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MASTER

SOLCOST-PHOTOVOLTAIC
SOLAR ENERGY DESIGN PROGRAM
USER'S GUIDE

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Prepared By:

Martin Marietta Aerospace

Denver Division

P.O. Box 179

Denver, Colorado 80201

For:

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FOREWORD

This User's Guide documents the capabilities and data inputs for the SOLCOST-Photovoltaic Solar Energy Design Program. SOLCOST-Photovoltaic is intended for use by photovoltaic system designers and manufacturers of PV equipment. The coupled electrical performance and economic analyses within a single interactive computer program provides a useful tool for the photovoltaic design process. The input data requirements have been simplified so non-computer specialists can easily use the program to rapidly generate system performance estimates for a range of design variables.

The photovoltaic performance methodology in SOLCOST-Photovoltaic is based on the systems design and simulation work of the Power Systems Section at Martin Marietta Aerospace in Denver. The computer implementation of the resulting SOLCOST - PV design method in the interactive SOLCOST framework was performed by Martin Marietta Aerospace for the U.S. Department of Energy, Education and Communications Branch.

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I. INTRODUCTION

The SOLCOST-PHOTOVOLTAIC solar energy design program is a public domain interactive computer design tool intended for use by non-solar specialists to predict the long term performance for photovoltaic systems. A life cycle cost analysis is included in the program along with the ERDA-EPRI standard economic analysis which predicts levelized busbar energy costs for the photovoltaic system assuming ownership by an electric utility.

SOLCOST-PV currently can evaluate flat plate arrays and concentrating arrays which use Fresnel lenses and passive cooling. The methodology could easily be extended to include all the known types of concentrators, however the scope of the version 1.0 activity was limited to only the flat plate and the passive Fresnel concentrators.

Section II of this guide contains an overview of the SOLCOST-PV capabilities and methodology. Users are referred to the supporting references for details which are beyond the scope of this guide. Section III is a detailed guide to the SOLCOST-PV input parameters. Section IV presents examples showing typical interactive execution sessions and the resulting SOLCOST-PV output. Appendices A and B provide additional information on the SOLCOST-PV analysis.

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I.2

II. OVERVIEW OF SOLCOST-PHOTOVOLTAIC ANALYSIS

A. Photovoltaic System Description - The basic system configuration modeled is shown in Figure II-1. Key components in the system are the solar array, a battery (if used), and an inverter. The system power flows are shown schematically in Figure II-2 along with the corresponding component efficiencies which can be input by the user. If a component is not present in the system, the component efficiency is set to unity and the analysis continues.

The baseline configuration shown in Figure II-1 uses peak power tracking via an auxiliary load. No dc battery charger is used, rather a shunt regulator is provided to insure a dc bus voltage compatible with battery charge voltage limits.

The shunt regulator operates only during periods when the solar array voltage exceeds the system voltage limits (determined by battery and inverter input requirements). When the shunt regulator is not operating, the system voltage is controlled by the battery terminal voltage.

The peak power tracking approach attempts to maximize the solar array utilization factor which is the fraction of solar array energy that is extracted from the total solar array energy available. Maximum energy is obtained from the solar array when operation is maintained at the peak power point. This point occurs at the knee of the solar array characteristic IV curve, as seen in Figure II-3 which shows typical solar array I-V characteristic curves for several cell temperatures.

II-2

Figure II-1 Baseline SOLCOST-PHOTOVOLTAIC System Configuration

Figure II-2 Power Flow Diagram for Baseline System

Figure II-3 I-V Characteristics of PST Baseline Solar Array Configuration

The auxiliary load shown is a noncritical load that is functional over a widely varying dc input. Such a load might be a heating element for a water container or a space heater coil. The primary purpose for the auxiliary load is to utilize excess energy from the array that is not consumed by the load or the system battery.

The ac battery charger provides for charging of the battery bank from the utility at night or at any time when the power from the solar array is inadequate for battery charging. The ac charger is not necessarily a required component, however, if batteries are used it may be cost effective to charge the batteries during off-peak times (i.e. at reduced power costs).

The utility interface provides the switching mechanism (contactors or solid state switches) to isolate the utility grid from the PV power system when the inverter is functioning or to allow parallel operation of the inverter output with the utility grid. The utility service box is the housing for the main circuit breakers and is a standard component of the utility service entrance.

The solar array distribution unit contains the blocking diodes that protect each series string of subarrays from reverse current.

When the battery is removed from the system, other components can also be removed. When a component is deleted, the power loss of that component is obviously also eliminated. For the baseline configuration both the shunt regulator and the auxiliary load can be removed for the no-battery condition. If the inverter capability is less than the solar array capability, the shunt regulator and auxiliary load must remain to prevent the array voltage from exceeding the inverter upper voltage limit.

B. Photovoltaic Systems Analysis Methodology - The SOLCOST-PHOTOVOLTAIC systems analysis methodology uses historical weather and solar insolation data to predict the annual average system performance, i.e. the quantity of solar energy delivered to the load. The methodology uses an energy balance technique

based on the work of Imamura et al (Ref. 1). One average day per month is simulated in detail taking hourly steps during the daylight hours to compute the instantaneous system performance. Results from this one day analysis are then weighted with an insolation dependent factor to project the expected long term performance. This approach is identical to the SOLCOST methodology for space and water heating systems which has been validated extensively with measured system performance data (See Reference 2).

Figure II-4 presents an overview of the key elements of the SOLCOST-PV methodology for direct systems (i.e. no storage battery). The following steps are executed on the 15th day of every month to compute the annual system performance:

1. An array of hourly insolation values is generated with the SOLCOST radiation algorithm as described in Reference 2.
2. A loop over the daylight hours is executed taking hourly steps to compute the following:
  - a. Solar cell temperatures from a heat balance on the solar array (details given in Appendix A).
  - b. Solar array output energy, EC, as a function of temperature and insolation (details in Section C).
  - c. Inverter efficiency, REFF, as a function of load (details in Section D).
  - d. Solar array output energy, SEDL, delivered to the load computed from:

$$SEDL = DEFF \times FU \times SLEFF \times REFF \times RLEFF \times EC$$

where DEFF = Array diode efficiency

FU = Solar array utilization factor

SLEFF = Line loss factor from array to inverter (or charger)

REFF = Inverter efficiency

RLEFF = Line loss factor from inverter to load bus

EC = Solar array output energy, watt-hrs

Typical array diode efficiency, DEFF, is readily computed from:

$$DEFF = (VBUS - 0.8) / VBUS$$

where VBUS is the bus voltage.

The solar array utilization factor, FU, is an engineering estimate of the system effectiveness in operating about the peak power point.

For design tool purposes, it is recommended that a value of 0.90 be

Figure II-4 SOLCOST-PHOTOVOLTAIC Analysis Overview

used until a sufficient data base on real systems is available.

- e. Auxiliary energy is then computed as required from the utility to satisfy the total load.
3. The resulting hourly energy terms are summed over the day for the 15th day of each month. Annual sums are formed from the monthly values and printed in the output summary.

For systems with battery storage, the following additional steps are taken at each hour in the analysis:

1. The battery initial state of charge, SOC, is initially set to the input Battery Fraction of Charge at dawn of each analysis day.
2. The solar energy available to the load, SEDL, is computed as in the no-battery option (Point A in Figure II-4). If SEDL is greater than the load, the battery charging algorithm is entered.

Battery Charging

- 2a. The solar energy to the battery, ETB is computed from:

$$ETB = EC \times EFF1 - LOAD/EFF2$$

where EC = Solar array output, watts-hrs

EFF1 = Product of battery diode efficiency and array utilization factor

LOAD = Load (energy) watt-hrs

EFF2 = Product of inverter efficiency and line loss factor from the inverter to the load bus.

- 2b. The new battery state of charge, SOC_{new}, is computed from:

$$SOC_{new} = (CAP \times SOC_{old} + ETB/EFF3)/CAP$$

where CAP = Battery capacity, watt-hrs

EFF3 = Product of DC charger efficiency and battery conversion efficiency.

If SOC_{new} is greater than 1.0, SOC_{new} is set equal to 1.0 and the excess energy is discarded.

3. If the quantity SEDL is less than the load, all of SEDL is delivered to the load and parallel utility operation is assumed to provide the auxiliary energy. (Or the load could be considered as sub-divided into smaller elements to be satisfied separately via switching).

Full Discharge Fraction, battery energy will also be sent to the load when SEDL is less than the load.

Battery Discharging

3a. The energy from the battery term, EFB, is computed from:

$$EFB = LOAD - EC \times EFF1 \times EFF2$$

where EFF1 = Product diode efficiency and solar array utilization factor

EFF2 = Product of inverter efficiency and line loss from the inverter to the load bus.

3b. The new SOC for the battery discharge case is given by:

$$SOC_{new} = (CAP \times SOC_{old} - EFB/EFF2 \times EFF4)/CAP$$

where EFF4 = Battery diode efficiency

If SOC_{new} is less than the input SOC_{min} , the algorithm adjusts the EFB term so the SOC_{new} is equal to SOC_{min} .

4. At the end of the simulation day the battery SOC is set to the input SOC.

C. Solar Module Performance Flat Panels - Performance specifications

for flat panel solar modules usually consist of a module efficiency or output power for given reference temperature and insolation conditions. SOLCOST-PV requires the module efficiency at 28°C and 1000 watts/m² and the cell temperature coefficient as inputs. The user can either calculate the efficiency from the available data, or he can input the cell data directly and allow the program to compute the module efficiency.

