sanders, Motorola
G. Husa, Motorola

FIG 1

FIG 2

1C-5

FIG 3

TELETYPE
INET

2750 WEST LOWME ABOULEARD

P.O. BOX 2343

TOPPAME CALIFORNIA 91111

(213) 325-4115 TELETYPE 411204

13 December 1978

Motorola, Incorporated
Government Electronics Division
8201 East McDowell Road
Scottsdale, Arizona 85252

Attention: Bob Sanders

Subject: Motorola 12-P04443L, Task 2

Dear Sir:

This is to confirm our understanding so far, in context with the EMI suppression requirement for the 375 KVA inverter modules, in consideration for your solar project.

As you indicated to us, that based on your D. Awerkamp's study of our 100 KVA converter module's EMI test results, it would be necessary to provide similar filters on these 375 KVA inverters.

It was discussed that we cannot guarantee compliance to MIL-STD-461. We do have EMI filters designed for 375 KVA converters which can be applied in this application.

The configuration of EMI filter on the AC output end of the inverter would be essentially the same as indicated per Figure 3 of the test data submitted to you. The output EMI filter for 375 KVA inverter in this application can be conveniently located in the lower part of the right hand side cabinet of the inverter module.

The filter traps for the DC input side of the inverter would have to be located in the inverter switchgear cabinet, right at the very input to CB4 and CB6. Iron cores used on each of the two +ve and -ve feed to the CB4 and CB6 can be easily accommodated in the DC section of the inverter switchgear.

The assembly details for these filters can be worked out in the following stages of our efforts.

Very truly yours,

N. Sharma
N. Sharma
Project Engineer

NS:jrm

cc: R. Brown; R. Lee; J. Weatherman

LOAD
END.

UPS
END.

FILTER No 2
FOR USE IN LOAD POWER LINES

FIGURE 3A
(OF TEST DATA)

FIGURE 3B. INVERTER DC INPUT EMI FILTER CONFIGURATION

PER TELEDYNE INET'S TASK 2 REPORT

13 March 1979

Motorola, Incorporated
Government Electronics Division
8201 East McDowell Road
Post Office Box 1417
Scottsdale, Arizona 85252

Gentlemen:

In the Task I (Motorola 12-PO4443L) related write-up of March 1, 1979, the basic control scheme of the power inverter was explained and the modifications required for operating the inverters in parallel mode with the APS grid were discussed.

For the load following mode of operation, the inverters would be operated essentially the same way as in UPS systems. The output voltage is tightly regulated with varying load conditions.

In the parallel mode, with the output of inverter system in parallel with the utility, the inverters would not have the same control on voltage regulation. To control the amount of power output from the inverter, the internal phase angle reference as well as the internal voltage would have to be varied.

For determining the variation of power flow from the inverter, a single line representation is considered per Figure 1. Only one inverter will be considered for further discussion. T1 and T2 are the 500 KVA transformers. TG is the 1500 KVA transformer feeding from the grid.

In the single phase equivalent representation per Figure 2, XT represents the combined impedance of T1 and T2. XG is for the grid transformer TG. These power transformers will be considered at 5 percent impedance on their base KVA reference. X(IN) is the series reactance of the inverter transformer about 25 percent on 375 KVA base. XS is the shunt reactance or so called air gap reactance of the inverter transformer at 400 percent. X(C) is single phase equivalent of $18 \times 55 \mu\text{F}$ capacitors connected between line to line across three phases of inverter output. Z(L) represents the load. E(G) is the grid reference voltage. E(IN) is the internal voltage of the inverter.

Considering all the quantities at 375 KVA base and 480 volts base voltage, the circuit on per unit basis looks as seen in Figure 3. It can be seen very easily that because of relatively negligible impedance between the load node and the utility, the load voltage will be predominantly controlled by the grid.

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13 March 1979
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Ignoring the impedance $X(G)$, Figure 4 shows further simplified circuit. For calculation of current or power delivered by the inverter to the load $Z(L)$ as shown in Figure 2, three loop equations are formulated as below.

$$[X(IN)][I1] + Z(S)[I1 - I2] = E(IN)$$

$$Z(S)[I2 - I1] + [X(T)][I2] + Z(L)[I2 + I3] = 0$$

$$[X(G)][I3] + Z(L)[I2 + I3] = E(G)$$

$Z(S)$ is parallel combination of $X(S)$ and $X(C)$

Simultaneous solution of above equations, neglecting $X(G)$ yields

$$I2 = \frac{E(IN) - [B][E(G)]}{A}$$

$$\text{where } A = [X(IN) + Z(S)][1 + X(T)/Z(S)] - Z(S)$$

$$B = [1 + X(IN)/Z(S)]$$

Tables I and II show the results of calculation for the two cases of inverter impedance $X(IN)$ at 0.25 p.u. and 0.50 p.u. Also, the calculation assumes that the grid voltage $E(G)$ is the reference voltage at 1.0 p.u. The power delivered by the inverter is calculated per the real part of complex expression below.

$$P = \text{Rel}[E(G)*I2]$$

Both the tables record the power and the current from the inverter. It can be seen that with the internal phase angle of the inverter -ve, power flow out of the inverter is also -ve. The results suggest that within 3 to 15 degrees phase angle advance the full 0 to 250 KW range of each inverter can be covered.

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Scottsdale, Arizona 85252

13 March 1979
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As stated earlier, the analysis carried out above makes simplifying assumptions. However, we have a technique for estimation of power flow for the system and it is believed that we have some guidelines for designing limits on the control logic so that dangerous power flow conditions can be avoided.

Very truly yours,

N. Sharma
N. Sharma
Project Engineer

NS:jrm

Attachments

FIG 1

FIG 2

FIG 3

FIG 4

10-12

Table I

$X(IN) = 0.25 \text{ p.u.}$; Base KW = 375 KW; Base Current 450A

Internal Phase Lead 0 degree	$E(IN) = 0.9 \text{ p.u.}$ Inverter Output		$E(IN) = 1.0 \text{ p.u.}$ Inverter Output	
	Power	Current	Power	Current
-15°	-.717	.819 $\angle 150^\circ$	-.796	.802 $\angle 173^\circ$
-5°	-.2414	.395 $\angle 127^\circ$	-.268	.268 $\angle 175^\circ$
0°	0.0	.303 $\angle 90^\circ$	0.0	.005 $\angle 90^\circ$
3°	.145	.339 $\angle 64^\circ$	.161	.161 $\angle 0^\circ$
6°	.289	.430 $\angle 47^\circ$	.321	.321 $\angle 2^\circ$
9°	.433	.549 $\angle 30^\circ$	.481	.482 $\angle 4^\circ$
12°	.576	.681 $\angle 32^\circ$	.64	.643 $\angle 6^\circ$
15°	.717	.819 $\angle 29^\circ$	.796	.802 $\angle 7^\circ$
30°	1.385	1.54 $\angle 26^\circ$	1.539	1.592 $\angle 15^\circ$

TABLE II

$X(IN) = 0.50 \text{ p.u.}$; Base KW = 375 KW; Base Current = 450A

Internal Phase Lead 0 degree	E(IN) = 0.9 p.u. Inverter Output		E(IN) = 1.0 p.u. Inverter Output	
	Power	Current	Power	Current
-15°	-.405	.462 $\angle 150^\circ$	-.450	.453 $\angle 173^\circ$
-5°	-.136	.221 $\angle 127^\circ$	-.151	.151 $\angle 180^\circ$
0°	0	.168 $\angle 90^\circ$	0	.005 $\angle -90^\circ$
3°	.082	.189 $\angle 64^\circ$	.091	.091 $\angle 0^\circ$
6°	.163	.241 $\angle 47^\circ$	.181	.181 $\angle 2^\circ$
9°	.247	.308 $\angle 37^\circ$	.272	.272 $\angle 3^\circ$
12°	.325	.383 $\angle 32^\circ$	.361	.363 $\angle 5^\circ$
15°	.405	.462 $\angle 28^\circ$	.450	.453 $\angle 7^\circ$
30°	.782	.809 $\angle 26^\circ$	.869	.899 $\angle 15^\circ$

INET

2750 WEST LOWE AVENUE

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FOURTH AVENUE, SCOTTSDALE, ARIZONA

(213) 325-5050 TELE 67-7228

5 December 1978

Motorola, Incorporated
Government Electronics Division
8201 East McDowell Road
Scottsdale, Arizona 85252

Attention: Bob Sanders

Subject: Motorola 12-P04443L, Task 4

Dear Sir:

The Task 4 requirement of the above pertains to the considerations of the auxiliary switching package which is intended to be housed in the outdoor enclosure over the concrete pad which brings in the power cables through conduits from the utility transformer and the step down transformer bringing in the solar power.

The enclosed Sheet 1 of the Installation Drawing 11D2137 reflects this outdoor switchgear with respect to the rest of the system. Note that the drawing has been changed to show another disconnect switch on the solar power side.

The proposed layout of the outdoor switchgear is shown per the enclosed drawing SK113078-1. Note that the outer enclosure covers the conduits bringing in the power cables through concrete pad. Of course the inside cabinet would have to be weatherproof. The main power components of the assembly are shown on the one-line diagram and can be identified as such. The drawing is merely to demonstrate that all the parts can be arranged in a manner to offer most ease of operation. Some of the parts may not be shown in exact proportion to their actual size.

The inner cabinet is divided in two separate sections, each of which can be locked behind its door. The three disconnect switches S3, S4 and S5 are planned in the left section as shown and described in Table 1 of 11D2137. All the busses are behind a safety panel. The warning lights are for indicating if certain bus is live. Two of the three sets of fuses are for protecting wire runs 6(c) and 7(c) per Table 2. The third set of fuses is for the control transformers to power the 120 VAC motor operators on CB2 and CB8 and another CB in the APS metering enclosure.

Motorola, Incorporated
Bob Sanders

5 December 1978
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Both the sets of CTs are 500/5 ratio. The CTs 1-3 are intended to feed another set of 5/0.5 air gap CTs on the logic assembly from where the control wires can be run to inverter end. CT4-6 are for feeding into a two element power transducer. The right hand side cabinet contains motor operated CB2 and CB8, the logic assembly and the static switch S1. The parallel combination of CB2 and CB8 is believed to add to the reliability of the operation. The motor operators typically take about 0.3 second for closing. The solid state static switch S1, which is operated in parallel with CB2, provides uninterrupted transfer of power to the load side. Teledyne Inet's 30D4503-2 (S1), chosen for the application has been proved for more than 1200 KVA switching in UPS applications. Under the extreme case when the 125 HP motor presents a starting inrush estimated at 800 KVA, the static switch can withstand it. Of course, the main consideration is the closing speed of motor operated CB2. Higher the time of operation, more would be the stress on the SCRs of the static switch. Although it does not seem so necessary, but it is pointed out that there are so-called stored energy type (like GE's power break circuit breakers), electrically operated circuit breakers with much faster closing speed, which can be applied for CB2. *3. Closing in load*

The system logic assembly will contain: a) ~~two~~ ^{THREE} 480/120, 4A control transformers for the motor operators; b) ~~two~~ ^{THREE} 24 VDC relays for each of motor operators; c) two separate toggle switches to disable the motor operators, when required; d) two pushbuttons for each of CB2 and CB8 for open and close operations; e) three 5/0.5A, air gap CTs; f) 480 VAC in, two-pole output UV sense relay; g) 24 VDC, 0.5A modular power supply; h) power transducer; i) TB1 and TB2 for 480 VAC control wires for sync sensing and load voltage sensing; j) TB3, terminal board for receiving 24 VDC level control wires from inverter end, for closing S1 and CB2 or CB2 only, for opening CB2, +24 VDC and logic common, etc.; k) TB4 to bring out control wires for inverter end information like status of CB2, UV relay, power transducer signal, parallel sense from air gap CTs. The control scheme would be such that the static switch S1 and CB2 will be operated simultaneously whenever there is UV condition at the load end or when for some reason, CB3 at the inverter end wants to go off the line. (It is understood that S1 will be called to operate only whenever the system is in load following mode. Under normal load following operation when it is decided to go to max power mode, it would be sufficient to close just CB2 without activating S1.) As stated before, CB2 and CB8 will always be operated in parallel. During the maintenance routine, the load can be supplied through CB8 with it's motor operator disabled and the rest of the system can be checked without effecting CB8.

The final design for manufacturing of this switchgear will require more detailed drawings, control and power wiring diagram, point-to-point connection details

INET

Motorola, Incorporated
Bob Sanders

5 December 1978
Page three

for the control wires coming in from the inverter end; however, it is believed that this write-up covers all the aspects of design and operation.

Very truly yours,

N. Sharma

N. Sharma
Project Engineer

NS:jrm

cc: R. Lee
J. Weatherman

Enclosure

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NOTE: "ALARM ROUTINE A" IS IDENTICAL TO "ALARM ROUTINE"
EXCEPT THAT AC U.V. ALARM IS IGNORED.

NOTE: "ALARM ROUTINE A-1" IS IDENTICAL TO "ALARM ROUTINE"
EXCEPT THAT AC U.V. ALARM IS IGNORED.

NOTE: "ALARM ROUTINE A-2" IS IDENTICAL TO "ALARM ROUTINE"
 EXCEPT THAT AC U.V. ALARM IS IGNORED.

APPENDIX 1D
EFFECT OF ARRAY FIELD VOLTAGE VARIATIONS ON
INVERTER DESIGN

TELETYPE UNIT
FBI LOS ANGELES
TELETYPE UNIT
LOS ANGELES CALIFORNIA 90509
(213) 475-6040 TELEX 67-7228

Motorola, Incorporated
Government Electronics Division
8201 East McDowell Road
Scottsdale, Arizona 85252

Reference: Motorola Spec 12-PO4443L

As required in the Task 3 report of the above, the following write-up responds to the DC load/voltage characteristic from the solar array and its implication on the inverter operation and the required modifications.

It has been established earlier in this project that the DC power output from the solar array will be fed into the DC busses of two 375 KVA inverters and the AC outputs from the output transformers of the inverters will feed the load.

The estimated DC voltage from the solar array per Table I (Motorola Spec 12-PO4443L, Revision C), ranges from 359 to 670 VDC under different conditions of loading, temperature and solar insolation. The highest current delivered in the maximum power mode of operation amounts to 640 ADC input to each of the two inverters. This is within the range of the inverter operation as shown above.

The SCRs in the 375 KVA UPS inverter are rated for 1200 volts and thus there is enough safety margin.

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Scottsdale, Arizona 85252

13 November 1978
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The commutation capacitors are rated for 800 VAC. Estimating about a 20 percent overshoot above the DC bus voltage during commutation process, leaves less of a safety margin but is still within its rating. Also, the higher DC voltage will make the charging current pulses into the commutation capacitors higher.

The snubber network capacitors across the SCRs are rated for 1000V and thus do not present a problem.

The filter capacitors are connected in series to get 800 VDC rating. 670 VDC on the caps is considered acceptable since there is no ripple voltage. However, unlike the UPS mode of operation where DC voltage across the input to inverter builds up gradually in this application, the capacitors will see 670 VDC instantly and initially there will be a heavy inrush, which is not desirable.

It must be understood that although the operation of the components of the inverter bridge seems within their rating, even at the higher DC voltage up to 670 VDC, there is no prior experience of working at such DC voltage level. Thus any such arrangement of solar array to reduce the high end voltage will be favored.

In conclusion, the present 375 KVA design will require the following modifications to be more compatible with the solar array characteristics per Revision C.

- a. Addition of inrush limit resistor on the DC power input line, such that before input circuit breakers are closed, the initial charging current into the filter capacitors would be limited by this power resistor. Upon sensing the completion of charging, this series resistor can be shorted by a series combination of SCR and contactor, then the input circuit breaker can be closed.

Similar arrangements have been used in UPS equipment to limit inrush current into the input transformer. However, in this application, because of DC current, the contactor would be subjected to severe arcing at times and which would cause its deterioration over long use.

It will be necessary to use some interlocks in the control scheme to make sure that the input circuit breaker is turned on, only after a limiting resistor has been placed in the series path.

- b. As for the commutation capacitors, instead of 37.5 μ F (800 VAC), 25 μ F 900 VAC rated capacitors can be used in the same space available in the inverter drawers. With the reduced commutation capacitance, the inrush pulses will be less but we will lose commutation capability. It is estimated that at the maximum power of 250 KW required from one of the two inverters, there will be no problem.

INET

Motorola, Incorporated
Scottsdale, Arizona 85252

13 November 1978
Page three

It will be proper to point out here that the overload rating spec per 3.1.h may have to be limited to 110 percent for 15 minutes in the light of the above.

Also, it will be reasonable to have current limiting in the inverters at 130 percent because the solar array is limited to 130 percent of its rating.

- c. It is also felt that the addition of series inductors on the DC input lines to each inverter would not only help reduce the inrush current into the filter caps, but also reduce the conducted noise feeding back into the solar array field. These filter inductors can be placed in the input cabinet which will otherwise be empty.

It is believed that this letter has covered the review of inverter operation from the standpoint of its major components, rating. The analysis of power flow, the control scheme to adjust power output as required by the maximum power tracker circuit, another scheme to go from one mode to another, etc., are intended to be covered in Task 1 report.

Very truly yours,

N. Sharma

N. Sharma
Project Engineer

NS:jrm

cc: G. Husa
J. Weatherman

FIGURE 1 INVERTER OPERATION

APPENDIX 1E
INVERTER COOLING REQUIREMENTS

1 November 1978

Motorola, Incorporated
Government Electronics Division
8201 East McDowell Road
Scottsdale, Arizona 85252

Gentlemen:

The following discussion is presented in response to Task 5 of the above subject. (Please reference your spec 12-P04443L).

It is assumed that the power conditioning equipment will use Teledyne Inet's two 375 KVA modules.

Since the input power to the system is DC power from the solar array, the input power transformer and the rectifier charger otherwise required for UPS mode operation will not be used. Only 66 percent of UPS mode losses are estimated for the case in consideration.

Combined Load (KW)	0	120	240	360	480	600
Losses (KW)	21.12	22.4 (18.7%)	26.4 (11%)	31.68 (8.8%)	38.28 (8.5%)	46.2 (7.7%)

The above data is primarily intended for determining air-conditioning needs. At 500 KW output from both inverters, 40 KW losses would have to be extracted from the room air. (8%)

Using the formula 1) 1 KW = 3413 BTU/H and 11) 12000 BTU/H = 1 ton of air-conditioning; it is estimated that 11.4 tons of air-conditioning capacity would be required for maintaining room temperature. Of course, the added heat dissipation from other equipment, the inverter room may have and the heat transfer from the outside of building, would have to be accounted for.

The inverter modules in consideration are speced to operate with 20° C to 30° C intake air at the vents in front of the cabinets as shown in the attached drawing. Each inverter would have eight fans discharging 8000 cubic feet per minute from the top of the cabinets.

The Alternate Number 1 per 3.4.1 of the spec suggests removal to hot exhaust air from the inverters and bringing in the outside air into the room directly.

Motorola, Incorporated
Scottsdale, Arizona 85252

1 November 1978
Page two

However, the temperature range of outside air up to 52° C would make this choice unacceptable.

The Alternate Number 2 per 3.4.1 would be more conducive. It is assumed that all the room air is circulated in the close loop and only some make up air is drawn from outside.

It is important to point out that the room air would have to be clean and thus additional air filters will not be needed on the inverter. Without the air filters, cooling of inverters will be more effective.

In conclusion, there is a definite need for air-conditioning. The installed capacity would have to be based on the calculation indicated earlier. However, during the cold weather, the air-conditioning load can be reduced if there is provision to duct out part of hot air from the exhaust and drawing cold air directly from outside.

Very truly yours,

N. Sharma / RSV
N. Sharma
Project Engineer

NS:jrm

Enclosure

cc: J. Weatherman, Teledyne Inet
R. Sanders, Motorola Government Electronics Division

1E-3

Figure 1.

APPENDIX 1F
STATEMENT OF WORK
INVERTER EQUIPMENT - PHASE II & III

SOW

PRDA 35 - PHASE II

Inverter, Inverter Switchgear, and Auxiliary Switchgear

1.0 INTRODUCTION

The following Statement-of-Work describes the effort required to design, fabricate, and install the inverter, inverter switchgear, and auxiliary switchgear to the specific job of converting the DC energy from a large, photovoltaic, concentrator type, solar collector to the AC energy required by standard 60 Hz AC equipment. This power conditioning equipment is to be part of a 500 peak kW solar power plant being designed for experimental use at the Phoenix Sky Harbor International Airport. Arizona Public Service Company (APS) is the prime contractor with the United States Department of Energy (DOE) for this demonstration solar power plant.

2.0 GENERAL REQUIREMENTS

The effort described herein for Phase II of the Airport Solar Photovoltaic Concentrator Project (ASPCP) will include (1) detailed design finalization and component modification, (2) fabrication and factory test, and (3) on-site installation and test. The design finalization and modification phase will consist of five tasks some of which are specific and others which are broadly defined. Manufacturing will be per the inverter manufacturer's standard procedures with quality assurance meeting the objectives and requirements of MIL-Q-9858A. Equipment definition will be as specified in Motorola specification 12-P04443L,

Rev. C, which reflects all requirements for the ASPCP power conditioning equipment.

3.0 SPECIFIC TASKS

3.1 DESIGN FINALIZATION AND COMPONENT MODIFICATION (TASK #1)

- A. Design and/or modify inverter components to facilitate the large inverter input voltage variation from the solar array. Sense reverse power flow into the inverters and isolate the inverter package from the utility. Checkout of all design modifications should be done at the sub-assembly level.
- B. The input EMI filter of each inverter must be designed to prevent inverter generated EMI from being fed back to the solar arrays and radiated.
- C. The output filter of each inverter must be designed such that permissible EMI levels will be as described in MIL-STD-461A pertaining to radiated and conducted interference with the conducted levels relaxed 10 dB. The Motorola "Control Plan for Generated Interference from the ASPCP", drawing 00-P04447L also offers pertinent information relating to EMI requirements. Checkout of all design modifications should be done at the sub-assembly level.
- D. Logic circuitry internal to the inverter, inverter switchgear, and auxiliary switchgear must be designed and/or modified to include the following non-standard UPS logic:

1. Sense dedicated load undervoltage and reconnect utility.
2. Match inverter to load power when switching from maximum power to load following mode.
3. Allow for inverter ϕ -control from an external computer source programmed with a "maximum power" algorithm.
4. Detect sudden and rapid decreases of solar array voltage while in the load following or maximum power mode and decrease inverter ϕ accordingly.
5. Maintain low inverter output power (30-40 kW) prior to closing CB3 and putting the inverter load bus on line.
6. Reconnect utility if the inverter switchgear output breaker opens when in the load following mode.

Check out all designs or modifications for customer specification compliance.

- E. Design interface of inverter, inverter switchgear and auxiliary switchgear for compatibility with the ASPCP system as outlined in Motorola inverter specification number 12-P04443L, Rev. C. Checkout must be performed on all sub-assemblies prior to system assembly.

3.2 FABRICATION AND FACTORY TEST (TASK #2)

Fabrication of all power conditioning equipment including all switching assemblies must be in accordance with good manufacturing practice and must comply with Motorola's inverter specification #12-P04443L, Rev. C. Testing at various intervals throughout the fabrication process must show compliance with Motorola specifications. Prior to shipment, a final test and demonstration must be performed to show compliance at a system level.

3.3 ON-SITE INSTALLATION AND TEST (TASK #3)

The inverter manufacturer will be responsible for shipment to the site and installation of procured equipment. Sufficient on-site testing will be performed by the manufacturer to show that all Motorola specifications have been met.

4.0 SCHEDULE OF ACTIVITY

A total of eight months will be required to procure the power conditioning equipment, starting from the date of DOE funding of the project to the date of having an installed, operating system. A detailed PERT of scheduled activities is attached.

LYR	REL. DATE	DCN NO./DESCRIPTION	DATE	BY
A	12-14-78	15000 CDS en

TABLE 1 SWGR DEFINITION					
CB DESIGNATION	FUNCTION	VOLTAGE RATING	POLES	FRAME/TRIP	NOTES
SW1	MAIN DISCONNECT	670 VDC	2	1600 AF	MANUAL SWITCH BY APS, INDOOR
CB4, 6	INV INPUT	670 VDC	SEE NOTE	800/800	3 POLE MOLDED CASE, 3 POLES IN +VE LBD SHUNT TRIP 24 VDC, AUX 2A-2B, MTC OP
CB5, 7	INV OUTPUT	480 VAC	3	600/900	MOLDED CASE, MOT. OP. 120 VAC SHUNT TRIP 24 VDC, AUX 2A-2B
CB3	SYS. OUTPUT	480 VAC	3	1200/1000	MOLDED CASE, MOT. OP. 120 VAC SHUNT TRIP 24 VDC, AUX 2A-2B
SW2	AC DISCONNECT	480 VAC	3	1200 AF	MANUAL SWITCH BY APS, INDOOR
CB2, 8	AUX SWITCH	480 VAC	3	600/600	MOLDED CASE MOT. OP. 120 VAC SHUNT TRIP 120 VAC, AUX 2A-2B
SI	STATIC SWITCH	480 VAC	3	800 A/100	INET 3004503-2, 480 VAC, 800A (A SEC. RATING)
SW3, 4	GRID/LOAD	480 VAC	3	600 F	BOLT SWITCH, TYPE T, 600V, 600A 3Ø
SW5	SOLAR SIDE ISOLATION	480 VAC	3	800 F	BOLT SWITCH, L367-X3, 600V, 800A

TABLE 2 CONTROL AND POWER WIRING		
RUN #	NO. OF WIRES	NOTES
1 (P)	2 WIRES	MAIN DC POWER IN
2 (P)	3 WIRES	AC POWER OUT
3		
4		
5 (C)	4 WIRES, 10 AWG	480 VAC GRID SYNC SIG. AND CONTROL PWR 480 VAC LAMP, TWISTED, GROUND SHIELD
6 (C)	4 WIRES, 12 AWG	LOAD VOLTAGE REGULATOR SIGNAL 480 VAC, 0.3A TWISTED, GROUND SHIELD
7 (C)	2 WIRES, 18 AWG	24 VDC, CONTROL WIRE TO AND FROM AUX CONT. PNL
8 (C)	PWR MOTOROLA	FOR MCU INTERFACE MAIN PWR TRACKER ETC.
9 (C)	AS REQD.	120 VAC 15A FOR MOT. OPERATION CONT. PWR SUPPLY
10		
11		
12		
13 (C)	2 WIRES, 18 AWG	FOR LOAD FOLLOWING AND DETERMINING SIGNAL ALSO AVAILABLE FOR INVERTER

NOTE: NOT FOR CONSTRUCTION
FOR PLANNING ONLY

REV	BY	DESCRIPTION	CODE	PART NO.	SPEC	DATE
LIST OF MATERIAL						
TELEDYNE INET						
11-13-78						
NPL 11-14-78						
D 90911						
11D2137

CONVERTER
 WT. OF LEFT CABINET APPROX 7000 lbs.
 WT. OF RIGHT CABINET 5000 lbs.
 WT. OF SWGR CABINET 3000 lbs.
 MINIMUM CLEARANCE REQ'D:
 IN THE FRONT 4'
 SIDES & REAR 1'
 ON THE TOP 2'

① CONV. RT. CABINET WOULD REQ. STUD
 MOUNTINGS ON THE FLOOR.

NOTES:

NOTE - THIS DWG. NOT FOR CONSTRUCTION,
 FOR PLANNING ONLY.

REV	SYN	DESCRIPTION	CODE	PART NO.	SPEC	MATERIAL	UNIT

REV	SYN	DESCRIPTION	CODE	PART NO.	SPEC	MATERIAL	UNIT

LIST OF MATERIAL							
TELEDYNE INET							
INSTALLATION DWG.							
D 90911 11D2137							

APPENDIX 2
EMI CONTROL PLAN - ASPCP

V

* APPLICATION		REVISIONS			
NEXT ASSEMBLY	USED ON	LTR	DESCRIPTION	DATE	APPROVED

ASTERISK INDICATES DATA WHICH IS NONMANDATORY - FOR INFORMATION ONLY.

PROJECT CONTROL	LTR	DESCRIPTION	DATE	APPROVED
	—	INITIAL RELEASE	1-29-79	B16120-6

REV	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26			
SHEET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26			
REV STATUS	REV																												
SHEETS	SHEET																												

FOR ASSOCIATED LISTS SEE	
INTERPRET DRAWING IN ACCORDANCE WITH STANDARDS PRESCRIBED BY	
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES AND END USE. FOR TOLERANCES SEE NOTE	DR BY <i>Wm. R. Quisenberry</i> CHK BY <i>[Signature]</i> MFG <i>[Blank]</i> PROJ NO. 6251
MATERIAL:	MOTOROLA INC. / 8201 EAST McDOWELL ROAD Government Electronics Division / POST OFFICE BOX 1417 SCOTTSDALE, ARIZONA 85252
	CONTROL PLAN FOR GENERATED INTERFERENCE FROM THE AIRPORT SOLAR PHOTOVOLTAIC CONCENTRATOR PROJECT
	APPROVED <i>R.L. [Signature]</i> DATE 1-29-79
	APPROVED <i>[Blank]</i> DATE <i>[Blank]</i>
SIZE A	CODE IDENT NO. 94990
SCALE	DWG. NO. 00-P04447L
2-1	SHEET 1 OF 26

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SIZE

A

FSCM NO.

94990

DWG NO.

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REV

DRAWN

ISSUED

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DWG NO.

00-P04447L

REV

-

SCALE

2-3

SHEET

3

0 - PURPOSE

This document comprises the Generated Interference Control Plan for the Airport Solar Photovoltaic Concentrator Project (ASPCP).

0 SCOPE

The scope of this document is to discuss the approach used in determining the ASPCP generated interference requirements, and the design and analyses used in assuring compliance with these requirements.

0 APPLICABLE DOCUMENTS

MIL-STD-461A	Electromagnetic Interference Characteristics Requirements for Equipment, Notice 6, 3 July 1973.
MIL-STD-462	Electromagnetic Interference Characteristics, Measurement Of, Notice 1, 1 August 1968.
Teledyne Inet Document	Test Plan for Electromagnetic Interference Suppression (For 100 KVA UPS).
Teledyne Inet Document	Test Report for 100 KVA UPS, 29 December 1977
Motorola GED Document	Proposal for Airport Solar Photovoltaic Concentrator Project, 13 January 1978
Arizona Public Service/ Motorola GED Document	Environmental Assessment Report, ASPCP, 30 September 1978

MOTOROLA INC. Aircraft Electronics Division MCDOWELL ROAD, P.O. BOX 1417, SCOTTSDALE, ARIZONA 85252	SIZE A	FSCM NO. 94990	DWG NO. 00-P04447L	REV
ED	SCALE	2-Y	SHEET	4

4.0 DESCRIPTION OF EQUIPMENT

4.1 FUNCTION

The ASPCP consists of a solar array for converting sunlight to dc power which in turn is processed by an inverter to 60 Hz power. The necessary control equipment is also included. Figure 1 shows the basic ASPCP system configuration. Figure 2 shows the ASPCP site location relative to the Phoenix Airport.

4.2 ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS

The ASPCP control electronics operate from commercial power and will not be a source of any significant interference signals. Two three-phase power inverters switch the dc power and transform it to ac power superior to commercial quality. Their switching rate occurs at 60 Hz. The rise and fall times of the switching generate high frequency harmonics of 60 Hz. This is a potential source of undesired interference. The inverters are modified 375 KVA Uninterruptible Power Systems (UPS) built by Teledyne Inet.

5.0 TECHNICAL REQUIREMENTS

5.1 GENERAL

The overall intent on this control program is to comply with any existing radiation requirements and specifically not to degrade the performance of any existing systems at or in the near vicinity of the ASPCP site. This program

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ISSUED					

2-6

Figure 1. ASPCP Detailed System Block Diagram
(Sheet 1 of 3)
REV -
00-P04447L
SHEET 6

2-8

Figure 1. ASPCP Detailed System Block Diagram
(Sheet 3 of 3)

REV -
00-P04447L
SHEET 0

REV -
00-P04447L
Sheet 9

Figure 2. ASPCP Location Within The Phoenix Sky Harbor International Airport Complex

has been approached from two directions. The first effort has been to determine if there are any actual requirements. A second effort has been to evaluate the existing ASPCP site environment.

5.2 REQUIREMENTS

5.2.1 Federal Communications Commission (FCC)

The FCC office in Washington, D.C. was contacted (Art Wall on 9/78 and 11/13/78). No specific requirements exist, but reference was made to Parts 15 and 18 of the FCC rules. Part 15.25 deals with incidental radiation devices and Part 18 deals with Industrial, Scientific, and Medical (ISM) equipment. The inverter characteristics are such that it is classified as an incidental radiator and not an ISM equipment. The requirement for an incidental radiator is that it not cause harmful interference. The requirement for miscellaneous ISM is that the radiated level be less than 15 μ V/m at 1000 feet.

A notice was sent out 29 September 1978 on docket 20718. It is proposed in subpart B, 18.112, "Conducted RF Voltage Limits", that allowed levels be set at 1 mV from 10 KHz to 500 KHz and 100 μ V from 500 KHz to 30 MHz.

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DRAWN		SCALE		2-10	SHEET 10
ISSUED					

5.2.2

Federal Aviation Administration (FAA)

A contact with the FAA Office (Charles Innes, August 1978) in Washington, D.C. was referred to the Los Angeles office (John Kemper, September 1978). No requirements existed so long as the emissions did not disrupt communications. The office was interested in receiving a copy of our approach and report. A referral to the Phoenix FAA office was suggested for specific frequencies. In this contact (Leo Paquette, 25 October 1978), it was determined that the overall frequency range of interest in airport operations was 100 MHz to 400 MHz, with a few still higher frequencies involved. Table I is extracted from the "Environmental Assessment Report, ASPCP".

5.2.3

Local Power Companies

Personnel at the local (Phoenix area) power companies (Bob Lash and Paul Bolster of SRP, September 1978; Pete Thomas of APS, 13 November 1978) were contacted and no requirements were identified for power generating equipment. For large users, there is a requirement that they not generate emanations causing interference to other users. If so, they are responsible for correcting any problems.

