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STEAEC—Solar Thermal Electric Annual Energy Calculator Documentation

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STEAEC - SOLAR THERMAL ELECTRIC ANNUAL ENERGY CALCULATOR
DOCUMENTATION

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ABSTRACT

The Solar Thermal Electric Annual Energy Calculator (STEAEC) is a computer model which estimates the annual performance of a solar thermal electric power plant. Written in FORTRAN IV for the CDC 6600, STEAEC is a quasi-steady state model with a constant (but user-variable) time step. Factors such as energy losses and delays incurred in start-up, effects of ambient weather conditions on plant operation and efficiency, effects of hold time and charge and discharge rates on deliverable energy in storage, subsystem maximum and minimum power limits, and auxiliary power requirements are taken into account in the computation of the annual electrical output of the plant. Default parameters may be easily modified through the use of NAMELIST inputs.

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STEAEC - SOLAR THERMAL ELECTRIC ANNUAL ENERGY CALCULATOR
DOCUMENTATION

1.0 Introduction

The Solar Thermal Electric Annual Energy Calculator (STEAEC) is a computer model developed at Sandia Laboratories as part of the 10 MW_e Solar Pilot Plant concept selection. The program was used to size subsystems and calculate annual energy production as input to the (Bucks) cost/performance analyses. STEAEC is used in conjunction with two other models developed at Sandia Laboratories. MIRVAL (1) provides field efficiencies as a function of sun position. The performance and subsystem sizes calculated by STEAEC are then used by the computer model BUCKS (2) to compute the plant levelized busbar energy cost. Figure 1.1 depicts the relation of these models.

A block diagram of the simulation model is presented in Figure 1.2. At each time step the power flows shown in this diagram are computed using a sun following thermal storage dispatch strategy. Auxiliary (fossil) power requirements for each time step are computed on a subsystem basis. Simulation for a year yields a prediction of the annual net electrical output of the solar plant.

An overview of the model is presented in Section 2.0. The methodology used in the model development for each block is presented in Section 3.0. Section 4.0 contains a brief description of the main program and each of the subroutines. The input data is discussed in Section 5.0. Finally, the output format and options are presented in Section 6.0. Appendix A presents a correlation of the mathematical symbols used in Section 3.0 with the FORTRAN

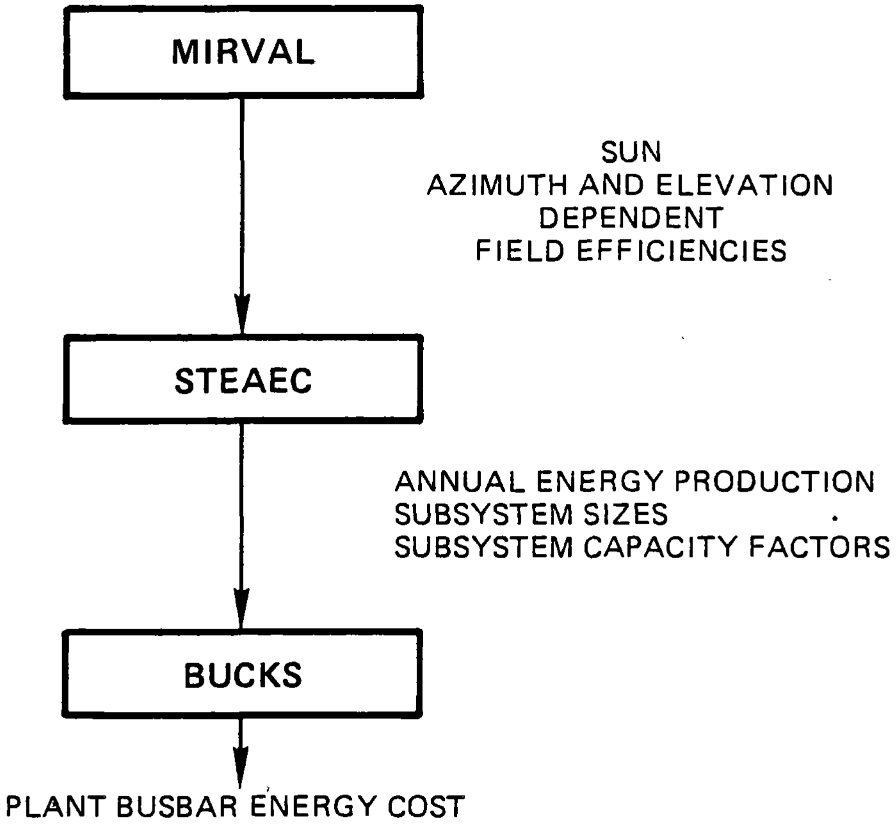

Figure 1.1. Solar Thermal Electric Power Plant Analysis Models

variable names used in the program. The logical unit assignments and external library routines employed by the program are discussed in Appendices B and C. A sample problem is discussed in Appendix D. The sample problem output and program listings are included in Appendicies E and F on microfiche.