In either case, the module performance equation for flat panel arrays is as follows:

$$EC = (EMOD + TDMOD(T-28) + HMOD(HI-1000)) \times N \times ARMOD \times HI$$

where EC = Array output energy, watt-hrs

EMOD = Module efficiency at 28°C, 1000 w/m²

TMOD = Module temperature coefficient, °C⁻¹

T = Cell temperature, °C

HMOD = Module insolation coefficient, m²/w

HI = Incident solar insolation, over time step, w-hrs/m²

N = No. of modules in array

ARMOD = Gross module area, m²

For each step in the simulation, the cell temperature is computed directly in a heat balance routine prior to computing the solar array output. Details on this temperature calculation are given in Appendix B.

Concentrating Array

Version 1.0 of SOLCOST-PV can evaluate Fresnel concentrators which are passively cooled with finned heat exchangers. The performance equation for the concentrator is similar to the flat array equation with the addition of two factors:

$$EC = EC_{\text{flat panel}} \times OPEFF \times CONRA$$

where OPEFF = Total optical efficiency of the Fresnel system

CONRA = Geometric concentration ratio

The incident radiation for the Fresnel system is computed for a full tracking device, only direct normal radiation is used since the lens cannot concentrate diffuse radiation.

D. Inverter Performance Simulation* - Inverters modeled in SOLCOST-PV are high efficiency switching types. This class of inverter is characterized by an efficiency characteristic that rises from zero at no load (due to tare losses), to a maximum value at moderate loads, and then falls off slightly at high loads due to the effects of series resistance losses. This efficiency characteristic can be modeled to high accuracy with three parameters as shown in Figure II-5. A resistor, R_T , in parallel with the input represents tare loss. The constant efficiency η_0 represents power transfer in the high efficiency series resistance losses which become significant at high loads. The end-to-end inverter efficiency defined by

$$\eta = \frac{P_L}{P_i} = \frac{\text{Load Power}}{\text{Input Power}} \quad (\text{D-1})$$

can be derived from these three model parameters.

The total input power at a given load P_L , and line voltage, V_i , is given by

$$P_i = \frac{P_L + P_L^2/P_S}{\eta_0} + P_T \quad (\text{D-2})$$

where P_S , a power parameter representing loss in the series output resistance, is given by

$$P_S = V_L^2/R_0 \quad (\text{D-3})$$

and P_T , a power parameter representing tare loss is given by

$$P_T = V_i^2/R_T \quad (\text{D-4})$$

Figure II-5 Equivalent Circuit

*This section is based on the work of R. Donovan (Ref.3)

The inverter efficiency is then obtained by substituting Eq. D-2 into D-1 to obtain

$$\eta = \frac{\eta_0}{1 + \eta_0 \frac{P_T}{P_L} + \frac{P}{P_S}} \quad (D-5)$$

For general applicability, Eq. D-5 can be normalized to maximum power output rating, P_M , by defining

$$P_L = P_L/P_M \quad (D-6)$$

$$P_T = P_T/P_M \quad (D-7)$$

$$P_X = P_S/P_M \quad (D-8)$$

then

$$\eta = \frac{\eta_0}{1 + \eta_0 \frac{P_T}{P_L} + \frac{P_L}{P_S}} \quad (D-9)$$

The general efficiency characteristic of the inverter model represented by Eq. D-5 is shown in Figure II-6 for two values of P_S . The characteristic can be tailored to different inverters by calculating the three model parameters R_O , R_T , and η_0 from inverter specifications. This is done internally in SOLCOST-PV using three input points of efficiency η versus P_L/P_M taken from the manufacturer's specification for inverter performance as shown in Figure II-7.

Figure II-6 General Efficiency Characteristic of the Inverter Model

Figure II-7 Normalized Inverter Performance Curve

E. Load Model - The load model in SOLCOST-PV simply consists of an input daily total energy requirement which is impressed over the simulation day by an array of hourly fractions input on Line 75. The load power demand rate is assumed constant over each hour. Hence if a total daily load of 9000 watt-hrs is input on Line 74 and the constant hourly fractions of 0.04166 are used for every hour in the day, the power demand at any hour would be $0.04166 \times 9000/1000 = 0.37$ kW.

F. Economics - The SOLCOST-PV economics were taken directly from the SOLCEL program (Ref.4).

Two different economic methodologies are available in the program, including:

- 1) Life Cycle Cost Methodology for-
  - A. Residentially Owned System
  - B. Commercially Owned System
- 2) ERDA/EPRI or ERDA/JPL Methodology for-
  - A. Commercially Owned System
  - B. Utility Owned System (Public or Private)

The LCC methodology is based on the work of A. Perino, see reference (5). This methodology is designed to handle both residential and commercial applications. These two categories must be handled differently, due to tax law differences. A commercial enterprise is allowed to take tax deductions for O&M costs, energy costs, property taxes, interest, and depreciation while a homeowner is allowed to deduct only interest and property taxes. The methodology was modified to allow the user to specify the base year, price year, expenditure year, the first year of operation independently. In addition the SOLCOST-PV analysis accounts for escalation during the first year and uses the convention of beginning-of-the-year measurement of the end-of-the-year cash flows.

The LCC methodology calculates the total (after tax) life cycle cost of the PV system including the backup energy costs and the total (after tax) life cycle cost of supplying the load using backup energy only. Another useful parameter is called the breakeven energy cost. It is the (before tax) price of backup or conventional energy in base year dollars which will yield a conventional LCC exactly equal to the (after tax) life cycle cost of the PV system excluding backup energy. The pertinent equations are

given below:

For residential ownership

$$PVSLCC = BEEC * (1+GP)^{(IC-IB)} * SUMPVL * PVF(DISCRT,0,LIFE)$$

For commercial ownership

$$PVSLCC = BEEC * (1+GP)^{(IC-IB)} * (1-TAX) * SUMPVL * PVF(DISCRT,0,LIFE)$$

The ERDA/EPRI methodology used in options 3 and 4 (See Input Line No. 81) is taken from reference (6). For the commercial ownership option the following parameters are calculated:

TOTLAC = Levelized annual cost of the PV system (including backup energy)

CONLAC = Levelized annual cost of conventional system (backup energy only)

AS = Levelized Annual Savings (After taxes)

PVSLEC = Levelized cost of photovoltaic energy (after taxes)

CONLEC = Levelized cost of backup energy (after taxes)

For the utility ownership the most important economic parameter is the

Levelized busbar energy cost, BBEC. The BBEC is the levelized price the utility must charge for electricity from the PV system over its operating lifetime in order to generate enough revenues to cover its expenses. Since this price does not include the transmission system costs, administrative costs, etc., it is not the total price that the consumer must pay.

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III. GUIDE TO SOLCOST-PHOTOVOLTAIC INPUT DATA

SOLCOST-PHOTOVOLTAIC is an interactive program which interrogates the user for the input data set needed to execute the analysis. Section IV explains the mechanics of the program operation.

This section presents additional information on the SOLCOST-PHOTOVOLTAIC inputs, which are listed on pages III-2 through III- . Sample problems for several input decks are explained in Section IV; the user should examine those examples to get acquainted with the parameters and data formats.

The SOLCOST-PHOTOVOLTAIC inputs consist of constants and arrays of data values. Each input is described in this guide under a Line Number, which ranges from Line 11 to Line 113. An input may be one of the following:

Floating Point Constant

83, 15. is the system installed cost per sq. ft.

101, .10 is a 10% loan interest rate

100, 20. is a 20 year term for the life cycle cost analysis

Integer Constant

11, 25 is a flag for site location number 25

81, 3 is a flag for the EPRI economics

Floating Point Array

17, 32., 38., 50., 60., 65., 68., 70., 62., 50., 40., 31.,*

is an array of monthly minimum average temperatures. (Note the * at the end of the array is required to terminate array input. Additional information on array input is given by the HELP command in the program.)

Remember, the input parameters are listed by line numbers in this User's Guide. These line numbers agree with the SOLCOST-PHOTOVOLTAIC line numbers in the data input file.

The program contains "built in" values for all of the inputs. If the user accepts these default values, he enters GO in the conversation and the program

automatically uses the defaulted system. Therefore, it is critical that the user check each defaulted value to verify that it applies to his analysis. Values of the defaulted parameters are given on Pages III-2 through III .

SECTION 1 Site Data

<u>Line No.</u>	<u>Parameter</u>	<u>Default Value</u>	<u>Description</u>
11	Location No.	55	Appendix A contains a list of city numbers in the SOLCOST-PV data bank
12	Latitude, Degrees	0	
14	Clearness Factor	0	
15	Ground Reflectance	0.2	Array of monthly values
16	Fraction of Possible Sunshine	0.	Array of monthly values
17	Minimum Daily Average Temperature, Deg. C	0.	Array of monthly values
18	Maximum Daily Average Temperature, Deg. C	0.	Array of monthly values
19	Average Daily Total Horizontal Radiation W-Hr. Sq. Meter	0.	Array of monthly values
20	Average Daily Wind Speed, M/Sec	4.0	Array of monthly values

---

Note: Lines 12, 14 and 16 thru 19 need not be input if a city in the SOLCOST-PV data bank is specified.