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DRAWN		SCALE		2-11	SHEET 11
ISSUED					

TABLE I

PRINCIPLE RADIO SERVICES AT THE AIRPORT OR IN THE VICINITY OF THE AIRPORT			
DESCRIPTION OF RADIO SERVICE	TYPE OF RADIATION	FREQUENCY (ALL IN MHz)	APP. DISTANCE FROM INV. BLDG. (IN FEET)
Communications; Aircraft to Tower and other Aircraft (Airborne Rec.)	cw (Voice FM Mod)	118-160	Variable Min = 1500
Communications; Tower to Aircraft	cw (Voice FM Mod)	118-160	4000
Airport Radar (ASR-8)	Pulse	2700-2900	5000
Airborne Rec: Glide Path and Localizer Beacon	cw	330	Variable Min = 1500
Airborne Rec: Marker Beacon	cw	75	Variable Min = 1500
Airborne Transponder:	Pulse	1030-1090	Variable Min = 1500
Television Broadcast	cw AM Mod	54-88 174-216 470-890	Variable Min = 2000
FM Broadcast	cw FM Mod	88-108	Variable Min = 1400.
AM Broadcast	cw AM Mod	0.535-1.605	Variable Min = 1400
Citizens Band	cw (Voice FM Mod)	26.9-27.3 462-468	Variable Min = 1400
Radio Range Rec. Equipment (Airborne)	cw	0.326 0.281	Variable Min = 1500

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DRAWN		SCALE		2-12	SHEET 12
ISSUED					

5.2.4

IEEE Energy Committee

The EMC group involved with the IEEE Energy Committee was contacted (A. H. Sullivan, September 1978) to determine if any requirements had been discussed or established for energy generation equipment. There are not any requirements, but there are measurements and data available which indicate the existing ambients on power systems.

5.2.5

Department of Energy

In a letter dated 25 September 1978 (reference AD-662), the Department of Energy indicates that a Solar Power Station is classified as an Industrial, Scientific, and Medical (ISM) device. As such, the inverter should be in compliance with Section 7.10 of the National Telecommunications and Information Administration (NTIA) manual. They request a report providing an analysis of the performance of the inverter relative to these requirements.

5.2.6

Summary of Requirements

There are a number of organizations which have an interest in unwanted or extraneous emissions. The criteria they specify is that these emissions not disrupt or degrade existing system operation. The exception is the Department of Energy which has called out some specific radiated limits for the inverter. The FCC has

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DRAWN		SCALE		2 - / 3	SHEET 13
ISSUED					

some conducted limits under discussion that in the future may apply to this type of equipment. Thus, the analysis in Section 6.0 of this document will evaluate the inverter emanations against the following criteria:

- 1) Will it add to the environment and be a cause of additional interference?
- 2) Will it comply with the NTIA levels specified by the Department of Energy?

5.3 AMBIENT

5.3.1 Conducted

A number of reports are available with the measured ambient levels on power lines. In addition, Motorola has had occasion to make measurements on power lines. This data provides a range of typical levels which will be used to evaluate the significance of the inverter generated levels.

5.3.2 Radiated

Radiated ambient levels vary significantly with location. Measurements were made of the actual levels at the proposed future site of the inverter.

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DRAWN		SCALE		2-14	SHEET 14
ISSUED					

6.0 ANALYSIS

6.1 MEASURED UPS LEVELS

The conducted and radiated emissions from a Teledyne-Inet 100 KVA UPS were measured to the limits of MIL-STD-461A, Notice 6, in accordance with the procedures of MIL-STD-462, Notice 2. In reviewing the theory of operation of the inverters, it was determined that the functional operation of the 375 KVA unit is identical to the 100 KVA unit tested. The switching rate and rise time of the wave shape is the same for the two units. The UPS contains input rectifiers and battery charging circuitry which are not necessary when the input power source is dc. Therefore, for the ASPCP application, this input circuitry will not be present and may reduce the EMI levels. In addition, Motorola GED has requested that Teledyne Inet add a filter to the inverter input to reduce the possibility of inverter generated noise being fed back to the solar arrays and radiated. Thus, the generated emissions of the 375 KVA inverter are predicted to be less than or equivalent to the 100 KVA UPS. The 100 KVA UPS measured data can be used for prediction purposes.

6.2 CONVERSION OF MEASURED LEVELS

The receiver bandwidth used for measuring the UPS radiated emissions was greater than 1.0 kHz. So the 60 Hz harmonics appeared as a broadband signal and is plotted

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DRAWN		SCALE		2-15	SHEET 15
ISSUED					

in Figure 3 as dB μ V/m/MHz. To calculate the amplitude of a single 60 Hz harmonic, a factor of 84.4 dB needs to be subtracted from the graph*. This indicates the level of CW components at a distance of 3 feet from the inverter. This calculated level is plotted as Figure 4. The calculated value at 1000** feet would be 50.5 dB lower than that shown in Figure 4. The measurements are then in units that can be compared to FCC and DOE levels.

6.3 RADIATED REQUIREMENTS

Communications from the U.S. Department of Energy (AD-662 dated 25 September 1978) indicate that a Solar Power Station is classified as an Industrial, Scientific and Medical (ISM) device. Section 7.10 of the National Telecommunications and Information Administration (NTIA) Manual lists the requirements for ISM equipment. The inverter operates with spurious frequencies on other than those designated for ISM equipment and, therefore, is covered under Section 7.10.2 of the NTIA Manual. Under the paragraph entitled "Miscellaneous ISM Equipment" power line filters are required and the radiated level of each spectral line at 1000 feet from the unit must be below 15 μ V/m (23.5 dB μ V/m)

* $20 \log (1 \text{ MHz}/60 \text{ Hz}) = 84.4 \text{ dB}$

** $20 \log (1000/3) = 50.5 \text{ dB}$

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DRAWN					
ISSUED		SCALE	2-16	SHEET	16

MOTOROLA INC.
Government Electronics Division

8701 EAST McDOWELL ROAD SCOTTSDALE ARIZONA

ELECTROMAGNETIC INTERFERENCE

UNIT UNDER TEST 100 KVA UPS With Output EMI Filters

TYPE OF MEASUREMENT Radiated Emissions

TEST BY _____ DATE _____

APPLICABLE SPECIFICATION _____

LINE OR CONDITION Broadband Levels

Frequency

REV -
00-P04447L
SHEET 17

MOTOROLA INC.
Government Electronics Division

8701 EAST McDOWELL ROAD SCOTTSDALE ARIZONA

ELECTROMAGNETIC INTERFERENCE

UNIT UNDER TEST 100 KVA UPS With Output EMI Filters

TYPE OF MEASUREMENT Radiated Emissions

TEST BY _____ DATE _____

APPLICABLE SPECIFICATION _____

LINE OR CONDITION 60 Hz Narrowband Equivalent Levels

As mentioned in paragraph 6.1, measurements were taken in accordance with the procedures of a military specification. Figure 5 shows a comparison of the results vs the military limits.

6.4 EVALUATION OF MEASURED UPS DATA VS NTIA REQUIREMENTS

A comparison of the NTIA requirements with the measured levels shows the generated emissions to be below the requirements, at any distance beyond 6 feet from the UPS. This comparison is plotted as Figure 6.

NTIA Required Level = 23.5 dB μ V/m

Measured Level at 14 kHz = 29.6 dB μ V/m

29.6-23.5=6.1 dB difference

6.1 = 20 log (X/3)

X = 6.0 ft

6.5 EVALUATION OF MEASURED UPS DATA VS SITE AMBIENT

On 30 October 1978, a set of broadband ambient levels were measured at the proposed site of the ASPCP installation. This level is plotted on Figure 7. It will be observed that the existing ambient exceeds the measured UPS values at several frequencies. The worst case difference between the measured UPS emissions and the ambient exists at 400 kHz. Calculations show that at a distance beyond 150 feet from the UPS, the radiation emissions will be below the existing site ambient. This comparison is shown as Figure 8.

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DRAWN		SCALE		2-19	SHEET 19
ISSUED

MOTOROLA INC.
Government Electronics Division

8201 EAST McDOWELL ROAD SCOTTSDALE ARIZONA

ELECTROMAGNETIC INTERFERENCE

UNIT UNDER TEST 100 KVA UPS With Output EMI Filters

TYPE OF MEASUREMENT Radiated Emissions

TEST BY _____ DATE _____

APPLICABLE SPECIFICATION _____

LINE OR CONDITION Comparison of Measured Levels vs Typical Military Limits

Frequency

Figure 5

2-20

REV -
00-P04447L
SHEET 20

MOTOROLA INC.
Government Electronics Division

201 EAST McDOWELL ROAD SCOTTSDALE ARIZONA

ELECTROMAGNETIC INTERFERENCE

UNIT UNDER TEST 100 KVA UPS With Output EMI Filters

TYPE OF MEASUREMENT Radiated Emissions

TEST BY _____ DATE _____

APPLICABLE SPECIFICATION _____

LINE OR CONDITION Comparison of Levels vs NTIA Limits

MOTOROLA INC.
Government Electronics Division

8701 EAST McDOWELL ROAD SCOTTSDALE ARIZONA

ELECTROMAGNETIC INTERFERENCE

UNIT UNDER TEST Ambient at Proposed Site

TYPE OF MEASUREMENT Broadband Radiated

TEST BY R. D. Stoner

DATE 30 October 1978

APPLICABLE SPECIFICATION _____

LINE OR CONDITION Broadband Levels

MOTOROLA INC.
Government Electronics Division

8701 EAST McDOWELL ROAD SCOTTSDALE ARIZONA

ELECTROMAGNETIC INTERFERENCE

UNIT UNDER TEST 100 KVA UPS With Output EMI Filters

TYPE OF MEASUREMENT Radiated Emissions

TEST BY _____ DATE _____

APPLICABLE SPECIFICATION _____

LINE OR CONDITION Comparison of Measured Levels vs Site Ambient

Ambient = 68 dB μ V/m/MHz

Emission level = 102 dB μ V/m/MHz

102-68 = 34 dB difference

34 = 20 log (X/3)

X = 150 feet

6.6 EVALUATION OF CONDUCTED EMISSIONS VS AMBIENT

Another area for analysis is concerned with interference being generated by the inverter which would couple into the power system. A plot of the conducted measurements on a 100 KVA UPS is given as Figure 9. The dashed lines indicate measurements on commercial 60 Hz power lines for comparison. This indicates that at the proposed site, the UPS will not add detectable interference to the line ambient.

7.0 CONCLUSIONS

The analysis shows that if the proposed 375 KVA inverter complies with the radiated requirements of MIL-STD-461A, Notice 6, no interference with existing services is predicted, and no levels above the NTIA requirements are predicted. If the inverter complies with MIL-STD-461A, Notice 6, relaxed by 10 dB, conducted emissions on the power system will not exceed that which is normally present.

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DRAWN		SCALE		2-24	SHEET 24
ISSUED

MOTOROLA INC.
Government Electronics Division

8201 EAST McDOWELL ROAD SCOTTSDALE ARIZONA

ELECTROMAGNETIC INTERFERENCE

UNIT UNDER TEST 100 KVA UPS With Output EMI Filters

TYPE OF MEASUREMENT Broadband Conducted Emissions

TEST BY _____ DATE _____

APPLICABLE SPECIFICATION _____

LINE OR CONDITION Comparison of Measured Levels vs Commercial Power
Line Levels

8.0

RECOMMENDATIONS

It is recommended that the inverter supplied by Teledyne Inet comply with the radiated and conducted emission levels of MIL-STD-461A, Notice 6, with the exception that the conducted emissions limits be relaxed by 10 dB.

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DRAWN		SCALE		2-26	SHEET 26
ISSUED					

APPENDIX 3
ENVIRONMENTAL IMPACT REPORT - ASPCP

APPENDIX 4A
SPECIFICATION - ARRAY FIELD
COMMUNICATIONS EQUIPMENT

Specification - Array Field Communications System

The communications systems shall have the following requirements and specifications:

1. Public Address/Intercom System Speakers - The speakers shall have a frequency response from 200 to 7000 Hz and be capable of handling 30 watts each. At an input power level of 30 watts, each speaker shall deliver a sound pressure level (SPL) of 123 dB (referenced to 0.0002 dyne/cm²) at a distance of four (4) feet on the center-line of its acoustical axis. The speaker shall have a horizontal sound distribution angle of 120° (+60°). The input impedance shall be weatherproofed.

Handset/Speaker Amplifiers - The handset/speaker amplifiers shall be the wall mounted type and be weatherproofed. The amplifier must be capable of delivering 12 watts into a 16 ohm load with less than 5% total harmonic distortion at 1000 Hz. The amplifier shall have a frequency response from 250 to 15,000 Hz ± 1.5 dB. It shall have an handset with mouth piece and earpiece compatible with the amplifier must be provided.

Also a switching arrangement must be provided so that the handset can be used to initiate a page call or to be used in a "telephone" type mode to provide private communications to the other handset positions.

2. Sound Powered Phone System - The sound powered phone system shall consist of an interconnecting cable and J-Box mounted open-circuit insulated two-wire jacks. All jacks will be parallel connected. The cable shall conform to U.S. Dept. of Agriculture - Rural Electrification Administration Specification #PE-22.

APPENDIX 4B
SPECIFICATION - ENCLOSING FENCE

SUBSTATION

STANDARDS

FENCE SPECIFICATIONS FOR 8'-0" FENCE (96" FABRIC)

POSTS: Terminal, corner and walk in gate posts to be 2-7/8" O.D. pipe (5.79#/ft.). Double swing gate posts to be 4" O.D. pipe (9.11#/ft.). Line posts to be 2-3/8" O.D. Pipe (3.65#/ft.). (Line post alternate may be 2-3/8" O.D. steel structural tubing, .116" min. wall thickness.) Line posts spaced 10'-0" O.C. max. unless otherwise specified.

FABRIC: 96" high No. 9 ga. wire woven in a 2 inch mesh. Basic open hearth steel, hot dip galvanized after fabrication with 1.2 ounces of zinc per square ft. of wire surface. Standard finish, twisted and barbed selvaige top and bottom.

GATES: 1-7/8" O.D. Pipe (2.72#/ft.) frame, hot dip galvanized inside and out. All joints welded and braced wherever necessary. Welds to be continuous around pipe, cleaned and treated with zinc rich paint. Corners to have mortised joints for proper fit (hammering of pipe is not acceptable). Cover with fabric to match fence. Furnish with suitable hinges and locking devices, gate keepers and center stop.

BRACING: All terminal and corner posts to be furnished with horizontal braces spaced midway between top of fabric and ground, extending from terminal or corner post to first adjacent line post. Braces to be of 1-5/8" O.D. pipe (2.27#/ft.). Where more than one line post is needed, each brace is to be diagonally trussed, using a 3/8" round rod with suitable pressed steel connectors and necessary fittings.

TIE WIRES: Galv. steel wire. For line posts, furnish one tie to every foot of fabric height. For tension wires and braces, furnish ties approx. 24 in. apart.

TENSION WIRES: #7 gauge galv. coil spring wire shall be used at top and bottom of fence.

BARBED WIRE AND POST ARMS: Three lines of 4-point pattern, each composed of two strands of No. 12-1/2 Ga. galv. wire, running entire length of fence above fabric and gates. Line post arms to be of one solid piece, galv. pressed steel, made to carry 3 barbed wires at a 45° angle. Gate, terminal, and corner posts to have ball caps.

FITTINGS: Hot-dip galv. malleable, cast iron or pressed steel.

GALVANIZING: To be by hot-dip process per applicable ASTM specs.

STANDARD REFERENCE DRAWINGS:

Fence Details	UC06
Gate Details	UC03, UC04, UC07, UC08
Ground Details	WE02

8'-0" FENCE
SPECIFICATIONS

US03

REVISION NO	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	1221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SUBSTATION

STANDARDS

FENCE SPECIFICATIONS FOR 8'-0" FENCE (96" FABRIC)

SETTING: Terminal, corner and walk-in gate posts shall be set 36" below fin. grade. Double swing gate posts shall be set 42" below fin. grade. Line posts shall be set 32" below fin. grade. Concrete footing top shall be set at fin. grade and trowelled to shed water. When fence is installed before final surface course, projecting part of footing shall be formed with round fiber tube.

CLEARANCE: The fence follows contour of property. Fabric shall have a clearance of 1" from finished grade in graded areas. For ungraded areas, fabric shall have a clearance from grade of from 1" min. to 4" max.

NOTE: If fence is installed prior to final grading, fence contractor will return after grading to align gates and pin fittings.

REVISION NO.

DRAWN

EXAMINED

APPROVED

DATE

BY

DRAWN

EXAMINED

APPROVED

STANDARD REFERENCE DRAWINGS:

Fence Details UC06
Gate Details UC03, UC04, UC07, UC08
Ground Details WE02

8'-0" FENCE
SPECIFICATIONS

US04

SUBSTATION

ARIZONA

Public Service COMPANY

STANDARDS

DOUBLE SWING GATE LOCKWALK IN GATE LOCKNOTE:

AFTER INSTALLING CHAINS -
LOCK WITH FEWEST LINKS PRACTICAL
AND REMOVE EXCESS LINKS.

SECTION A

STANDARD REFERENCE DRAWINGS:

8' FENCE DETAILS - UC04, UC06, UC07, UC08
8' FENCE SPECS - US03, US04

FENCE
GATE LOCKING
DETAILS
UC03

CUTTING PATTERN
FOLDING HANDLE FOR SUBSTATION
DOUBLE SING GATES

-11 GA. (.125") METAL.
GRIND & SMOOTH ALL EDGES.
ROUND OFF ALL CORNERS
FOR FINGER CONTACT.

SECTION (A) (A)

EXTERIOR VIEW

ELEVATION

STANDARD REFERENCE DRAWINGS:

DOUBLE SWING GATE DETAILS - UC02, UC03

FENCE
DOUBLE SWING
HANDLE DETAIL
UC 04

REVISION NO.	5	4	3	2	1
DRAWN					
EXAMINED					
APPROVED					
DATE	5-20-77	5-25-77	5-25-77		
DRAWN	3. M. H.	H. E.			
EXAMINED					
APPROVED					

SUBSTATION

ARIZONA

Public Service COMPANY

STANDARDS

TURN TOP ARM OUT
UNLESS OTHERWISE NOTED

ONE PIECE GALVANIZED
TOP ARM W/3 STRANDS
4 POINT BARBED WIRE

R 1/4" x 2" x 2" W/9/16" ϕ
MOLE FOR GROUND. ZINC
RICH PAINT AFTER WELD.
INSTALL PARALLEL TO
FABRIC ON APPROX.
EVERY THIRD POST

GROUND TAB DETAIL

FURNISH ON 1/3 OF LINE POSTS

DETAIL - POST INSTALLED
BEFORE FINISHED GRADE

TYP. LINE POST - 8' FENCE

STANDARD REFERENCE DRAWINGS:

8' GATE DETAILS - UC03, UC04, UC07, UC08

8' FENCE SPECS. - US03, US04 GROUNDING - WE02

8' FENCE
DETAILS

UC06

SUBSTATION

STANDARDS

ARIZONA **Public Service COMPANY**NOTE:FABRIC & BARBED WIRE IN
GATE TO CONFORM TO ADJACENT FENCING DOUBLE SWING GATENOTES:

1. TROWEL TOP OF FOOTINGS TO SAVED WATER.
2. EMBED GATE STOPS IN CONCRETE FOOTING SAME AS CENTER STOP.
3. A CONCRETE THRESHOLD OR APRON MAY BE SPECIFIED UNDER GATES. REFER TO STATION FENCING PLAN.

STANDARD REFERENCE DRAWINGS:

8' FENCE - LINE POST - UC06
 GATE LOCKING DETAILS - UC03, UC04
 8' FENCE SPECS. - US03, US04

GROUNDING DET. - WE02

8' FENCE
 DOUBLE SWING GATE
 DETAILS
 UC07

SUBSTATION

ARIZONA

Public Service COMPANY

STANDARDS

ELEVATION - WALK IN GATE

STANDARD REFERENCE DRAWINGS:

8' FENCE DETAILS - UC03, UC06, UC07
 8' FENCE SPECS. - US03, US04 GROUNDING - WE02

8' FENCE
 WALK IN GATE
 DETAILS
 UC08

4B-7/8

APPENDIX 4C
SPECIFICATION - EXCAVATION AND BACKFILL

EXCAVATION AND BACKFILL1. Scope of Work

Work included under this section comprises excavation, backfill, and grading for any or all of the following items:

- a. Footings and foundations of all types.
- b. Equipment support slabs, building floor slabs, and miscellaneous concrete slabs or aprons.
- c. Precast concrete vaults, manholes, or other buried or partially buried structures.
- d. Trenches for pipe, conduits, ducts, or cables.
- e. Miscellaneous excavations which are local in nature.

Termite treatment under building floor slabs is also included in this section. General area grading or surfacing is not included.

2. Excavation

All excavations shall be made to the dimensions and depths required by the specifications or indicated on the drawings. Bottoms of all excavations shall be level, or to uniform slopes where required by the specifications or drawings, and to line.

Where excavations are carried out below elevations indicated on the plans or directed by the Inspector, the excess excavation shall be filled with aggregate base course material conforming to ~~Arizona Highway Department~~ Arizona Highway Department "Standard Specifications for Road and Bridge Construction" and compacted to 90% of maximum density at optimum moisture content (ASTM D698).

In general, it is anticipated that it will be practicable to cut foundation trenches to the exact size of footings. Where this is not practical, excavation shall be carried a sufficient distance outside of the footing lines to allow adequate working space for installation of form work.

EXCAVATION
&
BACKFILL
SPECIFICATIONS

YS07

Formerly A-20133

4C-1

[illegible]

3. Drainage of Excavation Areas

Grading in vicinity of structures shall be controlled to prevent surface water from running into excavated areas. Any accumulated water shall be removed by pumping or other means at the Contractor's expense.

4. Protection of Adjacent Buildings and Existing Structures

Excavation shall not be carried below existing building foundations until underpinning and shoring to be performed by others or by this Contractor have been completed. All existing structures, pipes and foundations which are to be incorporated into the final work shall be protected or replaced by the Contractor without cost to the Company.

5. Stockpiles

Excavated material to be used for backfill shall be stockpiled in an area approved by the Inspector so as not to interfere with other work.

6. Waste

Excess material from excavation not suitable or required for backfill or filling shall be removed from the site and disposed of as approved by the Inspector.

7. Classifications of Excavated Material

It is understood that there will be no classification of materials to be excavated and that the Contract price covers full compensation to the Contractor for such excavation, whatever material is encountered.

8. Backfill

a. Special Requirements

Contractor shall conform with all requirements of the specifications and drawings for the particular work involved, such as providing sand or gravel cushions

Formerly A-20133

EXCAVATION
&
BACKFILL
SPECIFICATIONS

YS08

4C-2

under vaults, cradles under pipe, protective cushions of select material around cables, etc. In all cases, care shall be exercised to avoid damage to the finished work. All timber shall be removed and all trash shall be cleaned out from the excavation before backfilling.

b. Common Backfill

Backfill shall be made with suitable material approved by the Inspector. Such material shall not contain rock larger than 6 inches in greatest dimension. No rocks larger than 3 inches in greatest dimension shall be placed in the top 6 inches of any backfill. No brush, trash, grass or organic matter shall be placed in any backfill.

Backfill shall be placed and compacted in 12 inch maximum layers. Material shall be uniformly moistened to the optimum moisture content and compacted by hand or mechanical work methods which will provide the required uniform minimum density without injury to the installation or adjacent structures. The completed backfill shall have a minimum relative density throughout of 90% of maximum at optimum moisture content (ASTM D698), and in no case shall the in-place dry density be less than 100 pounds per cubic foot.

c. ABC Backfill

Backfill under streets, roads, curbs, or sidewalks and where indicated on the drawings shall use aggregate base course material conforming to Arizona Highway Department "Standard Specification for Road and Bridge Construction". Placement and compaction shall conform to the provisions of sub-paragraph b, "Common Backfill", above. On public rights-of-way, additional compaction shall be provided where required to meet the codes, specifications, regulations, or instructions of the Federal, State, County, or local authority having jurisdiction.

d. Surface Replacement

In general, the surface over any backfilled excavation shall be returned to its original condition. On public rights-of-way, pavement, curbs, gutters, sidewalks, and other features shall be replaced in accordance

Retyped, Rev. 2

Formerly A-20133

EXCAVATION & BACKFILL SPECIFICATIONS

YS09

		REVISION NO	1	2	3	4	5	6	7	8	9
DRAWN	4-12-65	DWC/BW	12-28-66	6/14	10-1-71	20					
EXAMINED	4-12-65	EW X	2-22-69	4/22	10-8-71	W/22					
APPROVED	4-12-65	STOP	2-18-69	9/22/70	28-7	NT					

SUBSTATION

ARIZONA

STANDARDS

with applicable codes, specifications, regulations, or instructions of the Federal, State, County, or local authority having jurisdiction.

e. Compaction Tests

Company may have compaction tests made at such depths and locations as the Inspector may select in any backfill. Contractor, at his own expense, shall remove, replace, and recompact any backfill not conforming to the requirements of these specifications. Any delay as a result of such work shall not be justification for an extension of the contract completion date.

Maximum density and optimum moisture content will be determined in accordance with ASTM D698. (Where applicable, adjustment shall be made by applying a rock correction factor in accordance with Arizona Highway Department Test Designation ARIZ 227.) Field determination of density will be made in accordance with ASTM D2167 (rubber ballon method) or Arizona Highway Department Test Designations ARIZ 229 and ARIZ 230 (sand cone method).

9. Termite Treatment

Grade under all concrete floor slabs for buildings shall be termite treated with dieldrin applied in accordance with the manufacturer's instructions, but at a rate not less than .25 pounds of active dieldrin per 100 square feet of surface.

One acceptable application system using California Chemical Company "Ortho Dieldrin 1.5" (1.5 lb. dieldrin/gal., 17.9% dieldrin, 79% solvent, 3.1% inerts) is as follows:

Dilute liquid 1 qt. to 15 gallons of water and spray resulting mixture at the rate of 10 gallons per 100 square feet.

REVISION NO.	1	2	3	4	5	6	7	8	9
DRAWN	12-30-40								
EXAMINED	2-27-49								
APPROVED	2-28-49								
DRAWN	DWC/BW								
EXAMINED	CWH								
APPROVED	TAP								
DRAWN	4-12-65								
EXAMINED	4-12-65								
APPROVED	4-12-65								

Formerly A-20133

EXCAVATION
&
BACKFILL
SPECIFICATIONS

YS10

40-4

SUBSTATION

STANDARDS

10. Work On Public Rights-of-Way, Phoenix Metropolitan Area

In addition to any other requirements of these specifications, all work on public rights-of-way within the Phoenix Metropolitan Area shall conform to the applicable portions of the latest edition of City of Phoenix Standard Detail No. 175, "Pavement Replacement", and City of Phoenix Specifications No. 553, "Pavement and Surfacing Replacement"; No. 556, "Aggregate Base Course"; and No. 600, "Trench Excavation, Backfilling, and Compaction"; and shall be done to the full satisfaction of the Municipal, County, or local authority having jurisdiction. In case of conflict with other provisions of these specifications the City of Phoenix requirements shall govern.

REVISION NO			
DRAWN	EXAMINED	APPROVED	
1-30-69	CHB/bib		
2-27-69	H/ATEC		
2-28-69			

EXCAVATION
&
BACKFILL
SPECIFICATIONS

YS11

40-5/b

APPENDIX 4D
SPECIFICATION - FOUNDATIONS AND CONCRETE

CONCRETE

1. Scope of Work

Work included under this section comprises all Portland Cement Concrete as shown on the drawings or specified herein.

2. Material

- a. Portland Cement Concrete shall be "ready mixed" conforming to ASTM C94 "Tentative Specifications for Ready Mixed Concrete". Slump, minimum compressive strength, and maximum aggregate size shall be as specified for the class of concrete required.

Portland Cement used shall be Type I or II in accordance with ASTM C150, and shall be low-alkali (less than 0.6 percent sodium equivalent as determined by summation of the percentage of sodium oxide plus 0.658 times the percentage of potassium oxide).

- b. Reinforcing bars shall be deformed billet-steel bars conforming to ASTM A615, Grade 40.

Reinforcing steel shall be kept free from scale, oil and structural defects.

- c. Welded Wire Reinforcing Mesh shall conform to ASTM A185, latest editions.
- d. Miscellaneous material not specifically mentioned shall conform to latest appropriate ASTM standards.

3. Classes of Concrete:

- ### а. General Purpose

Portland cement concrete not otherwise shown or specified shall be considered to be general purpose. Minimum compressive strength at 28 days shall be 3000 psi. Slump shall be 4 inches. Minimum cement content shall be 5 sacks per cubic yard. Maximum aggregate size shall be not larger than either of the following:

- (1) 3/4 of minimum clear spacing between reinforcing.
- (2) 1/2 of minimum concrete cover over reinforcing.

**FOUNDATIONS
CONCRETE
SPECIFICATIONS**

Formerly A-14002

YS01

4D-1

At elevations over 4,000 feet above sea level, "Darex", or equal, air entraining agent shall be added to produce 3% minimum to 6% maximum entrained air.

b. Duct Encasement

Portland cement concrete used solely for the encasement of electrical ducts or conduit shall have a minimum compressive strength of 2,000 psi at 28 days. Maximum aggregate size shall be 1/2 inch. Slump shall be 6 inches.

c. Grout for Concrete Block Work

Portland cement concrete used for grouting of the cavities of concrete block work shall have a minimum compressive strength of 3,000 psi at 28 days. Maximum aggregate size shall be 3/8 inch. Slump shall be 6 inches.

d. Grout Under Steel Base Plates

Grout used under steel base plates shall be Portland cement concrete with the coarse aggregate omitted. Minimum compressive strength shall be 3,000 psi at 28 days. Slump shall be the minimum permitting placement.

e. Special Purpose

Portland cement concrete not falling in any of the above classes shall conform to the requirements for slump, strength, aggregate size, and air entrainment shown or noted on the drawings or covered elsewhere in the specifications.

4. Workmanship

a. Concrete for footings shall be placed against natural soil where practicable. Unless otherwise directed, soil shall be wet before placing concrete. Forms, where used, shall be substantially constructed, true to line and grade, and tight against leakage. Forms shall be clean and either oiled or wet prior to placing concrete.

b. Reinforcing steel shall be effectively supported to insure proper positioning in the finished work.

c. Anchor bolts set in concrete for structural steel or equipment shall be accurately positioned as shown on the drawings. Bending of anchor bolts or slotting of steel will not be permitted.

FOUNDATIONS
CONCRETE
SPECIFICATIONS

		REVISION NO.								
		1	2	3	4	5	6	7	8	9
DRAWN	4-12-65	DWC / BW	7-10-68	b/h	181658	b/h				
EXAMINED	4-12-65	CHW/N	7-26-68	7-26-68	7-27-69	7-26-68				
APPROVED	4-12-65	524	7-26-68	7-26-68	7-26-68	7-26-68				

- d. Concrete placing and finishing shall be in accordance with ACI 614, "Recommended Practice for Measuring, Mixing, and Placing Concrete". All concrete, except for encasement of ducts, shall be thoroughly vibrated with high frequency mechanical vibrators of an approved type. All concrete shall be properly cured by either keeping exposed surfaces continually moist or by sealing such surfaces with Type II, white pigmented, liquid membrane-forming compound for curing concrete (ASTM C309). Curing shall commence immediately after the final finishing operations and after the free water has disappeared and shall be continued for a minimum of 7 days.
- e. Where danger of freezing exists, protective measures shall be taken in accordance with ACI 306, "Recommended Practice for Winter Concreting".
- f. During periods of hot weather, procedures as outlined in ACI 605, "Recommended Practice for Hot Weather Concreting" shall be followed in order to keep the temperature of the concrete at time of placement below 85° F.
- g. Honeycomb or other surface imperfections on formed exposed concrete surfaces shall be repaired. An approved concrete bonding adhesive shall be used when so directed by the Inspector. All exposed surfaces shall then be stoned. Contractor shall install a 3/4 inch chamfer on all corners and edges of all concrete forms above sub-grade. Round foundations may be chamfered with a concrete edging trowel.

Unless otherwise shown or specified, exposed unformed concrete surfaces shall be finished as follows:

Building Floors -----	Hard Trowel
Vault or Manhole Floors -----	Wood Float or Light Broomed
Equipment Slabs -----	Wood Float or Light Broomed
Under Grouted Base Plates ----	Rough, grout shall be finished vertical along perimeter of base plate.

All finished work shall be done to the Inspector's satisfaction.

FOUNDATIONS CONCRETE SPECIFICATIONS

YS03

Formerly A-14802

6. Inspection and Testing

a. Notification of Inspector:

Contractor shall notify the Inspector at least 24 hours in advance of all proposed concrete placement. Anchor bolts, reinforcing steel, and any forms shall be installed sufficiently in advance of concrete placement to provide the Inspector reasonable opportunity to check these and any similar items. All concrete placement, unless specifically waived, shall be done in the presence of the Inspector and shall not be commenced until he has authorized the work to proceed.

b. Field Tests:

The Inspector will make such field tests and take such samples as he or the Company deem necessary. Minimum routine tests and samples which will be required are:

- (1) Slump test, standard cone type (ASTM C143). At least one slump test will normally be taken for each 24 cubic yards of concrete.
- (2) Compression test cylinders (ASTM C31). At least three test cylinders will normally be taken for the concrete placed each day. One 7 day test, two 28 day tests for Type I or II.
- (3) For air entrained concrete, entrained air test (either ASTM C173 or C231). At least one test will normally be taken for the concrete placed, each day.

The Contractor shall afford the Inspector all reasonable facilities, without charge, for securing samples to determine whether material is being furnished in accordance with these specifications. All tests and inspections will be so conducted as not to interfere unnecessarily with the work.

FOUNDATIONS
CONCRETE
SPECIFICATIONS

Formerly A-14802.

YS05

4D-5

All bolts and nuts shall be free of oil or other deleterious substances.

		REVISION NO								
		1	2	3	4	5	6	7	8	9
DRAWN	7-10-68	blh								
EXAMINED	7-26-68	W REC								
APPROVED	7-26-68	[Signature]								
		11-24-70	blh							
		7-22-78	W REC							
		7-28-78	W REC							

FOUNDATIONS CONCRETE SPECIFICATIONS

YS06-A

APPENDIX 4E
INSTALLATION INSTRUCTIONS - TEMEPHONE INTERFACE YARD

Substation Telephone Interface Yard
Engineering Details

This drawing provides the engineering information needed to install a Telephone Company Interface Yard at an APS Substation.