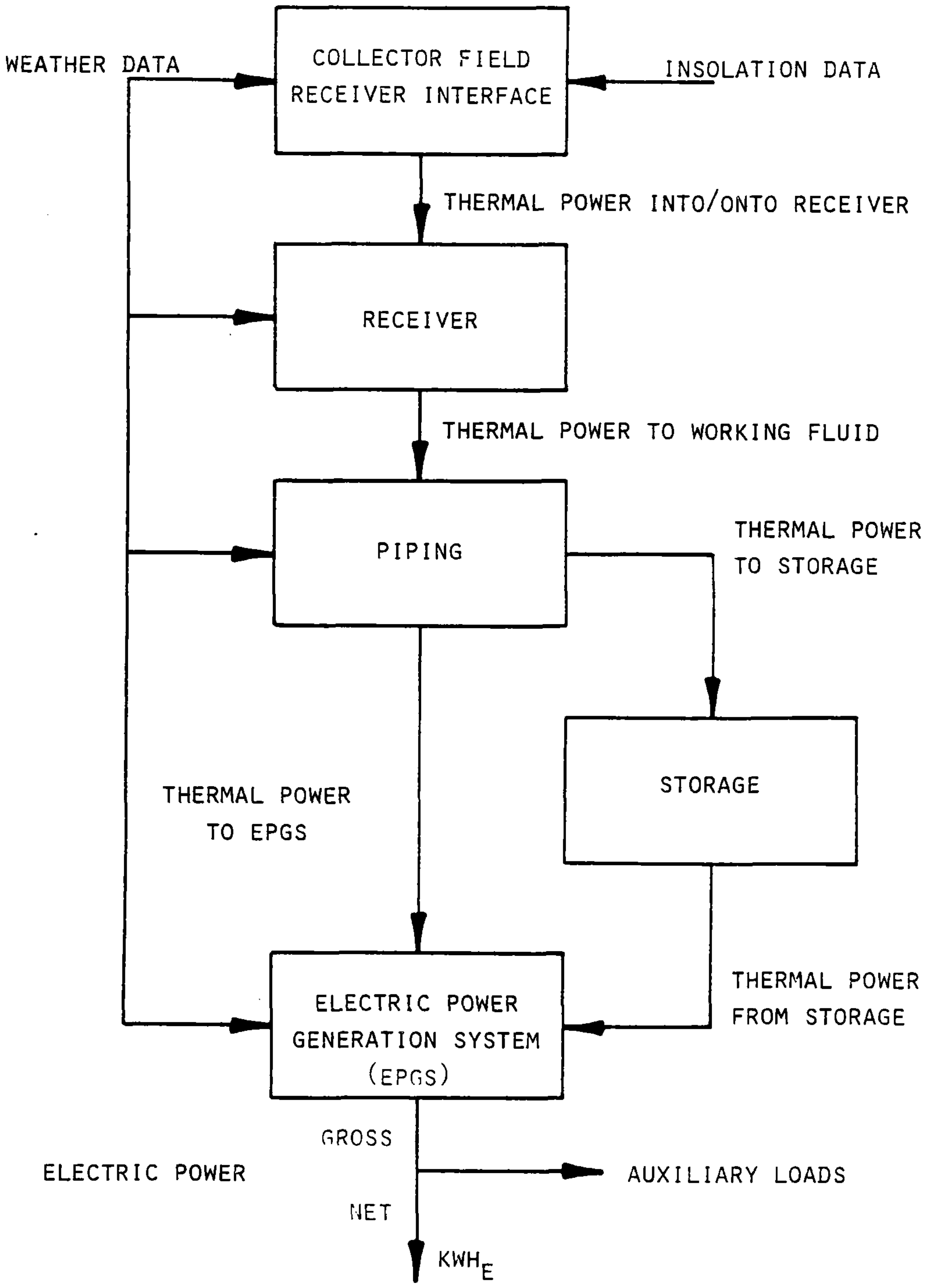

Figure 1.2. Solar Thermal Electric Annual Energy Calculator

2.0 Overview

STEAEC computes the annual electric energy produced by a solar plant by computing the power flows shown in the block diagram (Figure 1.2) at each time step and accumulating these results for a year. The time step used depends on the available weather and insolation data (15 minutes to an hour). As indicated by the block diagram, STEAEC is a power flow/efficiency model; mass flows, temperatures, and pressures are not modeled. Transients are handled in a quasi-steady state manner; differential equations are not considered.

The collector field-receiver interface block computes the receiver input power and the collector field auxiliary power requirement at each time step. Direct normal insolation, sun position, and ambient temperature and wind speed are considered. Alternate heliostat, collector field and receiver designs may be accommodated.

The receiver block computes the thermal power absorbed by the receiver working fluid and the receiver auxiliary power requirement at each time step. Reflection, weather dependent reradiation, convection and conduction and startup are considered. External or cavity receivers, a derated mode for low power operation, and minimum input power requirements may be accommodated.

The piping block considers thermal losses to compute the thermal power input to the turbine and storage at each time step. The effect of piping pressure drop on turbine performance is considered in the Electric Power Generating Subsystem (EPGS) block.

The thermal storage block computes the thermal energy in storage available for electric power production and the storage auxiliary power requirement at each time step. Storage tank and heat exchanger heat losses and thermocline degradation are considered. Minimum charge and discharge rates may be accommodated. Thermal power for trace heating and turbine sealing is supplied by storage. If storage is depleted this thermal power is included in the auxiliary power requirement.

The EPGS block computes the gross electric power produced and the EPGS auxiliary power requirement at each time step. Ambient wet bulb temperature, input power level, and start-up are considered. Different conversion efficiencies and minimum power requirements for storage and receiver power may be accommodated. Most of the plant control, including the dispatch of thermal storage is modeled in this block.

The methodology used in representing the performance of each of the subsystems is presented in Section 3.0.

3.0 Methodology

In this section the methodology used to represent each of the blocks shown in Figure 1.2 is briefly discussed. The default parameters for the models are also given when their presentation aids in the explanation of the models.

3.1 Collector Field - Receiver Interface

The optical performance of the collector field and receiver is modeled as follows.

$$\boxed{P_{tr}(t) = F\Big(\Theta_a(t), \Theta_e(t)\Big)\, G\Big(W(t)\Big)\, S_f\, I_{dn}(t)} \tag{3.1}$$

where

$P_{tr}(t)$: thermal power into/onto the receiver at time t (MW)

$F(\Theta_e, \Theta_a)$: field efficiency as a function of sun elevation and azimuth

$\Theta_a(t)$, $\Theta_e(t)$: sun azimuth and elevation at time t (degrees)

$G(W)$: multiplicative correction factor for wind speed

$W(t)$: wind speed at time t (m/s)

S_f: field size (number of square meters of relective surface)

$I_{dn}(t)$: direct normal insolation at time t (MW/m^2)

The effects of reflectivity, atmospheric attenuation, blocking, shading, cosine, tower shadow, tracking errors, alignment errors, receiver interception and heliostat reliability are all included in the function F. F is represented by a bicubic spline fit to a rectangular array of data (Θ_e, Θ_a). The effects of wind speed are modeled as a multiplicative correction factor G. G is evaluated using a spline fit to a vector of data. Tables 3.1 and 3.2 present the default values for the fit data for functions F and G.

The elevation and azimuth of the sun are calculated as follows:

$$(3.2) \qquad \Theta_e(t) = \sin^{-1} \{ \cos(\ell) \cos(h(t)) \cos(d(t)) + \sin(\ell) \sin(d(t)) \}$$

$$\Theta_a(t) = \cos^{-1} \{ \frac{\sin(\ell) \cos(h(t)) \cos(d(t)) - \cos(\ell) \sin(d(t))}{\cos(\Theta_e(t))} \}$$

where ℓ: latitude of solar plant

h(t): hour angle at time t (zero at solar noon)

d(t): solar declination at time t

The solar declination measured in degrees is given approximately by the following equation:

$$(3.3) \qquad d(t) = 0.302 - 22.93 \cos(c(t)) - 0.229 \cos(2c(t)) - 0.243 \cos(3c(t)) + 3.851 \sin(c(t)) + 0.002 \sin(2c(t)) - 0.055 \sin(3c(t)))$$

$$(3.4) \qquad c(t) = 2\pi \{ \frac{\text{day of the year + time of day/24}}{366} \}$$

The collector field is shut down if the ambient wind speed, ambient temperature, or solar elevation is outside the operating range specified. Collector field auxiliary loads are assumed to be proportional to the reflective area of the field. Auxiliary loads for the collector subsystem are represented as two constant values: standby and tracking.

Table 3.1

Field Efficiency Data -- F

Azimuth - (degrees)

Elevation - (degrees)	0.	30.	60.	75.	90.	110.	130.
5.	.250	.249	.242	.236	.231	.226	.223
15.	.481	.467	.456	.441	.431	.410	.406
25.	.573	.570	.541	.535	.521	.507	.494
45.	.622	.612	.614	.599	.583	.571	.560
65.	.630	.639	.619	.612	.607	.601	.603
89.5	.625	.622	.623	.624	.625	.626	.635

Table 3.2 Wind Speed Correction Factor

Data -- G

Wind Speed (m/s)	Correction Factor
0	1.0
2	.999
4	.998
6	.996
8	.994
10	.985
12.	.964
13.4	.942

3.2 Receiver

The receiver block calculates the fraction of the power redirected into/onto the receiver which is transferred to the working fluid by the receiver subsystem. Receiver loss mechanisms include reflection, reradiation, conduction, and convection. Reradiation, conduction, and convection losses are determined primarily by the temperature profile of the working fluid, which is not sensitive to the input power level. Reflection losses on the other hand are proportional to the incoming power. Thus, receiver losses are represented by a sum of two terms: a constant loss term and a term proportional to the input power.