SECTION 2 - Module/Cell Efficiency Data

<u>Line No.</u>	<u>Parameter</u>	<u>Default Value</u>	<u>Description</u>
23	Module Efficiency Fraction	0.	Flat plate module efficiency at 28°C and 1000 W/Sq. M
24	Module Temperature Coefficient, °C ⁻¹	0.	Negative sign required
25	Cell Efficiency Fraction	0.12	Cell efficiency at 28°C and 1000 W/Sq. M
26	Cell Temperature Coefficient, °C ⁻¹	-0.0005	Note negative sign
27	Module Area, Sq. M.	0.2322	Gross area for one flat plate module. Input the cell area for concentrating system.
28	Cell Area, Sq. M	0.00456	Effective area for one cell
29	No. of cells per Module	36	
30	Total No. of Modules in the Array	100	
31	Azimuth Angle, Deg.	0.	West = +, East = -
32	Tilt Angle, Deg.	41.5	Tilt from horizontal
33	Tracking Flag	0	0 = Non-Tracking, 1 = Tracking
34	Cell Insolation Coefficient, Sq.M/W	0	Cell efficiency insolation coefficient
35	Rated System Power, kW	10.	Inverter rated capacity

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*Lines 25, 26, 28, and 29 are not required if Lines 23 and 24 are input. The data in Lines 25, 26, 28, and 29 are used to calculate the flat plate module efficiency.

Section 3 - Cell Temperature Data

<u>Line No.</u>	<u>Parameter</u>	<u>Default Value</u>	<u>Description</u>
37	Cell Solar Absorptance	0.9	
38	Infrared Emittance of Cell Encapsulant	0.5	
39	Infrared Emittance of Heatsink	0.8	
40	Infrared Emittance of Cell Collector Glazing	0.9	
41	Cell Electrical Insulator Thermal Conductance, W/Sq, M - °C	10 ⁴	
42	Heatsink Finned Area Ratio	1.0	Ratio of total heatsink area with fins to total heatsink area without fins.
43	Array Cooling Type Flag	2	Options: 0 = User input temperatures 1 = Front surface cooling only 2 = Front and rear surface cooling 4 = Fresnel concentrator passive cooling
44	Cell Temperature (Fixed) °C	0.0	Array of monthly fixed cell temperatures. Input only when Line 43 = 0
45	Aperture (or lens) Area per cell, Sq. M	0.0929	Input for Fresnel concentrator only
46	Heatsink Base Area per Cell, Sq. M	0.0929	Input for Fresnel concentration only
47	Heatsink (or flat Array) Length, M	10.	
48	Geometric Concentration Ratio	1.0	
49	Heatsink Conductivity X Thickness W/°C	1.0	
50	Optical Efficiency of Fresnel Concentrator		

SECTION 4 - System Efficiency Data

<u>Line No.</u>	<u>Parameter</u>	<u>Default Value</u>	<u>Description</u>
52	Line Loss Factor, Array to Charger	0.98	
53	Inverter Efficiency Pairs	0.1, 0.60 0.2, 0.75 1.0, 0.90*	Input three pairs of (Load _____, Effic) Rated Output
54	Line Loss Factor Inverter to Load Bus	0.98	
56	Utility Feedback Flag	0	Options: 0 = No feedback 1 = Utility feedback
57	Load Bus Voltage, V	120.	
58	Solar Array Utilization Factor	0.90	
60	Number of Batteries	1	
61	Initial State of Charge	0.7	
62	Rated Capacity of Battery Amp-Hr	400	
63	Average Discharge Voltage, V	120	
64	Battery Conversion Efficiency	0.75	
65	Battery DC Charger Efficiency	1.0	
67	Battery Full Discharge Fraction	0.1	

SECTION 6 - Load Data

74	Average Daily Load, W-Hrs.	9000	Array of monthly values
75	Hourly Load Distribution Fractions	0.041667	Array of 24 fractions Sum must equal 1.

SECTION 7 - Economics

<u>Line No.</u>	<u>Parameter</u>	<u>Default Value</u>	<u>Description</u>
80	Economics Flag	0	Options = 0 Perform economics = 1 Skip economics
81	Economics Methodology Flag	1	Options = 1 Residential = 2 Commercial = 3 Commercial with ERDA-EPRI method = 4 Utility owner with ERDA-EPRI
82	Total System Fixed Cost, \$	0.	
83	Array Unit Cost, \$/Sq.M. of Net Aperture	150.	
84	Battery cost, \$/Amp-Hr	1	
85	Power conditioning cost \$/Kw of Output Rating	250.	
86	Misc. System Cost, \$/Sq.M. Aperture	100.	
87	Annual Oper. and Maint. Cost Fraction of Initial Cost	.01	
88	Discount Rate, Fraction	.12	
89	General Inflation Rate, Fraction	.07	
90	Escalation Rate of Capital Fraction	.07	
91	Escalation Rate of O + M Costs, Fraction	.07	
92	Escalation Rate of Backup Elec. Costs, Fraction	.10	
93	Base Year	1980	
94	First year of Capital Expenditures	1981	
95	First Year of Operation	1982	

SECTION 7 - Economics

<u>Line No.</u>	<u>Parameter</u>	<u>Default Value</u>	<u>Description</u>
96	Price Year	1981	
97	System Operation Lifetime, Years	20.	
98	Battery Lifetime, Years	5	
99	Down Payment, Fraction of Initial Cost	.10	
100	Loan Term, Years	20	
101	Loan Interest Rate, Fraction	.10	
102	Effective Income Tax Rate, Fraction	.30	
103	Investment Tax Credit, Fraction of Initial Cost	.10	
104	Property Tax Rate, Fraction of Initial Cost	.015	
105	Salvage Value, Fraction of Initial Cost	0.	
106	Backup energy costs, \$/Kw-Hr	.05	
***** NOTE ***** If Line 81 input = 3 or 4, then Lines 107 thru 113 must be input.			
107	Ratio of Debt to Total Capitalization	.50	
108	Ratio of Common Stock to Total Capitalization	.40	
109	Ratio of Preferred Stock to Total Capitalization	.10	
110	Annual Rate of Return on Debt	.08	
111	Annual Rate of Return on Common Stock	.12	
112	Annual Rate of Return on Preferred stock	.08	
113	Annual other taxes and Insurance Premiums	.0225	

IV. SOLCOST-PHOTOVOLTAIC INPUT DESCRIPTION WITH SAMPLE DESIGN CASES

The SOLCOST-PHOTOVOLTAIC solar energy design tool contains the following features:

- o Interactive conversational input mode,
- o Restart capability with an input file saved from a previous run (or created external to SOLCOST-PHOTOVOLTAIC),
- o Short form input mode,
- o Output printing at terminal or written to separate file for off-line printing.

Figure IV-1 shows the flow of data in SOLCOST-PHOTOVOLTAIC. System dependencies shown in Figure IV-1 are for a CDC host computer. Some minor changes in control statements are required for other host computers.

The SOLCOST-PHOTOVOLTAIC inputs are free format in nature. Integers can be input for real values and vice-versa. Also, the position of the numeric values on the input line is not important; however, they must be separated by a comma or blank. Arrays must be terminated with an asterisk (*). Arrays can also be continued on additional cards, if necessary. A dollar sign (\$) is a special character designating comments. The input subroutine ignores everything after a dollar sign on each input image.

A shorthand feature is available for those arrays requiring 12 inputs. The program will fill the array with the last value encountered. Don't forget the * terminator.

Figure IV-1. SOLCOST-PHOTOVOLTAIC Data Schematic

Example No. 1 - Fresnel Concentrating System for a Park Visitors Center in Denver

This example problem is based on a visitors center building for a Colorado state park located near Denver. A passively cooled point focus Fresnel system with a geometric concentration of 40X is being considered as a photovoltaic demonstration project. The proposed solar array consists of 36 tracking concentrators with each containing 224 silicon solar cells. Each cell is mounted on a finned aluminum heat sink under a one square foot Fresnel lens which has a nominal optical efficiency of 83%. The nominal power rating of the solar system under 1.0 KW/M^2 insolation (direct normal) and 28°C ambient temperature is 67.4 KW.

The building load is a steady 347 KW-hrs per day. Batteries for energy storage are included in the system with rating of 1500 amp-hrs. A minimum state of charge of 25% is allowed for the batteries before backup utility power is drawn.

Since this is a demonstration project, economics were not included in the initial performance analysis.

Figure IV-2 shows the interactive session required to input this example. Output from the session is given in Figure IV-3 and the listing of the resulting file OUTFIL is shown in Figure IV-4.