DESCRIPTION

The Telephone Interface Yard is an 8 foot by 12 foot fenced in area containing the ground mat potential rise protection equipment. There shall be a gate in the outside fence for use by Telco personnel; this gate shall be locked with a Telco lock. There shall also be a gate in one of the inside fences for use by APS personnel; this gate shall be locked with an APS lock. In the interface yard APS shall install two stub poles, 2 inch conduit to an adjacent right-of-way, and a 2 inch conduit with a 6 pair cable to the control house or telephone panel.

LOCATION

The Telephone Interface Yard shall have at least one side common with the substation fence. The yard shall be located to allow easy access from adjacent right-of-way by Telco facilities and personnel. See sheet 6 of the drawing for graphical representation of this requirement. Contact Communications Engineering for approval of the Telephone Interface Yard.

MATERIAL

The following material is needed for the telephone interface:

1. Quantity, 2 - 10 foot, 15 inch circumference top (Class 7) western pine pole treated with Dow process. Order from Southwest Forest Industries, Prescott, Arizona.
2. Quantity, 1 - Box, Junction, 12"x12"x6" screw cover with knockouts, C/I #717/1516.
3. Quantity, 2 - 2" G.I. 90° 36" sweep C/I #717-4449.
4. Quantity, 2 - 2" Adapter 2" IPS plastic female slip to 2" G.I. female thread C/I #331/0795.
5. Quantity, as required - 2" ABS direct burial plastic, 25' length with coupling C/I #331/1285.
6. Quantity, as required - 6 pr #19 Interstation Communications Cable C/I #313-1300.

CONSTRUCTION

See sheets 3,4,5 and 6 of this drawing. APS is responsible for the following construction:

1. The fence and gates around the interface yard.
2. Setting the two 10 foot poles.
3. Install 2 inch conduit from right end pole to adjacent right-of-way for use by Telco. Coordinate the location of this conduit with Communications Engineering.
4. Install 2 inch conduit from left end pole to the control house or telephone panel. A 12"x12"x6" junction box is to be installed on the left end pole for termination of this conduit. See sheet 3 of this drawing.

SHEET NO. 1 OF 8 SHEETS		
COMMUNICATION TYPICAL SUBSTATION TELEPHONE INTERFACE YARD ENGINEERING DETAILS		
ARIZONA PUBLIC SERVICE COMPANY PHOENIX		
DRAWN	S.W.	DATE: 10-25-78
CHECKED	T.R.H.	W.A.
EXAMINED	W.H.	ACCT.
APPROVED	R.L.H.	A-54422
APPROVED	H.C.	

NO.	DATE	REVISION	DWN	CND	EXD	APPD	APPD	W.A.
-----	------	----------	-----	-----	-----	------	------	------

4E-1

INDEX

5. Install a substation ground lead on the left end pole leaving a seven foot loop available for Telco use. Use 9/16" copperweld wire for this lead. This is the ONLY ground that is to be exposed inside the interface yard.
6. Install a 6 pair #19 Interstation Communication Cable in the conduit going to the control house or telephone panel. Leave a 6 foot cable end at the junction box. After Telco has installed their equipment enclosure the cable end is to be terminated per sheet 7 of this drawing.

Telco is responsible for the following construction:

1. Install cross arms, equipment enclosure with flex conduit, neutralizing transformer(s), lighting arrester, and central office cable.
2. Make appropriate connections to the APS ground mat lead.

DRAWINGS

The information on sheet 3 of this drawing should be included on the substation foundation drawing. The information of sheets 7 and 8 should be included with substation wiring diagrams.

TELEPHONE SERVICE

Telephones for substations are installed on written request to Communications Engineering from the Power Operations-System Operations Manager. The request should include the number and location of telephone instruments needed. Communications Engineering will make application to the proper telephone company for service.

If there are any questions on telephone voice or data circuits into a substation contact Communications Engineering.

SHEET NO. <u>2</u> OF <u>8</u> SHEETS	
COMMUNICATION TYPICAL SUBSTATION TELEPHONE INTERFACE YARD ENGINEERING DETAILS	
ARIZONA PUBLIC SERVICE COMPANY PHOENIX	
DRAWN	S.W.
CHECKED	T.R.H.
EXAMINED	W.A.
APPROVED	RLH
DATE	10/24/75
W.A.	ACCT.
APPROVED	J.V.
A-54422	

SUBSTATION TELEPHONE "H" FIXTURE

PLAN VIEW

SHEET NO. 3 OF 8 SHEETS		
COMMUNICATION TYPICAL SUBSTATION TELEPHONE INTERFACE YARD ENGINEERING DETAILS		
ARIZONA PUBLIC SERVICE COMPANY PHOENIX		
DRAWN	SIV	DATE: 10/11/73
CHECKED	P.R.H.	W.A.
EXAMINED	AAA	ACCT.
APPROVED	RLH	A-54422
APPROVED	HV	

NO.	DATE	REVISION	DWN	CHD	EXD	APPD	APPD	W.A.
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4E-3

SUBSTATION TELEPHONE 'H' FIXTURE

REAR VIEW

NOTE

ITEMS THAT ARE SHADED
TO BE INSTALLED BY A.P.S.

SHEET NO. 4		OF	8	SHEETS
COMMUNICATION TYPICAL SUBSTATION TELEPHONE INTERFACE YARD ENGINEERING DETAILS				
ARIZONA PUBLIC SERVICE COMPANY PHOENIX				
DRAWN	S.H.	DATE:	10/11/74	
CHECKED	T.R.H.	W.A.		
EXAMINED	WAT	ACCT.		
APPROVED	RLH			
APPROVED	WAT			
			A-54422	

NO.	DATE	REVISION	DWN	CHD	EXD	APPD	APPD	W.A.
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YE-4

SUBSTATION TELEPHONE 'H' FIXTURE

FRONT VIEW
DIMENSIONS SHOWN ON REAR VIEW

NOTE
ITEMS THAT ARE SHADED
TO BE INSTALLED BY A.P.S.

SHEET NO. 5 OF 8 SHEETS	
COMMUNICATION TYPICAL SUBSTATION TELEPHONE INTERFACE YARD ENGINEERING DETAILS	
ARIZONA PUBLIC SERVICE COMPANY PHOENIX	
DRAWN	S.H.
CHECKED	T.P.H.
EXAMINED	W.A.
APPROVED	R.L.H.
DATE	10/17/78
W.A.	ACCT.
A-54422	

NO.	DATE	REVISION	DWN	CHD	EXD	APPD	APPD	W.A.
-----	------	----------	-----	-----	-----	------	------	------

4E-5

"INCHES"

SHEET NO. 6		OF	8	SHEETS
COMMUNICATION TYPICAL SUBSTATION TELEPHONE INTERFACE YARD ENGINEERING DETAILS				
ARIZONA PUBLIC SERVICE COMPANY PHOENIX				
DRAWN	S.W.	DATE:	10/17/73	
CHECKED	T.R.H.	W.A.		
EXAMINED	VAT	ACCT.		
APPROVED	R.L.H.			
APPROVED	AVI	A-54122		

NO.	DATE	REVISION	DWN	CHD	EXB	APPD	APPD	W.A.
-----	------	----------	-----	-----	-----	------	------	------

YE-6

TELCO
WIRING

NOTE
THIS TERMINAL BLOCK IS
LOCATED IN TELCO'S EQUIPMENT
ENCLOSURE IN THE TELEPHONE
INTERFACE YARD AND IS SUPPLIED
BY TELCO.

APS CABLE

TO CONTROL
HOUSE OR 6 FR
TELEPHONE #19
PANEL

SHEET NO. 7 OF 8 SHEETS	
COMMUNICATION TYPICAL SUBSTATION TELEPHONE INTERFACE YARD ENGINEERING DETAILS	
ARIZONA PUBLIC SERVICE COMPANY PHOENIX	
DRAWN	J.W.
CHECKED	T.R.H.
EXAMINED	W.H.
APPROVED	RLH
DATE	10/17/78
W.A.	ACCT.
A-54122

SUBSTATION
WIRING

TO TELEPHONE 6 PR
INTERFACE YARD #19

NOTE
THIS TERMINAL BLOCK IS TO BE
LOCATED IN THE CONTROL HOUSE
OR TELEPHONE PANEL. THIS
TERMINAL BLOCK CAN BE PART
OF A LARGER TERMINAL CABINET.
TERMINAL BLOCK TO BE SUPPLIED
BY ARS.

SHEET NO. 8 OF 8 SHEETS	
COMMUNICATION TYPICAL SUBSTATION TELEPHONE INTERFACE YARD ENGINEERING DETAILS	
ARIZONA PUBLIC SERVICE COMPANY PHOENIX	
DRAWN	DATE: 10/17/73
CHECKED	W.A.
EXAMINED	ACCT.
APPROVED	A-54422
APPROVED	

APPENDIX 4F
DRAWINGS

SEE DRAWING	
DNAS OF MTE'S	
SOC REMOTE SECTION	A-24829
B-DG, INVA, PRE, AIR	A-25000
VISITOR DISPLAY	A-67876
SOC REMOTE SM	A-24828
VISITOR DISPLAY PANEL	G-67875

4F-1

PRELIMINARY

AIRPORT SOLAR PHOTOVOLTAIC SOLAR ARMY FIELD FACILITIES BUILDING FLOOR PLAN	
PUBLIC SERVICE	
DATE: 10-1-68	BY: [Signature]
PROJECT NO: G-95302	1-1

PRELIMINARY

THE DATA
BILLS OF 1974

4F-3
A-5000

IMPORT SOLAR PHOTOVOLTAIC
CONCENTRATOR PROJECT
FACILITIES BUILDING
ELEVATIONS
PUBLIC SERVICE COMPANY
PAPER

AP'S STANDARD REFERENCE DWG'S.

FENCE DETAILS
GATE DETAILS

STRUCTURE DIA. 85.6'
RAIL DIA. 58.0'
(NOT TO SCALE)

4F-4

PROJECT NO. 10-10-10-10		DATE 10-10-10	
AIRPORT SOLAR PHOTOVOLTAIC CONCENTRATOR PROJECT SOLAR ARRAY FIELD ROADWAYS AND FENCES			
DESIGNED BY PUBLIC SERVICE COMPANY			
CHECKED BY G. J. JONES			
APPROVED BY G. J. JONES

SCALE 1"=100'
 DATE OF PHOTOGRAPHY 5/20/70

ELEVATIONS ARE BASED ON CITY OF PHOENIX
 DATUM USING A BENCHMARK AT 34TH STREET
 AND NEAR THE EAST WHICH IS A B.C. M.H.
 WITH AN ELEVATION OF 100.01'

PRELIMINARY	
TOPOGRAPHIC MAP	
OF	
AIRPORT SOLAR SITE	
PREPARED FOR	
4F-5/6	ARIZONA PUBLIC SERVICE CO.
APR 3-80	D-5530

DOE/CS/05317-1

FINAL REPORT

PHASE I

**AIRPORT SOLAR PHOTOVOLTAIC
CONCENTRATOR PROJECT**

By

Arizona Public Service Company
and
Motorola Government Electronics Division

30 August 1979

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SECTION 1 — OBJECTIVES OF PHASE I

The objective of PRDA EG-78-D-04-0035 is to design, implement, and operate application experiments for photovoltaic (P-V) concentrator systems. These experiments are to provide technical, operational, and performance data on concentrating systems employed in on-site power generation applications and to provide information on all nontechnical issues that can be identified.

More specifically, the PRDA requires the design of a complete P-V system that converts solar energy to electrical energy for use at specific proposer-identified application sites. AC or DC systems with or without on-site electrical energy storage using any type of passively or actively cooled optical concentrator with a concentration ratio greater than 5:1 are responsive. AC systems shall include the necessary control and interfacing equipment to integrate the P-V power output into the conventional energy source. Total energy systems and systems with electrical energy storage are responsive, but emphasis should be placed on the P-V portion of the project. The system should be designed using components, where available, that do not require extensive research and development.

During phase I of the program, Arizona Public Service Company (APS) and the Government Electronics Division of Motorola Inc. (GED), in conjunction with the Arizona Solar Energy Research Commission (ASERC) and the City of Phoenix, completed a definition of the application experiment, performed system analyses, designed unique system components, developed a fabrication and installation plan for phase II, and prepared a phase III operating plan.

The Phoenix Sky Harbor International Airport was selected as the site for this application experiment because:

1. The amount of yearly direct normal insolation in Phoenix, Arizona, is high.
2. Otherwise nonproductive land around major airports can be beneficially used for P-V power generation.
3. The airport location has very high public visibility to both air travelers and travelers on nearby U.S. I-10, which overlooks the airport and the array field.
4. The airport is presently undergoing major expansion on a schedule compatible with this P-V application experiment.
5. The implementation of the P-V system at the airport will provide the solution to numerous technical and nontechnical issues.

SECTION 2 — SYSTEM REQUIREMENTS

To satisfy the objectives and requirements of PRDA-35, the following general objectives were established for the Airport Solar Photovoltaic Concentrator Project (ASPCP) by APS and GED:

1. Implement a system that operates at a standard utility working voltage of 480 volts, 3 phase, 60 Hz.
2. Implement a system of sufficient size to produce meaningful data to utility companies.
3. Implement a system large enough to truly evaluate high volume fabrication techniques.
4. Implement a system large enough to statistically evaluate the environmental and maintenance effects on materials and components.
5. Configure the system to evaluate various methods of operation, maintenance, and repairs.
6. Instrument the system sufficiently to measure component degradation and to allow accurate and complete life cycle cost analyses.

The ASPCP has been designed to:

1. Provide 500 peak kW of 60 Hz power to a specific load in the South Concourse Building of Airport Terminal Module 3.
2. Be both manually and automatically controllable consistent with normal APS operating policies for a power generating station of this size.
3. Operate in either a maximum power mode in parallel with the utility grid, a load following mode, or a utility stand-alone mode.
4. Include the necessary public displays and facilities to promote wide-scale public acceptance of P-V systems.
5. Be compatible with a passively-cooled optical concentrator with a concentration of 70X on the solar cell.
6. Limit the system power loss to 10 percent, including the DC/AC inverter.

Having established these system level specifications, GED developed several computer analysis programs to model the system components and to analyze them using weather data acquired from Sandia. In addition, analyses of several array configurations were performed and a final design choice was made based on the availability and size of materials, practicality of design, cost tradeoffs, and ease of maintenance.

SECTION 3 — SYSTEM DESCRIPTION — GENERAL

3.1 System Sizing

The 500 kWe ASPCP system size was selected to satisfy the requirements delineated in this section. System level specifications for the major components and subsystems were determined by performing various analyses based upon the power output of the Motorola Meinel optical module and estimated system losses. These specifications are summarized in Table 3-1.

3.2 Site Selection

APS worked with the City of Phoenix and Sky Harbor Airport officials to select an appropriate site for the array field. Several sites were identified and considered. Selection of the 14-acre site was based on size, nearness to Terminal Module 3, minimum site preparation cost, aircraft and personnel safety, and visibility to the public. The geographical relationship of the ASPCP to the Sky Harbor Airport area is depicted in Figure 3-2. The APS System Operation Center (SOC) is not shown, since it is located in downtown Phoenix.

3.3 System Block Diagram

A detailed ASPCP system block diagram is presented in Figure 3-1. The block diagram depicts the major subsystems and components by physical segregation.

Table 3-1. ASPCP System Level Specifications

Ambient Conditions	
Insolation	1000 watts/m ²
Ambient temperature	28°C
Air mass	2.0
Optical Module	
Voltage	1.94 VDC
Current	20.6 ADC
Power	39.9 watts
Module Panel	
Number of modules per panel	12 modules
Module configuration	3 high x 4 wide
Array	
Number of panels per array	20 frames
Number of modules per array	240 modules
Power output	9576 watts

Table 3-1. ASPCP System Level Specifications (Cont)

Series String	
Number of arrays per string	3 arrays
Number of strings per field	59 strings
Number of modules per string	240 modules
String voltage	465.6 VDC
String power output	9576 watts
Array Field	
Field dimensions	1016 feet (E-W) x 600 feet (N-S)
Field area	13.99 acres
Field border width	20 feet
Number of roadways	5 roadways
Width of roadways	16 feet
Number of arrays per field	59 arrays
Number of module panels per field	1180 module panels
Number of modules per field	14160 modules
Field power output	565 kW
System Losses	
Inverter + field wiring + miscellaneous	= 8% + 1% + 1%
Field Voltage drop	2% x 465.6 volts = 9.3 VDC
Inverter Input	
Voltage	465.6 - 9.3 volts = 456.3 VDC
Current	20.6 A x 59 = 1215.4 ADC
Power	456.3 V x 1215.4 A = 554.6 kW
System Power Output	0.92 x 554.6 kW = 510.2 kW

Figure 3-1. ASPCP System Block Diagram

Major elements of the ASPCP shown in the system block diagram (Figure 3-1) are:

1. An array field containing 59 two-axis tracking arrays, including one specially instrumented array.
2. A facilities building that houses the inverters, data acquisition and control equipment, visitor center, and maintenance and storage areas.
3. An array paralleling and monitoring panel (APMP) that permits the array to be connected in parallel and to be monitored individually.
4. Two 250 kW, 3 ϕ , power inverters and associated control circuitry and switchgear.
5. A master control unit (MCU) to control the inverters, system mode of operation, system displays, switchgear, output power, and emergency stop operation of the arrays.
6. A manual/automatic control and display panel (MACDP) that serves primarily as a means to control the ASPCP in the event of an MCU failure.
7. An on-site data acquisition system (ODAS) to acquire and display system data and to transmit data as required to a Department of Energy (DOE) data reduction center.
8. A roof weather station to provide solar and environmental data for data acquisition and analyses.
9. A facilities building visitor's display to display selected ASPCP data.
10. An SOC interface to continuously transmit the plant status to the APS SOC in downtown Phoenix.
11. A 12.5 kV underground transmission cable, with associated transformers and protective devices, to transmit the inverter output power to the load in Airport Terminal Module 3.
12. A total load divided into two separate loads for the purpose of evaluating different modes of system operation.
13. A 3 ϕ solid state switch that permits the two loads to be connected in the configurations necessary to evaluate the three operating modes.
14. Cables from the utility grid to provide synchronizing and voltage regulation signals to the inverter and, when required, power to the load.
15. A main terminal display to be located in the new airport main terminal building for public viewing.

The ASPCP does not include provisions for energy storage, other than the utility grid. Emergency power will be supplied to the facilities building by feeding utility power back from Terminal Module 3 through switch SW6.

3.3.1 ARRAY FIELD

The 14-acre array field and the facilities building are enclosed by an 8-foot chain-link fence for security. The array field layout is depicted in Figure 3-3. There are 59 Motorola solar arrays in the array field.

3.3.1.1 Motorola Solar Array

The Motorola solar array is a two-axis tracking array. The array is depicted in Figure 3-4. There are three subarrays, 20 module panels, and 240 Motorola Meinel optical modules on each array.

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Figure 3-2. ASPCP Location within the Phoenix Sky Harbor International Airport Complex

- LEGEND
- CABLE TRENCH (FIBERGLASS COVER EXCEPT AT ROAD CROSSINGS)
 - FENCE
 - UNDERGROUND CONDUIT
 - CABLE TRENCH (PAINTED STEEL COVER)
 - JUNCTION BOX
 - CABLE TRENCH NUMBER
 - UC UNDERGROUND CONDUIT
 - JR PAD MOUNTED JUNCTION BOX WITH ADJACENT TELEPHONE CABINET BOX
 - JRA ARRAY MOUNTED JUNCTION BOX
 - JBS STATIONARY JUNCTION BOX ON THE GROUND BELOW ARRAY MOUNTED BOXES
 - TR TELEPHONE CABINET BOX (NOT SHOWN)

Figure 3-3. Array Field Layout

Figure 3-4. Selected Array Configuration

3.3.1.2 Array Field Design

The modules are mounted on each panel in a three tier by four column configuration. To minimize subarray and array shading effects and maximize yearly energy output, an array triplet interconnection scheme is used.

The array field is electrically divided into 19 series strings of array triplets plus two individual arrays. Arrays 7 and 8 are individually connected, each forming a single series string.

A typical triplet group is detailed on the system block diagram (Figure 3-1) to depict the major array components. A stationary junction box, array junction box, control panel enclosure, and electronics enclosure are located at each array. All are NEMA-type weatherproof enclosures. The control panel enclosure and the electronics enclosure are located outside the array sweep circle for operating safety reasons.

The significant advantage of the array triplet interconnection is that useful power is obtained during sunrise and sunset when the array is partially illuminated. The possible disadvantage is that when one of the arrays in a triplet group is shaded, all three arrays are off. However, the likelihood of one array being shaded and not the other two is very low.

Each array has a hybrid tracking system that controls the azimuth and elevation drive subsystems. The hybrid tracker automatically operates in the closed loop, sun tracking mode when the sun is unobscured, and it operates in the open-loop, array positioning mode when the sun is obscured. AC power is fed to each array from the facilities building to supply the tracking electronics, drive motors, and maintenance outlets. Azimuth position, elevation position, azimuth limit, and elevation stow limit signals are generated and utilized by the hybrid tracker and control electronics on each array. The only control signals transmitted between the arrays and the facilities building are stow command and stow verification. A telephone communications system is also included in the array field and facilities building design to provide greater coordination throughout the ASPCP site.

Array number 25, one of the triplet arrays, is instrumented with insolation, wind, temperature, deflection sensors and a reference solar cell. The wind speed and insolation data will be used for both control and analysis, and the other sensor data will be used for analysis purposes.

There will be 118 DC power cables from the array field to the APMP in the facilities building. The modules and arrays are interconnected in a two-wire system isolated from ground; consequently, there will be a +DC and a -DC conductor. The DC voltage level in each of the 59 strings is nominally 466 VDC; and the string current is nominally 20.6 ADC.

Grounding rods will be connected to each array and to the facilities building for lightning protection. Area lighting will be provided in the array field for any night maintenance requirements and for security.

3.4 Facilities Building Design

The APMP, inverter switchgear, two 250 kW inverters, MCU, ODAS, MACDP, visitors display, and power distribution panels will be located inside the facilities building. Maintenance and storage areas will be included in the building. A weather station will be installed on the roof. The building elevations are shown in Figure 3-5 and the building floor plan in Figure 3-6.

Figure 3-5. Facilities Building Elevations

Figure 3-6. Facilities Building Floor Plan

3.4.1 ARRAY PARALLELING AND MONITORING PANEL (APMP)

The 59 array field strings are paralleled in the APMP to provide a nominal 456 VDC, 1215 ADC, 554 kW input to the inverters. The APMP contains isolation circuit breakers, fuses, blocking diodes and receptacles for monitoring and troubleshooting. A main disconnect switch, SW1, is located between the APMP and the inverter switchgear for maintenance and safety purposes.

3.4.2 INVERTERS AND SWITCHGEAR

Two 250 kW inverters connected in parallel and the inverter switchgear condition and invert the array field DC voltage to an AC voltage compatible with the utility grid. The inverter equipment contains:

1. An input trap filter to keep internally generated inverter transients from feeding back to the solar modules which could act as radiating antennas.
2. Internal logic to synchronize the inverter phase to the utility phase.
3. Internal logic to regulate the inverter voltage to match the utility voltage at the load.
4. Internal logic to start the inverter automatically or manually, sense inverter status, shutdown the inverter, and provide alarms for abnormal inverter conditions.
5. Output EMI filters to ensure that radiated and conducted EMI does not interfere with the airport radar and communications equipment.
6. Motorized manual/automatic circuit breakers for protection and isolation.

The AC main disconnect switch, SW2, is located between the 480 volt, 60 Hz, 3 ϕ , 4-wire inverter output and a 750 kVA step-up transformer. SW2 is required for maintenance, safety, and emergency power purposes.

3.4.3 MANUAL/AUTOMATIC CONTROL AND DISPLAY PANEL (MACDP)

The purpose of the MACDP is to allow initial testing and evaluation of individual portions of the system as they are installed and incorporated into the system. When the system is up and operating normally, the MACDP will display the system status for operator convenience. In the event of an MCU failure, the MACDP provides independent manual control of the system.

3.4.4 MASTER CONTROL UNIT (MCU)

The MCU is a computer-based control system that automatically starts, monitors, and shuts down the ASPCP system as required and provides operator control of the system through the video terminal of the MCU. The MCU also transmits system status information to the APS SOC in downtown Phoenix.

3.4.5 ON-SITE DATA ACQUISITION SYSTEM (ODAS)

The ODAS is a computer-based data acquisition system that will have government furnished equipment (GFE). The ODAS will be completely independent of the system control functions. The weather station will be GFE.

3.4.6 VISITOR'S CENTER

A visitor's center will be located in the facilities building and tours will be established by the Arizona Solar Energy Research Commission (ASERC). A visitor's display panel will display system status and parameters. In addition to providing a highly visible focal point of interest to visitors, the display will also function as a status board for the system operator.

3.4.7 POWER DISTRIBUTION EQUIPMENT

Standard utility power distribution panels will be installed in the facilities building to provide power for lighting, heating, ventilating and air conditioning, and the AC array power.

3.5 Underground Transmission Cable

The inverter output power is transmitted to the South Concourse Building of Terminal Module 3 via a 4500 foot, underground, 12.5 kV transmission cable. The voltage is stepped-up from 480 volts to 12.5 kV to reduce transmission losses. It is then stepped down to 480 volts for use in Terminal Module 3.

3.6 South Concourse Building

Located inside the South Concourse Building are the nondedicated and dedicated loads and remote computer measurement, control, and data processing equipment.

3.6.1 AUXILIARY SWITCHGEAR

The auxiliary switchgear comprises the necessary motor driven circuit breakers, solid state switch, and sensor that automatically or manually operate the system in any one of the three operating modes. The auxiliary switchgear is located outside the South Concourse Building in a weatherproof enclosure.

3.7 Main Terminal Building Display

A main terminal display will be designed and installed in the new airport main terminal building of Terminal Module 3 by the ASERC. A modem and TV monitor will be provided for the display. The display will also include an architectural model of the ASPCP and solar energy information displays.

SECTION 4 — SYSTEM ANALYSIS

4.1 System Interface Analysis

System interfaces were defined and analyzed to ensure system compatibility. The system definition at the beginning of phase I was the phase I proposal definition. The phase I proposal system configuration is shown in Figure 4-1, and the initial system sizing analysis is shown in Table 4-1.

Table 4-1. Array and Array Field Sizing Analysis, Phase I Proposal

REQUIREMENTS	
Load: 500 kWe, 480V, 3 ϕ , 60 Hz at inverter output	
Inverter input voltage: 350 VDC minimum	
ASSUMPTIONS	
Solar insolation: 1000 W/m ²	
Ambient temperature: 27°C	
Meinel optical module power: 39 We	
Meinel optical module voltage: 1.94 VDC	
Meinel optical module current: 20.1 ADC	
Inverter loss: 8 percent	
Wire loss: 2 percent	
ANALYSIS	
• Array output voltage = inverter input voltage + interconnection losses	
• Number of modules per array = $\frac{\text{array output voltage}}{\text{concentrator voltage}} = \frac{(350 + 7) \text{ VDC}}{1.94 \text{ VDC}} = 184 \text{ modules}$	
(For mechanical reasons, number of modules per array = 190 modules)	
• Array output power	= Concentrator module voltage x number of modules per array = 39 We x 190 = 7410 We
• Array output voltage	= Concentrator module voltage x number of modules per array = 1.94 VDC x 190 = 369 VDC
• Required array field	= Required load power + inverter loss + wire loss
Output power	= 500 kWe + 55.6 kWe = 555.6 kW
• Required number of arrays	= $\frac{\text{Required array field output power}}{\text{array output power}}$ $\frac{555.6 \text{ kWe}}{7.42 \text{ kWe}} = 75 \text{ Arrays}$

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Figure 4-1. Overall System Configuration, Phase I Proposal

During phase I, the system analysis and design and component analysis and design were performed in parallel. The system definition changed from the phase I proposal definition due to further definition of the program objectives and detailed definition of the system components. The major changes were due to:

1. The Sandia directive to make the control and data acquisition subsystems completely independent. This change was requested to achieve a uniform data acquisition system design and to ensure commonality in data retention. For a large system, this change requires significant redundancy in computer based equipment.
2. The decision by APS and GED to demonstrate automatic control by the Master Control Unit (MCU). The change was made based on economic trade-off analyses and the desire to operate the ASPCP in accordance with standard utility operating procedures for a generating plant of this size. This change required the inclusion of motorized circuit breakers and redesign of the standard inverter logic and control circuitry.
3. The decision by GED to use two 250 kW inverters in parallel. This change was primarily based on the unavailability of a single 500 kW inverter from Teledyne Inet. However, GED also feels that if the economic penalties are not too severe, there is a need to evaluate the parallel operation of large inverters in a solar P-V system. Eventually, the size of solar P-V systems will exceed the practical size of inverters and they will have to be paralleled to perform the DC-to-AC conversion. In addition, the use of parallel inverters provides the added benefit of redundancy. Teledyne Inet has experience in the parallel operation of large inverters.
4. The array design change from a single-pedestal array to a low-profile, circular-rail array. This change was based on economic trade-off analyses and engineering judgement as to the practicality of design (see paragraphs 3.3.1.1 and 5.3).

The final system configuration is described in Section 3, and is depicted in Figure 3-1. The system interfaces are described below.

The requirements for interfaces between data points are as follows:

1. Use an interconnecting cable that can physically and environmentally endure the outdoor, ambient environment.
2. Use an interconnecting cable that will prevent electromagnetic interference and/or cross-talk of signals.
3. Use sensors that are signal level and impedance compatible with the MCU/ODAS input circuitry. In the event that such sensors are not available, use or develop appropriate interface circuitry.
4. Provide spare cables for redundancy.

4.1.1 ARRAY-TO-ARRAY INTERFACE

Two array interconnection configurations have been defined and are described in paragraphs 3.3.1.2 and 5.4.2. One is the series connection of all modules on a single array. There is no array-to-array interface for this configuration. The second is the series connection of all modules on the same subarray tier level on a single array and the interconnection of those modules with modules on the same tier level on two other arrays.

The array-to-array interface requirements are to:

1. Connect the arrays together with connecting devices and wire of a size sufficient to keep the total system losses below two percent.

2. Include appropriate switches and/or circuit breakers to allow isolation of individual arrays for maintenance and repair.

The wire size was determined on the basis of voltage drop rather than current capacity. The subarrays on interfacing arrays are connected by way of a control panel enclosure, array junction box, and stationary junction box located on each array. Varying wire sizes from 4/0 to 2/0 will be used to levelize the interconnect losses in the array field.

4.1.2 ARRAY-TO-APMP INTERFACE

The DC output of each of the 57 array triplet groups and the two series arrays is separately wired to the Array Paralleling and Monitoring Panel (APMP). The arrays are wired from the control panel enclosure to the APMP with a two-wire system isolated from ground. The DC voltage level in each of the 59 strings is nominally 466 VDC, and each string current is nominally 20.6 ADC.

The array-to-APMP interface requirements are to:

1. Connect the arrays to the APMP with connecting devices and wire of a size sufficient to keep the total system losses below two percent.
2. Include appropriate switches and/or circuit breakers to allow isolation of individual arrays for maintenance and repair.

The wire sizes will be the same as the array-to-array interconnection wire sizes and will range from 4/0 to 2/0 depending on the length of the wire runs.

4.1.3 ARRAY-TO-AC POWER DISTRIBUTION INTERFACE

The array-to-AC power distribution interface consists of 3 ϕ circuits plus a ground wire to each array to provide AC power for the hybrid tracker electronics, the azimuth and elevation drive systems, and the maintenance outlets.

As with the DC power wiring, the AC wiring will consist of a variety of sizes to maintain minimum voltage drops. The wire sizes required will range from 2 AWG to 6 AWG depending on the length of the wire run. The ground wire can be 6 AWG in all cases.

4.1.4 ARRAY-TO-MCU INTERFACE

The array-to-MCU interface consists of signal control lines for each of the 59 arrays for stow command stow verification signals. Additional signal control lines come from the instrumented array (array number 25) for wind speed and direction, direct normal insolation, reference solar cell, and possibly module primary surface temperature signals.

The signal control lines will be shielded, twisted-pair, insulated cables. The MCU interface circuitry has been identified and tentatively selected pending final definition of the On-Site Data Acquisition System (ODAS) computer type. The sensor interfaces were not completely defined during phase I due to the lack of definition of the weather instruments.

4.1.5 ARRAY-TO-ODAS INTERFACE

The array-to-ODAS interface consists of signal data lines from the instrumented array for module cell temperature, module heat sink temperature, reference solar cell, module cover temperature, array strain gauges, module cell

mount temperature, module internal air temperature, wind speed and direction, module primary surface temperature, and direct normal insolation signals.

The signal control lines will be shielded, twisted-pair, insulated cables. As soon as the ODAS equipment type is defined, definition of the interfacing circuitry can be completed.

4.1.6 ARRAY-TO-COMMUNICATIONS SYSTEM INTERFACE

Personnel working on the solar arrays must have the capability to communicate with each other and with personnel in the facilities building to perform the initial installation and test, to operate the system, to perform maintenance and repair, and to ensure safety.

The communications system has been defined, and specifications are included as an appendix to this report. Each solar array junction box will have an insulated, two-wire phone jack with a weatherproof hinged cover. Personnel equipped with sound powered telephones will be able to communicate with each other while working on the solar arrays. In addition, seven speaker/handset stations will be strategically located throughout the array field to provide public address and intercom functions.

4.1.7 APMP-TO-INVERTER INTERFACE

The APMP-to-inverter interface consists of a two-conductor DC bus isolated from ground and a manual, main disconnect switch. The requirements of the APMP-to-inverter interface are:

1. The two-conductor, DC bus shall be isolated from ground, nominal 456 VDC.
2. The two-conductor, DC bus shall be of sufficient capacity to safely conduct up to 1250 ADC and shall be of sufficient size to keep the total system losses within 2 percent.
3. A manual, main disconnect switch of the proper rating shall be installed between the APMP and the inverter to allow isolation from the solar power source.

4.1.8 APMP-TO-MCU INTERFACE

The APMP-to-MCU interface consists of signal control and signal data lines for system bus voltage and system bus current.

These signals will be used to determine the array field power and will be processed by the MCU to perform maximum power point (MPP) tracking.

4.1.9 APMP-TO-ODAS INTERFACE

The APMP-to-ODAS interface consists of signal data lines for array string current and bus voltage. These lines are used to analyze individual array performance.