The time required for receiver start-up is assumed to depend only on the length of time the receiver was on stand-by, not on the incoming power level. A generalized receiver state parameter is introduced to represent this phenomenon.

Receiver performance during normal operation is represented as follows

$$\boxed{P_{wf}(t) = \varepsilon_r \, P_{tr}(t) - L_r(T_a(t), W(t)) \, R_s \, X(t)} \tag{3.5}$$

where

$P_{wf}(t)$: thermal power transferred to the working fluid at time t (MW)

$P_{tr}(t)$: thermal power into/onto the receiver from collector field at time t (MW)

R_s: receiver size (maximum power to receiver) (MW)

$X(t)$: receiver state parameter (between zero and one; one for rated operation, less than one for derated operation) at time t.

$L_r(T_a, W))$: receiver subtractive loss parameter at ambient temperature T_a and wind speed W.

$T_a(t)$: ambient temperature at time t (°F)

$W(t)$: wind speed at time t (m/s)

Receiver performance during start-up is represented as follows:

$$\boxed{\begin{aligned} &P_{wf}(t) = \varepsilon_r P_{tr} - L_r(T_a(t),W(t))\, R_s\, X(t) - H_r R_s \\ &X(t) = X_0 + (t-t_0)/T_{cs} \end{aligned}} \tag{3.6}$$

where

X_0: X-value at beginning of start-up

t_0: time start-up begins (hour)

t: time (hour)

T_{cs}: time required for a cold start (hours)

During periods of receiver shut-down X(t) is represented as follows

$$X(t) = X_1 \exp \{ \alpha_r (t-t_1)\} \tag{3.7}$$

where

X_1: X-value at time of receiver shut-down

t_1: time of receiver shut-down.

The proportional efficiency, ε_r, is a constant determined by reflection losses. The subtractive loss parameter, L_r, is a function of wind speed and ambient temperature determined by reradiation, convection, and conduction losses. The start-up thermal capacity parameter, H_r, is a constant determined by the receiver thermal capacity and start-up rate. H_r is computed by dividing the energy required to heat the receiver to operating conditions by the receiver size and the time required for a cold start. The cool down parameter, α_r, is determined by the receiver cool down rate and should be adjusted to yield the correct start-up time after an overnight shut-down. L_r was represented by a bicubic spline. Table 3.3 presents the default values for the L_r fit data.

One STEAEC receiver option is a derated mode to be used for low receiver input power. In this mode, receiver power can only be used to charge storage or initiate turbine start-up. Figures 3.1 and 3.2 present hypothetical daily cycles for the receiver state parameter, X(t), for receivers with and without a derated mode. If the receiver has a derated operating mode, STEAEC automatically goes to derated operation whenever the power to the receiver drops below the rated/derated threshold. During derated operation X(t) is held constant at X_D, a value between zero and one. With or without a derated mode, the receiver is shut down if the input power is below the minimum requirement.

Receiver auxiliary load is assumed to be proportional to the receiver size. The auxiliary load for the receiver subsystem is modeled as zero when the receiver is on standby and constant when the receiver is operating.

TABLE 3.3 Spline Fit Data for L_r

TEMPERATURE (°F)	WIND SPEED (m/s) 0.	3.	8.	10.	16.
-4	2.45×10^{-2}	2.63×10^{-2}	2.86×10^{-2}	2.93×10^{-2}	3.06×10^{-2}
32	2.39×10^{-2}	2.57×10^{-2}	2.80×10^{-2}	2.87×10^{-2}	3.01×10^{-2}
68	2.34×10^{-2}	2.52×10^{-2}	2.75×10^{-2}	2.82×10^{-2}	2.95×10^{-2}
104	2.29×10^{-2}	2.45×10^{-2}	2.70×10^{-2}	2.77×10^{-2}	2.90×10^{-2}
140	2.23×10^{-2}	2.41×10^{-2}	2.64×10^{-2}	2.71×10^{-2}	2.85×10^{-2}

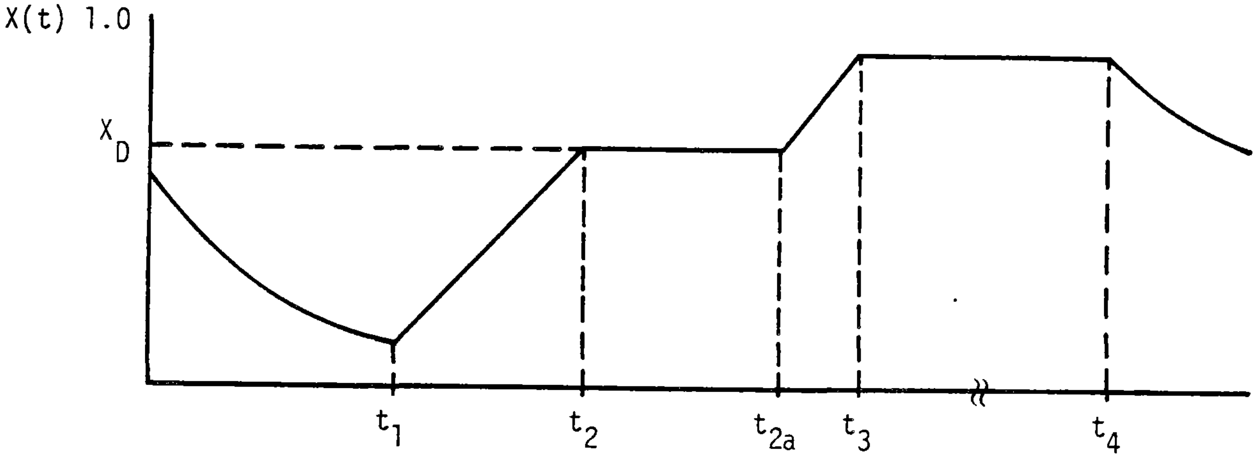

Figure 3.1 Daily Cycle For X(t) -- With Derated Mode

Symbols:

t_1: time receiver start-up begins

t_2: time receiver reaches derated conditions

t_{2a}: time power to receiver exceeds rated/derated threshold

t_3: time receiver start-up is complete

t_4: time receiver is shut down

X_D: X value for derated operation

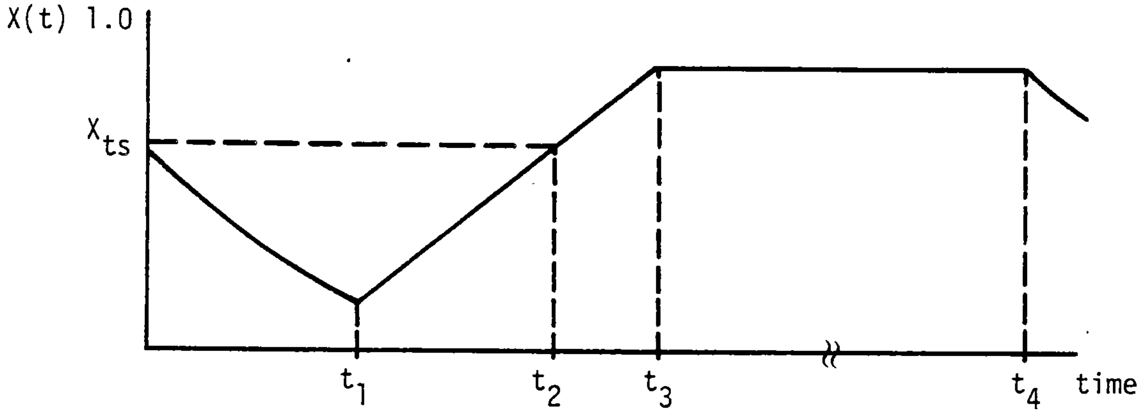

Figure 3.2 Daily Cycle For X(t) -- No Derated Mode

Symbols:

t_1: time receiver start-up begins

t_2: time receiver power may be used to initiate turbine start-up

t_3: time receiver start-up is complete

t_4: time receiver is shut down

X_{ts}: receiver state parameter value at time t_2.