WELCOME TO THE SOLCOST-PHOTOVOLTAIC PROGRAM
NOTES --
TYPE HELP FOR A LIST OF USER COMMANDS

DO YOU WISH TO HAVE A LIST OF CITIES YES OR NO
? H

USER COMMANDS (MAY BE ENTERED AS SINGLE-CHARACTER)

HELP - LIST USER INPUT COMMANDS
DISPLAY - DISPLAY LINE INPUT OPTIONS AND/OR
DEFAULT VALUES
GO - TO TAKE THE DEFAULT VALUE AND GO TO NEXT LINE
DURING PROMPTS.
NEXT - STOP FILLING AN ARRAY BEFORE IT IS FILLED
LIST - LIST CURRENT USER FILE
LIST,NO. - LIST THE LINE NO. SPECIFIED
LIST,NO. - LIST THE SECTION SPECIFIED
PURGE - PURGE CURRENT LINE NUMBER FROM FILE
PURGE,NO. - PURGE LINE NUMBER SPECIFIED FROM FILE
RUN - TO SAVE THE INPUT FILE AND EXECUTE THE PROGRAM
EXIT - SAVE THE USER FILE AND END SESSION

WHERE: NO. IS A NUMBER,
1-7 IS A SECTION NUMBER
11-113 IS A LINE NUMBER

NOTES--

1. COMMANDS CAN BE ENTERED AT ANYTIME EXCEPT WHEN A "YES" OR "NO" RESPONSE IS EXPECTED. COMMAND "HELP" CAN BE ENTERED AT ANYTIME.
2. ALL PERCENTAGES ARE TO BE ENTERED AS DECIMAL FRACTIONS.
3. THE REPEAT OPTION FOR AN ARRAY IS "♦NO" WHERE "NO" IS THE NUMBER OF TIMES THAT THE LAST VALUE IS TO BE REPEATED. CAUTION ONLY ONE "♦" PER LINE.
(EXAMPLE: 16,0.65♦6)
4. A "NEXT" WILL END AN ARRAY BEFORE IT IS FILLED.
(EXAMPLE: 16,0.66♦4
NEXT)
5. TO FILL AN ARRAY WITH THE LAST VALUE INPUT SIMPLY END THE ARRAY WITH AN "♦".
(EXAMPLE: 16,0.72♦)

Figure IV-2
SOLCOST-PHOTOVOLTAIC
Interactive Session for Example 1

DO YOU WISH TO HAVE A LIST OF CITIES YES OR NO
? N
DO YOU HAVE AN OLD FILE TO START WITH YES OR NO.
? N
DO YOU WISH TO HAVE PROMPTS YES OR NO
? Y
DO YOU WISH TO HAVE PROMPTS FOR ALL THE SECTIONS.
IF YES ENTER "YES"
IF NO ENTER THE SECTION NUMBER
(1,2,3,4,5,6,7)
? Y
LINE: 11
LOCATION CODE
? 55
LINE: 15
GROUND REFLENTANCE
? 6
LINE: 20
WIND VELOCITY (M/S)
? 4.♦
LINE: 23
NORMAL MODULE EFFICIENCY
? .14
LINE: 24
TEMPERATURE COEFFICIENT FOR MODULE
? -.0005
LINE: 27
AREA OF EACH MODULE (SQ M)
? .00179
LINE: 30
NUMBER OF MODULES IN THE ARRAY
? 8064
LINE: 31
AZIMUTH ANGLE OF THE ARRAY
? 6
LINE: 32
TILT ANGLE OF THE ARRAY
? 6
LINE: 33
FLAG FOR TRACKING COLLECTOR
? 1
LINE: 34
INSOLATION COEFFICIENT FOR MODULE
? 6
LINE: 35
RATED POWER OF SYSTEM, KW
? 67.4
LINE: 37
CELL SOLAR ABSORPTANCE
? 6

Figure IV-2
Example 1 Input Session
(Continued)

	LINE:	38	INFRARED EMITTANCE OF CELL ENCAPSULENT
? G			
	LINE:	39	INFRARED EMITTANCE OF HEATSINK
? G			
	LINE:	40	INFRARED EMITTANCE OF COLLECTOR GLAZING
? G			
	LINE:	41	ELECTRICAL INSULATOR CONDUCTIVITY (W/SQ C)
? G			
	LINE:	42	RATIO OF FINNED HEATSINK AREA
? G			
	LINE:	43	TYPE OF COOLING FLAG
? 4			
	LINE:	45	APERTURE AREA FOR EACH CELL (M**2)
? .0929			
	LINE:	46	HEATSINK BASE PLATE AREA EACH CELL (M**2)
? G			
	LINE:	47	FLOW CHANNEL LENGTH (M)
? G			
	LINE:	48	GEOMETRIC CONCENTRATION RATIO
? 40			
	LINE:	49	HEATSINK CONDUCTIVITY THICKNESS (W/C)
? G			
	LINE:	50	OVERALL OPTICAL EFFICIENCY
? .83			
	LINE:	52	LINE LOSS FACTOR TO INVERTER
? G			
	LINE:	53	INVERTER EFFICIENCY POINTS
? G			
	LINE:	54	LINE LOSS FACTOR TO LOAD BUS
? G			
	LINE:	56	FLAG TO FEED EXTRA ENERGY TO UTILITY CO.
? G			

Figure IV-2
Example 1 Input Session
(Continued)

```

      LINE:      57
                  LOAD BUS VOLTAGE
? 6
      LINE:      58
                  ARRAY UTILIZATION FACTOR
? 6
      LINE:      60
                  NUMBER OF BATTERIES
? 1
      LINE:      61
                  BATTERY FRACTION OF CHARGE
? 6
      LINE:      62
                  RATED CAPACITY OF BATTERY (AMP-HR)
? 1500.
      LINE:      63
                  AVERAGE DISCHARGE VOLTAGE
? 215.
      LINE:      64
                  BATTERY CONVERSION EFFICIENCY
? 6
      LINE:      65
                  DC BATTERY EFFICIENCY
? 62
      LINE:      67
                  FULL DISCHARGE FRACTION
? .25
      LINE:      74
                  DAILY LOAD (WATT-HRS)
? 347000+
      LINE:      75
                  LOAD DISTRIBUTION PER HOUR
? 6
      LINE:      80
                  ECONOMICS FLAG (=1 TO SKIP )
? 1
  DO YOU WISH TO MAKE CHANGES TO THE FILE
  YES OR NO
? N
  DO YOU WISH TO HAVE THE INPUTS LISTED WITH THE OUTPUT YES OR NO
? N
  DO YOU WISH TO HAVE THE OUTPUT WRITTEN ON FILE OUT YES OR NO
  (A "NO" WILL CAUSE OUTPUT TO BE PRINTED AT THE TERMINAL)
? N

```

Figure IV-2
Input Session
(Concluded)

DENVER, CO
 LATITUDE 39.80
 LONGITUDE 81.70
 CLEARNESS NUMBER 1.019
 GROUND REFLECTANCE .2000

MONTH	SOLAR INSOLATION	MINIMUM TEMPERATURE	MAXIMUM TEMPERATURE	FRACTION SUNSHINE	WIND SPEED
	(W/SQ M)	(DEGREE C)	(DEGREE C)		(M/S)
1	2649.	-8.8	6.4	.670	4.0
2	3554.	-7.0	7.9	.670	4.0
3	4827.	-4.6	10.1	.650	4.0
4	5927.	1.1	16.1	.630	4.0
5	6733.	6.4	21.3	.610	4.0
6	7414.	11.1	26.7	.690	4.0
7	7167.	14.8	30.8	.680	4.0
8	6447.	14.1	29.9	.680	4.0
9	5446.	8.8	25.4	.710	4.0
10	4101.	2.9	19.3	.710	4.0
11	2786.	-3.7	11.8	.670	4.0
12	2308.	-7.3	7.9	.650	4.0

Figure IV-3
 SOLCOST-PV Output
 Data for Example 1

COLLECTOR INPUT DATA

NORMAL MODULE EFFICIENCY	.1400
TEMPERATURE COEFFICIENT FOR A MODULE	-.5000E-03
NUMBER OF MODULES	8064
AREA OF EACH MODULE	.1790E-02
INSOLATION COEFFICIENT FOR A MODULE	0.
AZIMUTH ANGLE	0.
TRACKING COLLECTOR	

CELL TEMPERATURE INPUT DATA

CELL SOLAR ABSORPTANCE	.9000
INFRARED EMITTANCE OF CELL ENCAPSULENT	.5000
INFRARED EMITTANCE OF HEATSINK	.8000
INFRARED EMITTANCE OF COLLECTOR GLAZING	.9000
ELECTRICAL INSULATOR CONDUCTIVITY	.1000E+05
RATIO OF FINNED HEATSINK AREA	1.000
POINT FOCUS CONCENTRATING COLLECTOR PASSIVE COOLING	
APERTURE AREA FOR EACH CELL (M ²)	.9290E-01
HEATSINK BASE PLATE AREA FOR EACH CELL	.9290E-01
FLOW CHANNEL LENGTH (M)	10.00
GEOMETRIC CONCENTRATION RATIO	40.00
HEATSINK CONDUCTIVITY THICKNESS (W/C)	1.000
OVERALL OPTICAL EFFICIENCY	.8300

SYSTEM EFFICIENCY

BATTERY EFFICIENCY

NUMBER OF BATTERIES	1
BATTERY FRACTION OF CHARGE	.7000
RATED CAPACITY OF BATTERY (AMP/HR)	1500.
AVERAGE DISCHARGE VOLTAGE	215.0
BATTERY CONVERSION EFFICIENCY	.7500
DC BATTERY EFFICIENCY	1.000
BATTERY DIODE EFFICIENCY	.9963
FULL DISCHARGE FRACTION	.2500

ARRAY EFFICIENCY

ARRAY DIODE EFFICIENCY	.9933
ARRAY UTILIZATION FACTOR	.9000

DISTRIBUTION EFFICIENCY

LINE LOSS FACTOR TO INVERTER	.9800
LINE LOSS FACTOR TO LOAD BUS	.9800

RATED SYSTEM POWER, KW	67.400

Figure IV-3

SOLCOST-PV. Output

Data for Example 1

(Continued)

MONTH	AVERAGE CELL TEMPERATURE CLEAR DAY (DEGREE C)	SOLAR ARRAY INPUT (KW-HR)	SOLAR ARRAY OUTPUT (KW-HR)
JAN	30.9	111720.	12840.
FEB	34.5	112624.	12774.
MAR	36.8	142567.	16033.
APR	41.9	145890.	16101.
MAY	45.7	158211.	17209.
JUN	50.0	164190.	17565.
JUL	53.1	162775.	17201.
AUG	52.7	152213.	16113.
SEP	48.5	140940.	15162.
OCT	43.8	129663.	14207.
NOV	36.3	102322.	11529.
DEC	31.6	101074.	11586.
ANNUAL		1624189.	178320.