4.1.10 INVERTER-TO-UNDERGROUND TRANSMISSION LINE INTERFACE

The inverter-to-underground transmission line interface consists of the necessary connecting equipment required to step up the output of the inverter to 12.5 kV for transmission underground to the switchgear located just outside the South Concourse Building of Terminal Module 3.

4.1.11 INVERTER-TO-MACDP INTERFACE

The inverter-to-MACDP interface consists of signal control, status, and alarm lines. During normal operation, the MACDP will serve as a visual display panel, and the signals will automatically feed into the MCU. In the event that the MCU is down for repair or maintenance, the MACDP will be used to provide manual control of the system.

4.1.12 INVERTER-TO-UTILITY REFERENCE INTERFACE

The inverter must operate in synchronism with the utility. To accomplish this, sync lines are provided which originate on the utility side of the south concourse.

4.1.13 INVERTER-TO-LOAD INTERFACE

The inverter must regulate its output voltage with respect to the load voltage. The requirements of the inverter-to-load interface are to: Provide to the inverters directly connected 3 ϕ , 480 volt, 60 Hz lines for voltage regulation. These lines shall originate on the load side of the south concourse step-down transformer. The length of these lines should be kept to a minimum.

4.1.14 MCU-TO-MACDP INTERFACE

All signal control, status, and alarm lines necessary to operate the ASPCP must be routed both to the MCU and to the MACDP. This is necessary to allow manual operation of the ASPCP via the MACDP in the event that the MCU is down.

4.1.15 MACDP-TO-APMP INTERFACE

The MACDP-TO-APMP interface consists of signal control lines for system bus voltage and system bus current. These signals will be used to determine the array field power and will be processed by hardware in the MACDP to perform MPP tracking in the manual mode (prior to MCU installation or when the MCU is down for repair or maintenance.).

4.1.16 MACDP-TO-ARRAY INTERFACE

The MACDP-to-array interface consists of signal control lines to each of the 59 arrays for manual stow command and stow verification signals. Additional signal control lines come from the instrumented array (array number 25) for wind speed and direction, direct normal insolation, reference solar cell, and possibly module primary surface temperature signals.

The signal control lines will be shielded, twisted pair, insulated cables. The MACDP has conceptually been designed during phase I and is discussed in paragraph 5.9.2. The detail design of the MACDP will be completed during phase II once the MCU, ODAS, and weather station definitions are complete. The sensor interfaces depend on the weather station instrument definition.

4.1.17 MACDP-TO-AUXILIARY SWITCHGEAR INTERFACE

The MACDP-to-auxiliary switchgear interface consists of signal control and status lines from the solid state switch (S1), the motorized circuit breakers CB1, CB2, and CB8, and the air-gap current transformers.

The signal control lines will be shielded, twisted pair, insulated cables. The interfaces have been identified and are defined in paragraphs 5.8 and 5.9.2.

4.1.18 MACDP-TO-LOAD INTERFACE

The MACDP-to-load interface consists of signal data lines for the dedicated load power measurement.

The signal data lines will be shielded, twisted pair, insulated cables. The interfaces have been designed and are defined in paragraphs 5.7, 5.8, and 5.9.

4.1.19 MCU-TO-VISITORS DISPLAY INTERFACE

The MCU-to-visitors display interface consists of signal data lines for display of pertinent ASPCP operation information.

4.1.20 MCU-TO-SOC INTERFACE

The MCU-to-System Operations Center (SOC) interface consists of signal data lines and a MODEM remote station for monitoring the operational status of the ASPCP by APS operations personnel located at the SOC in downtown Phoenix. The requirement of this interface is to install a remote communications system to allow the sensing and transmittal of ASPCP operational status to the APS SOC.

The SOC interface design was analyzed by APS and GED during phase I. The details of the trade-off analysis is presented in paragraph 2.2.4.

4.1.21 MCU-TO-REMOTE DATA TERMINAL INTERFACE

The MCU-to-remote data terminal interface consists of a single serial data link line for load power data, solid state switch and motorized circuit breaker status and control, and the dedicated load undervoltage signals.

The signal data lines will be shielded, twisted-pair, insulated cables. The interfaces have been identified and are defined in paragraph 5.9.5.

4.1.22 ODAS-TO-WEATHER STATION INTERFACE

The ODAS-to-weather station interface consists of signal data lines for data retention of direct normal insolation, total horizontal insolation, ambient air temperature, reference solar cell output, humidity, precipitation, barometric pressure, and wind speed and direction information. Both the ODAS and the weather station equipment will be GFE.

The signal data lines will be shielded, twisted-pair, insulated cables. The interface design was not done during phase I. When the detailed designs of both the ODAS and the weather station equipment are available, the interface design can be accomplished. The ODAS is discussed in paragraph 5.10.

4.1.23 ODAS-TO-POWER SENSORS INTERFACE

The ODAS-to-power sensors interface consists of signal data lines for the collection and analysis of system power demand and generation data. The data will be used in the system life cycle cost analyses.

The signal data lines will be shielded, twisted pair, insulated cables. The interfaces have been identified and are total facilities building AC power demand, array AC power demand, and inverter output current, voltage, and phase.

4.1.24 ODAS-TO-TELEPHONE NETWORK INTERFACE

The ODAS-to-telephone network interface consists of a MODEM to transmit selected ASPCP data to a DOE National Data Reduction Center for retention, reduction, and analysis. The requirements of this interface are to:

Provide appropriate telephone lines and data access equipment to allow the transmittal of ASPCP data to the Data Reduction Center.

This interface is defined in APS document A-54422.

4.1.25 REMOTE DATA TERMINAL-TO-AUXILIARY SWITCHGEAR INTERFACE

The remote data terminal-to-auxiliary switchgear interface consists of signal control and data lines for solid state

switch and motorized circuit breaker control and status, load power data, the undervoltage sensor data, and the power flow between the dedicated load and the nondedicated load.

The signal data lines will be shielded, twisted-pair, insulated cables. The interfaces have been identified and are defined in paragraphs 5.8 and 5.9.

4.1.26 AUXILIARY SWITCHGEAR-TO-UNDERGROUND TRANSMISSION LINE INTERFACE

The auxiliary switchgear-to-underground transmission line interface consists of the necessary equipment required to connect the high voltage, underground transmission line output to the auxiliary switchgear through a step-down transformer and a meter enclosure. The requirements of this interface are to:

1. Connect the output of the 12.5 kV underground transmission line to a 750 kVA step-down transformer.
2. Connect the transformer output to a metering enclosure that contains a motorized circuit breaker and standard utility metering equipment.
3. Connect the metering enclosure to the auxiliary switchgear with a standard utility 480/277 volt, 3 ϕ , Y connected system.
4. Connect circuit breaker motor power, control, and status lines from the metering enclosure to the auxiliary switchgear enclosure using the appropriate wire and/or cable.

The details of these interfaces are discussed in paragraph 6.8.

4.1.27 AUXILIARY SWITCHGEAR-TO-DEDICATED LOAD INTERFACE

The auxiliary switchgear-to-dedicated load interface consists of a 480 volt, 3 ϕ , 4-wire power line that feeds either solar generated or utility generated power to the dedicated load as determined by the state of the auxiliary switchgear. The requirements of this interface are to connect the power output line from the auxiliary switchgear to the dedicated load using standard 480 volt, 3 ϕ , 4-wire interconnecting equipment.

The details of this interface have been defined and the airport electrical contractor drawing modifications have been prepared. The actual interface wiring modifications will be made in accordance with the airport schedule and with the phase II award announcement.

4.1.28 AUXILIARY SWITCHGEAR-TO-NONDEDICATED LOAD INTERFACE

The auxiliary switchgear-to-nondedicated load interface consists of a 480 volt, 3 ϕ , 4-wire power line that feeds either the solar generated power to the nondedicated load or the utility generated power to the auxiliary switchgear (and eventually to the dedicated load) depending on the state of the auxiliary switchgear. The requirements and definition status are the same as paragraph 4.1.27.

4.1.29 UTILITY FEEDER-TO-LOAD INTERFACE

The utility feeder-to-load interface consists of a 3000 ampere, 480 volt, 3 ϕ , 4-wire system connected to the South Concourse Building load through appropriate interconnecting transformers, meter panels, circuit breakers, etc. The requirements for this interface are to connect the utility feeder to the nondedicated load and to the dedicated load (through the auxiliary switchgear) in a manner that assures uninterrupted service to the load at all times, independent of the ASPCP power output. Use standard utility interconnecting equipment.

4.1.30 MAIN TERMINAL DISPLAY-TO-ODAS INTERFACE

The main terminal display-to-ODAS interface consists of a telephone data link to allow transmission of selected ASPCP solar data to a public display in the main terminal building of Terminal Module 3. The requirements of this interface are to connect the ODAS MODEM output to the main terminal display MODEM using the telephone system standard equipment.

The details of this interface will be defined during the early part of phase II upon the determination of the data requirements for the main terminal display. This display will be designed and provided by the Arizona Solar Energy Research Commission (ASERC).

4.1.31 UTILITY FEEDER-TO-FACILITIES BUILDING INTERFACE

The utility feeder-to-facilities building interface consists of a 480 volt, 3 ϕ , 4-wire system connected to the facilities building through appropriate interconnecting transformers, circuit breakers, power distribution panels, etc. This feeder line originates at a different source than the airport feeder line. The requirements of this interface are to connect the utility feeder to the power distribution panel in the facilities building using standard utility interconnecting equipment.

The details of this interface are described in paragraphs 6.4 and 6.5.

4.1.32 AC POWER DISTRIBUTION-TO-ASPCP INTERFACES

The AC power distribution-to-ASPCP interfaces consist of:

1. 480 volt HVAC power panel.
2. 208/120 volt power panel for AC power requirements of all electronic equipment, lights and receptacles, and the water heater in the facilities building.
3. 480 volt, 3 ϕ , power for outdoor lighting. Each of the segments of lights will be supplied by a single phase wire.

The requirements of this interface are to connect the necessary electrical distribution equipment from the power distribution panel to all electrical equipment in the facilities building using standard electrical construction procedures in accordance with applicable codes.

The details of this interface are discussed in paragraph 6.4 and 6.5.

4.1.33 EMERGENCY POWER-TO-ASPCP INTERFACE

In the event that the utility feeder line that feeds the facilities building suffers a sustained outage, power will be fed back to the facilities building from the airport utility feeder line. The requirements of this interface are to connect the AC power line at the inverter output to the AC power distribution panel using appropriate utility interfacing equipment.

This interface is discussed in paragraphs 4.6 and 6.5.

4.1.34 LIGHTNING PROTECTION-TO-ASPCP INTERFACES

The lightning protection-to-ASPCP interfaces are at:

1. Each array-to-ground.
2. Facilities building-to-ground.

The requirements of these interfaces are to connect a grounding system to the ASPCP arrays and facilities building adequate to protect the solar array electronics and the facilities building equipment from being damaged during lightning storms. Use standard grounding components wherever possible. The details of this interface are discussed in paragraph 6.4.3.

4.2 Weather Data Modeling

An investigation was made locally to acquire a detailed weather data history for Phoenix. The Arizona Climatological Laboratory, located at Arizona State University, offered very general data on temperature and wind speed but did not have readily available detailed data on direct normal solar radiation, temperature, and wind speed.

The lab suggested that it might be possible to research their temperature and wind speed computer tapes to generate a detailed data bank for our requirements, but time and cost were limiting factors.

For these reasons, it was decided to contact Sandia for weather data.

Sandia provided typical meteorological year (TMY) data for Phoenix. These data were compiled from data rehabilitated and maintained by the National Climatic Center. Each month in the TMY, data were selected as being most typical of that month in data collected from January 1953 through December 1975. Weather data are given for hourly intervals. Wind speed resolution is 0.1 meter per second. Air temperature resolution is 0.1 degree C. Solar radiation resolution is 1 watt per meter squared.

Weather data is used in the SYSTEM (refer to paragraph 4.3) program to predict system performance for a typical year. Direct normal solar radiation, air temperature, and wind speed are used by the program. The SYSTEM program linearly interpolates between the hourly data to generate more frequent data. This is necessary to evaluate shading effects in the morning and evening. One-tenth hour to one-quarter hour intervals have been used, depending on the accuracy desired. Air temperature and wind speed may be used to determine the solar cell temperature. Solar radiation data determines the illumination falling on the solar cell. This allows the cell output power to be calculated, which determines the system output power.

4.3 System Performance Analysis

A system model computer program named SYSTEM was developed by GED to provide the basic analytical tool for system analysis. In addition, computer models for individual components were developed to aid in component design and to predict performance.

The program listings are included herein for reference. These programs will be kept up to date and on file at GED as the system definition continues in phase II and as data becomes available throughout phases II and III.

4.3.1 PROGRAM DESCRIPTION

SYSTEM (Figure 4-2) is a model of a solar power system. Its primary purpose is to predict the energy output of the system. It can also predict system conditions at intervals during a day. The program is most useful in selecting system configurations that maximize the energy output.

The system model includes the effects of insolation, air temperature, wind speed, shading, module efficiency, cell performance, heatsink performance, inverter efficiency, and wiring losses. Each effect is calculated in a separate subroutine, allowing easy modification.

C	AH	SUB-ARRAY HEIGHT. IF MODULES ARE MOUNTED IN OFFSET ROWS,
C		THE EFFECTIVE SHADING HEIGHT BETWEEN SUB-ARRAYS ON THE
C		SAME TRACKER MAY BE LESS THAN THE ACTUAL SUB-ARRAY
C		HEIGHT. THIS HEIGHT IS ENTERED IN AH(1). AH(2) CONTAINS
C		THE ACTUAL SUB-ARRAY HEIGHT, WHICH IS USED FOR INTER-
C		ARRAY SHADING. FEET
C	NT	NUMBER OF TRACKERS
C	NST	NUMBER OF STRINGS PER TRACKER. STRINGS ARE HORIZONTALLY
C		ORIENTED SERIES STRINGS OF MODULES. MODULES OF THE SAME
C		HEIGHT ON EACH SUB-ARRAY ARE ALL WIRED TOGETHER TO GIVE
C		POWER OUTPUT BEFORE THE FULL SUB-ARRAY IS UNSHADED.
C	NAT	NUMBER OF SUB-ARRAYS PER TRACKER
C	AS	SUB-ARRAY SEPARATION. DISTANCE BETWEEN SUB-ARRAYS ON
C		TRACKER. SUB-ARRAYS ARE CENTERED ON THE TRACKER. FEET
C	ENOSH	ANGLE, IN DEGREES ELEVATION, AT WHICH NO SHADING
C		CAN OCCUR. THIS SPEEDS UP THE PROGRAM IF CAREFULLY
C		USED. AT LEAST ONE INTERVAL OF NO SHADE MUST OCCUR
C		BEFORE THIS ANGLE.
C	EFF	MODULE OPTICAL EFFICIENCY
C	PR	RADIUS OF PRIMARY MIRROR, INCHES
C	SR	RADIUS OF SECONDARY MIRROR, INCHES
C	EFFW	WIRE EFFICIENCY
C	MPS	NUMBER OF MODULES PER ARRAY SERIES STRING
C	NSS	NUMBER OF ARRAY SERIES STRINGS NEEDED TO REACH
C		INVERTER INPUT VOLTAGE.
C	RFC	HEATSINK THERMAL RESISTANCE, C/WATT
C		6 VARIABLE ARRAY, RFC(1) IS FOR 0-.9 M/S WIND, RFC(6)
C		IS FOR 5M/S WIND AND ABOVE
C	WF	WIND FACTOR, NOT USED
C	LAT	LATITUDE OF ARRAY FIELD (NORTH)
C	LONG	LONGITUDE OF ARRAY FIELD (WEST)
C	STDLONG	STANDARD LONGITUDE FOR TIME ZONE
C	GVO	SOLAR CELL OUTPUT VOLTAGE (FOR CONSTANT VOLTAGE
C		OPERATION) OR GUESS AT MAX POWER VOLTAGE (1 CELL)
C		TRY .6 VOLTS.
C	MAXP	1 FOR MAX POWER CELL OUTPUT
C		0 FOR CONSTANT VOLTAGE CELL OUTPUT
C	JOP	2 VARIABLE ARRAY. JOP(1)=1 FOR UPDATE PRINT
C		JOP(2)=1 FOR DAILY PRINT. (SEE OUTPUT).
C		IF BOTH ARE 0, NO OUTPUT WILL RESULT.
C	DS	DAY (1-365) AT WHICH CALCULATION STARTS
C	DE	LAST DAY CALCULATED
C	DT	UPDATE INTERVAL. PERFORMANCE IS CALCULATED AT INTERVALS
C		OF 'DT' HOURS. .1 HOUR HAS BEEN USED SO FAR.
C	XYO	TRACKER POSITIONS. X AND Y COORDINATES, IN FEET,
C		OF EACH ARRAY. ANY CONVENIENT TRACKER OR POINT
C		MAY BE SELECTED AS ZERO. XYO(1,N) = X POSITION OF ARRAY
C		N, XYO(2,N) = Y POSITION OF ARRAY N.
C	MULT	TRACKER MULTIPLIER. EACH TRACKER CAN REPRESENT OTHER
C		IDENTICALLY SHADED TRACKERS. MULT CONTAINS THE NUMBER
C		OF TRACKERS EACH TRACKER IN XYO REPRESENTS. THIS
C		REDUCES THE NUMBER OF SHADE CALCULATIONS NEEDED.
C		(MUST BE ALL 1'S UNLESS NOWIRE=1)
C	NWIRE	STRING WIRING ARRAY. STRINGS ARE NUMBERED BOTTOM

Figure 4-2. SYSTEM Program (Sheet 2 of 14)

```

C      TO TOP, 1-NST. TRACKERS ARE NUMBERED IN ORDER
C      OF INPUT. NWIRE CONSISTS OF NST*NT/NSS SETS
C      OF NSS SETS OF STRINGS. STRINGS ARE IDENTIFIED
C      BY TRACKER NUMBER AND STRING NUMBER. (SEE INPUT
C      FORMAT FOR FURTHER INFORMATION)
C      NOWIRE 1 FOR NO STRING WIRING. THE INTEGER PORTION OF
C      ACTIVE ARRAY STRINGS DIVIDED BY NSS WILL BE
C      CONSIDERED THE ACTIVE INPUT STRINGS TO THE
C      INVERTER. 0 FOR NORMAL WIRING.
C      CL,SLF INVERTER EFFICIENCY IS :
C      (PWR-CL-((PWR-CL)/SLF)**2)/PWR
C      PWR=INPUT POWER IN WATTS
C      (CL=21120,SLF=3795)
C      CA CELL ABSORPTION. FRACTION OF ILLUMINATION ABSORBED
C      BY CELL, FOR HEATING PURPOSES
C
C      INPUT FORMAT:
C
C      ALL VARIABLES EXCEPT XY0, NWIRE, AND MULT ARE ENTERED VIA AN
C      'INPUT'
C      STATEMENT. VARIABLES ARE INPUT AS DS=1,DE=2 WITH AN * AT THE END
C      OF ALL DATA. THEN ARRAY FIELD DATA IS ENTERED. THE X COORDINATE
C      IS ENTERED, THEN THE Y COORDINATE, THEN THE MULTIPLIER FOR THAT
C      TRACKER. FOR A TWO ARRAY FIELD :
C
C      ...
C      NT=2
C      *
C      0,0,1
C      100,100,1
C
C      AFTER ARRAY POSITIONS ARE ENTERED, STRING WIRING IS
C      ENTERED. AN EXAMPLE FOR THE TWO ARRAY FIELD (NST=3,
C      NSS=3) IS:
C
C      1,1
C      1,2
C      2,1
C      2,2
C      2,3
C      1,3
C
C      THIS WOULD WIRE STRINGS 1 AND 2 OF TRACKER 1 TO STRING
C      1 OF TRACKER 2, AND STRINGS 2 AND 3 OF TRACKER 2 TO STRING
C      3 OF TRACKER 1. CARE MUST BE TAKEN TO USE EACH STRING
C      ONCE AND ONLY ONCE, THE PROGRAM WILL NOT CHECK WIRING.
C      IF NOWIRE=1, WIRING NEED NOT BE ENTERED.
C
C      WEATHER DATA IS ENTERED THROUGH DEVICE #1 AND SHOULD
C      BE INITIALIZED AS:
C
C      !SET F:1/TMYPHX
C
C      OUTPUT:
C
C      JOP(1)=1:

```

Figure 4-2. SYSTEM Program (Sheet 3 of 14)

THE DAY IS PRINTED OUT FOLLOWED BY A TABLE WITH:

1. THE HOUR OF DAY (0-24 SOLAR)
2. SOLAR FLUX DENSITY, W/M**2
3. CELL TEMPERATURE, KELVIN
4. NUMBER OF ACTIVE ARRAY STRINGS
5. FIELD VOLTAGE, VOLTS
6. FIELD CURRENT, AMPS
7. SYSTEM POWER, WATTS
8. ENERGY OUTPUT SINCE SUNRISE, WATT HOURS
9. ENERGY AVAILABLE SINCE SUNRISE, WATT HOURS

JOP(2)=1:

AFTER JOP(1) HAS PRINTED, THE DAY IS AGAIN PRINTED AND THE ENERGY OUTPUT FOR THE DAY IS PRINTED IN WATT HOURS. IF THIS IS THE LAST DAY (DE), THE ENERGY OUTPUT FROM THE FIRST DAY TO LAST IS PRINTED (WITH A DAY ONE AFTER DE).

```

DIMENSION XY0(2,200),MULT(200),JOP(2),RFC(6)
DIMENSION AH(2),AL(10),OUTPUT(10,200),NWIRE(2,10,200)
NAMelist DS,DE,JOP,GVO,MAXP,DT,LAT,LONG,STDLONG
NAMelist EFF,PR,SR,EFFW,MPS,NSS,RFC,WF,CA,SLF,CL
NAMelist NT,AH,AL,NST,NAT,AS,ENOSH,NOWIRE,HSH
REAL LONG,LAT,LATH
INTEGER DAY
GLOBAL DS,DE,JOP,GVO,MAXP,DT,LAT,LONG,STDLONG
GLOBAL EFF,PR,SR,EFFW,MPS,NSS,RFC,WF,CA
GLOBAL NT,AH,AL,XY0,MULT,PI,NST,NAT,AS,HSH
GLOBAL ENOSH,NWIRE,NOWIRE,CL,SLF
READ (105,21) MULT(I),I=1,40
21 FORMAT (40A)
WRITE (108,21) MULT(I),I=1,40
PI=3.14159
INPUT
LATR=LAT*2*PI/360
DO 10 J=1,NT
INPUT XY0(1,J),XY0(2,J),MULT(J)
10 CONTINUE
IF(NOWIRE.EQ.1) GOTO 17
DO 15 I=1,NT*NST/NSS
DO 12 J=1,NSS
INPUT NWIRE(1,J,I),NWIRE(2,J,I)
12 CONTINUE
15 CONTINUE
17 ENERGY=0
AENG=0
DO 900 DAY=DS,DE
IF(JOP(1).EQ.1) OUTPUT DAY
DENENERGY=0
DAENG=0
SRI=-TAN(LATR)*TAN(.40928*SIN(2*PI*(284+DAY)/365))
SRI=12-AINT((57.296*ACOS(SRI)/15)/DT+1)*DT+DT/2
SS=24-SRI

```

Figure 4-2. SYSTEM Program (Sheet 4 of 14)

```

DO 100 HOUR=SKI,SS,DT
20 CALL WEATHER(DAY,HOUR,FLUX,TEMP,WIND)
   CALL SHADE(DAY,HOUR,OUTPUT)
   CALL MODULE(FLUX,PWR)
   CALL HEATSINK(TEMP,WIND,PWR,CTEMP)
   CALL CELL(PWR,CTEMP,GVO,MAXP,CVOLTS,CAMPS)
   CALL WIRING(OUTPUT,CVOLTS,CAMPS,SVOLTS,SAMPS,ACTIVE)
   CALL INVERTER(SVOLTS,SAMPS,POWER)
   AENG=FLUX*DT+AENG
   DAENG=FLUX*DT+DAENG
   ENERGY=POWER*DT+ENERGY
   DENERGY=POWER*DT+DENERGY
30 IF(JOP(1).EQ.1) WRITE(108,1) HOUR,FLUX,CTEMP,ACTIVE,
   C                               SVOLTS,SAMPS,POWER,DENERGY
1   FORMAT(F6.2,I7,F8.1,I7,F10.2,F10.1,I9,F15.1)
100 CONTINUE
   IF(JOP(2).EQ.1) WRITE(108,2) DAY,DENERGY,DAENG
2   FORMAT(I4,2G30)
900 CONTINUE
   IF(JOP(2).EQ.1) WRITE(108,2) DAY,ENERGY,AENG
   STOP
   END

C
C
C   SUBROUTINE POSITION(DAY,HOUR,LAT,A,E)
C
C *****
C
C   INPUT
C   DAYS=    NUMBER OF DAY (1-365)
C   HOUR=    HOUR OF DAY (0-24 SOLAR)
C   LAT=     LATITUDE OF ARRAY FIELD
C
C   OUTPUT
C   A=       AZIMUTH ANGLE OF SUN (0=SOUTH)
C   E=       ELEVATION ANGLE OF SUN (0=HORIZON)
C *****
C
C   INTEGER DAY
C   REAL LAT, LONG, LATR
C   CONV=3.141593/180
C   LATR=LAT*CONV
C   DECL=23.45*CONV*SIN(360*((284+DAY)/365)*CONV)
C   HA=((15*HOUR)-180)*CONV
C   E=ASIN(SIN(LATR)*SIN(DECL)+COS(LATR)*COS(DECL))*
C   COS(HA))/CONV
C   A=ATAN(SIN(HA)/(SIN(LATR)*COS(HA)-COS(LATR)*
C   TAN(DECL)))/CONV
C   CHECK=A-HA/CONV
C   IF(CHECK.GT.90) A=A-180
C   IF(CHECK.LT.-90) A=A+180
C   RETURN
C   END

```

Figure 4-2. SYSTEM Program (Sheet 5 of 14)


```

C
C
SUBROUTINE CLKTIME(CHOUR,SHOUR,DAY,LONG,STDLONG)
C
C*****
C
C      INPUT
C      SHOUR    SOLAR HOUR (0-24)
C      DAY      NUMBER OF DAY (1-365)
C      LONG     LONGITUDE OF ARRAY FIELD
C      STDLONG  STANDARD LONGITUDE OF TIME ZONE
C
C      OUTPUT
C      CHOUR    CLOCK TIME HOUR (0-24)
C
C      ARRAY E IS USED FOR THE EQUATION OF TIME CORRECTION
C              IN MINUTES IF DESIRED
C*****
C
C      REAL LONG
C      INTEGER DAY
C      DIMENSION E(365)
C      CHOUR=SHOUR-(E(DAY)+4*(STDLONG-LONG))/60
C      RETURN
C      END
C
C
SUBROUTINE MODULE(FLUX,POWER)
C
C*****
C
C      INPUT
C      FLUX      SOLAR FLUX DENSITY ON MODULE, W/M**2
C      EFF       MODULE OPTICAL EFFICIENCY
C      PR        PRIMARY MIRROR RADIUS, INCHES
C      SR        SECONDARY MIRROR RADIUS, INCHES
C      PI        3.14...
C
C      OUTPUT
C      POWER     SUN POWER STRIKING SOLAR CELL, WATTS
C*****
C
C      GLOBAL EFF,PR,SR,PI
C      POWER=FLUX*.64516/1000*(PR**2-SR**2)*PI
C      POWER=POWER*EFF
C      RETURN
C      END
C
C
SUBROUTINE INVERTER(SVOLTS,SAMPS,POWER)
C

```

Figure 4-2. SYSTEM Program (Sheet 6 of 14)

```

C*****
C
C      INPUT
C      SVOLTS  FIELD VOLTAGE, VOLTS
C      SAMPS   FIELD CURRENT, AMPS
C      EFFI    INVERTER AND WIRE EFFICIENCY
C
C      OUTPUT
C      POWER   SYSTEM POWER, WATTS
C
C*****
C
C      GLOBAL EFFW,CL,SLF
C      POWER=SVOLTS*SAMPS
C      IF(POWER.LT.CL)POWER=0; GOTO 100
C      POWER=(POWER-CL-((POWER-CL)/SLF)**2)*EFFW
100  RETURN
C      END
C
C      SUBROUTINE WIRING(OUTPUT,CVOLTS,CAMPS,SVOLTS,SAMPS,ACTIVE)
C
C*****
C
C      INPUT
C      CVOLTS  CELL VOLTAGE, VOLTS
C      CAMP    CELL CURRENT, AMPS
C      MPS     MODULES PER ARRAY STRING
C      NSS     NUMBER OF ARRAY STRINGS/INVERTER INPUT STRING
C      OUTPUT(S,A) =1 IF STRING S, ARRAY A IS ON, 0 IF OFF
C      NWIRE   SEE MAIN PROGRAM
C      NT      NUMBER OF TRACKERS
C      NST     NUMBER OF STRINGS PER TRACKER
C
C      OUTPUT
C      SVOLTS  FIELD VOLTAGE, VOLTS
C      ACTIVE  NUMBER OF ACTIVE ARRAY STRINGS
C
C*****
C
C      DIMENSION NWIRE(2,10,200),OUTPUT(10,200),MULT(200)
C      GLOBAL MPS,NSS,NWIRE,MULT,NT,NST,NOWIRE
C      SVOLTS=CVOLTS*MPS*4*NSS
C      ACTIVE=0
C      IF(NOWIRE.NE.1) GOTO 100
C      DO 60 J=1,NT
C      DO 50 I=1,NST
C      ACTIVE=ACTIVE+OUTPUT(I,J)*MULT(J)
50  CONTINUE
60  CONTINUE
C      ACTIVE=AINT((ACTIVE+.1)/NSS)
C      GOTO 400
100  DO 300 J=1,NT*NST/NSS
C      SA=1

```

Figure 4-2: SYSTEM Program (Sheet 7 of 14)

```

DO 200 I=1,NSS
SA=OUTPUT(NWIRE(2,1,J),NWIRE(1,I,J))*SA
200 CONTINUE
ACTIVE=ACTIVE+SA
300 CONTINUE
400 SAMPs=CAMPs*ACTIVE/A
RETURN
END

C
C
C SUBROUTINE HEATSINK(TEMP,WIND,PWR,CTEMP)
C
C *****
C
C INPUT
C TEMP AIR TEMPERATURE, K
C WIND WIND SPEED, M/S
C PWR SUN POWER ON CELL, WATTS
C RFC HEATSINK THERMAL RESISTANCE, C/WATT
C WF WIND FACTOR
C
C OUTPUT
C CTEMP CELL TEMPERATURE, K
C
C *****
C
C DIMENSION RFC(6)
C GLOBAL RFC,WF,CA
C W=AIN(T(WIND))+1
C IF(W.GT.6) W=6
C R=RFC(W)
C CTEMP=TEMP+R*PWR*CA
C RETURN
C END

C
C
C SUBROUTINE WEATHER(DAY,HOOR,FLUX,TEMP,WIND)
C
C *****
C
C INPUT
C DAY NUMBER OF DAY (1-365)
C HOOR HOUR OF DAY (0-24 SOLAR)
C
C OUTPUT
C FLUX SOLAR FLUX DENSITY, W/M**2
C TEMP AIR TEMPERATURE, K
C WIND WIND SPEED, M/S
C
C *****
C
C DIMENSION WIND0(3),TEMP0(3),FLUX3(3),FLUX0(3)
C INTEGER RDAY,DAY
C IF(DAY.EQ.1.AND.HOOR.LT..5) HOOR=.5

```

Figure 4-2. SYSTEM Program (Sheet 8 of 14)

```

IF(DAY.EQ.365.AND.HOUR.GE.23.5) HOUR=23.499
NR=(DAY-1)*24+AIN(T(HOUR-.5)+2
IF(NR.LT.NRR) GOTO 900
IF(NR.EQ.NRR) GOTO 300
100 IF(NR.EQ.NRR+1) GOTO 200
120 IF((NR-NRR-2)/24.EQ.0) GOTO 150
READ (1,3)
3 FORMAT(8/)
NRR=NRR+24
RDAY=RDAY+1
GOTO 120
150 IF(NRR-RDAY*24.EQ.0) READ(1,2) RDAY
IF(NCR.EQ.0) READ (1,1) WIND0(J),TEMP0(J),FLUX3(J),FLUX0(J),
C J=1,3;NCR=3
NRR=NRR+1
NCR=NCR-1
WIND2=WIND0(3-NCR)
TEMP2=TEMP0(3-NCR)
FLUX2=FLUX0(3-NCR)
GOTO 100
200 WIND1=WIND2
TEMP1=TEMP2
FLUX1=FLUX2
HOUR1=NRR-(RDAY-1)*24-.5
IF(NRR-RDAY*24.EQ.0) READ (1,2) RDAY
IF(NCR.EQ.0) READ (1,1) WIND0(J),TEMP0(J),FLUX3(J),FLUX0(J),
C J=1,3;NCR=3
NRR=NRR+1
NCR=NCR-1
WIND2=WIND0(3-NCR)
TEMP2=TEMP0(3-NCR)
FLUX2=FLUX0(3-NCR)
HOUR2=NRR-(RDAY-1)*24-.5
300 R=(HOUR-HOUR1)/(HOUR2-HOUR1)
FLUX=FLUX1+(FLUX2-FLUX1)*R
WIND=WIND1+(WIND2-WIND1)*R
TEMP=TEMP1+(TEMP2-TEMP1)*R
900 RETURN
1 FORMAT (3(1X,F3.1,F4.1,I4,I4))
2 FORMAT (I3)
END

C
C
SUBROUTINE SHADE(DAY,HOUR,OUTPUT)
C
C *****
C
C INPUT
C DAY NUMBER OF DAY (1-365)
C HOUR HOUR OF DAY (0-24 SOLAR)
C SEE MAIN PROGRAM INPUT FOR OTHER VARIABLES
C