3.3 Piping

The performance of the piping from the receiver to the turbine main throttle valve or storage charging heat exchanger is represented as follows:

$$(3.8) \quad \boxed{P_{ft}(t) = P_{wf}(t) - L_p(T_a(t))\; R_s\; X(t)}$$

where

$P_{ft}(t)$: thermal power from the tower at time t (MW)

$P_{wf}(t)$: thermal power transferred to working fluid at time t (MW)

$X(t)$: receiver state parameter at time t

$L_p(T_a)$: piping subtractive loss parameter at ambient temperature T_a

$T_a(t)$: ambient temperature at time t (°F)

R_s: receiver size (MW)

The piping loss parameter, L_p, is represented as a function of the ambient temperature by a spline fit. Table 3.4 presents the default values.

It should be noted that the effect of any pressure drop from the receiver to the turbine is represented in the EPGS conversion efficiency, not in the piping block.

TABLE 3.4

Spline Fit Data for L_p

AMBIENT TEMPERATURE (°F)	L_p
-22	3.47×10^{-4}
-4	3.39×10^{-4}
-14	3.31×10^{-4}
32	3.23×10^{-4}
50	3.15×10^{-4}
68	3.07×10^{-4}
86	2.99×10^{-4}
104	2.91×10^{-4}
122	2.83×10^{-4}

3.4 Thermal Storage

The thermal storage representation used in STEAEC was motivated by the sensible heat storage systems proposed for the 10 MW Solar Pilot Plant. In these systems, thermal energy from receiver generated steam is transferred to the storage media as sensible heat. Steam (at a lower temperature and pressure) is later produced by removing the sensible heat from the storage media. These systems are designed to produce steam at a constant temperature and pressure for injection into the turbine through a secondary admission valve.

The thermodynamic availability loss (Second Law) in the charge and discharge cycle is represented in STEAEC by the difference in receiver and storage conversion efficiencies in the EPGS block. The heat losses (First Law) in these storage systems are represented in the thermal storage block. These heat loss mechanisms include heat exchanger losses, tank conduction losses, and thermocline degradation losses in systems with backed beds.

Thermal storage performance is represented as follows

$$(3.9)\quad \boxed{\begin{aligned} & E_s(t_{n+1}) = \alpha_L E_s(t_n) + \alpha_c(P_{ts}(t_n))\, P_{ts}(t_n) - P_{fs}(t_n)/\alpha_d(P_{fs}(t_n)) \\ & \alpha_c(P) = (c_o + c_1\, P + c_2\, P^2) \cdot (t_{n+1} - t_n) \\ & \alpha_d(Q) = (d_o + d_1\, Q + d_2\, Q^2)/(t_{n+1} - t_n) \end{aligned}}$$

where

$E_s(t)$: energy in storage at time t (MWH)

$P_{ts}(t)$: storage charge rate at time t (MW)

$P_{fs}(t)$: storage discharge rate at time t (MW)

The tank conduction losses are represented by α_L. The charge and discharge efficiencies, $\alpha_c(\cdot)$ and $\alpha_d(\cdot)$, include the effects of both heat exchanger heat losses and thermocline degradation. Heat exchanger heat losses may be assumed proportional to their charge and discharge rates; but energy recovery from a packed bed storage system is a more complicated function of charge and discharge rate, due to thermocline degradation. The representation expressed by Equation 3.9 is a least squares approximation to the solution of a set of coupled one dimensional partial differential equations used to determine the shut-down times for a series of charge/discharge cycles. This results in a conservative representation of thermocline degradation since all energy remaining in the tank after each charge/discharge cycle is assumed to be unrecoverable.

It is assumed that the storage heat exchangers will be kept in a hot standby condition when they are not in use. The thermal power required is assumed to be a percentage of the maximum charge or discharge rate and is supplied from storage if possible. Turbine standby sealing steam thermal power requirements are also supplied from storage if possible. If storage is depleted, the standby thermal power requirements for heat exchanger heating and turbine sealing steam are supplied using auxiliary electric power. To minimize these auxiliary power requirements, electric power is not generated from storage if there is less than a threshold quantity of energy remaining in storage.

The thermal storage auxiliary load is used primarily to pump storage fluids through heat exchangers; but, as indicated above, STEAEC assumes an auxiliary electric boiler is employed to supply standby thermal requirements if storage is depleted.

The auxiliary load for the storage subsystem is modeled as follows

(3.10) Standby -- Energy In Storage

$$P_{sa}(t) = X\ (A\ P_{tsm} + B\ P_{fsm}) + B\ P_{ss}\ I_{sbt}$$

Standby -- No Energy In Storage

$$P_{sa}(t) = X\ (P_{tsm} + P_{fsm}) + P_{ss}\ I_{sbt}$$

Charging

$$P_{sa}(t) = A\ P_{ts}(t) + X\ B\ P_{fsm}$$

Discharging

$$P_{sa}(t) = X\ A\ P_{tsm} + B\ P_{fs}(t)$$

Simultaneous Charging and Discharging

$$P_{sa}(t) = A\ P_{ts}(t) + B\ P_{fs}(t)$$

where

$P_{sa}(t)$:	auxiliary electric power required by the storage subsystem at time t (MW)
$P_{ts}(t)$:	charge rate at time t (MW)
$P_{fs}(t)$:	discharge rate at time t (MW)
P_{tsm}:	maximum charge rate (MW)
P_{fsm}:	maximum discharge rate (MW)
P_{ss}:	turbine sealing steam thermal power requirements (MW)
I_{sbt}:	control variable (1 if turbine on standby, 0 otherwise)

X: ratio of heat exchanger standby thermal requirements to the maximum heat transfer capability of the heat exchangers (e.g., the thermal power required to keep the charging heat exchanger in a hot stand-by condition is given by X P_{tsm} MW_{th})

A, B: ratio of auxiliary electric pumping power to the heat transferred, (MW_e/MW_{th}) (e.g., the storage auxiliary load required for pumping fluids through the charging heat exchangers at time t is A $P_{ts}(t)$ MW_e)

3.5 Electric Power Generation System

The electric power generation system (EPGS) has six operating modes:

1. standby
2. start-up from receiver
3. start-up from storage
4. operation from receiver alone
5. operation from storage alone
6. operation from both receiver and storage

The daily sequencing through these modes is determined by the dispatch strategy, insolation profile, and energy in storage. Dispatching strategies are discussed in greater detail in Section 3.6, but two sun following dispatching strategies were investigated: turbine priority and storage priority. Sun following dispatching maximizes the electric power or energy generation from the plant.

The EPGS may be started from storage any time and from the receiver any time the receiver state parameter, X(t), exceeds the threshold value.