MONTH	SYSTEM LOAD (KW-HR)	SOLAR ENERGY DELIVERED TO LOAD (KW-HR)	ADDITIONAL ENERGY NEEDED (KW-HR)	SOLAR ENERGY DISCARDED (KW-HR)
JAN	10757.	7287.	3470.	1866.
FEB	9716.	6834.	2882.	2711.
MAR	10757.	8330.	2427.	3744.
APR	10410.	8623.	1787.	3443.
MAY	10757.	9070.	1687.	4077.
JUN	10410.	9000.	1410.	4612.
JUL	10757.	9279.	1478.	3789.
AUG	10757.	8980.	1777.	2965.
SEP	10410.	8049.	2361.	3440.
OCT	10757.	8014.	2743.	2354.
NOV	10410.	6892.	3518.	1304.
DEC	10757.	7118.	3639.	852.
ANNUAL	126655.	97476.	29179.	35158.

Figure IV-3
SOLCOST-PV Output
Data for Example 1
(Continued)

MONTH	AVERAGE BATTERY CHARGE (FRACTION)	ENERGY TO BATTERY (KW-HR)	ENERGY FROM BATTERY (KW-HR)
JAN	.754	5350.	3526.
FEB	.774	4226.	2785.
MAR	.779	5227.	3445.
APR	.782	5186.	3418.
MAY	.804	4835.	3186.
JUN	.816	4528.	2984.
JUL	.806	4864.	3206.
AUG	.785	5292.	3488.
SEP	.794	4528.	2984.
OCT	.770	5136.	3385.
NOV	.765	4528.	2984.
DEC	.747	5280.	3480.

ANNUAL	58981.	38871.

DO YOU WISH TO MAKE CHANGES AND EXECUTE THE PROGRAM AGAIN YES OR NO
(IF PROMPTS ARE DESIRED ENTER PROMPT)

? Y

Figure IV-3
SOLCOST-PV Output
Data for Example 1
(Concluded)

```

$          NORMAL MODULE EFFICIENCY
23,      .1400
$          TEMPERATURE COEFFICIENT FOR MODULE
24,     -.5000E-03
$          TEMPERATURE COEFFICIENT FOR THE CELL
26,     -.5000E-03
$          AREA OF EACH MODULE (SQ M)
27,      .1790E-02
$          NUMBER OF MODULES IN THE ARRAY
30,       8064
$          FLAG FOR TRACKING COLLECTOR
33,         1
$          RATED POWER OF SYSTEM, KW
35,       67.40
$          TYPE OF COOLING FLAG
43,         4
$          APERTURE AREA FOR EACH CELL (M**2)
45,      .9290E-01
$          GEOMETRIC CONCENTRATION RATIO
48,       40.00
$          OVERALL OPTICAL EFFICIENCY
50,       .8300
$          NUMBER OF BATTERIES
60,         1
$          RATED CAPACITY OF BATTERY (AMP/HR)
62,       1500.
$          AVERAGE DISCHARGE VOLTAGE
63,       215.0
$          FULL DISCHARGE FRACTION
67,       .2500
$          DAILY LOAD (WATT-HRS)
74,      .3470E+06   .3470E+06   .3470E+06   .3470E+06   .3470E+06   .347
0E+06
      .3470E+06   .3470E+06   .3470E+06   .3470E+06   .3470E+06   .347
0E+06
$          ECONOMICS FLAG (=1 TO SKIP )
80,         1
  RUN

```

Figure IV 4
Listing of OUTFIL
File for Example 1

Example No. 2 - Flat Plate Array for Denver Park Visitors Center

This example is identical to the Example No. 1 except the solar array is now made up of flat plate modules tilted at 40 degrees. The gross area of each module is 1.5 square meters, the module net efficiency is 6% based on the gross module area, and 500 modules comprise the solar array.

Figure IV-5 presents the input file for this example. Figure IV-6 shows the resulting flat plate performance data tables.

\$		LOCATION CODE					
\$	11,	55					
\$		GROUND REFLENTANCE					
\$	15,	.2000					
\$		WIND VELOCITY (M/S)					
\$	20,	4.000	4.000	4.000	4.000	4.000	4.00
0							
0		4.000	4.000	4.000	4.000	4.000	4.00
\$		NORMAL MODULE EFFICIENCY					
\$	23,	.6000E-01					
\$		TEMPERATURE COEFFICIENT FOR MODULE					
\$	24,	-.5000E-03					
\$		AREA OF EACH MODULE (SQ M)					
\$	27,	1.500					
\$		NUMBER OF MODULES IN THE ARRAY					
\$	30,	500					
\$		TILT ANGLE OF THE ARRAY					
\$	32,	40.00					
\$		FLAG FOR TRACKING COLLECTOR					
\$	33,	0					
\$		RATED POWER OF SYSTEM, KW					
\$	35,	67.40					
\$		TYPE OF COOLING FLAG					
\$	43,	2					
\$		LOAD BUS VOLTAGE					
\$	57,	230.0					
\$		ARRAY UTILIZATION FACTOR					
\$	58,	.9000					
\$		NUMBER OF BATTERIES					
\$	60,	1					
\$		BATTERY FRACTION OF CHARGE					
\$	61,	.7000					
\$		RATED CAPACITY OF BATTERY (AMP/HR)					
\$	62,	1500.					
\$		AVERAGE DISCHARGE VOLTAGE					
\$	63,	215.0					
\$		BATTERY CONVERSION EFFICIENCY					
\$	64,	.7500					
\$		FULL DISCHARGE FRACTION					
\$	67,	.2500					
\$		DAILY LOAD (WATT - HR)					
\$	74,	.3470E+06	.3470E+06	.3470E+06	.3470E+06	.3470E+06	.347
0E+06							
0E+06		.3470E+06	.3470E+06	.3470E+06	.3470E+06	.3470E+06	.347
\$		ECONOMICS FLAG (=1 TO SKIP)					
\$	80,	0					
\$		ECON. METHODOLOGY FLAG					
\$	81,	2					
		RUN					

Figure IV-5

Example 2 Input Data
for Flat Plate Array

MONTH	AVERAGE CELL TEMPERATURE CLEAR DAY (DEGREE C)	SOLAR ARRAY INPUT (KW-HR)	SOLAR ARRAY OUTPUT (KW-HR)
JAN	25.0	117073.	7174.
FEB	28.6	117668.	6991.
MAR	31.0	145076.	8439.
APR	35.8	140327.	7825.
MAY	39.4	142106.	7670.
JUN	43.5	140556.	7296.
JUL	47.2	141921.	7107.
AUG	47.2	142682.	7145.
SEP	43.7	139864.	7246.
OCT	38.6	134961.	7341.
NOV	30.6	108275.	6325.
DEC	25.8	105966.	6454.
ANNUAL		1576475.	87015.

MONTH	SYSTEM LOAD (KW-HR)	SOLAR ENERGY DELIVERED TO LOAD (KW-HR)	ADDITIONAL ENERGY NEEDED (KW-HR)	SOLAR ENERGY DISCARDED (KW-HR)
JAN	10757.	4956.	5801.	0.
FEB	9716.	4959.	4757.	0.
MAR	10757.	5863.	4894.	0.
APR	10410.	5330.	5080.	0.
MAY	10757.	5069.	5688.	0.
JUN	10410.	4825.	5585.	0.
JUL	10757.	4620.	6137.	0.
AUG	10757.	4613.	6144.	0.
SEP	10410.	4976.	5434.	0.
OCT	10757.	5084.	5673.	0.
NOV	10410.	4335.	6075.	0.
DEC	10757.	4494.	6263.	0.
ANNUAL	126655.	59123.	67532.	0.

1

Figure IV-6

Example 2 Output

Data for Flat Plate

Solar Array

MONTH	AVERAGE BATTERY CHARGE (FRACTION)	ENERGY TO BATTERY (KW-HR)	ENERGY FROM BATTERY (KW-HR)
JAN	.691	2716.	1790.
FEB	.700	2068.	1363.
MAR	.689	3043.	2005.
APR	.660	3300.	2175.
MAY	.648	3935.	2593.
JUN	.642	3730.	2458.
JUL	.630	3989.	2629.
AUG	.635	4154.	2738.
SEP	.678	2879.	1897.
OCT	.681	2724.	1795.
NOV	.690	2546.	1678.
DEC	.686	2285.	1506.
ANNUAL		37370.	24628.