```

Figure 4-2. SYSTEM Program (Sheet 9 of 14)

```

C      OUTPUT
C      ACTIVE  NUMBER OF ACTIVE ARRAY STRINGS
C      *****
C
    DIMENSION XY(2,200),NAP(200),OUTPUT(10,200),XY0(2,200)
    DIMENSION NAPO(200),MULT(200),BOUTPUT(10)
    GLOBAL  NT,AH,AL,NST,NAT,NATO,AS
    GLOBAL XY0,MULT,LAT,ENOSH,BOUTPUT
    INTEGER DAY
    REAL LAT
    PI=3.141593
    CALL POSITION(DAY,HOUR,LAT,A,E)
    IF(E.GT.ENOSH) NA=NT*NAT; GOTO 900
    IF(E.LT.0) ACTIVE=0; GOTO 900
    NATO=NAT;ASO=AS
    AO=A*2*PI/360
    EO=E*2*PI/360
    DO 220 I=1,10
    BOUTPUT(I)=1
220  CONTINUE
    MS=0
    NA=1
    CALL SUNVIEW(AO,EO,XY,XY0,NA,NAP,NAPO,NATO,ASO)
    J=2
    IF(NAT.EQ.1) J=1
    CALL SHADOW(AH,AL,XY,NAP,NAPO,J,NA,BOUTPUT,SHAD,MS,NSH,NST)
    NA=NT;NATO=2;ASO=(NAT-1)*AS
    IF(NAT.EQ.1) NATO=1
    CALL SUNVIEW(AO,EO,XY,XY0,NA,NAP,NAPO,NATO,ASO)
    DO 300 J=1,NA*NATO,NATO
    CALL SHADOW(AH,AL,XY,NAP,NAPO,J,NA,OUTPUT,SHAD,MS,NSH,NST)
300  CONTINUE
900  RETURN
    END

C
C
    SUBROUTINE SUNVIEW(A,E,XY,XY0,N,NAP,NAPO,NAT,AS)
C      *****
C
C      USED WITH SHADE
C      *****
C
    DIMENSION XY(2,600),NAP(600),NAPO(600),XY0(2,600)
    CA=COS(A)
    SA=SIN(A)
    SE=SIN(E)
    DO 100 I=1,N
    X2=XY0(1,I)*CA-XY0(2,I)*SA
    Y2=(XY0(2,I)*CA+XY0(1,I)*SA)-(NAT-1)*AS/2
    DO 50 J=1,NAT
    XY(2,(I-1)*NAT+J)=Y2+AS*(J-1)

```

Figure 4-2. SYSTEM Program (Sheet 10 of 14)


```

      XY(1,(I-1)*NAT+J)=X2
50    CONTINUE
100   CONTINUE
      N=N*NAT
      DO 150 J=1,N
      NAPO(J)=J
150   CONTINUE
      DO 300 J=1,N-1
      DO 200 I=J+1,N
      IF(XY(2,I).LE.XY(2,J)) GOTO 200
      Y=XY(2,I)
      XY(2,I)=XY(2,J)
      XY(2,J)=Y
      X=XY(1,I)
      XY(1,I)=XY(1,J)
      XY(1,J)=X
      NAPOT=NAPO(I)
      NAPO(I)=NAPO(J)
      NAPO(J)=NAPOT
200   CONTINUE
      XY(2,J)=XY(2,J)*SE
300   CONTINUE
      XY(2,N)=XY(2,N)*SE
      DO 400 J=1,N
      NAP(NAPO(J))=J
400   CONTINUE
      N=N/NAT
      RETURN
      END

C
C
      SUBROUTINE SHADOW(AH,AL,XY,NAP,NAPO,N,NA,OUTPUT,SHAD,MS,NSH,NST)
C
C*****
C
C      USED WITH SHADE
C
C*****
C
      DIMENSION NAP(200),XY(2,200),OUTPUT(10,200)
      DIMENSION NAPO(200),AL(10),AH(2),BOOUTPUT(10)
      GLOBAL NATO,BOOUTPUT,MSH
      DST=(AH(1)-MSH)/NST
      I=0
      NSH=0
      J=NAP(N)
      DO 150 JI=1,NST
      OUTPUT(JI,(N-1)/NATO+1)=BOOUTPUT(JI)
150   CONTINUE
100   I=I+1
      IF(OUTPUT(NST,(N-1)/NATO+1).EQ.0) GOTO 900
      IF(J+I.GT.NA*NATO) GOTO 900
      NAH=2
      IF((N-1)/NATO.EQ.(NAPO(J+I)-1)/NATO) NAH=1

```

Figure 4-2. SYSTEM Program (Sheet 11 of 14)

```

      IF(ABS(XY(2,J+1)-XY(2,J)).GT.AH(NAH)) GOTO 900
      AL0=(AL((NAP0(J+1))-NAT0*((NAP0(J+1)-1)/NAT0))
C      +AL(N-NAT0*((N-1)/NAT0)))/2
      IF(ABS(XY(1,J+1)-XY(1,J)).GT.AL0) GOTO 100
      NSH=NSH+1
      SHAD=XY(2,J)-XY(2,J+1)-AH(NAH)
      NSST=-SHAD/DST+1
      IF(NSST.GT.NST.OR.NSST.LT.1) NSST=NST
      DO 200 JI=1,NSST
      OUTPUT(JI,(N-1)/NAT0+1)=0
200  CONTINUE
900  RETURN
      END

```

```

C
C
C      SUBROUTINE CELL(PWR,T00,GVO,MAXP,GV,CURT)

```

```

C*****
C      INPUT
C      PWR      POWER STRIKING CELL, WATTS
C      T00      CELL TEMP, K
C      GVO      CELL VOLTAGE (IF CONSTANT VOLTAGE OUTPUT
C              DESIRED), OR GUESS AT MAX POWER VOLTAGE
C      MAXP      1 FOR MAX POWER OUT, 0 FOR CONSTANT
C              VOLTAGE OUT
C      OUTPUT
C      GV       CELL VOLTAGE, VOLTS
C      CURT     CELL CURRENT, AMPS

```

```

C*****
C      GLOBAL PI

```

```

      R=1.37
      T0=T00
      FC=-.05
      GVIN=GVO
      IF(PWR.LE.0) GOTO 900
      FCC=FC
      CF=PWR/(PI*R**2)
      CURT=0
      C=0
      POLD=-250
171  GV=GVIN
      CALL IV(GV,CURT,T0,CF)
      POWEROUT=GV*CURT
      IF(MAXP.EQ.1) GOTO 175
      ENEW=GVO-GV
      IF(ABS(ENEW).LT..001) GOTO 900
      IF(ENEW*FCC.LT.0) FCC=-FCC/3; IF(C.EQ.0) FCC=FCC*3
      IF(ABS(ENEW).LT.ABS(FCC*3)) FCC=ENEW/3
      GOTO 176
175  IF(POWEROUT.LT.POLD) FCC=-FCC/3;

```

Figure 4-2. SYSTEM Program (Sheet 12 of 14)

```

C IF(POLD=POWEROUT.LT.POLD/200) GOTO 900
176 C=C+1
    IF(C.GT.100) GOTO 900
    GVIN=GVIN+PCC
    POLD=POWEROUT
    GOTO 171
900 RETURN
    END

C
C SUBROUTINE 'IV' FINDS THE CURRENT FROM THE MODULE.
C     INPUTS ARE:
C     V = MODULE VOLTAGE, VOLTS
C     T = SOLAR CELL TEMPERATURE, KELVIN
C     PWR= POWER OF LIGHT STRIKING SOLAR CELL, WATTS/IN**2
C           (UNIFORM ILLUMINATION, 1 SUN=.64516 WATTS/IN**2)
C
C     OUTPUTS ARE:
C     I = MODULE CURRENT, AMPERES
C     V,T,PWR UNCHANGED
C
C SUBROUTINE IV(V,I,T,PWR)
    REAL I,IL,IO,KTO
    VC=V
    C=0
    IL=1.668*PWR
    IO=.894*I**3*10**(-6080/T)
    KTO=.617E-5*T
    I=IL-IO*EXP(VC/KTO)
100 DI=IL-IO*EXP((VC+(I*1.12E-3*(1+.3*EXP(4*(I/IL-1)))))/KTO)-I
    IF(ABS(DI).LT.IL/100) GOTO 900
    DI=DI/(IO*(1.12E-3)*EXP((VC+(I*1.12E-3*(1+.3*EXP(4*(I/IL-1)))))/KTO)+1)
C     I=I+DI
    C=C+1
    IF(C.GT.100) GOTO 900
    GOTO 100
900 I=I
    RETURN
    END

```

Figure 4-2. SYSTEM Program (Sheet 13 of 14)

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Figure 4-3. Predicted Energy Output of the System During a Year

4.3.2 PROGRAM OPERATION

The program determines the system output energy by calculating the power output of the system at a specific time. This power output is assumed to apply for a small interval of time: the update interval. The energy during this time is therefore the power output times the update interval. The energy for each interval of time from sunrise to sunset is summed to obtain a daily energy output. Daily energy outputs are summed to obtain a total energy output.

4.3.3 PROGRAM STRUCTURE

4.3.3.1 Main Program

The program will begin with the day selected as the first day. The sunrise and sunset times (solar time) are calculated for that day. The first interval for which system power is calculated is selected to include sunrise, and subsequent times are spaced one update interval apart until after sunset.

System output power is calculated for each interval by calling subroutines WEATHER, SHADE, MODULE, HEATSINK, CELL, WIRING, and INVERTER. The program structure is shown in Figure 4-4. The output power for that update interval is then multiplied by the update interval and added to previous results.

For cell update intervals accumulated since sunrise, it is possible to print out day, time of day, insolation, cell temperature, number of active series strings, field voltage, field current, system power, and system energy output. Since the program generates one line of output for every update interval, it is not recommended for full year predictions. A normal printout for a full year includes the energy output for each day and energy total for all days.

4.3.3.2 Subroutine WEATHER

Subroutine WEATHER selects the proper weather data for a given day and time from typical meteorological year data compiled by Sandia. The weather data is for hourly intervals. Data between measured points is found by linear interpolation. Day and time inputs may be any day or time after the last day and time input.

4.3.3.3 Subroutine SHADE

Given the day and time, Subroutine SHADE will determine the state, on or off, of each array string. An array string is considered to be off if any portion of it is shaded.

SHADE starts by finding the elevation and azimuth of the sun based on the day, time, and array field latitude. If the elevation is high enough so that no shading can possibly occur, the outputs of the array strings are left unchanged, and SHADE returns to the main program.

If shading is a possibility, the output of each array string must be found. This is done by projecting subarray centers onto a plane perpendicular to the sun's direction and then looking for overlapping arrays. From this view of the array field, all subarrays are aimed along the viewing direction. They will have their full horizontal and vertical dimensions. Any overlap of subarrays will cause a shadow with an area equal to the overlap. Subarrays are divided into horizontal sections, representing the tier strings. If any section is shaded, that string is set to off.

Computer time is saved by finding the output of only one nonfront subarray. This subarray is representative of all other nonfront subarrays due to the equal spacing and height of all subarrays. One array is used to determine the representative subarray's shading.

Shading of the front subarrays is found using only the front and rear subarrays on all arrays. Center subarrays will have no shading effect on other arrays, providing their lengths are reasonable.

The horizontal subarray modules are connected in a series string with the other subarray modules on corresponding tiers on the same array. Active array strings on an array will be only those that contain active subarray module strings in both the front subarray and the rear subarray. The state of each array string is stored in a data table in computer memory for use by the main program.

4.3.3.4 Subroutine MODULE

Subroutine MODULE determines the actual power striking the solar cell, given the solar direct normal radiation. This is accomplished by determining the power falling on the module aperture and multiplying it by the module efficiency.

4.3.3.5 Subroutine HEATSINK

Subroutine HEATSINK determines the temperature of the solar cell, given the power striking the cell, air temperature and wind speed. The model multiplies the power striking the cell by a factor equal to the cell reflection and energy conversion, thus establishing the power that must be dissipated as heat. The resultant power is

Figure 4-4. System Performance Analysis Program

multiplied by the heatsink thermal resistance, giving a temperature rise above ambient. The temperature rise is added to the air temperature to obtain the cell temperature.

4.3.3.6 Subroutine CELL

Subroutine CELL uses a model of a solar cell to arrive at the maximum power point, given the power striking the cell and cell temperature. The cell model can be any suitable formula; however, simplicity is important to maintain program speed. The following formula has successfully matched both a detailed computer cell model and measured I-V curves:

$$I = C_1 \cdot P - C_2 T^3 10^{\left(\frac{-6080}{T} \right) \exp \left[\frac{q}{KT} \left(V + (I \cdot R_s (1 + R_{ss} \exp \left[4 \frac{I}{C_1 \cdot P} - 1 \right] \right) \right) \right]}$$

P = power illuminating the cell (assumed uniform)

T = cell temperature

q = electron charge

K = Boltzman's constant

V = cell voltage

I = cell current

$C_1 \cdot P$ = short circuit current

$$V_{oc} = \frac{KT}{q} \ln \frac{C_1 \cdot P}{C_2 T^3 10^{\left(\frac{-6080}{T} \right)}} = \text{open circuit voltage}$$

R_s = series resistance at zero cell current

R_{ss} = is selected to match the I-V curve near the maximum power point

C = Empirically determined constant

A model of a 3-inch circular cell is used.

4.3.3.7 Subroutine WIRING

Subroutine WIRING uses a system voltage set at four times the number of modules in a series string times the cell voltage. The system current is the number of active series strings times the cell current divided by four. The multiplication and division by four accounts for the fact that the Motorola Meinel optical module uses a quadrated 3-inch solar cell.

The number of active series strings is determined by the output of the SHADE subroutine and a wiring chart. SHADE gives the state of each string on an array, and the wiring chart describes which strings on which arrays are further series-connected for input to the inverter. If all array strings in a series connection are on, then that string adds to the system current.

4.3.3.8 Subroutine INVERTER

Subroutine INVERTER accepts the field voltage and current and outputs the system power. A simple inverter efficiency of 90 percent was used.

4.4 Life Cycle Cost Analysis

The life cycle cost is the present value of the fixed and variable costs minus the present value of the fuel cost savings.

The present value of the fixed and variable costs was obtained from PVECON, a computer program that performs an economic analysis of the P-V system. Capital cost estimates were inputted to PVECON for the various subsystems of the P-V system, as was the expected annual operations and maintenance cost. See paragraph 4.5, Cost Model Analysis. The total capital cost estimate was \$9,092,104, and the expected annual operation and maintenance cost was \$35,000. The resulting fixed cost comprises the before-tax revenue required for the total plant investment, insurance and property tax, and income tax savings due to depreciation. The resulting variable cost comprises strictly the total operation and maintenance costs.

Fuel cost savings were calculated using the assumption that the energy generated from the P-V plant will displace generation from oil plants only on the APS system. Using the expected annual net energy from the P-V plant, which was calculated by the system's performance analysis computer program, and the expected 1979 APS fuel costs for oil, the annual fuel cost savings was calculated. A 7 percent escalation rate and a present worth factor of 11 percent were then used to calculate the present value of the fuel cost savings over the life of the plant. As shown below, the effect of the fuel cost savings was minimal on the life cycle cost.

$$\begin{aligned}\text{Life Cycle Cost} &= P-V_{(FC+VC)} - P-V_{(\text{Fuel Savings})} \\ &= \$16,937,932 - \$401,863 \\ &= \$16,536,069\end{aligned}$$

This shows that by today's economics, the P-V plant is not economical. However, this life cycle cost can be useful in the comparison of various photovoltaic systems.

4.5 Cost Model Analysis

PVECON is a computer program that performs an economic analysis of photovoltaic solar-electric power plants. It is a revised form of Sandia Laboratories' BUCKS¹, which was developed for economic analysis of solar thermal central receiver technology in utility networks and for comparative evaluation of alternate plant designs. BUCKS was revised to accommodate photovoltaic solar-electric technology; however, the methodology used in the economic analysis is the same.

PVECON calculates power production costs of a single P-V power plant. The production costs are output as the levelized busbar energy cost (BBEC). This is the constant revenue per unit output required over the plant lifetime to compensate for its fixed and variable costs, pay interest to bond holders, and provide return to shareholders. It does not include transmission and distribution costs or other indirect utility costs.

The basic inputs and components of PVECON are shown in Figure 4-5. The required input information to PVECON includes cost estimates, which are separated into 11 plant subsystems, plant operation and performance information, and utility economic data.

¹J.M. Brune, BUCKS, *Economic Analysis Model of Solar Electric Power Plants*, SAND77-8279, Sandia Laboratories.

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Figure 4-5. Flow Diagram, PVECON Program

The cost estimates are escalated to the time when they are required for payment on a plant expense. The escalated operation and maintenance costs are the total operation and maintenance costs accrued over the plant life. The escalated capital cost is added to the cost for use of money during the construction period to give the total capital investment at the year of commercial operation. This capital investment cost is added to additional fixed costs to give the total fixed costs over the plant life. Fixed costs are those that are independent of the plant annual generation level such as capital investment, depreciation, income tax allowance, and insurance and property tax. Both the fixed and operation and maintenance costs are then discounted and levelized to give the levelized annual required revenue. This estimate is normalized to the estimated annual generation to give the levelized busbar energy cost.

A base case was run using estimated costs for the 11 subsystems of the ASPCP. The subsystems are as follows:

1. Concentrator module \$3,010,756
2. Drive unit \$ 537,068
3. Sun tracking subsystem \$ 174,539
4. Master control and data
acquisition system \$ 125,452
5. Power conditioning \$ 306,908
6. Array support and protection \$2,570,345
7. Power wiring electrical structures
and wiring containers \$ 302,046
8. Site, structures, miscellaneous equipment \$ 429,651
9. Electric plant equipment \$ 27,270
10. Field assembly, startup and checkout \$1,124,379
11. Distribution and indirect costs \$ 483,690

These costs were based on budgetary figures for phases I, II and III. The result was a levelized busbar energy cost of \$1.6754/kWe-HR. Then cases were run that increased or decreased various subsystems costs or groups of subsystems costs. See Figure 4-6.

From Figure 4-6 estimates can be made of what effect the cost change of a subsystem will have on the BBEC.

The percent variable cost is the percentage the cost is of the total capital cost. Cases were run with ± 30 percent and ± 50 percent for the variable costs. For example, the concentrator module, which is 33.1 percent of the total cost, was increased and decreased by 30 and 50 percent. A 30 percent increase in the cost of the modules resulted in a 9.1 percent increase in the BBEC, and a 30 percent decrease resulted in a 9.1 percent decrease. Whereas, a ± 50 percent change in cost resulted in a ± 14.3 percent change in BBEC.

*VARIABLE COST GROUPS:
 7.8% - DRIVE UNIT, SUN-TRACKING SUB-SYSTEM
 33.1% - CONCENTRATOR MODULE
 69.2% - DRIVE UNIT, SUN-TRACKING SUB-SYSTEM,
 CONCENTRATOR MODULE, ARRAY SUPPORT
 AND PROTECTION

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Figure 4-6. Percent Busbar Energy Costs as a Function of Percent Variable Costs

4.6 Energy Storage Study

The energy storage assessment was made in view of the system design that has the solar power supply connected in parallel with the utility. Thus the evaluation was to determine if the utility could act as the storage source. Development of the system switching specifications indicated that transfer from solar power to utility power could be achieved in less than 100 microseconds. This capability, working in conjunction with the master control system, insures that the load will always be supplied, regardless of solar or other transients in the photovoltaic system.

In general, the timing of the peak output of the ASPCP agrees with the peak demand, and to the extent that matching does occur, the incentive to provide battery storage that would allow the photovoltaic system to operate as a true peaking system does not occur. As part of the operating evaluation, data will be generated that will allow a more detailed analysis of the potential value of battery storage. Since the cost of battery storage is high, it was not considered for this application.

Also included in the energy storage study was the emergency power supply for stowage of arrays in the event that the emergency stowage requirement occurs simultaneously with a loss of utility power at the array field. Three alternatives were considered: batteries, a diesel generator, and alternate utility power. An investigation of the utility feeder system at the airport and array field determined that a highly reliable source of emergency power is available from the utility grid system at the airport. The airport facilities, including the south concourse, are served by two separate underground feeder lines with an automatic switchover capability from one line to the other in the event either loses power. The array field is served by a separate overhead feeder line. In the event that the overhead line is lost, power will be available to be fed back through the transmission line from the south concourse to the array field if emergency stowage of arrays is required. Since the tie-in cost to achieve this function is very low as compared to the battery or diesel generator options, the utility source was the selected approach.

4.7 Environmental Impact Studies

4.7.1 GENERAL

Environmental considerations and possible hazards created by the ASPCP were the subjects of a comprehensive study made during the phase I effort. The study was performed to facilitate the evaluation of the proposed Airport Solar Photovoltaic Concentrator Project (ASPCP) as specified in Section 102 of the National Environmental Policy Act (NEPA) of 1969. The scope of the evaluation follows the Council on Environmental Quality Guidelines on Preparation of Environmental Impact Statements. In addition, problems of electro-magnetic interference, eye hazard and distractive glint were evaluated.

The analytical approaches, detailed analyses and results of that study are contained in a report entitled Environmental Assessment Report for the Airport Solar Photovoltaic Concentrator Project. The report, prepared after detailed investigations by the APS Environmental Management Department, Motorola Government Electronics Division and various independent environmental consultants, reflects numerous discussions with various governmental agencies. It is intended to provide DOE with sufficient information to effectively carry out its responsibilities as lead Agency for Environmental Review and Consideration under all applicable legislation and regulations including, but not limited to, NEPA (P.L. 91-190). Copies of the report have been delivered to DOE during phase I and are not repeated here.

The overall proposed project consists essentially of three separate portions. The solar array field, a 12.6 kV underground transmission line, and a load switch center located in the Sky Harbor International Airport Terminal Module Number 3. Since the airport terminal has been previously addressed in the 1973 Final Environmental Impact Statement for Expansion at Sky Harbor International Airport and because the transmission line will be buried, the report is limited strictly to the array field.

To analyze the environment affected and the potential environmental impacts to both the site and potential facility, the factors of geology, soils, biology, archaeology, land use/zoning, waste disposal, air, radio service interference and eye hazards were evaluated. The following paragraphs contain the more significant conclusions made as a result of the study.

4.7.2 SITE, STUDY PLAN DESCRIPTION, AND LAND USE

The study area was selected to encompass 358 acres surrounding and including the proposed 14-acre array field. The study area was then analyzed in terms of existing land use, proposed land use, existing zoning, proposed zoning, and land ownership. Results of these analyses are as follows.

4.7.2.1 *Existing Land Use*

The proposed solar project is compatible with other types of existing land use.

4.7.2.2 *Proposed Land Use*

The proposed public utilization of the majority of the study area is compatible with ASPCP. The proposed remaining open space area is also compatible with the ASPCP.

4.7.2.3 *Existing Zoning*

The site is presently classified as R-3 residential. However, the City of Phoenix has been trying to purchase the remaining privately owned residences (5 homes immediately west of the array field) for the past 10 years and rezone the area to a light industrial classification. A special permit is available from the city to allow construction of the solar plant with its present zoning.

4.7.2.4 *Proposed Zoning*

Future zoning plans are compatible with operation of the ASPCP.

4.7.2.5 *Ownership Compatibility*

The proposed site is a contiguous area under the single jurisdiction of the City of Phoenix, and thus relocating residences or purchasing of private property is not necessary to construct the ASPCP.

4.7.3 CULTURAL AND HISTORICAL STUDY

A survey of the site has been performed by the Museum of Northern Arizona, and based on their report, the State Historic Preservation Officer and Chief has determined that the project will have no apparent effect on cultural resources.

4.7.4 GEOLOGICAL DESCRIPTION

In light of the surface and subsurface geological information developed in the study, no subsidence and only minor erosion are expected.

4.7.5 EARTHQUAKE POTENTIAL STUDY

Moderate damage could be expected from an earthquake felt in this area. It is therefore recommended that adequate earthquake engineering be considered in the facility design.

4.7.6 SOILS DESCRIPTION

Based on an analysis of the soils at the site, the following recommendations were made: treat buried concrete or steel to protect from corrosion due to contact with the soil and strengthen subsurface supports to guard against the effects of expansive clays.

4.7.7 FLOOD POTENTIAL STUDY

The site is presently classified within the 100 year floodplain. To meet City of Phoenix codes regarding construction within this floodplan, the project must have its base elevation above the predicted level of the 100 year flood, or it must be well protected up to that level. An existing level south of the site, if extended and raised approximately four feet, would provide this protection. This would then change the site classification to the 500 year floodplain.

4.7.8 DRAINAGE STUDY

City of Phoenix Code specifies on-site retention of storm water for all developments greater than 1/2 acre or adequate drainage to a major outfall. Two alternatives will satisfy this requirement: drainage into the Salt River, which requires a national pollutant discharge elimination system (NPDES) permit depending on the amount and type of material held in solution in the water at the time, or a holding tank to satisfy retention time requirements.

4.7.9 BIOLOGICAL DESCRIPTION

The proposed site for the photovoltaic generation facility at Sky Harbor International Airport will sustain no impact ecologically, since the same area has already been significantly impacted due to removal of old homes previously occupying the area. There are no officially threatened or endangered plant or animal species recorded in the vicinity of the proposed site.

4.7.10 AIR POLLUTION CONTROL

During construction, a permit from the Maricopa County Air Pollution Advisory Council is required to insure that adequate dust control is maintained. The on-site soil characteristics indicate a potential wind blown soil erosion hazard. Therefore, some dust control measures are recommended, such as a gravel spread covering, landscaping, paving, or chemical treatment. No other air pollution problems are expected as a result of the operation of the photovoltaic system.

4.7.11 EYE HAZARD EVALUATION

One important consideration for the ASPCP proposed for installation at the Phoenix Sky Harbor International Airport is the potential eye hazard and distractive effect of sunlight reflected from the optical concentrator modules.

The optical concentrator module is a light trap by the nature of its design. The optical arrangement ensures that all direct light incident upon the module is trapped within the module. During normal operation, the solar array will track the sun and absorb all direct normal radiation. The possibility of reflected sunlight being a hazard does not exist under normal tracking conditions.

Several other possibilities do exist, however, for potential eye hazards. Four such cases were identified and classified as follows.

Case I: Sunlight reflected off the primary reflector when the solar array is off-axis.

Case II: Sunlight directed through the target opening in the module when the cell mount/heat dissipator assembly is removed and the solar array is on-axis.

Case III: Sunlight reflected from the surface of the solar cell with the array on-axis.

Case IV: Distractive glint hazards to aircraft and/or automobile operators.

The hazard in each of the four cases was defined in terms of the distance from the optical module within which the irradiance level would cause damage to the retina of the eye. The exposure time in cases I and II was assumed to be limited by the normal human blink reflex of 0.15 second.

For case I, the eye hazard was found to extend only 10 centimeters beyond the module front cover.

For case II, the eye hazard extends 25 centimeters beyond the target opening.

For case III, the eye hazard extends only 0.118 centimeter from the surface of the cell. This zone is contained entirely within the module and obviously poses no eye hazard to any observer.

For case IV, a worst case analysis revealed that array glint experienced by aircraft pilots or automobile drivers on the nearby freeway will never exceed that reflected from a large body of water.

The ASPCP Operation and Maintenance Manual will address the hazards identified for cases I and II. Adequate safety procedures will be provided to ensure the safety of operating personnel and visitors. The use of safety glasses, such as welder's goggles, will be required when entering the array field. Maintenance procedures will be defined to ensure safe conditions during maintenance. These procedures will also consider the possibility of injury or damage due to fire hazards in the intense irradiance zones created at very short distances from a module.

4.7.12 RADIO FREQUENCY INTERFERENCE

The possible radio frequency interference as a result of introducing large metallic surfaces in close proximity to the airport radar and communication systems was analyzed during the phase I effort. The ASR-8 radar will have no interference from the solar arrays, since they move very slowly and are considered fixed targets.

Should the site present any interference to the airport radar transponder system, a chicken wire fence, sloping 10 degrees from vertical, will be erected in front of the chain link fence to shield the field.

To avoid a potential source of EMI, the inverters to be used in the ASPCP will include output filters to comply with the requirements of MIL-STD-461 and MIL-STD-462 and will include input filters to minimize the radiation of inverter noise from the solar modules.

4.7.13 THERMAL IMPACT OF ARRAY FIELD

The effect of the solar array field will be to decrease the amount of incident radiation by less than 1.4 percent. Therefore, it will have negligible impact on the local thermal environment.

4.8 System And Component Reliability Analyses

4.8.1 SYSTEM RELIABILITY

A preliminary reliability analysis and prediction conducted on the ASPCP indicates a potential mean-time-between-failures (MTBF) of 2680 hours (about 16 weeks). This very preliminary prediction is based on MIL-HDBK-217B part failure rate models and data. It is good for a ground benign environment, 31 degrees C, and commercial quality parts applied at 30 percent of electrical stress ratings.

Part failure rates were assigned primarily from MIL-HDBK-217B, because the data search part of the reliability analysis showed that the commercial and power industries have not addressed reliability data of components such as those used in the ASPCP. Therefore, component (unit) failure rates had to be estimated using rough parts count

estimates and MIL-HDBK-217B part failure rates. The component failure rate estimates (LAMBDA) are summarized in Table 4-2.

In view of the lack of reliability data available on the components and parts that would be used in the ASPCP, it is recommended that a reliability growth plan be prepared and implemented for the ASPCP. The plan would include (1) additional industry data searches to establish better component failure rates and (2) a program of tests and failure correction actions. As more and better failure information is gathered on components, the predicted ASPCP MTBF will become more accurate. As the ASPCP is tested to uncover weaknesses, and as the weaknesses are corrected, the real ASPCP MTBF will increase. This is one of the better methods for achieving good reliability for particular designs.

Table 4-2. Reliability Prediction

The following is a summary of the system components that are required for the operation of the triplet array.

#	Component/Subsystem	Source	Lambda
1	Sun sensor	MIL-HDBK-217B	2.3118
2	Solar cell/cell mount	MIL-HDBK-217B	0.5752
3	Encoder	MOTOROLA SG	0.069
		MIL-HDBK-217B	
		MIL-HDBK-217C	
4	EL and AZ control	MIL-HDBK-217B	3.826
5	Mechanical/motors	MIL-HDBK-217B	38.50
6	Hybrid tracker interface	RADC-NORD-1	59.16
	M68MM15A/15A1 microsystem	MIL-HDBK-217B	63.6
		ANALOGIC	
	M68MM01B1 Micromodule*	MIL-HDBK-217B	138.0
7	Peak power tracker	MIL-HDBK-217B	25.6
8	Inverter/circuit breakers	Teledyne	40.66
9	APMP	MIL-HDBK-217B	0.74
		MIL-HDBK-217B	
		Total λ = 373 failures/10 ⁶ hours	
		MTBF = 2680 hours	

*Microboard Microcomputer M68MM01B1 is a stand-alone microcomputer providing the processing and control of an MC6802 MPU, sockets for 4K of EROM or static RAM, a peripheral interface adapter, a programmable timer module, an additional 256 bytes of static RAM, provision for off-board dynamic memory refresh, an asynchronous communications interface adapter, an audio tape interface circuit and bus drivers for the address, data and control bus signals.

4.8.2 COMPONENT AND PIECE PART RELIABILITY

Systems like the ASPCP introduce four areas in which additional reliability data is required. These four areas are:

1. Commercial parts/items
2. Mechanical/moving items
3. High power levels
4. AC as well as DC circuits

Traditionally, failure rate sources such as MIL-HDBK-217B cover only electrical and some electromechanical piece parts. Mechanical items such as the array structure, track and wheels are not covered in these data sources. The data used to establish the failure rates comes primarily from space (high reliability) and military equipments whose parts are biased at low levels of DC voltage. Additionally, space and military quality level parts have safety factors built in and lend themselves to derating.

The ASPCP is dealing with commercial parts and items for which reliability and life data are not readily available. Most suppliers of the various components and equipments anticipated for usage were not able to provide an MTBF for their items.

There is a need to define the reliability problem to suppliers and to set up and put into action a data collection plan. The reliability data can be obtained either by the supplier or user from both field use and tests. This is done by keeping track of component operating (and nonoperating) times and failures. The data is fed into a data bank from which the failure rate and MTBF are calculated.

SECTION 5 — SYSTEM DESIGN AND COMPONENT SPECIFICATION

5.1 Solar Cell

5.1.1 MOTOROLA SOLAR CELL DEVELOPMENT

The development of the Motorola 70X solar cell was an internally funded extension of the development accomplished by the Motorola Semiconductor Group in their Silicon Solar Cell Manufacturing Development Program under Sandia Contract No. 07-7079. The analysis and development accomplished during this program is described in detail in Silicon Concentrator Solar Cell Manufacturing Development Task 1 Report, Sandia Contract No. 07-7079.

As a result of this analysis, a 3-inch diameter, 70X concentrator cell was designed utilizing float zone silicon, 8 mils thick, with a bulk resistivity of 0.2 to 0.5 ohm centimeters. The first surface has a texture etch and a SiN_4 antireflective coating. The metallization pattern contains six annular rings plus the current collecting outer ring with varying numbers of radial grid lines between adjacent rings. Figure 5-1 is a photograph of the Motorola 70X solar cell.

Representative data taken on the Motorola solar cells are shown in Figure 5-2. These data indicate that the cell will have an efficiency of 15.5 percent at 70X concentration and 40 degrees C cell temperature.

5.1.2 OCLI SOLAR CELL DEVELOPMENT

Concentrator solar cells developed by OCLI were the product of analysis of the various cell parameters to yield cells that would perform as required. The following are the major considerations of this analysis.

1. Silicon bulk resistivity.
Low series resistance versus reduced carrier collection.
2. Diffused layer conditions.
Lower sheet resistance versus low short circuit current.
3. Low ohmic contact resistance.
Sintered palladium silicide plus nickel and silver.
4. Antireflective coating optical efficiency.
5. Metallization pattern.
Minimum shading versus low I^2R loss.

Figure 5-3 is a photograph of the OCLI 70X solar cell.

Test data from the OCLI cells are given in Figure 5-4. These data indicate that these cells will provide an efficiency of about 13 percent operating at 70X and 55 degrees C.