The time required for EPGS start-up depends on the average turbine shell temperature, which in turn depends on the time on standby and whether the turbine was operating on storage or receiver power prior to shut-down. The average shell temperature is assumed to decay during shut-down as follows

$$T_{ave}(t_{sb}) = 100 + 450\{e^{-\alpha(t_{sb}+\tau)} + e^{-\beta(t_{sb}+\tau)}\} \tag{3.11}$$

where

$T_{ave}(t_{sb})$: average turbine shell temperature after shut-down for t_{sb} hours (°F).

τ: chosen so that $T_{ave}(0)$ is equal to the steam temperature at time of shut-down (hours).

Three turbine start-up types have been identified: hot, warm, and cold. Table 3.5 presents the average shell temperature, synchronization delays and maximum ramp rates for these three types of start-ups.

The gross EPGS thermal to electric conversion efficiency is a function of flow rate and ambient wet bulb temperature, represented by a bicubic spline fit. The default data for the bicubic spline fit for receiver and storage power conversion is presented in Tables 3.6 and 3.7.

The EPGS is assumed to supply the auxiliary electric power requirements for all subsystems. If the turbine generator is not producing power, STEAEC assumes the network provides the auxiliary electric power required. The off net energy requirements for the plant are included in the STEAEC output.

Table 3.5 EPGS Start-up

Start-up Type	Average Shell Temperature	Synchronization Delay	Ramp Rate
Hot Start	1000-700°F	12 minutes	3% per minute
Warm Start	700-300°F	17 minutes	1 1/2% per minute
Cold Start	300-0°F	24 minutes	1/2% per minute

Table 3.6 Thermal To Electric Conversion Efficiency

From The Receiver

Gross, must be Barstow

Mass Flow Fraction

Wet Bulb Temperature (°F)	0.25	0.5	0.75	1.00
30	.345	.376	.384	.386
40	.344	.375	.383	.385
50	.343	.374	.383	.385
60	.342	.373	.382	.384
70	.331	.368	.378	.380
80	.323	.362	.372	.374

Table 3.7 Thermal To Electric Conversion Efficiency

From Storage

Wet Bulb Temperature (°F)	Mass Flow Fraction			
	0.25	0.50	0.75	1.0
30	.213	.254	.267	.284
40	.212	.254	.267	.283
50	.212	.253	.266	.282
60	.210	.252	.265	.280
70	.207	.249	.262	.277
80	.202	.244	.257	.270

The following two equations are assumed to hold when the turbine is operating from both receiver and/or storage power.

$$\boxed{\begin{aligned} P_e\,(t) &= \varepsilon_r(T_{wb}(t),X(t))\;P_{tt}(t) \\ &\quad + \varepsilon_s(T_{wb}(t),X(t))\;P_{fs}(t) \\ X(t) &= \frac{P_{tt}(t)}{P_{ttm}} + \frac{P_{fs}(t)}{P_{fsm}} \leq 1 \end{aligned}} \tag{3.12}$$

where

$P_e(t)$: gross electric power produced by EPGS at time t (MW_e)

$P_{tt}(t)$: thermal power to turbine from receiver at time t (MW_{th})

$P_{fs}(t)$: thermal power to turbine from storage at time t (MW_{th})

P_{ttm}: maximum thermal power to turbine from receiver (MW_{th})

P_{fsm}: maximum thermal power to turbine from storage (MW_{th})

$\varepsilon_r(T_{wb},X)$: gross EPGS conversion efficiency from receiver power at wet bulb temperature T_{wb} and mass flow fraction X.

$\varepsilon_s(T_{wb}\ X)$: gross EPGS conversion efficiency from storage power at wet bulb temperature T_{wb} and mass flow fraction X.

The EPGS auxiliary electric power is used primarily to provide feedwater pumping power. If the turbine is on standby there are additional auxiliary requirements to turn the turbine and maintain condenser vacuum.

The auxiliary power requirements for the EPGS were modeled as follows:

Standby

$$P_{ta}(t) = P_{tsb} + \alpha_r P_{ft}(t) \tag{3.13}$$

Operating

$$P_{ta}(t) = \alpha_r P_{ft}(t) + \alpha_s P_{fs}(t)$$

where

$P_{ta}(t)$ = auxiliary electric power required by the EPGS at time t (MW)

$P_{ft}(t)$: power from the tower at time t (MW)

$P_{fs}(t)$: power from storage at time t (MW)

P_{tsb}: constant standby power requirements (MW)

α_r, α_s: scale factors (MW_e/MW_{th})

3.6 Thermal Storage Dispatch Strategies

Two sun following dispatch strategies have been built into the program: turbine priority and storage priority. These two strategies differ only in the way they handle below minimum power flows. These differences are discussed below, but first the similarities.

Both dispatchers start the EPGS in the morning with receiver power as soon as possible and continue to operate the turbine as long as possible. Receiver power is sent to the EPGS for electric power production. Power not needed by the EPGS is dispatched to storage. Whenever receiver power is insufficient to provide full turbine output, storage power is used to augment receiver power. If the receiver has a derated mode, whenever the receiver drops below the threshold, derated receiver power is dispatched through storage to the EPGS. The turbine is shut down each evening only after all available thermal energy from storage has been used (leaving only enough energy to supply standby thermal requirements).

The basic objectives of the sun following dispatcher are to (1) operate the turbine at maximum output and (2) produce as much electricity as possible. These two objectives conflict in two situations. The first occurs when the power from the receiver exceeds the turbine capability by less than the minimum storage charge rate. The second situation occurs when the storage power required to augment the power from the receiver is less than the minimum turbine flow from storage.

The storage priority dispatcher attempts to conserve energy. In the first situation the power to the turbine is reduced to allow the power to storage to exceed the minimum charge rate. In the second situation, no storage power is used unless the requirements for receiver power augmentation exceed the minimum flow from storage to the turbine.

The turbine priority dispatcher attempts to maximize turbine output. In the first situation, the excess power from the receiver goes unused. In the second situation some receiver power is allowed to bypass the turbine to increase the power drawn from storage if that results in higher turbine electric power output.

4.0 Program Description

4.1 Program Components

4.1.1 STEAEC

The main program is primarily a driver and output routine. DELT, the simulation time step, is defined in the first executable statement. Its value may be as low as 0.125 hours without revising variable dimensioning. Code initialization includes reading a single data card and calls to INPUT1 and COEF which initialize NAMELIST values and calculate collector field efficiency matrices.

The daily loop begins at statement 30. One day of insolation and weather data are obtained from INPUT2 as are azimuth and elevation values from DEA. COLF, the collector field model, calculates a day's array of power to receiver values.

The DO 500 statement begins the loop for each DELT period of the day. RCVR, the receiver model, is called resulting in determination of PTWF, power to the working fluid. Thermal power transmission losses to the EPGS and/or storage facilities are determined in PIPE yielding PWF, power in working fluid. Most of the operational logic of the plant is contained in TRBN, the EPGS model, to include the charge and/or discharge demands to be made on the storage model, STRG. In the event the storage model is unable to accommodate these demands, it calculates the excess and the driver program reenters TRBN and STRG to suitably alter the storage demands. In the event that TRBN and STRG are unable to use all the receiver power, mirror deflection is simulated.

The remainder of the main program is concerned with output.

4.1.2 INPUT1

This routine initializes all NAMELIST constants via either the default data statements or new values read from the NAMELIST file, or a combination thereof. The default values represent a 100 MW plant capable of derated operation. NAMELIST constants are listed at the beginning of each run.

4.1.3 COEF

COEF calls IBCICU, an interpolatory natural bicubic spline routine, to generate matrices representing collector field efficiencies. They are based on NAMELIST values obtained from the code MIRVAL (1).