Figure IV-6

Example 2 Output Data

(Continued)

IV. SOLCOST-PHOTOVOLTAIC INPUT DESCRIPTION WITH SAMPLE DESIGN CASES

The SOLCOST-PHOTOVOLTAIC solar energy design tool contains the following features:

- o Interactive conversational input mode,
- o Restart capability with an input file saved from a previous run (or created external to SOLCOST-PHOTOVOLTAIC),
- o Short form input mode,
- o Output printing at terminal or written to separate file for off-line printing.

Figure IV-1 shows the flow of data in SOLCOST-PHOTOVOLTAIC. System dependencies shown in Figure IV-1 are for a CDC host computer. Some minor changes in control statements are required for other host computers.

The SOLCOST-PHOTOVOLTAIC inputs are free format in nature. Integers can be input for real values and vice-versa. Also, the position of the numeric values on the input line is not important; however, they must be separated by a comma or blank. Arrays must be terminated with an asterisk (*). Arrays can also be continued on additional cards, if necessary. A dollar sign (\$) is a special character designating comments. The input subroutine ignores everything after a dollar sign on each input image.

A shorthand feature is available for those arrays requiring 12 inputs. The program will fill the array with the last value encountered. Don't forget the * terminator.

Figure IV-1. SOLCOST-PHOTOVOLTAIC Data Schematic

Example No. 1 - Fresnel Concentrating System for a Park Visitors Center in Denver

This example problem is based on a visitors center building for a Colorado state park located near Denver. A passively cooled point focus Fresnel system with a geometric concentration of 40X is being considered as a photovoltaic demonstration project. The proposed solar array consists of 36 tracking concentrators with each containing 224 silicon solar cells. Each cell is mounted on a finned aluminum heat sink under a one square foot Fresnel lens which has a nominal optical efficiency of 83%. The nominal power rating of the solar system under 1.0 KW/M^2 insolation (direct normal) and 28°C ambient temperature is 67.4 KW.

The building load is a steady 347 KW-hrs per day. Batteries for energy storage are included in the system with rating of 1500 amp-hrs. A minimum state of charge of 25% is allowed for the batteries before backup utility power is drawn.

Since this is a demonstration project, economics were not included in the initial performance analysis.

Figure IV-2 shows the interactive session required to input this example. Output from the session is given in Figure IV-3 and the listing of the resulting file OUTFIL is shown in Figure IV-4.

WELCOME TO THE SOLCOST-PHOTOVOLTAIC PROGRAM

NOTES --

TYPE HELP FOR A LIST OF USER COMMANDS

DO YOU WISH TO HAVE A LIST OF CITIES YES OR NO
? H

USER COMMANDS (MAY BE ENTERED AS SINGLE-CHARACTER)

HELP - LIST USER INPUT COMMANDS
DISPLAY - DISPLAY LINE INPUT OPTIONS AND/OR
DEFAULT VALUES
GO - TO TAKE THE DEFAULT VALUE AND GO TO NEXT LINE
DURING PROMPTS.
NEXT - STOP FILLING AN ARRAY BEFORE IT IS FILLED
LIST - LIST CURRENT USER FILE
LIST,NO. - LIST THE LINE NO. SPECIFIED
LIST,NO. - LIST THE SECTION SPECIFIED
PURGE - PURGE CURRENT LINE NUMBER FROM FILE
PURGE,NO. - PURGE LINE NUMBER SPECIFIED FROM FILE
RUN - TO SAVE THE INPUT FILE AND EXECUTE THE PROGRAM
EXIT - SAVE THE USER FILE AND END SESSION

WHERE: NO. IS A NUMBER,
1-7 IS A SECTION NUMBER
11-113 IS A LINE NUMBER

NOTES--

1. COMMANDS CAN BE ENTERED AT ANYTIME EXCEPT WHEN A "YES" OR "NO" RESPONSE IS EXPECTED. COMMAND "HELP" CAN BE ENTERED AT ANYTIME.
2. ALL PERCENTAGES ARE TO BE ENTERED AS DECIMAL FRACTIONS.
3. THE REPEAT OPTION FOR AN ARRAY IS "♦NO" WHERE "NO" IS THE NUMBER OF TIMES THAT THE LAST VALUE IS TO BE REPEATED. CAUTION ONLY ONE "♦" PER LINE.
(EXAMPLE: 16,0.65♦6)
4. A "NEXT" WILL END AN ARRAY BEFORE IT IS FILLED.
(EXAMPLE: 16,0.66♦4
NEXT)
5. TO FILL AN ARRAY WITH THE LAST VALUE INPUT SIMPLY END THE ARRAY WITH AN "♦".
(EXAMPLE: 16,0.72♦)

Figure IV-2

SOLCOST-PHOTOVOLTAIC

Interactive Session for Example 1

DO YOU WISH TO HAVE A LIST OF CITIES YES OR NO
? N
DO YOU HAVE AN OLD FILE TO START WITH YES OR NO.
? N
DO YOU WISH TO HAVE PROMPTS YES OR NO
? Y
DO YOU WISH TO HAVE PROMPTS FOR ALL THE SECTIONS.
IF YES ENTER "YES"
IF NO ENTER THE SECTION NUMBER
(1,2,3,4,5,6,7)
? Y
LINE: 11
LOCATION CODE
? 55
LINE: 15
GROUND REFLENTANCE
? 6
LINE: 20
WIND VELOCITY (M/S)
? 4.♦
LINE: 23
NORMAL MODULE EFFICIENCY
? .14
LINE: 24
TEMPERATURE COEFFICIENT FOR MODULE
? -.0005
LINE: 27
AREA OF EACH MODULE (SQ M)
? .00179
LINE: 30
NUMBER OF MODULES IN THE ARRAY
? 8064
LINE: 31
AZIMUTH ANGLE OF THE ARRAY
? 6
LINE: 32
TILT ANGLE OF THE ARRAY
? 6
LINE: 33
FLAG FOR TRACKING COLLECTOR
? 1
LINE: 34
INSOLATION COEFFICIENT FOR MODULE
? 6
LINE: 35
RATED POWER OF SYSTEM, KW
? 67.4
LINE: 37
CELL SOLAR ABSORPTANCE
? 6

Figure Iv-2
Example 1 Input Session
(Continued)

LINE: 38
 INFRARED EMITTANCE OF CELL ENCAPSULENT
 ? 6
 LINE: 39
 INFRARED EMITTANCE OF HEATSINK
 ? 6
 LINE: 40
 INFRARED EMITTANCE OF COLLECTOR GLAZING
 ? 6
 LINE: 41
 ELECTRICAL INSULATOR CONDUCTIVITY (W/SQ C)
 ? 6
 LINE: 42
 RATIO OF FINNED HEATSINK AREA
 ? 6
 LINE: 43
 TYPE OF COOLING FLAG
 ? 4
 LINE: 45
 APERATURE AREA FOR EACH CELL (M♦♦2)
 ? .0929
 LINE: 46
 HEATSINK BASE PLATE AREA EACH CELL (M♦♦2)
 ? 6
 LINE: 47
 FLOW CHANNEL LENGTH (M)
 ? 6
 LINE: 48
 GEOMETRIC CONCENTRATION RATIO
 ? 40
 LINE: 49
 HEATSINK CONDUCTIVITY THICKNESS (W/C)
 ? 6
 LINE: 50
 OVERALL OPTICAL EFFICIENCY
 ? .83
 LINE: 52
 LINE LOSS FACTOR TO INVERTER
 ? 6
 LINE: 53
 INVERTER EFFICIENCY POINTS
 ? 6
 LINE: 54
 LINE LOSS FACTOR TO LOAD BUS
 ? 6
 LINE: 56
 FLAG TO FEED EXTRA ENERGY TO UTILITY CO.
 ? 6

Figure IV-2
 Example 1 Input Session
 (Continued)

```

      LINE:      57
      LOAD BUS VOLTAGE
? 6
      LINE:      58
      ARRAY UTILIZATION FACTOR
? 6
      LINE:      60
      NUMBER OF BATTERIES
? 1
      LINE:      61
      BATTERY FRACTION OF CHARGE
? 6
      LINE:      62
      RATED CAPACITY OF BATTERY (AMP-HR)
? 1500.
      LINE:      63
      AVERAGE DISCHARGE VOLTAGE
? 215.
      LINE:      64
      BATTERY CONVERSION EFFICIENCY
? 6
      LINE:      65
      DC BATTERY EFFICIENCY
? 62
      LINE:      67
      FULL DISCHARGE FRACTION
? .25
      LINE:      74
      DAILY LOAD (WATT-HRS)
? 347000+
      LINE:      75
      LOAD DISTRIBUTION PER HOUR
? 6
      LINE:      80
      ECONOMICS FLAG (=1 TO SKIP )
? 1
      DO YOU WISH TO MAKE CHANGES TO THE FILE
      YES OR NO
? N
      DO YOU WISH TO HAVE THE INPUTS LISTED WITH THE OUTPUT YES OR NO
? N
      DO YOU WISH TO HAVE THE OUTPUT WRITTEN ON FILE OUT YES OR NO
      (A "NO" WILL CAUSE OUTPUT TO BE PRINTED AT THE TERMINAL)
? N