Figure 5-1. Motorola SG 70X Solar Cell

Typical Test Data Taken on Motorola SG 70X Quarter Solar Cell

Test No.	Cell No.	Pwr Into 1/4 Cell	V_{OC}	I_{SC}	P_{MP}	V_{MP}	I_{MP}	FF	η	Cell T	NIP Insolation	Suns
211	6M		.671	8.9	4.9155	.565	8.7	82.31	16.24	40°C	952.21	30.27
212	6M		.678	11.8	6.498	.57	11.4	81.22	16.19	40°C	946.09	40.14
213	6M		.685	14.6	8.023	.565	14.2	80.22	16.16	40°C	943.64	49.66
214	6M		.69	17.7	9.605	.565	17.0	78.65	15.95	40°C	938.73	60.20
215	6M		.694	20.6	11.159	.565	19.75	78.05	15.92	40°C	953.44	70.07
216	6M		.695	23.5	12.7125	.565	22.5	77.84	15.89	40°C	953.44	80.0

Figure 5-2. Motorola SG 70X Solar Cell Test Data (Sheet 1 of 2)

Figure 5-2. Motorola SG 70X Solar Cell Test Data (Sheet 2 of 2)

Figure 5-3. OCLI 70X Solar Cell

Figure 5-4. Typical Data from OCLI 70X Solar Cells (Sheet 1 of 2)

OCLI 70X Q CELLS
 CELLS 9, 10, 11, 12
 FLUX DENSITY $\approx$ 50 SUNS
 10-11-78

Test No.	Cell No.	Avg Flux Density	Pwr Into 1/4 Cell	V_{OCV}	I_{SCA}	P_{MPW}	V_{MP}	I_{MP}	FF %	$\eta\%$	Cell T°C	Insolation
25	2	29.18	27.73	.648	8.3	3.86	.500	7.71	71.8	13.92	40.5	898.3
26	2	29.50	28.04	.640	8.38	3.79	.495	7.65	70.6	13.52	44°C	908.1
27	2	28.74	27.32	.628	8.32	3.65	.480	7.60	69.9	13.36	50°C	884.8
28	2	29.57	28.11	.620	8.41	3.61	.470	7.69	69.3	12.86	55°C	910.6
29	2	29.57	28.11	.608	8.43	3.496	.460	7.60	68.2	12.44	60°C	910.6
30	2	34.12	32.44	.644	10.0	4.43	.490	9.05	68.8	13.66	44°C	916.7
31	2	39.91	37.95	.644	12.0	5.11	.480	10.65	66.1	13.47	45°C	916.7
32	2	50.57	48.08	.647	16.2	6.42	.465	13.80	61.2	13.35	46°C	914.2

Figure 5-4. Typical Data from OCLI 70X Solar Cells (Sheet 2 of 2)

5.1.3 SOLAR CELL PROTECTION

There are two conditions that can exist in a string of series-connected solar cells that can be damaging to individual cells during instances of partial string shading. These damaging conditions are reverse voltage breakdown and excessive heat dissipation. These conditions can be alleviated in large series strings by the use of bypass diodes and adequate thermal dissipation. In the ASCPC, a series string consists of 960 solar cell sections. A bypass diode will be connected around each four cell section contained within a Meinel module.

Partial shading of a solar cell can occur in the Meinel module when it is pointed off-axis from the sun. Figure 5-5 shows the interconnection diagram of the four solar cell quarters and the bypass diode in the Meinel module.

Figure 5-5. Module Schematic

Figure 5-6 depicts a family of I-V curves that characterize a solar cell under no illumination, partial illumination and full illumination. In analyzing the module under partial illumination, it is assumed that all other modules in the string are producing full power at a current I_{string} . When a solar cell section is partially shaded, it cannot produce power at the I_{string} level and is forced to operate in the third quadrant of its I-V curve. It becomes a passive device and dissipates much of the power generated by the three remaining, fully illuminated cell quarters. The reverse voltage developed across the shaded cell quarter is restricted to three reverse diode drops and one forward diode drop or approximately 3.5 volts. This value is well below the reverse breakdown voltage (V_{rb}) exhibited by the concentrator cells produced by the Motorola Semiconductor Group (15 volts) or OCLI (30 volts). The electrical power that is dissipated by the shaded cell is equal to the product of the short circuit current of the cell and the reverse voltage developed across it. Table 5-1 outlines the operating performance of a cell section that receives 80 percent illumination. The cell section temperature will rise to approximately 88 degrees C, which can be tolerated.

Table 5-1. Partial Shading Analysis

100 Percent Illumination	
Power incident on cell section	70.44 watts
Solar cell efficiency	14 percent
Electrical output (normal)	9.86 watts
Thermal input to dissipator	60.58 watts
80 Percent Illumination	
Power incident on cell section	56.35 watts
Reverse voltage	3.5 volts
Cell current	26.48 amps
Excess power dissipation	57.68 watts
Total power dissipation	114.03 watts
Solar cell temperature	88°C (est.)

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Figure 5-6. Illuminated Solar Cell I-V Characteristics

5.2 Motorola Meinel Optical Module

The Motorola Meinel optical module is a Cassegrain-type optical concentrator that illuminates a circular target area.

Off-axis performance at a high concentration ratio is enhanced by the use of a cusp reflector. The module includes a bypass diode for solar cell protection. Table 5-2 lists the general characteristics of the optical module.

Table 5-2. General Characteristics of the Motorola Meinel Optical Concentrator Module

Module diameter	30 inches
Solar cell	3 inch diameter-silicon
Concentration ratio	70X
Type of cooling	Passive
Output voltage	1.94 volts
Output current	20.6 amperes
Output power	39.9 watts

Figure 5-7 is a photograph of a prototype module developed at Motorola Government Electronics Division.

5.3 Tracking Array

5.3.1 CONCEPT ANALYSIS

The selection of an array size and configuration involves a complex set of trade-offs to develop an optimum cost array design. The approach taken by Motorola GED was to first design three different array configurations and determine the optimum size of each. A cost estimate was prepared for each of the three configurations and reduced to a cost per peak watt basis. These array configurations were then compared on a cost basis, even though they supported different quantities of optical modules. In this way, an array design was selected that minimized the cost per watt of supporting optical modules.

The analysis included four different design areas:

1. foundation
2. structure
3. elevation and azimuth drive systems
4. sun tracking sensor and electronics

The loads imposed on these design areas (except for the sun tracking sensor and electronics, which are independent of array size) were determined by the weight of the optical modules to be supported and by wind loads. Wind loads were determined by studying weather data for the Phoenix area and for similar desert locations where heliostat fields have been proposed. A maximum wind velocity of 30 miles per hour for any array tracking position and 90 miles per hour survival in the stowed position were chosen for array design.

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Figure 5-7. Motorola Meinel Optical Module

The structure design was developed by first specifying deflection limitations in both a 30 mile per hour wind and in an average Phoenix wind of 10 miles per hour. Then a structural space frame was designed to meet the deflection requirements using a minimum amount of material. The structural sections were selected by performing a three dimensional structural dynamic analysis using finite element analysis techniques. At the same time, the design was checked to ensure that the array structure was not overstressed in the stow position and the natural frequency of the array structure was calculated to ensure that it was greater than 1 Hz.

The structure was designed using both aluminum and steel, and cost estimates were obtained for both materials.

5.3.1.1 Configurations Considered

The first array configuration considered was a conventional single pedestal array as shown in Figure 5-8, view A. This array consists of a large support frame pivoted about the elevation axis. The frame is supported by a pedestal and rotates in the azimuth axis on a pedestal top bearing.

To design the optimum size array, curves were developed to find the span of the array that minimized the cost per watt. Cost curves showing array size versus array cost per peak watt are depicted in Figure 5-9. The analysis assumed an array frame with a height one-half the width of the frame. The array cost is presented on a unit cost per watt basis. The curves show cost relationship only and do not attempt to show actual cost.

The foundation cost is assumed to vary directly with array size and is shown as a horizontal line. The sun sensor and tracking electronics cost is fixed and does not vary with array size. Therefore, it is plotted as a steadily decreasing curve. The cost for the elevation and azimuth drive components does increase with array size but not proportionally with array size; thus the cost per watt curve decreases as array size increases.

The structure cost per watt does increase as array size increases. This occurs because the supporting structure sections begin to increase rapidly once the width of an array, supported at a single point, exceeds 30 feet.

The four cost curves are summed to obtain the total array cost curve. The total cost curve shows that the array cost is minimized with an array span of about 33 feet capable of supporting modules generating 4000 watts peak.

The second configuration considered was a track-mounted array as shown in Figure 5-8, view B. This configuration allows the array frame to be supported at two points, thus reducing the structural sections required. The array rotates in elevation about the two supporting points, and motion on the track provides azimuth rotation. A cost analysis performed on this array, similar to that done for the single pedestal array, determined that the array cost is minimized when the track diameter is about 60 feet. This 60-foot array supports enough modules to generate about 9000 watts.

The third configuration considered was a variation of the track mounted array. The "low profile" concept, shown in Figure 5-8, view C, divides the array frame into three low-height subarrays mounted on a base. This configuration has several important advantages over those discussed previously.

1. The low height and the three-subarray configuration reduce the wind load on the system.
2. The lower height makes it easier and safer to erect the array and to install and maintain the solar modules.
3. The three subarrays spread the load more evenly over the base and minimize overturning forces on the array.
4. The lower profile reduces the risk of interfering with Federal Aviation Administration (FAA) radar systems, an important consideration at an airport location.

SINGLE POINT-PEDESTAL SUPPORT

A

TRACK MOUNTED-2 POINT SUPPORT

B

LOW PROFILE CONCEPT

C

8004-27

Figure 5-8. Array Configurations Considered

Figure 5-9. Array Cost versus Array Size for a Single Pedestal Array

A cost analysis yielded the same optimum array track size as for the previous configuration. The resulting array supports enough modules to generate nearly 10000 watts.

5.3.1.2 Cost Trade-Offs

Actual costs were obtained for the three array configurations. The costs for the various elements of each array were summarized and reduced to a cost per peak watt. The relative cost per peak watt is shown in Table 5-3.

Table 5-3. Relative Array Cost

Configuration	Single Pedestal Figure 5-8 view A	Track Mount Figure 5-8 view B	Low Profile Figure 5-8 view C
Relative cost per peak watt	1.00	0.82	0.76

5.3.2 ARRAY SHADOWING ANALYSIS

5.3.2.1 Introduction

Minimization of array shadowing effects was governed by a number of fixed constraints imposed by land availability and system requirements as follows:

1. Available land area is restricted to 14 acres.
2. Site dimensions are fixed at 1016 feet (east-west) by 600 feet (north-south)
3. The ASPCP is designed to deliver 500 peak kWe power.
4. The optical module is designed to deliver approximately 40 watts peak.

In addition, further constraints on permissible array size and form factor were imposed by structural considerations, and material, installation and maintenance costs.

The final selection of the array structure was based on evaluation of the cost/performance trade-offs between the various options considered. System performance was evaluated with the aid of a computer program that includes array form factor, structure spacing and module interconnection as variables. An array shadowing subroutine within the main program calculates system yearly energy output as a function of these array shadowing variables. Figure 5-10 shows a flow chart of the array shadowing subroutine.

5.3.2.2 Analysis

The results of the computer analysis are summarized in Table 5-4 for the three array configuration options considered.

As shown in Table 5-4, the percentage variation in energy output between options 1 and 3 is only 1.26 percent or 14,000 kWh per year. The variation in construction costs, however, is 21.8 percent or roughly \$800,000. Option 3 is clearly superior to option 1.

The comparison of options 2 and 3 is not as dramatic. The variation in energy output is 2.6 percent or 29,000 kWh per year, while the difference in construction cost is 4.5 percent or approximately \$130,000. The added cost of the small increase in annual output is far greater than the nominal array field cost per annual unit output. Since the ASPCP needs are satisfied by all three options, the most cost effective option, option 3, was selected.

Preliminary calculations indicated that a significant increase in energy output could be obtained by changing the array wiring configuration from one series string to three series strings. This method resulted in a 10 percent increase in yearly energy output with minimal increase in wiring complexity.

The final parameter considered in the shadowing analysis for the option 3 array was the spacing between subarrays. A computer analysis determined that the optimum spacing between subarrays for the available site is 27 feet. This configuration, and the wiring scheme described above, are reflected in the Table 5-4 performance summary.

5.3.2.3 Conclusions

The low profile track-mounted array was chosen for the airport project. Not only does it result in the lowest cost per peak watt of any of the configurations studied, but it also offers several unique advantages. The detailed design of the low profile array is discussed in paragraph 5.3.3

Figure 5-10. Array Shadowing Subroutine Flow Diagram

5.3.3 LOW PROFILE CONCEPT

The Motorola solar array is shown in Figure 5-11. It is a two-axis tracking array supporting 240 Motorola Meinel optical concentrator modules with a total peak output of 9576 watts. The base of the array is a frame mounted on wheels that roll on a circular track, thus providing azimuth rotation. On the base are mounted three subarrays that rotate to provide elevation tracking. Concentrator modules are mounted 12 to a frame. Twenty of these frames are mounted on three subarray frames. Table 5-5 lists the general specifications for the array system.

Table 5-4. Performance Summary For Array Configuration Options

Option No.	1	2	3
Type of Structure	Center Pedestal Support Structure 30 ft. Array	Circular Rail Support Structure 60 ft. Array	Low Profile Circular Rail Support Structure
Array height	26 ft.	26 ft.	9.65 ft.
Subarray length	30 ft.	60 ft.	62/82/62/ ft.
Sweep circle diameter	30 ft.	60 ft.	85 ft.
No. of modules per array	108	216	240
No. of arrays per field	132	66	59
Energy output (kWh/year)	1.113×10^5	1.128×10^5	1.099×10^5
Array field construction cost	$\$3.62 \times 10^5$	$\$2.96 \times 10^5$	$\$2.83 \times 10^5$

Note. Array field costs are preliminary costs available at the time analysis was made.

Figure 5-11. Selected Tracking Array

Table 5-5. General Array Specifications

Concentrator modules	240
Peak power output	9,576 watts
Number of arrays in field	59
Turning diameter of array	85 feet
Diameter of support rail	58 feet
Maximum height of array	10 feet
Total weight of array	15,250 pounds
Designed to track in maximum wind of 30 mph	
In winds above 30 mph, array must be in stow position	
Tracking system-active sun sensor with open loop backup	

The "low profile" concept using three low height array frames was selected over alternate configurations (see paragraph 5.3.2.2) because it offered several unique advantages.

1. The low height and frame shadowing reduce wind load on the array.
2. The low height makes it convenient and safe to erect the array and to install and maintain the solar modules.
3. The three frames spread the load more evenly over the base and minimize overturning forces on the array.
4. A cost study indicated that the low profile configuration provided the lowest array cost per peak watt.
5. The low profile reduces the risk of interfering with FAA radar systems, an important consideration at an airport location.

A cost trade-off to determine the optimum array size showed that a track diameter of about 60 feet minimized the array cost per peak watt. A large space frame structure was designed to support the modules under the selected wind loads using a minimum of structural material. A three-dimensional structural dynamic analysis using finite element analysis was used to select the structural member sizes and to ensure that the natural frequency of the system was above 1 Hz.

Position control for both azimuth and elevation are provided by the hybrid sun tracker and motor drive circuits discussed in paragraphs 5.3.8 and 5.3.9.

5.3.4 STRUCTURE DESIGN

The array structure (see Figure 5-11) was designed as a large space frame to minimize the material required while maintaining deflections within specified limits.

The base for the array is supported on a circular rail at four points and is supported at these points on standard monorail crane-type wheels. Rotation of the base on the track provides azimuth tracking.

The subarray frames rotate to provide elevation tracking. The center subarray frame is 78 feet long, and the two outer subarray frames are 57 feet long. The subarray frames mount on pillow block bearings onto supports provided on the array base. The subarray frames have been designed as 25-inch square box beams formed with structural

angles at the four corners mounted to formed sheet metal webs on 30.5-inch centers. Diagonal struts are used between the webs near the elevation bearings to limit torsional deflection.

The solar modules are supported on panel frames that are mounted on the subarray frames. The panel frames are 10-foot square frames, each supporting 12 solar modules; eight frames are mounted on the center subarray, and six frames are mounted on each outboard subarray.

Solar modules will be assembled and aligned on the panel frames in the factory where the solar modules are manufactured. The completely assembled panel frames will then be shipped to the field for installation onto the array structure. This will allow as much assembly as possible to be done in a manufacturing facility, taking advantage of lower labor costs and more efficient manufacturing techniques. Leveling of the panel frames on the subarray frames will be done in the field.

5.3.4.1 Solar Array Foundation

The foundation design for the tracking array takes into account the expected array loadings and the load bearing characteristics at the site. The resulting solar array foundation design consists of a reinforced concrete circular beam having an outside diameter of 60 feet, a width of 1 foot and a depth of 3 feet. The reinforcing consists of three #7 bars at top and bottom. These beam dimensions are minimum to provide reasonable stiffness in holding the rail true and level. They are also more than adequate for the design loads (see attached calculations).

5.3.5 WIND LOAD ANALYSIS

Wind load forces on the array structure were a major factor in the structure design. A thorough wind load analysis of proposed array configurations was required to determine all of the forces imposed on the structure by the wind. The design wind velocities chosen were 30 miles per hour for any tracking position and 90 miles per hour survival in the stow position.

5.3.5.1 Basic Approach

Wind striking a flat surface at some angle other than normal to the surface will produce some torque about the geometric center of the surface. The center of pressure is the point at which the pressure on the surface can be approximated with a single force (see Figure 5-12). The center of pressure changes its location on the surface as the surface changes its angle to the wind (see Figure 5-13). The force on a plate in wind is considered to be normal to the plate and is given by:

$$F_N = \frac{\delta}{2} P_\infty M^2 C_N A$$

where

F_N = normal force on the plate

δ = specific heat ratio

P_∞ = ambient pressure

M = mach number of wind

A = surface area of the plate

C_N = normal coefficient for the plate

The normal force or pressure on a plate in wind also varies with angle to the wind and can be determined for any angle from Figures 5-12 and 5-13.

SOURCE: LOENIG, G.G., MILITARY AEROPLANES, W.S. BEST, BOSTON, 1918, PP 60.

8702-1

Figure 5-12. Normal Coefficient versus Angle of Incidence

SOURCE: LOENIG, G.G., MILITARY AEROPLANES, W.S. BEST, BOSTON, 1918, PP 60.

8702-2

Figure 5-13. Angle of Incidence versus Center of Pressure Position

5.3.5.2 Computer Calculations

A computer program was written to carry out static wind load calculations for various array angles. The program utilized standard aerodynamic data on drag coefficients and center of pressure shifts versus angle of incidence (see Figures 5-12 and 5-13) and calculated pressures and torques on the array as it stepped the array surface through all possible azimuth and elevation angles.

The actual array will have some porosity because of the circular solar module shape. The maximum porosity it could have was calculated to be 7 percent. This gives a corresponding maximum reduction in wind drag¹ of less than 5 percent. The computer program neglects this effect, yielding calculated load values slightly higher than may actually be encountered.

¹Hoerner, S.F., "Fluid Dynamic Drag," Hoerner, 1965, p. 8-1.

The program also neglects shadowing effects caused by wind blockage by the front subarrays. Shadowing effects were investigated, and it was found that the amount of shadowing varies with wind angle and can cause as much as a one-third reduction in overall total wind loading². In most cases, the load reduction will be considerably less. The computer program reflects worst case values of wind loading. Computer output of load data is shown in Figures 5-14, 5-15 and 5-16.

WIND ANGLE (DEGREES)	WIND PRESSURE (LB/SQ FT)	TORQUE ON 62 FT FRAME (FT-LB)	TORQUE ON 82 FT FRAME (FT-LB)	TOTAL TORQUE (FT-LB)
-----	-----	-----	-----	-----
.00	3.08	.00	.00	.00
5.00	3.06	230.27	304.55	765.10
10.00	3.03	456.57	603.85	1517.00
15.00	3.00	565.75	748.25	1879.76
20.00	2.98	672.95	890.03	2235.93
25.00	2.93	771.21	1019.99	2562.41
30.00	2.87	865.50	1144.70	2875.70
35.00	2.82	920.42	1217.33	3058.18
40.00	2.77	972.70	1286.47	3231.86
45.00	2.69	1012.40	1338.98	3363.78
50.00	2.61	1048.13	1386.24	3482.50
55.00	2.53	1114.10	1473.48	3701.68
60.00	2.41	1152.42	1524.17	3829.02
65.00	2.28	1181.16	1562.19	3924.52
70.00	2.16	1200.33	1587.53	3988.19
75.00	2.11	1254.17	1658.75	4167.09
80.00	1.82	1461.03	1932.33	4854.39
85.00	1.03	1187.09	1570.02	3944.19
90.00	.00	.00	.00	.00

Figure 5-14. Elevation Axis Values at a Worst Case Azimuth Angle of 45 Degrees

²Castro, I.P., "Wake Characteristics of Two Dimensional Perforated Plates Normal to an Air-Stream," *Journal Fluid Mechanics*, 1971, Vol. 46, Part 3, pp. 599-609.

5.3.5.3 Vortex Shedding Calculations

Wind effects on the structure must also be considered from a dynamic standpoint because of a phenomenon known as vortex shedding. In a steady flow stream, a turbulent wake called a vortex system can be set up behind an object. A two-dimensional plate in a flow stream will have a vortex system developed and shed from alternate edges of the plate. This vortex shedding causes a regular fluctuation in pressure distribution on the front surface of the plate. The vortex shedding for a given object in a given flow field occurs at a constant frequency. This frequency is presented in nondimensional form as the Strouhal number. For the array configuration subjected to a constant 30 mile per hour wind, a Strouhal number of 0.15 was calculated³. The equation relating Strouhal number and shedding frequency is:

$$S = \frac{fh}{V}$$

where

S = Strouhal number

f = shedding frequency

h = plate height

V = wind velocity

A shedding frequency of 0.73 Hz was calculated for a 30 mile per hour wind. This frequency is less than the fundamental structural frequency of the array, thus no problem with vortex shedding phenomenon is anticipated.

5.3.5.4 Conclusions

The worst case wind load forces during a 30 mile per hour wind on the chosen array configuration are summarized in Table 5-6.

³Castro, I.P., "Wake Characteristics of Two Dimensional Perforated Plates Normal to an Air-Stream," *Journal Fluid Mechanics*, 1971 Vol. 46, Part 3, pp. 599-609.

WIND ANGLE (DEGREES)	WIND PRESSURE (LB/SQ FT)	TORQUE ON 62 FT FRAME (FT-LB)	TORQUE ON 82 FT FRAME (FT-LB)	TOTAL TORQUE (FT-LB)
-----	-----	-----	-----	-----
.00	2.53	.00	.00	.00
5.00	2.54	879.93	1539.18	3299.03
10.00	2.56	1771.04	3097.96	6640.05
15.00	2.58	2673.39	4676.32	10023.10
20.00	2.59	3586.93	6274.32	13448.17
25.00	2.63	4545.92	7951.81	17043.64
30.00	2.66	5529.82	9672.89	20732.54
35.00	2.70	6538.66	11437.52	24514.84
40.00	2.85	10850.41	18979.75	40680.57
45.00	3.09	16029.02	28038.27	60096.30
50.00	3.02	17785.11	31110.04	66680.25
55.00	2.74	16608.16	29051.31	62267.63
60.00	2.27	14123.47	24705.06	52952.00
65.00	1.77	11489.32	20097.35	43076.00
70.00	1.27	8597.38	15038.71	32233.47
75.00	.90	6279.90	10984.93	23544.73
80.00	.52	3766.26	6588.01	14120.53
85.00	.19	1580.48	2764.61	5925.57
90.00	.00	.00	.00	.00

Figure 5-15. Azimuth Axis Values at a Worst Case Elevation Angle of 0 Degrees

ELEVATION ANGLE (DEGREES)	HORIZ WIND LIFT FORCE (LB)	HORIZ WIND DRAG FORCE (LB)	10 DEG WIND LIFT FORCE (LB)	10 DEG WIND DRAG FORCE
-----	-----	-----	-----	-----
.00	.00	5716.22	.00	5618.50
5.00	493.94	5645.80	493.94	5645.80
10.00	975.64	5533.14	992.61	5629.38
15.00	1441.53	5379.87	1466.82	5474.25
20.00	1888.22	5187.85	1921.64	5279.67
25.00	2291.89	4914.98	2353.83	5047.82
30.00	2662.68	4611.90	2760.39	4781.15
35.00	2998.45	4282.24	3110.55	4442.33
40.00	3297.46	3929.77	3423.08	4079.47
45.00	3523.77	3523.78	3696.50	3696.51
50.00	3705.20	3109.04	3929.76	3297.46
55.00	3842.01	2690.21	4082.14	2858.35
60.00	3862.75	2230.16	4188.79	2418.40
65.00	3834.05	1787.85	4250.79	1982.18
70.00	3759.23	1368.25	4191.32	1525.52
75.00	3775.35	1011.61	4086.26	1094.92
80.00	3319.89	585.39	3939.72	694.68
85.00	1898.16	166.07	3893.66	340.66
90.00	.00	.00	3371.10	.01

STOP 0

Figure 5-16. Lift and Drag Forces for Horizontal Wind and Wind Inclined Upwards at 10 Degrees

Table 5-6. Maximum Loads in 30 mph Wind on ASPCP Array

		Torque ft-lb	Force (lb)	Pressure (lb/ft ²)	Corresponding Elevation Angle	Corresponding Azimuth Angle
Moments about Elevation Axis	82 ft. frame	1930			80°	45°
	62 ft. frame	1460			80°	45°
	Total	4855			80°	45°
Moments about Azimuth Axis	82 ft. frame	31110			0°	50°
	62 ft. frame	17790			0°	50°
	Total	66680			0°	50°
Pressure and Force	82 ft. frame		2270	3.08	0°	45°
	62 ft. frame		1720	3.08	0°	45°
	Total		5710	3.08	0°	45°
Lift on Structure			3860		60°	45°
Drag on Structure			5720		0°	45°

5.3.6 STRESS ANALYSIS OF STRUCTURE

A stress analysis utilizing a standard finite element computer program was performed on the array structure. Much of the effort was concentrated on the 82-foot long center subarray beam. Deflections due to bending and torsion as well as natural frequencies and the associated mode shapes were investigated. Also, optimum supporting points for the subarray frames were selected with a computer model of an overhanging beam.

Finite element analysis is used to determine stresses and strains in any part or structure due to an applied external load. This was accomplished by modeling the structure as a number of small elements. These elements are joined at nodes. Loads on the overall structure as well as support locations were input to the program. The effects of the loads on each element were calculated, and in this way, the effects of the loads on the overall structure were determined.

5.3.6.1 Computer Analysis

The structure most critical to the deflection and frequency requirements is the 82-foot subarray frame. The analysis was performed using the SAP IV Finite Element Program. By modeling the frame with 300 three-dimensional beam elements and 6 boundary elements, information about its structural behavior was obtained. A sketch model is shown in Figure 5-17.

The initial analysis of the subarray frame indicated that the torsional deflection exceeded the limits desired. by adding diagonal members as shown in Figure 5-18, a modified finite element model verified that required torsional rigidity was obtained.

Figure 5-17. Finite Element Model of Subarray Frame

Figure 5-18. Modified 82-foot Subarray Frame

5.3.6.2 Optimum Subarray Support Points

Each subarray frame is supported at two points, similar to an overhanging beam. The slope of the frame changes depending on the locations of the two support points as well as the external load and the flexural rigidity of the frame. It is desirable to optimize the locations of the supports for least angle.

An overhanging beam with uniform distributed load as shown in Figure 5-19, view A, was used as a model of the frame. The equation of deflection as a function of the distance x is:

$$y(x) = \frac{W}{EI} \left[\frac{((a+b)^4 - a^4)(x-a)}{24b} + \frac{L(x-a)^3}{12} - \frac{(x^4 - a^4)}{24} - \frac{Lb^2(x-a)}{12} \right] \quad (1)$$

The equation expressing the slope of the beam as a function of X can be obtained by differentiating Equation (1). That is:

$$\frac{dy}{dx} = \frac{W}{EI} \left[\frac{(a+b)^4 - a^4}{24b} + \frac{L(x-a)^2}{4} - \frac{x^3}{6} - \frac{Lb^2}{12} \right] \quad (2)$$

The overhanging beam will have a minimum value of slope when it is supported such that:

$$\left(\frac{dy}{dx} \right)_{a < x < a+b} = \left(\frac{dy}{dx} \right)_{x=0} \quad (3)$$

Substituting equation (2) into equation (3), a second order polynomial equation $2x^2 - 3Lx + 6aL = 0$ can be obtained for $x > 0$.

The roots of the equation are:

$$x_{1,2} = \frac{3L \pm \sqrt{aL^2 - 48aL}}{4}$$

The minimum slope occurs where $x_1 = x_2$ (see Figure 5-19, view B.) This condition implies that $aL^2 - 48aL = 0$.

Therefore,

$$a = \frac{3L}{16}$$

This then indicates that the optimum support locations from a flexural deflection standpoint are at a distance $3/16$ the length from either end. It must be noted that this analysis assumes no shear deformation.

In the actual design, the support points for the 82-foot beam are located approximately 0.24 times the length in from each end. The support points for the 62-foot beam are located approximately 0.17 times the length in from each end.

5.3.6.3 Resonant Frequency Analysis

An analysis of the natural frequencies in both bending and torsion for the system indicated that the lowest resonant frequency was about 5 Hz above the desired lower limit of 1 Hz.

Figure 5-19. Overhanging Beam Model

5.3.6.4 Conclusions

Table 5-7 lists the maximum deflections under various conditions for the array structure. The maximum deflection under no wind load is 0.93 degree. By leveling panel frames when they are installed onto the subarray frames, the misalignment caused by static deflection can be reduced significantly.

Table 5-7 also shows that with the array in the stow position, during a 90 mile per hour wind the worst case stress in the structure is 32,000 psi. This is a limit for the stress in structural steel members; therefore, the proposed structure meets the requirement for survival in a 90 mile per hour wind.

Table 5-7. Maximum Deflections

Condition	Maximum Deflection of Subarray Frame
Deflection due to solar module load only - no wind	0.93°
Deflection due to 10 mph wind	0.11°
Deflection due to 30 mph wind	1.00°
Worst case stress in frame under 90 mph in stow position	32,000 psi

5.3.7 ARRAY SWITCHGEAR

A functional schematic of the array switchgear is shown in Figure 5-20. Manual controls for disconnecting the array from the field network are provided by circuit breakers CB1, CB2 and CB3. These breakers may be operated individually to isolate the series strings on the array. Normally open circuit breakers CB4, CB5 and CB6 provide substring shorting capability to aid in fault isolation. These breakers can be used in conjunction with a clip-on ammeter to determine substring short circuit currents.

Safe operating procedures require that each substring removed from service must be shorted before its associated disconnect switch is opened. To return the substring to service, the disconnect switch must be closed before the shorting switch is opened. The array DC power switchgear is contained in a NEMA 4 type enclosure located outside the array turning circle. This enclosure also contains manual controls for the array drives. Its remote location permits manual array control for testing to be done safely.

5.3.8 HYBRID SUN TRACKER

While the sun tracker subsystem was not a contractual requirement of the phase I effort, its function is of such importance to the design of the solar array as to merit a brief description in this report.

The function of the hybrid sun tracker is to steer the tracking array so that it continuously faces the sun as the sun traverses the sky. It is "hybrid" because it can track the sun in two modes: open loop and closed loop. Figure 5-21 is a block diagram of the hybrid sun tracker.

Figure 5-20. Array Switchgear

5.3.8.1 Closed Loop Tracker

The function of the closed loop tracking mode is to accurately track the sun when the sun is not obscured. Closed loop tracking uses a sun sensor that contains four solar cells (two for azimuth and two for elevation) arranged in an orthogonal pattern with a sun shade above them. Signal conditioning circuitry provides motor drive signals to position the solar array causing the outputs from opposite solar cells in the sensor to be equal. The closed loop tracking mode will maintain tracking accuracy to within ± 0.1 degree.

The active closed loop sensor (see Figure 5-22) utilizes four 0.5 inch square solar cells, one in each of the four quadrants. Two opposite solar cells are used for detection in each axis. An opaque surface above the cells casts a shadow bisecting all four cells when normal to the sun. As the sun moves with respect to the sun sensor, one cell will receive more illumination and produce more current. The current from each solar cell is converted to a voltage by a current-to-voltage operational amplifier. The output of each operational amplifier in the sun sensor is an analog voltage that varies from 0 to 5 VDC in proportion to the amount of illumination on each particular solar cell. The voltages are digitized by an analog-to-digital converter. The digital voltage signals from opposite cells are then compared by the microprocessor to establish an error angle for tracking.

8004-100

Figure 5-21. Hybrid Sun Tracker Block Diagram

8804-12

Figure 5-22. Sun Sensor Mechanical Configuration

In operation, the microprocessor senses sun sensor voltages until it accumulates a specified error angle, then activates the drive system to maintain tracking within the design error angle.

The sun sensor has been tested, both electrically and optically, under actual operating conditions with the two-axis tracker built for Sandia. The sun sensor outputs were monitored and the performance checked out. Tests performed indicate that the sun sensor is tracking the sun within its design parameters. Table 5-8 gives the performance specifications for the closed loop sensor.

Table 5-8. Performance Specifications for Closed Loop Sensor

	Acquisition Angle	Active Sensing Region	Sun Sensor Accuracy	Voltage Range	Typical Output Voltage
Active Closed Loop Sensor	$\theta = \pm 8^\circ$	$\theta_1 = \pm 3^\circ$	$\pm 0.2^\circ$	0 to 5 Vdc	2 Vdc

5.3.8.2 Open Loop Tracker

The function of the open loop tracking mode is to track the sun during intervals when the sun is obscured by clouds. In this mode, tracking accuracy is not critical; it is only necessary to maintain track within the acquisition angle of the active closed loop sensor. Open loop tracking is accomplished by calculating the azimuth and elevation angles of the sun at a given moment, comparing the calculated values with the array position at that moment and providing motor drive signals to eliminate the difference between the two. Position accuracy for the open loop mode is ± 1 degree.

5.3.8.3 Microprocessor-Based Controller

Figure 5-23 shows a simplified flow chart of the program performed by the microprocessor. To initialize the tracker subsystem, the RUN/SET switch is placed in the SET position, and the month of the year, the day of the month, and the time of the day are set.

8004-9

Figure 5-23. Hybrid Sun Tracker Microprocessor Program Flow Diagram

In the operate mode, the microprocessor continuously calculates the sun location and measures the array position. If the calculated sun elevation is negative; i.e., the sun has "gone down," the tracking array is directed to go to the sunrise position. Tracking resumes when the calculated sun elevation becomes positive.

The microprocessor continuously calculates the sun location and determines the array position by means of precision potentiometers. The acquisition angle of the sun sensor (closed loop) is ± 8 degrees. The microprocessor enables closed loop control if the difference between calculated and actual position is less than the preset capture angle of the sun sensor in both azimuth and elevation. Until this difference is reached, the tracking array is steered by the open loop routine.