4.1.4 IBCICU

A routine that computes matrices of an interpolatory natural bicubic spline. It is an International Mathematical and Statistics Library (IMSL) routine. For documentation, see Appendix C.

4.1.5 INPUT2

This is the only routine that must be reviewed if the form of the insolation and weather data or plant location (Barstow, CA) is changed. It reads the values for direct normal insolation, wind direction, wind speed, dew point temperature, station pressure, and dry bulb temperature from TAPE2. It calculates the wet bulb temperatures and obtains the azimuth and elevation values from subprogram DEA. It lists all values if so desired.

4.1.6 DEA

On a given day (Julian Calendar) and time (in hours) this routine calculates the azimuth and elevation. It also determines sunrise and sunset.

4.1.7 COLF

The collector field model calculates the power to receiver (PTR) as a function of the direct normal insolation, the field size and field efficiency. It also calculates the auxiliary electrical power requirements of the field.

4.1.8 EFFIC

With the aid of LOCATE and IBCEVU, this routine calculates the collector field efficiency as a function of azimuth, elevation, wind speed and an efficiency constant.

4.1.9 LOCATE

For a particular azimuth and elevation, this routine locates the appropriate 4 x 4 bicubic spline matrix within the COF array.

4.1.10 IBCEVU

This IMSL library routine evaluates a bicubic spline at a specified point. For documentation, see Appendix C.

4.1.11 EFWS

With the aid of the cubic spline routines, SPLIFT and SPLINT, this routine calculates the effect of wind speed on collector field efficiency.

4.1.12 SPLIFT

Given independent and dependent variable arrays, this routines fits an interpolating cubic spline to the data points. For documentation, see Appendix C.

4.1.13 SPLINT

SPLINT evaluates a cubic spline generated by SPLIFT for any appropriate value of the independent variable. For documentation, see Appendix C.

4.1.14 RCVR

The receiver model is entered once each DELT period. Its mode of operation is determined by the current thermal power available and the previous status of the receiver. In addition to standby, startup and rated modes, a derated mode is included, the entry to which is controlled by the NAMELIST variable, MODPO.

The first section of coding determines that the thermal power is within the input operating range of the receiver. If below minimum flow criteria, the thermal power input is set to zero and the power loss tallied. If above, the input is diminished to the receiver size, simulating mirror deflection, and the power loss is tallied.

A branch jump is then made to the section of the applicable mode of operation.

The thermal power loss coefficient is the function XLR. The variable, XT, represents the current quality of the working fluid (between zero and one). RCVR also calculates the auxiliary electrical power requirements of the receiver.

4.1.15 XLR

This routine is used in the receiver model as a coefficient of the receiver size to determine reradiation, conduction and convection losses as a function of dry bulb temperature and wind speed.

4.1.16 IBCIEU

This IMSL library routine performs a two-dimensional interpolation to a given set of points. The natural bicubic spline is used to interpolate. For documentation, see Appendix C.

4.1.17 PIPE

PIPE models the transmission of the working fluid from receiver to the turbine and/or storage facilities. Function XLP is used to determine the magnitude of thermal losses.

4.1.18 XLP

XLP is used in the working fluid transmission model to determine conduction and convection losses, a function of dry bulb temperature.

4.1.19 TRBN

Similar to the receiver, the EPGS system responds to a given quality and quantity of thermal power and the operating status at the previous DELT period. TRBN modes of operation are standby, startup from receiver, startup from storage, rated operation from receiver, rated operation from storage, derated operation from receiver and simultaneous operation from receiver and storage. The startup from storage option has not been used and some minor logic would need to be added to exercise this option.

The control logic has been incorporated in this routine. The maximum and the minimum flow constraints for both the turbine and storage are implemented by TRBN. All storage charge and discharge strategy is controlled by this subroutine. If storage is unable to accommodate the desired strategy, a second pass is made through TRBN to modify its demands.

The routine uses the functions EPSR and EPSS to calculate power conversion efficiencies operating from receiver and storage.

4.1.20 EPSR

Routine uses a bicubic spline to compute the gross thermal to electric conversion efficiency as a function of wet bulb temperatures and mass flow fractions for power from the receiver.

4.1.21 EPSS

Routine uses a bicubic spline to compute the gross thermal to electric conversion efficiency as a function of wet bulb temperatures and mass flow fractions for power from storage.

4.1.22 STRG

The storage model receives desired charge or discharge commands from TRBN and if possible complies with them, in which case control is returned to the main program for completion of the DELT loop. If the charge rate is excessive or storage is full, the surplus power to storage is calculated and the driver program is reentered for the purpose of repeating a pass through the EPGS and storage models with the storage commands suitably altered. If the energy in storage is insufficient the unavailable power from storage is calculated and the same loop is repeated as described above.

The modes of operation are standby, charge, discharge, and simultaneous charge and discharge. The particular mode chosen is dictated by TRBN commands and the level of energy currently in storage.

Thermal losses due to conduction and providing sealing power to the turbine are taken into account. Auxiliary power needs are also calculated.

4.1.23 ZEROIN

ZEROIN finds the zero of a function over a given interval. For documentation, see Appendix C. The routine is used in the storage model and utilizes one of the four following functions; FMA, FMI, FMAI, or FMQ. These functions are included in the program.

5.0 Input

5.1 Data Card

Three integer variables, MFLAG, NDAF, and NDAL, provide options with respect to printed output and duration of run. The format is 3I5. Default values of 0, 1, and 366, respectively, are provided.

5.1.1 MFLAG

MFLAG controls the level of printing. Values from zero to five may be used. Zero inhibits all printing except the final summary. Five activates all print statements in the code. A further description is contained in the section on output.

5.1.2 NDAF

The day (Julian calendar) that MFLAG level of printing is to commence.

5.1.3 NDAL

The day (Julian calendar) the run is to terminate.

5.2 NAMELIST

The NAMELIST file is used to modify any of the variable values defined in the INPUT1 data statements. Since NAMELIST is a machine dependent feature, the remarks in this section pertain to CDC 6000/7000 equipment. The code was written such that ordering of the NAMELIST subsections is not required. If no changes are being made, a skeletal NAMELIST file may be required. Under the NOS-BE operating system it was inadvertently discovered that a vacuous file works just as well.

5.2.1 Skeletal Namelist File

```
$CONCOEF

$END

$CONCOLF

$END

$CONRCVR

$END

$CONPIPE

$END

$CONTRBN

$END

$CONSTRG

$END
```

5.2.2 NAMELIST Variable Definitions

5.2.2.1 CONCOEF

FR - Matrix of collector field efficiencies as a function of azimuth and elevation obtained from MIRVAL (1). (Table 3.1)

AZR - Row vector of corresponding azimuth values (must be NY values in ascending order).

ELR - Column vector of corresponding elevation values (must be NX values in ascending order).

NX - Number of rows (6 max) in FR matrix.

NY - Number of columns (7 max) in FR matrix.

5.2.2.2 CONCOLF

FS - Field area in square meters times the number of fields.

ASB - Collector field auxiliary power requirements on standby (MW_e/m^2).

AOL - Collector field auxiliary power requirements on line (MW_e/m^2).

TLIML - Plant temperature limit lower (dry bulb F).

TLIMU - Plant temperature limit upper (dry bulb F).

ELIM - Minimum sun elevation for collector field operation (degrees).