```

Figure IV-2
Input Session
(Concluded)

DENVER, CO
 LATITUDE 39.80
 LONGITUDE 81.70
 CLEARNESS NUMBER 1.019
 GROUND REFLECTANCE .2000

MONTH	SOLAR INSOLATION	MINIMUM TEMPERATURE	MAXIMUM TEMPERATURE	FRACTION SUNSHINE	WIND SPEED
	(W/SQ M)	(DEGREE C)	(DEGREE C)		(M/S)
1	2649.	-8.8	6.4	.670	4.0
2	3554.	-7.0	7.9	.670	4.0
3	4827.	-4.6	10.1	.650	4.0
4	5927.	1.1	16.1	.630	4.0
5	6733.	6.4	21.3	.610	4.0
6	7414.	11.1	26.7	.690	4.0
7	7167.	14.8	30.8	.680	4.0
8	6447.	14.1	29.9	.680	4.0
9	5446.	8.8	25.4	.710	4.0
10	4101.	2.9	19.3	.710	4.0
11	2786.	-3.7	11.8	.670	4.0
12	2308.	-7.3	7.9	.650	4.0

Figure IV-3
 SOLCOST-PV Output
 Data for Example 1

COLLECTOR INPUT DATA

NORMAL MODULE EFFICIENCY	.1400
TEMPERATURE COEFFICIENT FOR A MODULE	-.5000E-03
NUMBER OF MODULES	8064
AREA OF EACH MODULE	.1790E-02
INSOLATION COEFFICIENT FOR A MODULE	0.
AZIMUTH ANGLE	0.
TRACKING COLLECTOR	

CELL TEMPERATURE INPUT DATA

CELL SOLAR ABSORPTANCE	.9000
INFRARED EMITTANCE OF CELL ENCAPSULENT	.5000
INFRARED EMITTANCE OF HEATSINK	.8000
INFRARED EMITTANCE OF COLLECTOR GLAZING	.9000
ELECTRICAL INSULATOR CONDUCTIVITY	.1000E+05
RATIO OF FINNED HEATSINK AREA	1.000
POINT FOCUS CONCENTRATING COLLECTOR PASSIVE COOLING	
APERTURE AREA FOR EACH CELL (M**2)	.9290E-01
HEATSINK BASE PLATE AREA FOR EACH CELL	.9290E-01
FLOW CHANNEL LENGTH (M)	10.00
GEOMETRIC CONCENTRATION RATIO	40.00
HEATSINK CONDUCTIVITY THICKNESS (W/C)	1.000
OVERALL OPTICAL EFFICIENCY	.8300

SYSTEM EFFICIENCY

BATTERY EFFICIENCY

NUMBER OF BATTERIES	1
BATTERY FRACTION OF CHARGE	.7000
RATED CAPACITY OF BATTERY (AMP/HR)	1500.
AVERAGE DISCHARGE VOLTAGE	215.0
BATTERY CONVERSION EFFICIENCY	.7500
DC BATTERY EFFICIENCY	1.000
BATTERY DIODE EFFICIENCY	.9963
FULL DISCHARGE FRACTION	.2500

ARRAY EFFICIENCY

ARRAY DIODE EFFICIENCY	.9933
ARRAY UTILIZATION FACTOR	.9000

DISTRIBUTION EFFICIENCY

LINE LOSS FACTOR TO INVERTER	.9800
LINE LOSS FACTOR TO LOAD BUS	.9800

RATED SYSTEM POWER, KW	67.400

Figure IV-3

SOLCOST-PV. Output

Data for Example 1

(Continued)

MONTH	AVERAGE CELL TEMPERATURE CLEAR DAY (DEGREE C)	SOLAR ARRAY INPUT (KW-HR)	SOLAR ARRAY OUTPUT (KW-HR)
JAN	30.9	111720.	12840.
FEB	34.5	112624.	12774.
MAR	36.8	142567.	16033.
APR	41.9	145890.	16101.
MAY	45.7	158211.	17209.
JUN	50.0	164190.	17565.
JUL	53.1	162775.	17201.
AUG	52.7	152213.	16113.
SEP	48.5	140940.	15162.
OCT	43.8	129663.	14207.
NOV	36.3	102322.	11529.
DEC	31.6	101074.	11586.
ANNUAL		1624189.	178320.

MONTH	SYSTEM LOAD (KW-HR)	SOLAR ENERGY DELIVERED TO LOAD (KW-HR)	ADDITIONAL ENERGY NEEDED (KW-HR)	SOLAR ENERGY DISCARDED (KW-HR)
JAN	10757.	7287.	3470.	1866.
FEB	9716.	6834.	2882.	2711.
MAR	10757.	8330.	2427.	3744.
APR	10410.	8623.	1787.	3445.
MAY	10757.	9070.	1687.	4077.
JUN	10410.	9000.	1410.	4612.
JUL	10757.	9279.	1478.	3789.
AUG	10757.	8980.	1777.	2965.
SEP	10410.	8049.	2361.	3440.
OCT	10757.	8014.	2743.	2354.
NOV	10410.	6892.	3518.	1304.
DEC	10757.	7118.	3639.	852.
ANNUAL	126655.	97476.	29179.	35158.

Figure IV-3
SOLCOST-PV Output
Data for Example 1
(Continued)

MONTH	AVERAGE BATTERY CHARGE (FRACTION)	ENERGY TO BATTERY (KW-HR)	ENERGY FROM BATTERY (KW-HR)
JAN	.754	5350.	3526.
FEB	.774	4226.	2785.
MAR	.779	5227.	3445.
APR	.782	5186.	3418.
MAY	.804	4835.	3186.
JUN	.816	4528.	2984.
JUL	.806	4864.	3206.
AUG	.785	5292.	3488.
SEP	.794	4528.	2984.
OCT	.770	5136.	3385.
NOV	.765	4528.	2984.
DEC	.747	5280.	3480.

ANNUAL

58981.

38871.

DO YOU WISH TO MAKE CHANGES AND EXECUTE THE PROGRAM AGAIN YES OR NO
(IF PROMPTS ARE DESIRED ENTER PROMPT)

? Y

Figure IV-3
SOLCOST-PV Output
Data for Example 1
(Concluded)

```

$      NORMAL MODULE EFFICIENCY
23,    .1400
$      TEMPERATURE COEFFICIENT FOR MODULE
24,    -.5000E-03
$      TEMPERATURE COEFFICIENT FOR THE CELL
26,    -.5000E-03
$      AREA OF EACH MODULE (SQ M)
27,    .1790E-02
$      NUMBER OF MODULES IN THE ARRAY
30,      8064
$      FLAG FOR TRACKING COLLECTOR
33,      1
$      RATED POWER OF SYSTEM, KW
35,    67.40
$      TYPE OF COOLING FLAG
43,      4
$      APERATURE AREA FOR EACH CELL (M**2)
45,    .9290E-01
$      GEOMETRIC CONCENTRATION RATIO
48,    40.00
$      OVERALL OPTICAL EFFICIENCY
50,    .8300
$      NUMBER OF BATTERIES
60,      1
$      RATED CAPACITY OF BATTERY (AMP/HR)
62,    1500.
$      AVERAGE DISCHARGE VOLTAGE
63,    215.0
$      FULL DISCHARGE FRACTION
67,    .2500
$      DAILY LOAD (WATT-HRS)
74,    .3470E+06    .3470E+06    .3470E+06    .3470E+06    .3470E+06    .347
0E+06
    .3470E+06    .3470E+06    .3470E+06    .3470E+06    .3470E+06    .347
0E+06
$      ECONOMICS FLAG (=1 TO SKIP )
80,      1
    RUN

```

Figure IV-4
Listing of OUTFIL
File for Example 1

Example No. 2 - Flat Plate Array for Denver Park Visitors Center

This example is identical to the Example No. 1 except the solar array is now made up of flat plate modules tilted at 40 degrees. The gross area of each module is 1.5 square meters, the module net efficiency is 6% based on the gross module area, and 500 modules comprise the solar array.

Figure IV-5 presents the input file for this example. Figure IV-6 shows the resulting flat plate performance data tables.