If a cloud obscures the sun (as determined by a drop in the magnitude of the sum of the outputs of the solar cells in the sun sensor), open loop tracking will override the sun sensor.

Figure 5-24 shows the block diagram of the sun tracker. An MC6802 microprocessor is the heart of the unit. This device includes a small random access memory (RAM) for scratch pad calculations and variable data. The program will be stored in erasable programmable read only memories (EPROMs). The sun tracker includes a time of day clock, an analog-to-digital converter for sampling solar cells and position potentiometers, an arithmetic processor for making computations, and front panel controls to allow human interaction and monitoring. A liquid crystal display (LCD) will allow the operator to monitor month, day, time of day, calculated azimuth and elevation, and measured azimuth and elevation.

Figure 5-24. Hybrid Suntracker Detailed Block Diagram

A hybrid sun tracker was developed by Motorola GED for Sandia for use in conjunction with a two-axis tracking array for concentrator module testing at Sandia's facility. The Sandia unit has greater capability for test adaptation than is required by the ASPCP equipment. The sun tracker proposed for the ASPCP has been simplified to provide only those functions necessary for operation of the system as described in this section. Other changes involve the motor drive concept. Since there are two motors associated with the elevation drive, the computer program will be changed to drive the track motor and the slew motor as required. Likewise, azimuth tracking has been changed from bidirectional to unidirectional drive with night time repositioning via a motor reversing relay.

5.3.9 TRACKING DRIVE DESIGN

Electric motors, driving through large reduction gear reducers, are used to position the array in both the azimuth axis and elevation axis to provide sun tracking.

Both air and hydraulic motors were considered for the system and offer feasible tracking drive methods. However, the first cost of such a system is higher than for electric motors, and thus electric motors were selected. Worst case wind loads imposed the largest percentage of load on the drive system components. Array weight and friction were a small portion of the design load. The loads on the system in the worst case array attitude into the wind were calculated in a 30 mile per hour wind and the drive train components were sized appropriately.

5.3.9.1 Azimuth Axis Drive Train

Figure 5-25 shows the mechanical components used for the azimuth drive train. The array base structure is supported on a track at four points. At each point, a standard monorail crane trolley assembly is used. Two of the trolleys are used to drive the system; those drive wheels are supplied with a spur gear as shown in Figure 5-25. The drive wheel spur gear is driven by a pinion on the output shaft of a double worm reducer. The input to the reducer is driven by a continuously rotating 1725 rpm motor engaging the reducer through an electric clutch. The drive train is self-locking and no brake is required because the double worm reducer cannot be back-driven.

Each azimuth drive motor must deliver 0.1 hp under worst case wind loading of 30 miles per hour and maximum azimuth velocity of 1.5 degree per minute. Two 1/8 hp, 1 ϕ , standard AC motors are used. To minimize power consumption, each motor is continuously energized and is coupled to its load via a clutch to maintain the tracking error within design limits. This mode of operation requires that each motor operate under load for only a fraction of the solar day. In addition to minimizing the power required to drive the array, this method of operation also eliminates the power consumption and EMI associated with the high starting current surges demanded by AC motors.

Figure 5-25. Azimuth Drive System

A schematic of the azimuth control circuitry is shown in Figure 5-26. The clutch is energized and couples the motor to the load in response to signals from the hybrid sun tracker. Relay K1 provides motor reversing capability to return the array to the sunrise azimuth position at the end of the solar day. Switches SW-1 and SW-2 provide bidirectional manual control of array azimuth position. For safety, these switches are spring loaded to return to the positions indicated upon release.

5.3.9.2 Elevation Axis Drive Train

Figure 5-27 shows the elevation drive design. Two 5-ton capacity, 48-inch travel jack screws are used to move the subarray panels in elevation. The screws move the center subarray; the two outer subarrays are linked to the center subarray with tie rods.

The jack screw input shafts are linked by drive shafts to a 15:1 gear reducer that is driven by a 72 rpm hysteresis motor for tracking and a 3450 rpm motor for stow. The drive system is self-locking, and no brake is required. The machine screw type jack screws cannot be back driven.

The elevation drive has two separate drive rate requirements. It must be capable of tracking the sun at its maximum velocity of approximately 0.3 degrees per second in winds up to 30 miles per hour. When weather conditions indicate that winds will exceed 30 miles per hour, the elevation drive must also be capable of slewing the array to a horizontal stow position at a rate of 15 degrees per minute to prevent wind damage. To stow the array at a rate of 15 degrees per minute in a 30 mile per hour wind, the motor must deliver 1 hp. Under the same conditions of wind loading, only 0.02 hp is required to track the sun at its maximum rate in elevation.

A schematic of the elevation slew control circuitry is shown in the upper portion of Figure 5-28. As discussed previously, the slew motor is normally deenergized and is activated only for stow, unstow and manual control operations.

Power to the slew motor is controlled via relay K1. Energizing K1 applies power to the slew motor and simultaneously removes single phase power from the track motor. Relay K1 is energized either by a stow/unstow signal from the hybrid tracking system or by operator control via the manual slew enable switch SW-1.

Upon receipt of a stow command, relay K1 in Figure 5-28 energizes and disconnects the track motor from the AC source via contact K1-B. Power is then applied to the slew motor through the contacts of SW1, SW 2 and relay K2, which are in the positions shown in Figure 5-28. The slew motor then drives the array to the stow (horizontal) position at a rate of 15 degrees per minute.

Because the high power slew capability is required infrequently, it is impractical from a power consumption standpoint to use the same motor for both tracking and slewing. The elevation drive system therefore uses a 1 hp, 3 ϕ , 3450 rpm, standard AC motor for stowing and a 1 ϕ , 72 rpm, hysteresis motor for tracking. Both motors are directly coupled to the speed reducer shaft.

During tracking, the slew motor is deenergized and is driven at 72 rpm by the tracking motor. During stow, the track motor is deenergized and is driven at 3450 rpm by the slewing motor for the short time (6 minutes maximum) required to stow the array.

Figure 5-26. Azimuth Drive Schematic

Figure 5-27. Elevation Drive

Operation of the elevation drive is unidirectional with the direction of rotation reversed after the sun passes through its zenith position. A schematic of the elevation tracking control circuitry is shown in the lower half of Figure 5-28. The tracking drive motor is the permanent magnet, split-phase, AC hysterists type. This motor has the advantage of constant power consumption and freedom from high starting inrush currents. As shown in Figure 5-28, bidirectional operation of the tracking motor is obtained via solid-state relays S1 and S2. Both relays are normally open, disconnecting the motor from the single phase AC power source. Depending on whether the sun is ascending or descending, one or the other relay is closed only long enough to maintain the tracking error within design limits. This method has been selected to minimize the AC power required for tracking. Efficiency is high in that the average power consumption is directly proportional to the angular velocity of the sun.

5.3.9.3 Manual Control of Arrays

Controls for manual operation of the array are provided at the control panel enclosure. These controls permit manual override of auto track in azimuth or elevation at any time. To avoid the possibility of inadvertently leaving an array in the manual mode, all manual controls are spring-loaded to return to hybrid tracker control upon release.

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Figure 5-28. Elevation Drive Schematic

5.3.9.3.1 Azimuth Manual Control

A schematic of the azimuth drive circuit is shown in Figure 5-26. Switches SW-1 and SW-2 provide bidirectional manual control of the two drive motors. For normal automatic track, the azimuth track motors are continuously energized and are coupled to the load in response to clutch-driving signals from the hybrid sun tracker. When manual slew enable switch SW-1 is depressed, power is removed from the track motors and array rotation is disabled. At the same time, both clutches are energized via contact SW-1C. The operator may then assume manual control of the direction of rotation of the array using the slew direction switch SW-2. Both switches are spring-loaded to return to the positions shown in Figure 5-26 upon release.

5.3.9.3.2 Elevation Manual Control

Manual control of the array elevation drive is similar to that for azimuth. Figure 5-28 shows the schematic for elevation drive control. The operator may override automatic tracking by means of manual enable switch SW-1. When held in the ON position, SW-1 energizes relay K1 via contact SW-1B. This interrupts AC power to the track motor via relay contact K1-B and transfers control of slew motor power to the slew direction switch SW-2 via K1-B, SW-1A and SW-1B. At this time, rotation in elevation ceases. The operator may then select the direction of rotation in elevation using SW-2 while holding manual enable switch SW-1 in the ON position. Both switches are spring-loaded and will return to the automatic track position shown in Figure 5-28 when released.

5.3.10 WEIGHT ANALYSIS

Minimizing the weight of the array system has been a major goal of the array design activity. Table 5-9 summarizes the weight of an individual Meinel concentrating module. Since each array supports 240 modules, the total module weight is 4699 pounds.

Table 5-9. Weight of Concentrator Module

Part Name	Weight, lbs	Material
Primary reflector	5.00	ABS
Cover	2.10	Acrylic
Secondary support	0.23	Steel
Heat dissipator	5.00	Aluminum
Heat transfer fluid	2.00	Freon
Secondary reflector	0.19	Aluminum
Cusp	0.13	Aluminum
Support ring	1.56	Zinc
Cells and interconnections	0.05	Cells and interconnections
	45.6 cm ²	
Connector	0.13	Copper
Cell insulator	0.02	Alumina
Miscellaneous hardware	0.15	Steel
Seals	0.06	Silicone rubber
Conductor ring	0.26	Copper
Cell mount plate	2.70	Aluminum
Total	19.58 lbs	
240 modules per array		
Weight of modules in one array = 19.58 lbs x 240 = 4699 lbs		

Table 5-10 summarizes the weight of a tracking array. The total module weight (4699 pounds) plus the array weight (11920 pounds) equals 16619 pounds. Dividing by the nominal array output of 9576 watts results in a weight to power ratio of 1.74 pounds per watt.

Table 5-10. Weight of Tracking Structure

Part Name	Weight, lbs	Material
Base, tracking	4800	Steel
Center subarray	1700	Steel
Outboard subarray (2)	2500	Steel
Panel frame	1700	Steel
Module wiring	150	Copper
Base wheel assembly (4)	360	Steel
Elevation jack screw (2)	120	Gear box
Elevation drive parts	300	Steel
Azimuth gear reducer (2)	112	Gear box
Azimuth drive parts	50	Steel
Azimuth drive motor (2)	26	Motor
Elevation stow motor	30	Motor
Elevation track motor	12	Motor
Elevation gear reducer	10	Gear box
Miscellaneous hardware	50	Steel
Total	11920 lbs.	

5.3.11 ERROR BUDGET ANALYSIS

The concentrator module must be positioned within ± 1 degree of the true sun position to ensure full power output. Table 5-11 shows the error budget analysis for the tracking structure system. The following is a description of each error shown.

Table 5-11. Error Budget Analysis

	Degrees
Tracking Structure	
Hybrid tracking system	± 0.10
Drive system backlash	± 0.20
Drive system positioning	± 0.05
Subarray misalignment	± 0.24
Panel frame misalignment	± 0.19
Module Mounting Accuracy (into panel frames)	± 0.25
Total	± 1.03
Root of the sum of the squares	± 0.46
Deflection under 10 mph wind load	± 0.11
Total deflection variation	± 0.57

The sun sensor and closed loop hybrid tracker can position the tracking structure with a repeatability of ± 0.10 degree.

The mechanical backlash in the elevation and azimuth tracking drive components total ± 0.20 degree for each axis.

The tracking drive systems position the tracking structure in incremental steps. Since the sun moves continuously, there is some error as the tracking structure waits for a command to update the structure position. The maximum error because of this is ± 0.05 degree.

The two outboard subarrays that mount on the tracking base must be aligned with respect to the center subarray, since the sun sensor is mounted to the center subarray. The misalignment between the mounting plane of the center subarray to the mounting plane of either outboard subarray is designed to be less than ± 0.24 degree.

When the panel frames, each containing 12 modules, are mounted to the subarray frames, they will be leveled and shims will be used to align the planes of the panel frames. The aligning and shimming will be done to compensate for the manufacturing tolerances in fabricating the subarray frames and for the deflection due to the load on the subarray frames. It is estimated that the aligning accuracy can be held to ± 0.19 degree.

When the panel frames are assembled in the module manufacturing facility, the modules will be aligned and shimmed to compensate for inaccuracies in the panel frame and the module mounting points. This aligning procedure will result in a module alignment accuracy of ± 0.25 degree.

The total of all the errors is ± 1.03 degrees. Since it is extremely unlikely that all errors will be maximum for any one tracking system, the root of the sum of the squares has been calculated, and this value is ± 0.46 . This assumes that each error variation is normally distributed about a nominal value.

Since deflection under wind load will be fairly uniform for all arrays, the angular deflection due to a 10 mile per hour wind (Phoenix average wind) has been added to the total error for the structure. This results in a projected error of ± 0.57 degree for the modules, within the ± 1 degree accuracy required for full power module operation. In a 30 mile per hour wind the array deflection increases to 1.00 degree and thus the total off axis variation would be 1.46 degrees, which is greater than the 1 degree required for obtaining full power from the module. However, a situation of operating an array to obtain full power in a 30 mile per hour wind is extremely unlikely, and it is not cost effective to increase the strength of the array to obtain full array power in a 30 mile per hour wind.

5.4 Array Field

The array field comprises 59 Motorola tracking arrays and the facilities building enclosed by an 8-foot high chain-link fence for security. The Motorola solar array is a two-axis tracking structure having the configuration shown in Figure 5-29. Each array contains 3 subarrays, 20 module panels and 240 optical modules. Figure 5-30 defines the component nomenclature and configuration for the array structure.

5.4.1 FIELD LAYOUT

The array field layout is shown in Figure 5-31. The figure also shows the size and shape of the ASPCP site and access roadways provided for construction and maintenance. This layout evolved from computer-aided optimization with constraints imposed by the fixed land area and site form factor. The reduced lengths of roadways, power cables and wiring channels provided by the diagonal orientation of the arrays reduces construction and material costs and field wiring power losses. To meet the 1.0 percent maximum power loss specified for array field interconnections, the network is designed so that cable size is proportional to distance from the APMP. The dashed lines on Figure 5-31 represent the cable channel routing for field to APMP cable runs.

5.4.2 FIELD INTERCONNECTION

An array triplet interconnection scheme is used to minimize shading effects between arrays and subarrays as discussed in paragraph 4.3.1.2. This configuration maximizes the yearly energy output of the ASPCP.

Table 5-12 summarizes the triplet group interconnection plan in tabular form. The first column lists each of the 19 triplet groups by number and identifies the three arrays comprising each group. Column two indicates which of the 59 series strings is associated with a particular triplet group. The last column lists the identification numbers for each of the 59 strings. The TG-X prefix identifies the particular triplet group for the string. The letter suffix T, M, or B identifies the module tier level of the corresponding triplet group from which the string is derived.

Figure 5-29. Motorola Solar Array

Figure 5-30. Array Structure Nomenclature

Figure 5-31. Array Field Layout

Table 5-12. Triplet Group Interconnection Plan

Triplet Group Ident \ Array Ident	String No.	String Ident	Triplet Group Ident \ Array Ident	String No.	String Ident
TG-1 \ A1 A2 A3	1	TG-1T	TG-11 \ A38 A46 A54	31	TG-11T
	2	TG-1M		32	TG-11M
	3	TG-1B		33	TG-11B
TG-2 \ A4 A5 A6	4	TG-2T	TG-12 \ A14 A22 A30	34	TG-12T
	5	TG-2M		35	TG-12M
	6	TG-2B		36	TG-12B
TG-3 \ A9 A10 A17	7	TG-3T	TG-13 \ A39 A47 A55	37	TG-13T
	8	TG-3M		38	TG-13M
	9	TG-3B		39	TG-13B
TG-4 \ A18 A26 A34	10	TG-4T	TG-14 \ A15 A23 A31	40	TG-14T
	11	TG-4M		41	TG-14M
	12	TG-4B		42	TG-14B
TG-5 \ A35 A43 A51	13	TG-5T	TG-15 \ A40 A48 A56	43	TG-15T
	14	TG-5M		44	TG-15M
	15	TG-5B		45	TG-15B
TG-6 \ A11 A19 A27	16	TG-6T	TG-16 \ A16 A24 A32	46	TG-16T
	17	TG-6M		47	TG-16M
	18	TG-6B		48	TG-16B
TG-7 \ A36 A44 A52	19	TG-7T	TG-17 \ A41 A49 A57	49	TG-17T
	20	TG-7M		50	TG-17M
	21	TG-7B		51	TG-17B
TG-8 \ A12 A20 A28	22	TG-8T	TG-18 \ A25 A33 A42	52	TG-18T
	23	TG-8M		53	TG-18M
	24	TG-8B		54	TG-18B
TG-9 \ A37 A45 A53	25	TG-9T	TG-19 \ A50 A58 A59	55	TG-19T
	26	TG-9M		56	TG-19M
	27	TG-9B		57	TG-19B
TG-10 \ A13 A21 A29	28	TG-10T			
	29	TG-10M			
	30	TG-10B			

Legend

TG-X	Triplet Group No.
A	Array
T	Top (tier)
M	Middle (tier)
B	Bottom (tier)

Series Connected Array Ident	String No.	String Ident
Array 7	58	A7-58
Array 8	59	A8-59

Figure 5-32 shows the interconnection of the 59 arrays to form 19 array triplet groups plus two individual arrays. As shown in the figure, corresponding tiers on each of the three subarrays comprising an array are connected in series to form an array tier string of 155 volts. Each array tier string in turn is connected in series with corresponding array tier strings on two other arrays to form a triplet group string of 466 volts. The total number of triplet group strings formed in this manner is $3 \times 19 = 57$ strings. Strings 58 and 59 are derived from arrays 7 and 8, respectively. These two arrays are not partitioned into three individual tier strings. Instead, each is wired to form a single continuous series string of 466 volts.

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Figure 5-32. Array Field Interconnection Diagram

5.4.2.1 Subarray Interconnection

The partitioning of a subarray into three tier strings is the means by which maximum utilization of available insolation is obtained. The significant advantage of the three tier configuration is that useful power is obtained in the early morning and late afternoon. At these times, the sun is low in the sky, and the center and rear subarrays are partially shaded by the subarray directly in front.

The pertinent array geometry is illustrated in Figure 5-33. Figure 5-33, view A, is the elevation view of the array structure showing the 27-foot spacing between subarrays. Figure 5-33, view B, is a plan view of a module panel. When the array is tracking the sun, a particular module column can be shaded only by the corresponding module column in the subarray immediately in front. Then, for the purpose of shading analysis, the effective subarray height is three module diameters (8.2 feet) as shown in Figure 5-33, view B.

Figure 5-33, view C, gives the geometry and calculations for the three critical sun elevation angles associated with the three tier interconnection concept. From Figure 5-33, the critical angle is:

$$\theta_N = \text{ARCSIN} \frac{\frac{N}{3} \times 8.2}{27}$$

where

N = Number of fully illuminated tiers in the subarray

θ_N = Sun elevation angle when N tiers are illuminated

For Case 1, $N=1$ and $\theta_1=5.8$ degrees. The top tier is fully illuminated and delivers full power when the sun elevation angle exceeds 5.8 degrees.

For Case 2, $N=2$ and $\theta_2=11.8$ degrees. The middle tier is fully illuminated and delivers full power when the sun elevation angle exceeds 11.8 degrees.

For Case 3, $N=3$ and $\theta_3=17.7$ degrees. The bottom tier is fully illuminated and delivers full power when the sun elevation angle exceeds 17.7 degrees.

Case 3 identifies the critical angle when arrays are connected as a single series string. This configuration would yield no useful power for sun elevation angles less than 17.7 degrees.

By adopting the three tier interconnection method, a 10 percent increase in yearly output energy is obtained. This represents the output of nearly six complete array structures, which justifies the increase in wiring complexity required to implement the array triplet interconnection concept.

(C)

CASE 1		$\theta_1 = \text{ARCSIN} \frac{1/3 \times 8.2}{27}$ $= 5.8^\circ$	TOP TIER MODULES DELIVER FULL POWER AFTER SUN RISES ABOVE 5.8°
CASE 2		$\theta_2 = \text{ARCSIN} \frac{2/3 \times 8.2}{27}$ $= 11.8^\circ$	MIDDLE TIER MODULES DELIVER FULL POWER AFTER SUN RISES ABOVE 11.8°
CASE 3		$\theta_3 = \text{ARCSIN} \frac{3/3 \times 8.2}{27}$ $= 17.7^\circ$	ALL 3 TIERS ARE ILLUMINATED WHILE THE SUN ELEVATION IS GREATER THAN 17.7° FOR AN ARRAY WIRED AS A SINGLE SERIES STRING THIS CONDITION MUST BE TRUE BEFORE ANY POWER IS PRODUCED.

θ = ELEVATION OF SUN ABOVE THE HORIZON (DEGREES)

8702-5

Figure 5-33. Subarray Geometry for Shading Analysis

5.4.3 LIGHTNING PROTECTION

The lightning protection of the array structures has been designed to provide a low impedance path to ground for any direct lightning strokes to the array structure. Each array has an associated 3/4-inch diameter round copper-clad steel ground rod 8 feet long that is driven into the ground close to the circular track array structure rail support. A bare 4/0 AWG copper bonding wire will connect the driven ground rod to the rail by means of a powdered metal, exothermal welding process. Each driven ground rod also acts as an electrical equipment grounding electrode and will be used for this purpose. A No. 2 AWG bare copper conductor will connect the pad mounted junction box enclosure to the grounding rod.

Electrical continuity between the array structure and the circular rail is provided by the metal wheels in contact with the rail. Dirt or sandy dust on the rail will tend to lessen the quality of the contact but the structure weight acting over a small area should permit some metallic contact. Furthermore, the high voltage associated with all lightning strokes will break down the small gaps.

All power cables are insulated and protected from direct lightning strokes by the underground routing and by the array structure. The array framing members and the metallic module reflectors provide an effective shield for the DC power cables, just as the bare grounding cable positioned above high voltage transmission lines effectively shields the energized conductors.

5.4.4 INTERCOM SUBSYSTEM

5.4.4.1 Description

Personnel working in the solar array field must have the capability to communicate with each other throughout the area. Two independent communications are to be provided:

1. Public Address/Intercom System - Seven speaker/handset stations will provide public address and intercom functions. Any station shall have the capability to originate a public address-type call. Any two or more stations shall also have the capability to intercommunicate with each other in a telephone type operation for private conversations.
2. Sound Powered Phone System - Each solar array stationary junction box will have an insulated two-wire phone jack with a weatherproofed hinged cover conveniently mounted. One pair of the six pairs of No. 19 shielded cable will be parallel-connected to all phone jacks. Personnel equipped with sound powered telephones will be able to communicate with each other while working on the solar arrays.

5.4.4.2 Status of Development

1. Procurement Schedule

Procurement of intercom system components and cabling must be initiated no less than 3 months prior to the completion date of the installation of trenches and conduits. The laying and pulling of cables can start as soon as the digging of trenches and installation of conduits is completed.

Installation of the public address/intercom system components can begin when the heavy construction at the solar array locations is completed. Installation of the system components in the facilities building can begin upon completion of the fabrication of the facilities building.

2. Sources of Components

Procurement of speakers, speaker/handset stations, public address system cabling is to be from the Gai-tronics Corporation, Reading, Pennsylvania. Sound powered telephone cabling is available from the Anaconda Wire and Cable Company, Sycamore, Illinois. Sound powered telephone jacks are available from Newark Electronics, 4747 W. Century Blvd., Inglewood, California.

5.5 Facilities Building

The facilities building is a single story structure with approximately 2000 square feet of floor space. Located inside the building will be the following: the array paralleling and monitoring panel, inverter switchgear, two 250 kW inverters, master control unit, on-site data acquisition system, manual/automatic control and display panel, visitor's display, power distribution panels, and maintenance and storage areas. A weather station will be located on the roof. The building floor plan is shown in Figure 5-34. A 20-ton HVAC system will be provided for the building to supply the following loads: inverter cooling, 13 tons; other building loads, 7 tons.

Figure 5-34. Facilities Building Floor Plan

5.6 Load Definition

The load will be located in the South Concourse Building of Sky Harbor International Airport Terminal Module 3, about 5200 feet from the facilities building. The south concourse load is completely defined in Figure 5-35. The present system sizing calls for a total load of 700 kVA (at a power factor between 1.0 and 0.8 lag) that is divided into two separate loads. Switchboard SC1 will be rewired as shown at point A in Figure 5-35 to partition the load.

Each load is a mixture of lighting, heating and motors. The individual loads are sized so that the dedicated load is smaller than the ASPCP capacity to permit study of the system in a load following mode of operation. The total load is greater than the ASPCP capacity to permit study of the system in a maximum power mode of operation in parallel with the utility grid.

The dedicated load consists of the loads connected to switchboard panels SCDP1 and SCDP2. The detailed breakdown of power demand per phase for the dedicated load is shown in Table 5-13. The nondedicated load encompasses all other loads connected to switchboard SC1.

Table 5-13. Dedicated Load Power Demand

Switch-Board Panel	Switchboard Panel Breakdown		Motors Fans Heaters (3 ϕ)	Power Demand (kW) Per Phase									
				Lighting			Water Heaters			Receptacles			
				ϕ_A	ϕ_H	ϕ_C	ϕ_A	ϕ_H	ϕ_C	ϕ_A	ϕ_H	ϕ_C	
SCDP1	MCC-SC1	Air Handler	20.00										
		Exhaust Fan	0.75										
		Strip Heater	120.00										
	HSC1			5.71	2.51	2.31							
		HSC2		6.36	5.36	3.36	9.36	6.00	6.00				
		LSC1								0.54	0.36	0.36	
		LSC2								0.88	1.08	1.14	
	SCDP3	HSC5		2.70									
		HSC6		3.23				4.50	4.50				
		LSC5								0.54	0.18		
		LSC6		0.62	0.54							0.70	
		Air Handler	7.50										
		MCC-SC2 Supply Fan	125.00										
		Strip Htrs.	75.00										
		348.3	18.12	8.41	5.67	4.36	10.50	1.96	1.62	2.2			
Total				3 ϕ POWER DEMAND 416.64 kW _e									

Switch-Board Panel	Switchboard Panel Breakdown		Motors Fans Heaters (3 ϕ)	Power Demand (kW) Per Phase								
				Lighting						Receptacles		
				ϕ_A	ϕ_H	ϕ_C	ϕ_A	ϕ_H	ϕ_C	ϕ_A	ϕ_H	ϕ_C
SCDP2	HSC3			6.60	7.20	6.60						
	HSC4			10.16	7.27	4.75						
	LSC3									1.80	1.44	1.44
	LSC4			0.60						0.72	0.72	0.72
	Loading Bridges		20.0									
	SCX (Apron lights, night only)											
	SCDP4	HSC7			6.60	6.80	6.00					
HSC8				12.04	4.92	4.51						
LSC7										1.26	0.72	0.72
LSC8										0.54	0.54	0.54
			20.0	36.00	26.19	21.86				4.32	3.42	3.42
Total			3 ϕ POWER DEMAND 115.21 kW _e

Figure 5-35. ASPCP One-Line Wiring Diagram

5.7 Modes of Operation

Two active modes of operation are defined as well as a utility stand-alone mode in which the utility supplies all of the power. The maximum power mode provides the maximum energy return and is intended to be the primary mode for this application. The following mode provides less energy but represents a type of operation that may be required in other applications. The Auxiliary Switchgear will make it possible to obtain operating data in both modes.

5.7.1 LOAD FOLLOWING MODE

In the load following mode, the ASPCP will supply power to the dedicated load while sufficient insolation is available. The power to the nondedicated portion of the load is always supplied by the utility. When insolation levels are low, the utility will supply power to the dedicated load.

In this mode, the load dictates the amount of power used and the ASPCP provides a fixed output voltage. One advantage of this mode is the simplicity of system control. A disadvantage is that operation at less than maximum power output from the ASPCP is nearly always the case.

Transient cloud cover and nighttime operation of the dedicated load dictates the need for utility back-up power. This requirement makes it necessary to use a solid state switch as shown in the system block diagram, Figure 3-1. The solid state switch permits power transfer within 100 microseconds at current zero crossings and assures uninterrupted service to the dedicated load.

The load following mode is an experimental mode initiated by a manual command. The solar plant is always brought on-line in the maximum power mode in parallel with the utility. Upon receipt of a load following mode command, the MCU will compare the available solar power with the dedicated load power demand and switch modes if the solar plant output exceeds the load demand by a preset margin. Back-up power is provided by switching to the maximum power parallel mode whenever the solar power falls below the level required to support the dedicated load.

The power demand of the dedicated load is summarized in Table 5-14. The 337 kW load shown as subtotal No. 3 is the desired load for operation in the load following mode command. This load excludes the strip heaters; however, experiments using the load following mode of operation will not be affected by these heaters since they are operated only during the winter in the early morning when the insolation is low.

5.7.2 MAXIMUM POWER MODE

In the maximum power mode, the load presented to the solar array field by the inverter is controlled by the MCU in such a way that the array field operates at the maximum power point on its I-V curve. In this mode, the maximum power possible for the existing insolation level is extracted from the field and delivered in parallel with the utility to both the dedicated and nondedicated loads. Solar power in excess of load demand will be delivered to the utility grid while power demand exceeding the solar output will be supplied by the utility grid. Operating the ASPCP at its maximum power output agrees with the APS philosophy of always using fully the generating plant that contributes power at the lowest incremental cost.

Although the timing of the peak output of the ASPCP agrees roughly with the peak demand, power from the ASPCP will not be stored and used for true "peaking" operation. The maximum power mode of operation will provide the greatest return in kilowatt hours per dollar invested.

Table 5-14. Dedicated Load Power Demand Summary

Load	Power Demand	Notes
Lighting	116.25 kW	
Water heaters	30.36 kW	
Receptacles	16.94 kW	
Subtotal #1	163.55 kW	
Air handler (20 hp)	20.00 kW	
Exhaust fan (0.75 hp)	0.75 kW	
Air handler (7.5 hp)	7.50 kW	
Loading bridges (20 hp)	20.00 kW	1
Subtotal #2	211.80 kW	
Supply fan (125 hp)	125.00 kW	
Subtotal #3	336.80 kW	
Strip heaters	195.00 kW	2
Subtotal #4	531.80 kW	

NOTES:

1. It is anticipated that of the total number of six loading bridges, only two will be in operation simultaneously and these only for the short time required to run the bridges to and from the aircraft.
2. Strip heaters will be operated only during the winter months in the early morning.

5.7.3 UTILITY STAND-ALONE MODE

The utility grid will supply power to both loads during intervals of cloud cover and at night.

5.8 Power Conditioning Subsystem

5.8.1 INTRODUCTION

The power conditioning subsystem consists of the following major components (see Figure 5-36):

1. APMP
2. Inverter switchgear
3. Two 250 kW inverters in parallel
4. A 750 kVA step-up transformer (480 volts/12 kV)
5. A 750 kVA step-down transformer (12 kV/480 volts)
6. Auxiliary switchgear

The solar array field is organized into 59 strings, each consisting of 240 modules and capable of producing a maximum of 9650 watts of power at a typical voltage of 460 VDC. The 59 strings are routed to the APMP where they are connected in parallel. APMP capability is provided to manually isolate each string, open circuit each string, or short out each string. The APMP senses the solar array DC voltage and current and sends each analog signal to the MCU where they will be used in controlling the total system.

DC power is routed from the APMP to the inverter switchgear, which provides the switching capability to isolate the input and output of each inverter. Through a sequence of operations that can be controlled manually by an operator or automatically by the MCU, DC power can be routed to each inverter, each inverter can be brought up and put on line, and AC power can be routed from each inverter to the step-up transformer. The inverters transform the DC power from the solar array into 500 kW maximum of usable AC power (3 ϕ , 60 Hz, 480 VAC).

Figure 5-36. Block Diagram Power Conditioning Equipment

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AC power is transmitted at a stepped-up voltage of 12 kV to minimize line losses over the mile of cable. It is then stepped down to 480 volts at the new south concourse airport terminal where it ties into the load.

By means of auxiliary switchgear located at the south concourse, the ASPCP can supply the load in parallel with the APS utility grid, or it can supply the dedicated portion of the load entirely by itself.

In the "maximum power" mode of operation, the power conditioning equipment will operate to maximize the total available DC power from the solar array. Under this condition, the array will operate at maximum efficiency.

The "load following mode" of operation is an experimental mode designed for data acquisition. During this mode, power will be supplied exclusively by the solar power system to the dedicated load as required, and no attempt will be made to maximize the solar array efficiency.

5.8.2 ARRAY PARALLELING AND MONITORING PANEL

5.8.2.1 *Function*

The primary function of the APMP is to provide a central point for connecting the 59 solar array power strings to the DC power bus. The 59 strings are independently routed from the array field to the APMP, where they are paralleled to provide a nominal 456 VDC, 1215 ampere, 554 kW input to the inverters. The APMP (Figure 5-37) contains isolation circuit breakers, fuses, blocking diodes and test receptacles for monitoring and troubleshooting.

Additional functions include manual controls for isolating strings from the DC bus either individually or in combination and providing a test connector for each of the 59 strings for fault isolation and test purposes.

5.8.2.2 *Physical Configuration*

The APMP consists of two cabinets in a single enclosure as shown in Figure 5-38. Disconnect switch SW1 is mounted directly on the side panel of cabinet 1. Each panel contains a front door, ventilated rear door, internal fixed panel and internal hinged panel. Both cabinets are physically identical except that cabinet 1 services 30 power strings and cabinet 2 services 29 strings.

Figure 5-37. APMP Schematic Diagram

Figure 5-38. APMP Physical Configuration

5.8.2.3 Design and Cost Trade-offs

In keeping with the basic ASPCP system design philosophy, all passive APMP components have been selected from standard commercially available components and hardware. The only significant trade-off made was for the string isolation switch function where alternate approaches were considered. In addition to the mechanical switch finally selected, solid state components were evaluated because of the very long life and arcless switching inherent in semiconductor devices. The results of the study showed that the standby power dissipated in a solid state switch would be unacceptably high. A comparison of power losses for three types of switches evaluated is shown in Table 5-15.