WSLIM - Maximum wind speed for collector field operation (m/s).

RFLCTY - Efficiency coefficient for atmospheric attenuation and heliostat reliability. It should be set to unity if these factors are included in the MIRVAL (1) calculations as is the case in Table 3.1.

WSX - Wind speed values for spline fit (m/s). (Table 3.2)

WSEF - Wind speed efficiency factor values for spline fit (decimal percent).

NEFWS - Number of elements (8 max) in WSX array.

5.2.2.3 CONRCVR

EPS - Receiver proportional efficiency.

XHR - Heat capacity term.

RS - Receiver size - maximum thermal input (MW_{th}).

ALPHAR - Receiver cool down parameter (hours).

TCS - Cold start time factor (hours).

RMF - Receiver minimum flow factor. Fraction of RS.

CAXP - Auxiliary power coefficient (MW_e/MW_{th}).

DEPTF - Derated power threshold factor. Fraction of RS.

MODPO - Mode of plant options. 1 = no derated capability. 2 = derated capability available.

XTD - XT value at derated operation.

DTST - Time increment between turbine synchronization and rated conditions (hours).

FXLR - Matrix of receiver subtraction loss coefficients representing reradiation, conduction and convection losses. (Table 3.3)

NRXL - Number of rows (6 max) in FXLR matrix.

NCXLR - Number of columns (5 max) in FXLR matrix.

RXLR - Row vector of wind speed values (m/s) for bicubic spline. (Table 3.3)

CXLR - Column vector of dry bulb temperatures (°F) for bicubic spline. (Table 3.3)

5.2.2.4 CONPIPE

TXLP - Vector of temperature points (°F) for spline fit. Must be in ascending order (Table 3.4).

YXLP - Vector of corresponding thermal power loss coefficients for PIPE model (Table 3.4).

NXLP - Number of elements (9 max) in temperature vector.

5.2.2.5 CONTRBN

ALPHA - Turbine shell cool down parameter (hours^{-1}).

BETA - Turbine shell cool down parameter (hours^{-1}).

TAUR - Turbine operating temperature factor when previous shut-down was during operation from receiver (hours).

TAUS - Turbine operating temperature factor when previous shut-down was during operation from storage (hours).

ALPHR - Coefficient of auxiliary power needs when operating from receiver (MW_e/MW_{th}).

ALPHS - Coefficient of auxiliary power needs when operating from storage (MW_e/MW_{th}).

TPFRL - Maximum thermal power that turbine may receive from receiver (MW).

TPFSL - Maximum thermal power that turbine may receive from storage (MW).

AUXPC - Standby auxiliary power coefficient (MW_e/MW_{th}).

TMFR - Turbine minimum flow rate coefficient for power from receiver (fraction of maximum flow rate).

TMFS - Turbine minimum flow rate coefficient for power from storage (fraction of maximum flow rate).

SMFC - Storage minimum charge rate (fraction of maximum charge rate).

SMFD - Storage minimum discharge rate (fraction of maximum discharge rate).

TURBSS - Turbine sealing steam coefficient (MW_{th}).

MOPMF - Mode of operation during minimum flow conditions. 1 = turbine priority, 2 = Storage priority.

FEPSR - Matrix of thermal to electrical conversion efficiency coefficients for power from receiver as a function of wet bulb temperature (°F) and mass flow fraction. (Table 3.6)

REPSR - Row vector of fraction of rated power (th) for bicubic spline. Must be in ascending order. (Table 3.6)

CEPSR - Column vector of wet bulb temperatures (°F) for bicubic spline. Must be in ascending order. (Table 3.6)

NREPSR - Number of rows (6 max) in FEPSR matrix.

NCEPSR - Number of columns (4 max) in FEPSR matrix.

FEPSS - Matrix of thermal to electrical conversion efficiency coefficients for power from storage as a function of wet bulb temperature (°F) and mass flow fractions. (Table 3.7)

REPSS - Row vector of fraction of rated power (th) for bicubic spline. Must be in ascending order. (Table 3.7)

CEPSS - Column vector of wet bulb temperatures (°F) for bicubic spline. Must be in ascending order. (Table 3.7)

NREPSS - Number of rows (6 max) in FEPSS matrix.

NCEPSS - Number of columns (4 max) in FEPSS matrix.

5.2.2.6 CONSTRG

PTSMAX - Maximum storage charge rate (MW).

PFSMAX - Maximum storage discharge rate (MW).

EMAX - Maximum storage capacity (MWH).

EMIN - Minimum storage level allowed (MWH).

ES - Energy in storage at beginning of run (MWH).

XLL - Storage loss factor during standby.

A - Storage charge auxiliary power constant (MW_e/MW_{th}).

B - Storage discharge auxiliary power constant (MW_e/MW_{th}).

ALPHC - Storage loss factor during charge.

ALPHD - Storage loss factor during discharge.

ALPHL - Storage loss factor.

C1, C2, C3 - Quadratic coefficients for storage loss functions during charge.

D1, D2, D3 - Quadratic coefficients for storage loss functions during discharge.

LS - Storage flag. 1 = Non-thermocline, 2 = thermocline.

5.3 Insolation and Weather Data

The current form of INPUT2 requires that a binary file be furnished containing the following information. The first record should contain the year and station description (up to forty hollerith characters).

Subsequent records are identical in structure and should contain the following information.

Direct Normal Insolation - watts per meter squared.

Wind Direction - degrees from due north, clockwise.

Wind Speed - meters per second.

Dew Point Temperature - degrees Fahrenheit.

Station Pressure - inches of Hg.

Dry Bulb Temperature - degrees Fahrenheit.

There must be at least (24/DELT*NDAL) such records.

6.0 Output

6.1 LUN 6

A binary file of records, one being created for each DELT period of the run, which can be used for plotting and/or other analysis. Each record contains the following information.

TIM - Time of day (hours).

PTF - Power to the collector field - direct normal insolation times field size (MW).

PTR - Power to the receiver (MW).

PTWF - Power output from receiver (MW).

PWF - Power available to EPGS and/or storage (MW).

PTT - Power to the turbine (MW).

GPFT - Gross electrical power from turbine (MW).

PFT - Net electrical power from turbine (MW).

PTS - Power to storage (MW).

ES - Energy in storage (MWH).

PFS - Power from storage (MW).

6.2 LUN 7

A binary file is created at the end of the run which serves as input to BUCKS(2). It is a single record containing the following information.

YPFT - Yearly energy from turbine (MWH).

FS - Collector field size (square meters).

RS - Receiver size - maximum thermal input (MW).

GCOP74 - Gross maximum electrical output of EPGS at seventy-four degrees (wet bulb temperature, F) (MW).

YAPFN - Yearly electrical auxiliary power drawn from net (MWH).

PTSMAX - Maximum storage charge rate (MW).

PFSMAX - Maximum storage discharge rate (MW).

EMAX - Maximum storage capacity (MWH).

NHPY - Number of hours in year.

YIES - Yearly integral of energy in storage.

6.3 Printed Output

There are six levels of output detail available which are defined by MFLAG, commence on day, NDAF, and continue to the end of the run. The level designator is inclusive, i.e., MFLAG activates all levels of printing numerically less than and equal to the value of MFLAG.

6.3.1 MFLAG = 0

The following information is printed as a yearly summary.

Auxiliary energy furnished collector field.

Auxiliary energy furnished receiver.

Auxiliary energy furnished turbine.