\$		LOCATION CODE				
\$	11,	55				
\$		GROUND REFLENTANCE				
\$	15,	.2000				
\$		WIND VELOCITY (M/S)				
\$	20,	4.000	4.000	4.000	4.000	4.00
0						
\$		4.000	4.000	4.000	4.000	4.00
0						
\$		NORMAL MODULE EFFICIENCY				
\$	23,	.6000E-01				
\$		TEMPERATURE COEFFICIENT FOR MODULE				
\$	24,	-.5000E-03				
\$		AREA OF EACH MODULE (SQ M)				
\$	27,	1.500				
\$		NUMBER OF MODULES IN THE ARRAY				
\$	30,	500				
\$		TILT ANGLE OF THE ARRAY				
\$	32,	40.00				
\$		FLAG FOR TRACKING COLLECTOR				
\$	33,	0				
\$		RATED POWER OF SYSTEM, KW				
\$	35,	67.40				
\$		TYPE OF COOLING FLAG				
\$	43,	2				
\$		LOAD BUS VOLTAGE				
\$	57,	230.0				
\$		ARRAY UTILIZATION FACTOR				
\$	58,	.9000				
\$		NUMBER OF BATTERIES				
\$	60,	1				
\$		BATTERY FRACTION OF CHARGE				
\$	61,	.7000				
\$		RATED CAPACITY OF BATTERY (AMP/HR)				
\$	62,	1500.				
\$		AVERAGE DISCHARGE VOLTAGE				
\$	63,	215.0				
\$		BATTERY CONVERSION EFFICIENCY				
\$	64,	.7500				
\$		FULL DISCHARGE FRACTION				
\$	67,	.2500				
\$		DAILY LOAD (WATT-HR)				
\$	74,	.3470E+06	.3470E+06	.3470E+06	.3470E+06	.347
0E+06						
\$		.3470E+06	.3470E+06	.3470E+06	.3470E+06	.347
0E+06						
\$		ECONOMICS FLAG (=1 TO SKIP)				
\$	80,	0				
\$		ECON. METHODOLOGY FLAG				
\$	81,	2				
		RUN				

Figure IV-5

Example 2 Input Data

for Flat Plate Array

MONTH	AVERAGE CELL TEMPERATURE CLEAR DAY (DEGREE C)	SOLAR ARRAY INPUT (KW-HR)	SOLAR ARRAY OUTPUT (KW-HR)
JAN	25.0	117073.	7174.
FEB	28.6	117668.	6991.
MAR	31.0	145076.	8439.
APR	35.8	140327.	7825.
MAY	39.4	142106.	7670.
JUN	43.5	140556.	7296.
JUL	47.2	141921.	7107.
AUG	47.2	142682.	7145.
SEP	43.7	139864.	7246.
OCT	38.6	134961.	7341.
NOV	30.6	108275.	6325.
DEC	25.8	105966.	6454.
ANNUAL		1576475.	87015.

MONTH	SYSTEM LOAD (KW-HR)	SOLAR ENERGY DELIVERED TO LOAD (KW-HR)	ADDITIONAL ENERGY NEEDED (KW-HR)	SOLAR ENERGY DISCARDED (KW-HR)
JAN	10757.	4956.	5801.	0.
FEB	9716.	4959.	4757.	0.
MAR	10757.	5863.	4894.	0.
APR	10410.	5330.	5080.	0.
MAY	10757.	5069.	5688.	0.
JUN	10410.	4825.	5585.	0.
JUL	10757.	4620.	6137.	0.
AUG	10757.	4613.	6144.	0.
SEP	10410.	4976.	5434.	0.
OCT	10757.	5084.	5673.	0.
NOV	10410.	4335.	6075.	0.
DEC	10757.	4494.	6263.	0.
ANNUAL	126655.	59123.	67532.	0.

Figure IV-6

Example 2 Output

Data for Flat Plate

Solar Array

V. REFERENCES

1. M. Imamura, et al., "Definition Study for Prototype Residential Photovoltaic System", Final Report for NASA Contract NAS 3-19768, Sept. 1968.
2. R. Giellis, D. Hull III, "SOLCOST: A Solar Energy Design Program", Proceedings of the Systems Simulation and Economic Analysis Conference, Doc. No. SERI/TP-351-431, San Diego, California, Jan. 1980.
3. R. Donovan, "Photovoltaic Concentrator System for Roxborough Park", Final Report, DOE/CS/05312-1, December 1979.
4. E. Hoover, "SOLCEL-II User's Guide", Sandia Laboratories, 1980.
5. A. Perino, "A Methodology for Determining the Economic Feasibility of Residential or Commercial Solar Energy Systems," Sandia Laboratories, SAND 78-0931.
6. J. Doane, et al., "The Cost of Energy from Utility - Owned Solar Electric Systems", ERDA/JPL-1012-76/3, June 1976.

APPENDIX A Cell Temperature Analysis*

Flat Array Cooling

The thermal analysis follows the work by Kreith. Two different types of cooling may be specified on Line 43:

- 1) Passive cooling on the front surface only.
- 2) Passive cooling on both the front and back surface with or without a finned back surface only.

The analysis assumes there is no thermal resistance between the cells and the ambient except for the glazings in the water cooled case. The analysis is specifically for a packing factor of one. However, it will be accurate if cells and uncovered areas have similar thermal properties or if cells and uncovered areas do not thermally communicate.

For the passively cooled flat array the program calculates the average solar cell operating temperature for each hour. The incident thermal heat flux is assumed to be constant along the length of the receiver. That portion of the heatsink directly under the cell area is assumed to be at some uniform temperature (T_W). The temperature distribution in the remaining portion of the heatsink is considered analytically in the model. The heat deposited in the cell material is lost to the ambient via the cell encapsulant or conducted across the dielectric cell insulator into the heatsink where it is subsequently rejected to the ambient. The radiation heat transfer coefficients are linearized in order to obtain an algebraic solution. An iterative procedure updates the temperatures and heat transfer coefficients until convergence is achieved.

---

*The cell temperature calculation algorithms in SOLCOST-PV are based on the SOLCEL routines (Ref.4).

For Line 43:=1:

The array is passively cooled on the front surface only. The rear surface is assumed to be perfectly insulated. A diagram of front surface cooling is given below.

The heat deposited in the cell is given by

$$QHEAT = EI * (ABSCV - EFFC)$$

The heat transfer coefficient, H1, is calculated in HFREFR while the radiative heat transfer coefficient, H2, is given by

$$H2 = 5.688 \text{ E-}8 * (TC ** 4 - TRAD ** 4) / ((TC - TRAD) * (1./EMTCI)) * (TC - TRAD) / (TC - TA)$$

The apparent sky temperature and the effective radiative temperature are given by

$$TSKY = .0552 * TA ** 1.5$$

$$TRAD = (TSKY + TA) / 2.0$$

The cell temperature is given by the following expression:

$$TC = TA + QHEAT / (H1 + H2)$$

For Line 43 = 2: The collector array is passively cooled on both the front and the back surface. The rear surface may or may not have cooling fins.

H1 and H3 are the convective heat transfer coefficients. The top convection coefficient is modified to account for the increased cooling effect of a finned surface as follows:

$$H3 = H1 * (3.7 - 3.5 * \text{EXP} (-.25 * R_{\text{FIN}}))$$

The other coefficients are evaluated in a similar manner to those used for the single side cooling. The cell and mounting plate temperatures are calculated by solving the following heat balance equations algebraically.

$$Q_{\text{HEAT}} = (H1 + H2) * (TC - TA) + H_{\text{INCEL}} * (TC - TP)$$

$$H_{\text{INCEL}} * (TC - TP) = (H3 + H4) * (TP - TA)$$

Fresnel Concentration, input Line 43 = 4

Assumptions:

- 1) The heat flux on the cell is uniform.
- 2) The cell temperature is assumed to be uniform temperature, T_C .
- 3) All heat is assumed to be dissipated by the heatsink in order to calculate the overall heat transfer coefficient (H) and the average heatsink temperature, T_H .
- 4) The heatsink area is assumed to be much large than the cell area.
- 5) The top of the heatsink is assumed to be enclosed thus only free convection.

The heat deposited in each cell which must be rejected by the heatsink is:

$$Q_{HEAT} = EI * A_{LENS} * O_{PEFF} * (ABSCV - E_{FFC})$$

A heat balance on the heatsink yields

$$Q_{HEAT} = A_{RSINK} * (H_{CTOP} + H_{CBOT} + 2.*H_{RAD}) * (T_H - T_A)$$

where $H_{CTOP} = 4.0$ for free convection.

$$H_{CBOT} = (9.7 * V_A^{** .76} + 3.1) * (3.7 - 3.5 * \exp(-.25 * R_{FIN}))$$

$$H_{RAD} = \frac{5.67E-8 * \epsilon_{MTHI} * (T_H^{**4} - T_A^{**4})}{(T_H - T_A)}$$

Solving for the average heatsink temperature,

$$T_H = \frac{Q_{HEAT}}{A_{RSINK} * H} + T_A$$

where $H = H_{CTOP} + H_{CBOT} + 2.* H_{RAD}$

To calculate the avg. cell temperature, we treat it like a circular fin problem.

To simplify the analysis all the heat deposited in the cell is assumed to cross the boundary at RC into the rest of the heatsink. This is reasonable only if $RS \gg RC$. This is analogous to saying that the upper solar cell surface and the lower heatsink surface underneath the cell are perfectly insulated.

The governing differential equation is given below:

$$\frac{d^2 T}{dr^2} + \frac{1}{r} \frac{dT}{dr} - \frac{H}{HCOND} (T - T_A) = 0$$

Substituting for $(T - T_A)$ and solving

$$TS(r) = A I_0(\lambda r) + B K_0(\lambda r)$$

where $TS = T - T_A$

$$\lambda = \text{SQRT}(H/HCOND)$$

A, B are constants

The boundary conditions are

$$\begin{aligned} 1) \quad \left. \frac{dT}{dr} \right|_{r=RC} &= \frac{-Q_{HEAT}}{2 * \pi * RC * HCOND} \\ 2) \quad \left. \frac{dT}{dr} \right|_{r=RS} &= 0 \end{aligned}$$

Applying the boundary conditions we can get the solution for $T(r)$. The temperature of the heatsink under the cell is simply $T(RC)$. The temperature of the cell is calculated as follows:

$$T_C = T(RC) + \frac{Q_{HEAT}}{H_{INCEL} * \pi * (RC ** 2)}$$