Table 5-15. Comparison of Switch Power Losses

Type of Switch	Power Loss (Per String)
Mechanical	Negligible = 0.0 watts
Solid State Relay	1.6 volts x 20.6 amperes = 33.0 watts
Transistor	1.1 volts x 20.6 amperes = 22.7 watts

5.8.3 INVERTER, INVERTER CONTROLS

The inverter package consists of two 250 kW inverters in parallel with an appropriate switchgear arrangement to switch the inverter inputs and outputs onto line. A commercially available uninterruptible power system (UPS) was selected to minimize design time and initial development costs of designing an inverter system for conditioning power from a photovoltaic array. Some additional development is necessary for the UPS to interface with the ASPCP. The principal differences between the ASPCP requirements and standard UPS requirements are:

1. The DC input voltage from the solar array varies over a wide range and the source impedance is high.
2. The AC output must be capable of operating in parallel with the utility power grid.
3. The standard UPS input rectifier and battery-charging circuitry will not be required, since the inverter input power from the solar array is DC.
4. Computer control of the inverter system requires additional interfacing.

Two 250 kW inverters were selected because a parallel arrangement provides partial system utilization when one inverter is down for maintenance and will provide the insight into parallel operation of inverters that will be necessary as larger solar systems are implemented.

Based on performance data of similar equipment furnished by the manufacturer, the inverter/inverter switchgear efficiency is anticipated to be 94 percent minimum.

The inverter will be controlled by the MCU to adjust the output voltage and phase and to adjust the inverter loading to attain peak power tracking of the solar array. Several functions of the inverter will be monitored, and appropriate alarms and shutdown procedures will be initiated if a malfunction occurs.

5.8.4 INVERTER SWITCHGEAR

The inverter switchgear contains circuit breakers capable of automatically or manually switching the inverter inputs and outputs on line and providing inverter protection. All circuit breakers are motor-operated and are controlled with three 24 volt logic lines.

Control signals will originate from the MACDP pushbuttons, from the MCU through interface relays, or from logic internal to the inverter system. Each circuit breaker contains one or more sets of auxiliary contacts providing breaker status information to the MCU, MACDP, and inverter internal logic.

The inverter switchgear also provides system-level alarms to the MCU, MACDP, and internal inverter logic.

5.8.5 AUXILIARY SWITCHGEAR

The auxiliary switchgear assembly provides the capability of supplying the dedicated load from the solar power plant, from the utility power grid, or from the parallel combination of both.

A solid-state switch (S1) is capable of closing very rapidly to supply power to the dedicated load when the array can no longer support the dedicated load in the load following mode. Circuits within the auxiliary switch assembly will sense the amplitude of the voltage at the load. When this voltage falls below an adjustable predetermined "minimum" level, S1, CB2 and CB8 will automatically revert to the closed condition resulting in parallel operation of the utility and the inverter.

After switchback to the parallel mode of operation, the automatic sequence must be initiated by an operator to place the system in the load following mode.

5.9 System Control

The ASPCP system (see Figure 4-1) is normally controlled automatically by the MCU. Manual control of the system may be accomplished through the MACDP as a backup using the controls, status indicators and displays on the MACDP console.

5.9.1 MASTER CONTROL UNIT

The MCU is a computer-based control subsystem that will automatically start, monitor status, and shut down the ASPCP as required.

The MCU configuration has been selected for hardware reliability and software availability. To this end, the MCU is configured using standard off-the-shelf Hewlett-Packard computer components and peripherals. During the phase I effort, design of the MCU subsystem was developed to the point where definition of the control subsystem configuration and function has been completed.

5.9.1.1 MCU Functions

The MCU subsystem performs five basic automatic control functions as follows:

1. Maximum power point tracking control
2. Inverter and switchgear control
3. Array stowage
4. Visitor's display control
5. Operator's display control

In addition to the above, the MCU contains all the necessary hardware and software elements required for system program development. The MCU is completely independent of the ODAS.

5.9.1.2 Maximum Power Point Tracking Control

The maximum power or parallel load-sharing mode is the primary mode of operation for the ASPCP. In this mode, the maximum available power is extracted from the solar array field and is delivered to the combined dedicated and nondedicated loads in parallel with the utility.

It is well known that to maximize the efficiency of a photovoltaic system, it is necessary to operate the solar array at the maximum power point (MPP) of its I-V characteristic curve. Maximum power is obtained from the ASPCP array field by varying the load presented to the field by the inverter in such a way as to cause the field to operate at the MPP on its I-V characteristic curve. This is effected by controlling the internal phase angle of the inverter with respect to the utility phase reference. The controller periodically samples the array field output power level and adjusts the inverter phase to maintain the array field power output at the maximum value possible for existing insolation levels. Operation at the MPP is illustrated in Figure 5-39.

Figure 5-39. Array I-V Characteristics

MPP may be implemented either in hardware or entirely in software. Both methods will be employed in the operation of the ASPCP. The hardware approach will be used for operation of the system during the initial installation and checkout of the power conditioning equipment and also for manual operation of the complete ASPCP system for maintenance purposes. Software control of the MPP tracking function will be the primary control mode for automatic system operation and will be implemented in the MCU.

5.9.1.2.1 Maximum Power Control Algorithm. The detailed flowchart of the maximum power control algorithm, shown in Figure 5-40, is initiated at a preset repetition rate. Array field current and voltage data are input to the MCU from appropriate transducers located in the APMP. The present value of power P_N is compared with the power P_o computed during the previous update cycle. The program then branches to one of the three paths depending upon the result of the comparison.

The result ($P_N = P_o$) indicates that the array field is operating at its MPP. The program maintains the array load at its present value.

The result ($P_N < P_o$) indicates that the effect of the command signal to the inverter during the previous update cycle was to move the array field operating point away from the MPP. Since a departure from the MPP can take place along either the positive or negative slope of the power curve, decision logic is provided to resolve the slope ambiguity. This function is implemented by inserting an appropriate flag. If a decrease in power results from a decrement load correction made in the previous update cycle, an increment load instruction is given to the inverter, which drives the field operating point toward the MPP. If the decrease in power resulted from an increment load correction made in the previous update cycle, the decrement flag will be in the reset state and a decrement load command will go to the inverter and again the correction will drive the field operating point toward the MPP.

The result ($P_N > P_o$) indicates that the effect of the command signal to the inverter during the previous cycle was to move the array field operating point in the desired direction (i.e., toward the MPP). In this case, the particular command that yielded the power increase must be repeated. This is achieved by interrogating the increment flag. As shown in Figure 5-40, an increment or decrement command will be generated depending upon whether the increment flag is in the set or reset state, respectively.

5.9.1.2.2 Hardware Maximum Power Controller. During phase 1, a hardware system was designed and fabricated to operate the solar array at its maximum power by varying the loading to the array. The design configuration of this maximum power controller (see Figure 5-41) comprises three functional blocks:

1. Power to frequency converter,
2. Frequency sampling and comparing circuitry, and the
3. Electronic load.

Array voltage and current are sampled and multiplied to provide an analog signal to the frequency converter (Figure 5-42, sheet 1). This frequency, which is proportional to array power, is fed into a cascaded BCD counter (Figure 5-42, sheet 2). At an appropriate sampling rate, the contents of the BCD counter are compared with the contents of a hex D flip-flop from the previous BCD count, and the result is a digital signal indicating that the present value of power (P_N) is either greater or lesser than the previously sampled power (P_o). Since operation can be on either slope of the solar module power curve, the digital signal indicating $P_N > P_o$ or $P_N < P_o$ is processed through a digital slope discriminator (Figure 5-42, sheet 3) before being applied to an electronic load where the solar array current is varied.

Testing was performed using two series 24 watt (peak) solar flat-panel modules. At maximum power, 41 watts were achieved at 1.12 ADC. The open circuit voltage at the time when maximum power was attained was 48.94 VDC, and the short circuit current at this same time was 1.26 ADC. Sensitivity at the maximum power operating point was 1.2 percent ($\Delta \text{power} \leq 0.5$ watts). Approximately 30 seconds are required to reach maximum power from a short circuit condition.

Because of the sensitivity and because the MCU computer is available, the maximum power controller will be a function of a computer software algorithm when the ASPCP is operating in the automatic "maximum power" (prime) mode. The hardware version of controlling maximum power will be used to provide backup to the MCU.

Figure 5-40. Maximum Power Control Algorithm

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Figure 5-41. Maximum Power Controller Interconnection Diagram

Figure 5-42. Peak Power Tracker
Schematic Diagram (Sheet 1 of 3)

**Figure 5-42. Peak Power Tracker
Schematic Diagram
(Sheet 3 of 3)**

5.9.1.5 Visitor's Display

A conceptual layout of the proposed facilities building visitor's display is shown in Figure 5-43. In addition to providing a highly visible focal point of interest to visitors, the display also functions as a status board for the system operator. The display parameters are derived from the MCU. Data from sensors on instrumented array 25 and from system power transducers are monitored by the MCU, which then converts the raw data into suitable engineering units and periodically updates the display.

5.9.1.6 Operator's Display

Operator control of display parameters will be implemented using the CRT terminal operating under the H.P. RTE-IV real-time executive operating system software. Detailed definition of this function will take place during the phase 2 system software development effort.

5.9.2 MACDP

The purpose of the MACDP is to provide a means for manual control of the system to allow initial testing and evaluation of individual portions of the system as they are installed and incorporated into the system. Under normal conditions, all phases of system operation are controlled automatically by the MCU. In the event of an MCU failure, the MACDP provides the means for independent control of the system.

5.10 On-Site Data Acquisition System

The ODAS will consist of a computer-based data acquisition system and a weather station. All ODAS components including the weather station are to be supplied by DOE as Government Furnished Equipment (GFE). The computer and its associated peripherals will be installed inside the facilities building, and the weather station will be mounted on the roof. It should be noted that operation of the ASPCP will be completely independent of the ODAS. Data acquisition is the sole function of the ODAS, and the equipment will have no part in system control.

5.10.1 DATA SENSORS

A complete list of signals to be interfaced with ODAS is given in Table 5-17. As shown in Table 5-17, the sensor complement is divided into three signal groups.

Group 1 encompasses the signals from the weather station transducers to be supplied by DOE as GFE.

Group 2 sensors are those needed to satisfy the remaining requirements of the minimum data set established by DOE.

Group 3 sensors are not required in the minimum data set specified for ODAS, but they are needed for ASPCP control or for evaluation of the unique features of the system. Since these sensors will be available for system control, they may readily be used to provide additional data to the ODAS.

Figure 5-43. Visitor's Display Panel

Table 5-17. Signal List Interface with ODAS

Signal Group	Signal Name	Qty. Req'd.	Sampling Interval (Min)	Sensor Required By:		Sensor Supplied By:	
				DOE	MOT	DOE	MOT
I	Direct normal insolation	1	10	✓	✓	✓	
	Total horizontal insolation	1	10	✓		✓	
	Reference solar cell	1	10	✓	✓	✓	
	Ambient air temperature	1	30	✓		✓	
	Wind speed and direction	1	30	✓	✓	✓	
	Humidity or dew point	1	60	✓		✓	
	Precipitation	1	60	✓		✓	
	Barometric pressure	1	30	✓		✓	
	Array field current	1	10	✓	✓		✓
	Array field voltage	1	10	✓	✓		✓
	String current	59	10	✓			✓
II	Inverter output volts/phase	3	10	✓			✓
	Inverter output amperes/phase	3	10	✓			✓
	Inverter phase angle/phase	3	10	✓			✓
	Array field AC power drain	1			✓		✓
	Strain gauge	6			✓		✓
	Cell temperature	4			✓		✓
III	Module cover temperature	1	Note 1		✓		✓
	Heat sink temperature	2			✓		✓
	Cell mount temperature	2			✓		✓
	Primary surface temperature	1			✓		✓
	Module internal air temperature	1			✓		✓
Note 1. These update intervals will be determined in phase 2.							

SECTION 6 — SITE PREPARATION

This section describes those activities necessary to provide a complete design for the airport site construction. The following areas are considered: grading and surfacing, fencing, maintenance roads and parking lot, facilities building construction, electrical service, and underground ductwork.

6.1 Clearing, Grading, and Surfacing

The design included under this task of phase I comprises all clearing and removal; scarification and recompaction; excavation; furnishing, placement and compaction of fill; construction of dikes, ditches, and catch basins for site drainage or flood control; furnishing and application of soil sterilizing agent; furnishing, placement and compaction of surface course.

All brush, scrub timber, stumps, and refuse are to be removed from the area and disposed of.

Fills are to be placed and compacted in 12-inch maximum layers. Each layer is to be moistened where necessary and then compacted to a minimum relative density of 95 percent of maximum at optimum moisture content (ASTM D1557).

Only mechanical compaction methods are to be used in all grading operations. In no case is water settling or jetting to be employed.

The project site will need to be scarified and recompacted. Recompaction will be to a minimum relative density of 95 percent (ASTM D1557) and to a minimum depth of 12 inches. Roots uncovered during scarification will be removed.

A decomposed granite surface course is to be applied after all underground work, foundation work, road work, backfilling and compaction is completed. The surface course will be placed in a uniform layer over the areas shown on the drawings. Material bladed to a smooth surface conforming to the grades shown on the drawings will be watered and thoroughly rolled to a minimum relative density of 90 percent (ASTM D698). Rolling is to be done with a pneumatic tire and/or a power tandem roller.

The areas indicated on the drawings will be treated with a chemical soil sterilizing agent.

6.2 Fencing

Design work included under this task comprises the furnishing and installation of all chain-link fencing complete with gates and all other appurtenances as indicated on the drawings to secure the ASPCP.

A new 8-foot chain-link fence is to be installed around the entire outer perimeter of the project site (see fencing and grading drawings for details).

Fencing shall conform to ASP's Substation Standards Specifications for 96-inch Fabric Fence, Sheets US03, US04, UC03, UC04, UC06, UC07 and UC08, which are included as a reference in the specification appendix.

6.3 Maintenance Roads and Parking Area

The roads and parking area will be an aggregate base course in conformance with "Type AB5C" defined in the Arizona Highway Department "Standard Specifications for Road and Bridge Construction." In addition to conforming to the material gradation requirements presented in the Arizona Highway Department specification, the aggregate

shall also conform with regard to percentage of material passing the No. 200 sieve and plasticity index. The Arizona Highway Department standards have been used to provide a standard basis for design.

A sprayed asphalt prime coat will be applied over the base course using "Type MC-250" liquid asphalt as defined in the Arizona Highway Department specification.

Immediately after application of the prime coat, a double chip seal cover of 3/8-inch aggregate chips is to be placed.

The application and maintenance of the prime coat and chip seal will be in accordance with accepted techniques presented in the Arizona Highway Department Standard Specification for Road and Bridge Construction. The rate of application of the sealer is to be the amount that will be completely absorbed by the aggregate in a 24-hour period. This amount, in general, is between 0.20 and 0.50 gallons per square yard.

The asphaltic concrete surface course is to be placed as indicated on the drawing(s).

The mineral aggregate to be used for the asphaltic concrete mixture shall be in conformance with "Type MA-9" aggregate; the material shall conform with regard to maximum swell, maximum abrasion and plasticity index as presented in the Arizona Highway Department Specification.

Construction details such as stockpiling, drying and heating, bin separation, mixing, placing, rolling, finishing and tolerances shall be in accordance with the Arizona Highway Department specification.

6.4 Foundations For Arrays and Miscellaneous Equipment

Design work included under this task comprises the design of all excavation; furnishing, placement and compaction of backfill; furnishing and placement of reinforced concrete foundations and tracking rail.

Excavation and backfill is to conform to the applicable portions of APS's Substation Standard Specification Sheets YS07 through YS11 (a copy of the standards is attached with the drawings).

All foundations are to be constructed to the grades and dimensions shown on the drawing(s). The concrete and reinforcing steel will conform to the applicable portions of APS's Substation Standard Specification Sheets YS01 through YS06-A, which are included in the specification appendix.

6.5 Facilities Building Construction

This design task included the work to furnish and install a rigid frame steel building, complete with internal plumbing, heating and air conditioning systems and utility ties; all excavation; placement and compaction of backfill required for underground utility ties and equipment cables; furnishing and placement of reinforced concrete foundation and a computer floor; electrical lighting, power outlets, service entrance, conduits, wiring, lighting fixtures and related appurtenant equipment; exterior openings for wiring, structural and miscellaneous steel; exterior and interior doors with frames; partitions and ceilings; caulking, painting and other decorating items as specified; observation deck, roofing, roof insulation, metal work, and miscellaneous hardware; millwork, toilet partitions, and flooring and all other building appurtenances.

6.5.1 SURVEYING AND LOCATING

The purpose of this task is to locate the facility building in accordance with the drawings. All grades and elevations are to be set from existing references.

6.5.2 FOUNDATION PREPARATION

Preparation of the foundation to receive material is to be done by the building contractor. If the contractor elects to excavate and replace basement material to facilitate compaction, before replacement has begun and when ordered by APS, a layer of material below the excavated material will be compacted to the depth, width and degree of compaction specified by APS.

6.5.3 EXCAVATION AND BACKFILL

Excavation and backfill will conform to the applicable portions of APS's Substation Standard Specification Sheets YS07 through YS11, which are included in the specification appendix.

6.5.4 FOUNDATION

The foundation is to be constructed to the grades and dimensions shown on the drawing(s). All concrete and reinforcing steel will conform to the applicable portions of APS's Substation Standard Specification Sheets YS01 through YS06-A, which are included in the specification appendix.

6.5.5 PRE-ENGINEERED METAL BUILDING

1. The building contractor is to furnish and erect one nominal 40-foot by 50-foot Varco-Pruden rigid frame steel building or an equivalent building of another manufacturer. The eave height shall be approximately 12 feet. The building will be a clear span, gable type, with a roof slope of 1 inch in 20 inches.
2. Buildings will be furnished and erected complete with structural system, cover, flashing, doors and other accessories.
3. Roof live loads will be 20 PSF applied in accordance with Section 3 of the MBMA "Recommended Design Practice Manual." The wind load is to be 15 PSF supplied per the MBMA Manual.
4. Structural steel work will conform to the Association of Independent Software Companies' (AISC) "Specification for the Design, Fabrication, and Erection of Structural Steel for Building." Light gage steel work will conform to the American Iron and Steel Institute "Light Gage Cold Formed Steel Design Manual." All cutting, punching, welding and forming are to be done at the factory. All field connections shall be bolted.
5. Wall and roof sheathing are to be Varco-Pruden steel panel rib with "Spectrum 20" factory finish. A die formed ridge cap sheet will be used at the ridge line. The entire metal wall and roof area will be insulated with a Varco-Pruden 1/2-inch thick fiberglass blanket insulation having a maximum "U" factor of 12 Btu per hour per square foot per degrees F, with an integral 2 mil minimum thickness vinyl face. A 7-foot 4-inch high inner liner wainscot for the maintenance and storage portion of the building will be Varro-Pruden steel panel rib with "Spectrum 20" factory finish to match exterior wall siding.
6. Exterior single swing doors will be of the size and type indicated on the drawings and furnished as an integral part of the building.
7. Frames for overhead, roll-up type doors are to be of the size and type indicated on the drawings and furnished as an integral part of the building.

6.5.6 STRUCTURAL AND MISCELLANEOUS STEEL WORK

The building contractor will furnish, fabricate, unload, and erect all structural and miscellaneous steel.

6.5.7 COMPUTER FLOOR

A computer floor of approximately 11 feet by 35 feet shall be constructed to allow cooling air to the inverters, MCU and ODAS equipment.

6.5.8 EQUIPMENT FOUNDATION

A foundation of approximately 3 feet by 30 feet for inverter switchgear and inverter modules I and II will be constructed.

6.5.9 WEATHER STATION OBSERVATION DECK

A weather station observation deck as shown on Drawing No. G-55303 (Sheets 1 and 2) is to be furnished and installed.

6.5.10 ROOFING, ROOF INSULATION, AND SHEET METAL WORK

The building contractor will furnish and install roofing including insulation, drains, flashing and sheet metal work.

6.5.11 HOLLOW METAL DOORS AND FRAMES

The contractor will furnish and install all steel doors and steel frames indicated on the drawings. Doors will be mortised, reinforced, drilled, and tapped (for template hinges and locks) in the shop. After assembly, surfaces are to be thoroughly cleaned and primed and filler coats are to be sanded smooth. Rust inhibitive primer coat is to be applied, and the finish painting will be done in the field.

6.5.12 OVERHEAD ROLLING STEEL DOORS

The contractor will furnish and install the overhead rolling steel doors indicated on the drawings. Doors are to be weatherstripped and prepainted, with hot-dipped galvanized steel curtains made from interlocking flat slats. Doors will be interior face mounted, electrically operated, and furnished complete with guides, weather-stripping, hardware and accessories.

6.5.13 CAULKING

The building contractor will furnish all labor and materials to complete all caulking where necessary.

6.5.14 GLASS AND GLAZING

Glass is to be of the types and sizes indicated on the plans. Each piece of glass will have the manufacturer's label showing strength and quality.

6.5.15 CEILING AND ACOUSTICAL TILE

A suspended gypsum board ceiling and acoustical tile for the visitor's center and equipment portion of the building will be installed. Hangers for the suspended ceiling shall be securely anchored to the structural frame.

6.5.16 TOILET PARTITIONS

Toilet partitions will be as indicated on the drawings. Doors will be hung on stainless steel gravity hinges and will be fitted with chrome-plated brass combination keeper and bumper, heavy throw latch, and coat hook with rubber-tipped bumper.

6.5.17 RESILIENT FLOORING

Resilient floor tile, base, and edging strips are to be installed in the visitor's center and equipment portion of the building. Floor tile will be rubber or vinyl-asbestos.

6.5.18 FINISHING HARDWARE

The building contractor will furnish and install all finishing hardware such as locksets, passage sets, latches, and door closers.

6.5.19 GYPSUM WALLBOARD

Wainscot for the visitor's center and equipment portion of the building will be full height painted gypsum wallboard.

6.5.20 PAINTING

The building contractor will provide painting or finishing of wood, concrete, unfinished metal, and other surfaces for the visitor's center and equipment portion of the building.

6.5.21 PLUMBING

The plumbing work consists of, but is not necessarily limited to, the following:

1. Complete sanitary plumbing system including all connections to fixtures and equipment, all lines both inside and outside the building-including connection to the sewer.
2. Complete potable water piping system including all connections to fixtures and equipment and including both hot and cold systems.
3. Complete compressed air piping system.
4. Condenser cooling water drains from the air conditioning units.
5. Drains for condensate from air conditioning units.
6. Complete natural gas piping system including all connections to equipment.
7. Furnishing and installing all plumbing fixtures including water heaters.

Detailed specifications for the plumbing will be added as final design progresses.

6.5.22 LIST OF DRAWINGS*

<u>Drawing No.</u>	<u>Title</u>	<u>Sheet No.</u>	<u>Revision No.</u>
G-55302	Airport Solar Photovoltaic Solar Array Field Facilities Building Floor Plan	1	0
G-55303	Airport Solar Photovoltaic Concentrator Project Facilities Building Elevations	1 and 2	0
G-55310	Topographic Map Airport Solar Site	1	0
G-55307	ASPCP - Solar Array Field Roadways and Fencing	1	0

*Additional drawings will be prepared during final design.

6.6 Electrical Services

APS will install poles and transformers and service primary conductors at the solar site. Existing poles, primary conductors, secondary conductors, transformer services and street light poles will be removed from the proposed solar site. The work shall conform to the American National Standard Electrical Safety Code (ANSI/NFPA 70E) and APS electric distribution construction standards.

APS will install and connect the kWh meters and associated hardware and hook up in the airport south concourse area.

6.7 Underground Ductwork

An underground electric and control conduit system will be installed between the airport south concourse and the solar site facility building. The work includes: excavation of about 3095 feet of trench; installation of about 6150 feet of 4-inch plastic conduit and 3075 feet of 3-inch plastic conduit, 20 feet of 3-inch steel conduit, and 40 feet of 4-inch steel conduit; concrete encasement of the conduit; and installation of the rebar in concrete; and backfill. Approximately 340 feet of asphalt concrete will be cut and replaced at the airport. Two special load-bearing manholes and two standard pull boxes will be installed. A transformer pad will be installed at the solar building. Two 750 kVA transformers will be installed; one transformer is located at the solar facility building, and the other is at the airport south concourse area.

The following wiring will be installed:

1. About 5400 feet of 3-1/0 A1. 1/C 15KV XLPE with concentric neutral in new and existing duct bank.
2. Copper secondary voltage cable in existing duct from the step-down transformer, through the metering cubicle, and into the solid state switch.
3. Aluminum secondary voltage cable from the solid state switch to the south concourse service entrance section.
4. About 10,780 feet of 4-#10 copper control wires in the new and existing duct banks.

SECTION 7 — OPERATION AND EVALUATION PLAN

7.1 Introduction

The system will be available for full scale operation upon completion of system checkout at the end of phase II. The plan for operation has the following objectives.

1. Determine system performance characteristics.
2. Verify design predictions of operating conditions.
3. Verify material and component performance.
4. Provide information on operation and maintenance procedures.
5. Demonstrate reliability of system and components.

Based on the information gained in operating the system, it will be evaluated in terms of technical, economic, and nontechnical considerations.

To accomplish these objectives, four major tasks have been identified for the operating phase:

Task 1 - System Operation

Task 2 - Data Acquisition and Test Plan

Task 3 - Operation and Maintenance Manual Preparation

Task 4 - Detailed Operation and Maintenance Analysis

A two-year schedule to execute these tasks is shown in Figure 7-1.

7.2 System Operation

The solar plant has been designed for automatic operation. This is accomplished by the MCU, which monitors conditions such as time of day, insolation, and weather to determine if the system can operate. If the necessary conditions exist, the control system will act to either start up or shut down the P-V solar power system. In this manner, the system will be able to produce power without the assistance of an operator. It is contemplated, however, that on-site operator assistance will be required during the initial operation of the plant to assure smooth operation and to provide manual inputs necessary for execution of various experiments. The plant will be monitored by the APS system operation control center that will dispatch maintenance help to the site as required.

Except for the load following tests, the operating strategy will be to maximize the output of the solar plant.

7.2.1 MAINTENANCE REQUIREMENTS

Cleaning of the module covers represents the largest single item of maintenance. To accomplish this task, a trailer-mounted pressurized cleaning system is envisioned, similar to the unit now in use at the STTF facility. Exposure tests underway at this time at the airport site will provide additional data on cleaning requirements. As part of this testing, samples of the residue that collects on the module cover will be analyzed for chemical composition to aid in the selection of a cleaning agent.

Other maintenance requirements include the upkeep of mechanical and electrical components. These requirements will be defined in detail during the initial operation of the system and will be included in the operation and maintenance manual.

Figure 7-1. Schedule for Operating Plan

7.2.2 MODES OF OPERATION

The system has been designed to allow data collection for two different operating modes: load following and paralleling with the utility grid. Both modes will provide valuable information for assessing the photovoltaic operation, such as the total output for each mode of operation, the ability of the system to switch from solar to utility power and vice versa, and the necessity for energy storage. When sufficient testing has been performed in each mode to allow an evaluation, the system will be operated in the parallel mode to maximize electrical energy production from the solar system.

7.2.3 OPERATING PERSONNEL

During phase II, an APS operating crew will be selected and given a two-month training course prior to the preoperational testing of the system. In addition, the crew will assist in system check-out and perform the preoperational tests under engineering supervision. The basis of the crew will be two men selected from the APS plant system electric equipment group who will perform on-site operator and maintenance functions during operation.

In addition, members of the System Operation Center (SOC) group will receive training in providing remote monitoring of the generating plant. It is also expected that Motorola will provide technical assistance in both phases II and III. After a determination has been made that on-site operators are no longer required, an APS field maintenance crew will be available for dispatch upon notice from the SOC.

The anticipated operating staff for phases II and III is shown in Figure 7-2.

7.3 Test Plan

The phase III test plan is composed of three basic elements:

1. Demonstration of the load following mode of operation.
2. Demonstration of parallel operation with the utility grid.
3. Special tests.

Three experiments are scheduled for the first 12 months of operation as shown in Figure 7-1. Since the dedicated load in the south concourse includes 195 kW for strip heaters, it is planned to operate in the load following mode when the strip heaters are inactive. The expected peak load will then be 337 kW. To gain information on both parallel and load following modes, the plant will alternate between modes as required.

Special tests will also be conducted during the first year to determine system response to ground fault interruptions and other outages from the solar system and potential design modifications to the modules in the instrumented array to increase conversion efficiency. These modifications will reflect state-of-the-art improvements in cell efficiency and reflective surface performance.

The second year of operation is intended to be a one-year performance run to achieve a maximum annual output. The plant will be operated in the parallel mode.

7.4 Data Acquisition

7.4.1 FUNCTION OF THE ON-SITE DATA ACQUISITION SYSTEM

The data acquisition system will perform two primary functions:

1. Collection of data for transfer to a Data Reduction Center. This data will be used by DOE to compare various photovoltaic systems.
2. Collection of data for evaluating the performance of the system. This data will be used to gain information on the photovoltaic system and determine the various system and component efficiencies of the ASPCP.

In most cases, the data collected for one function will also be applicable to the other function. As specified by DOE, the data collection and control systems are separate to allow for sample interval differences, prevent interactions between the control and data acquisition systems, and permit uniform maintenance of the instrumentation.

Data reported to DOE will follow the format specified by the uniform data requirements and data collection techniques. An expense ledger and operating and maintenance logs will be incorporated in phases II and III to collect the soft data.

7.4.2 DATA TO BE COLLECTED

The list of signals to be collected in the data acquisition system is shown in Paragraph 5-10. These data will be evaluated for each mode of operation.

Figure 7-2. Operating Staff — Phases II and III

7.5 Operation and Maintenance Manuals

Preparation of the operation and maintenance manual will draw upon experience gained in operating the ASPCP during the preoperational test performed at the end of phase II. APS will have its SOC, which has the responsibility for dispatching all APS power plants; Power Plant Operations provide input to the manual. The SOC function is to define operating procedures for all new APS generating stations. The operating procedures that SOC will define pertain to how the ASPCP is to be operated on the APS system. Power Plant Operations, under the Operations Division, is charged with defining how an APS generating station is to be operated and maintained. Motorola GED will furnish to Power Plant Operations the necessary information that defines the ASPCP operating constraints and the procedures required to maintain all equipment supplied by GED. Power Plant Operations will then prepare a detailed procedure to be followed for operating and maintaining the ASPCP.

Preparation of the manual will be accomplished during the first three months of phase III operation. The manual format will conform to APS standards, which allows for updating based on experience gained through operation.

7.6 Technical Evaluations

7.6.1 SYSTEM LEVEL EVALUATION

Evaluation of the system operation will be an on-going process based on the data collected during the testing and operating phases. The areas of technical and economic performance and nontechnical issues will be investigated.

Each operating mode will be analyzed for system and component performance as determined by a comparison of inputs and outputs. For the system level:

- 1. Load Following**

For the load following mode, the primary data to be analyzed is the comparison of the load variation in the south concourse with inverter output. Also to be evaluated is the need for the system to be switched from solar to grid power during this mode of operation and the percent of time utility power (storage) is required. In addition, the ability of the inverter controls to match the array field output with the load requirements will be analyzed. From these analyses, conclusions will be drawn regarding the capability of the photovoltaic system to supply a dedicated load with the utility grid acting as the storage device.

- 2. Parallel Mode**

In the parallel mode of operation, emphasis will be placed on a comparison of the array field output with the inverter output to determine system efficiency. Also to be evaluated is correlation of the output with environmental transients. In addition, the south concourse load and the solar plant output will be equipped with special meters to determine how much solar power is going to the load and how much is going to the utility grid. These results will be compared with the system performance computer analysis results for agreement with design predictions. Conclusions will be drawn with respect to the system's ability to operate in parallel with the utility grid.

- 3. Fault Testing**

A simulated fault will be produced to evaluate the system's ability to switch the load from solar power to utility power without interruption in service.

4. Time Constant

The ability of the system to minimize phase shifts during switching operations will also be evaluated. To do this, the phase angle of the utility grid at the south concourse will be compared with the phase angle at the output of the inverter. Shifts that occur due to switching will be monitored, and a time constant will be defined that defines the maximum shift permissible without causing distortion of the power delivered to the load.

7.6.2 COMPONENT LEVEL EVALUATION

The acceptance and preoperational tests planned to be performed during phase II will provide the basis for evaluating the solar components. However, it is anticipated that continuing design improvements for the solar cells and optical surfaces will make it desirable to test these designs on the instrumented array as they become available.

In addition, weather and other environmental impacts will be evaluated with respect to their effect on component degradation and maintenance requirements.

7.7 Economic Evaluations

1. Operating and Maintenance Cost Analysis

The ASPCP operating and maintenance costs will be analyzed by the APS power production group in a manner similar to other generating stations. The photovoltaic plant will be assigned a unit number of responsibility to which all of its operating and maintenance costs will be charged. Also, there will be various account numbers that distinguish various activities under the unit of responsibility.

Each year, a budget is set for the plant for the following year. The budget sets the number of people on the payroll, their job descriptions and their salaries. This includes administrative, technical and union labor. Also set are auxiliary power costs, security costs, replacement equipment, tools and maintenance costs, land costs, and other miscellaneous expenses that are expected.

Then each month, the Accounting Department places the costs accrued to each account number in the computer. The computer compares the actual costs with the budget and compiles a variance list. These are then analyzed for causes.

2. PVECON Analysis

The PVECON computer program described in Paragraph 2.2.11 will be run with cost data developed during construction and operation and actual plant output values. Comparisons will be evaluated versus initial predicted results.

3. System Planning Analysis

Once the plant operating characteristics have been verified with operating data, the impact of placing an expanding number of photovoltaic power systems on the utility grid will be evaluated using system planning models.

7.8 Nontechnical Issues

7.8.1 ENVIRONMENTAL

An evaluation of the issues considered in paragraph 4.7 as they relate to actual operations will be made near the end of phase III. Additional issues that arise during operation will also be addressed.

7.8.2 RATE IMPACT

An analysis will be performed to determine a rate structure for the photovoltaic plant based on operating experience. Consideration will also be given to buy-back of energy from the solar plant to the utility grid.

7.8.3 EVALUATION OF FUTURE OPERATION

It is the intent of APS and Motorola to continue operation of the ASPCP as an experimental station to the extent that it is economically feasible to both companies.

Assuming that continued operation is viable, the visitor center and all of the ASPCP instrumentation and display equipment would also continue to operate and provide additional benefits.

7.8.4 PUBLIC ACCEPTANCE

Tours of the control and facility building as well as the airport terminal display will serve as focal points for feedback from the public regarding their reaction to the solar plant.

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