Auxiliary energy furnished storage.

Energy to collector field.

Energy to receiver.

Energy to working fluid.

Energy in working fluid.

Energy to turbine from receiver.

Energy to storage.

Energy to turbine from storage.

Integral of energy in storage.

Surplus energy to receiver.

Surplus energy to storage.

Excess charge rate to storage.

Receiver minimum flow losses.

Turbine minimum flow losses.

Storage minimum flow losses.

Gross electrical power from turbine.

Net electrical power from turbine.

Auxiliary energy purchases from net.

6.3.2 MFLAG = 1

Daily summaries of the information listed above are also printed.

6.3.3 MFLAG = 2

A twenty-three column table is printed with a line of information for each DELT period. The first sixteen columns contain the following information.

TIME - Time of day (hours).

PTWF - Power in working fluid from receiver (MW).

PWF - Power available to EPGS and/or storage (MW).

PTS - Power to storage (MW).

PFS - Power from storage (MW).

PFT - Electrical power from turbine (MW).

AXCE - Auxiliary power requirements of collector field. (If value is positive, units are KWH and power is drawn from external network. If value is negative, units are MWH and power is drawn from turbine output. Criteria is the same for next four entries.)

AXRE - Auxiliary power requirements for receiver.

AXTE - Auxiliary power requirements for turbine.

AXSE - Auxiliary power requirements for storage.

AXPT - Total auxiliary power requirements.

ES - Energy in storage (MWH).

SUPTS - Surplus energy to storage (MW).

UPFS - Unavailable power from storage (MW).

XES - A temporary value for ES - used if storage can not meet the demands of the EPGS systems.

XPFS - A temporary value for PFS - used if storage can not meet the demands of the EPGS system.

The last seven columns of integers are status flags where a one represents true; a zero means the condition is not true.

IBSR - Receiver is on standby.

ISBT - Turbine is on standby.

ISUT - Turbine is in startup from receiver.

ISUS - Turbine is in startup from storage.

IOFR - Turbine is in operation from receiver.

IOFS - Turbine is in operation from storage.

IOFRPS - Turbine is in operation from both receiver and storage.

Also, additional entries are made whenever storage can not meet the demands of the EPGS system.

6.3.4 MFLAG = 3

Two additional categories of entries will be added to the above table. If power losses occur due to minimum flow constraints, they will be listed. Also the times for TR1, TR2, TR2A, TR3, T3, and T4 will be printed.

TR1 - Time of receiver startup.

TR2 - Time that working fluid begins spinning turbine.

TR2A - Time that turbine starts ramp from derated to rated mode.

TR3 - Time that working fluid from receiver reaches rated temperature and pressure.

T3 - Time that turbine picks up load.

T4 - Time that EPGS goes to rated operation.

6.3.5 MFLAG = 4

The time of day, collector field efficiency and power to receiver will be printed in a condensed tabular form.

6.3.6 MFLAG = 5

The entire input generated by INPUT2 is listed. The data consists of the time of day, the suns declination, azimuth and elevation, the direct normal insolation, the wind direction and speed, the dry bulb temperature, the dew point temperature, the station pressure, and the wet bulb temperature.

Appendix A Correlation of Mathematical Symbols and FORTRAN Variable Names

This appendix presents the FORTRAN variable names corresponding to the mathematical symbols used in Section 3. The variable definitions are repeated here for convenience.

A.1 Collector Field - Receiver Interface

$P_{tr}(t)$: PTR: thermal power into/onto the receiver at time t (MW)

$F(\Theta_a, \Theta_e)$: RFLCTY*F: design point field efficiency as a function of sun azimuth and elevation

$\Theta_a(t)$: AZ: sun azimuth at time t (degrees)

$\Theta_e(t)$: EL: sun elevation at time t (degrees)

$G(W)$: EFWS: effect of wind speed on field performance

$W(t)$: WS: wind speed at time t (m/s)

S_f: FS: field size (number of square meters of reflective surface)

$I_{dn}(t)$: DNI*10^{-6}: direct normal insolation at time t (MW/m^2)

ℓ: LAT: latitude of solar plant

$h(t)$: HA: hour angle at time t (zero at solar noon)

$d(t)$:	DEC:	solar declination at time t

A.2 Receiver

$P_{wf}(t)$:	PTWF:	thermal power transferred to the working fluid at time t (MW)
$P_{tr}(t)$:	PTR:	thermal power into/onto the receiver from collector field at time t (MW)
R_s:	RS:	receiver size (MW)
$X(t)$:	XT:	receiver state parameter at time t
T_{cs}:	TCS:	time required for a cold start (hours)
L_r:	XLR:	receiver subtractive loss parameter
ε_r:	EPS:	receiver proportional efficiency
H_r:	XHR:	receiver start-up thermal capacity parameter
α_r:	ALPHA:	receiver cool down parameter (hours^{-1})
t_1:	TR1:	time receiver start-up begins
t_2:	TR2:	time receiver reaches derated conditions and receiver power may be used to initiate turbine start-up
t_{2a}:	TR2A:	time power to receiver exceeds rated/derated threshold
t_3:	TR3:	time receiver start-up is complete

X_D:	XTD:	X(t) value during derated operation

A.3 Piping

$P_{ft}(t)$:	PWF:	thermal power from the tower at time t (MW)
$P_{wf}(t)$:	PTWF:	thermal power transferred to the working fluid at time t (MW)
X(t):	XT:	receiver state parameter at time t
L_p:	XLP:	piping subtractive loss parameter
R_s:	RS:	receiver size (MW)

A.4 Thermal Storage

$E_s(t)$:	ES:	energy in storage at time t (MWH)
$P_{ts}(t)$:	PTS:	storage charge rate at time t (MW)
$P_{fs}(t)$:	PFS:	storage discharge rate at time t (MW)
α_L:	ALPHL:	storage holding efficiency
c_0, c_1, c_2:	C1, C2, C3:	storage charging efficiency parameters
d_0, d_1, d_2:	D1, D2, D3:	storage discharging efficiency parameters
α_c:	ALC, ALPHC:	storage charging efficiency
α_d:	ALD, ALPHD:	storage discharging efficiency
$P_{sa}(t)$:	AXSE:	auxiliary electric power required by the storage subsystem at time t (MW)

$P_{ts}(t)$:	PTS:	power to storage at time t (MW)
$P_{fs}(t)$:	PFS:	power from storage at time t (MW)
P_{tsm}:	PTSM:	maximum power to storage (MW)
P_{fsm}:	PFSM:	maximum power from storage (MW)
P_{ss}:	TURBSS:	turbine sealing steam thermal power requirements (MW)
I_{sbt}:	ISBT:	control variable (1 if turbine on standby, 0 otherwise)
X:	XLL:	ratio of heat exchanger standby thermal requirements to the maximum heat transfer capability of the heat exchanger
A, B:	A, B:	ratio of auxiliary electric pumping power requirements to the heat transferred (MW_e/MW_{th})

A.5 Electric Power Generation System

$T_{ave}(t_{sb})$:	TAVE:	average turbine shell temperature (°F)
t_{sb}:	TTSB:	length of time turbine has been on stand-by (hours)
τ:	TAU:	turbine shell temperature initialization parameter (hours)
α, β:	ALPHA, BETA:	shell temperature decay parameters ($hours^{-1}$)
$P_e(t)$:	PFT:	gross electric power produced by EPGS at time t (MW)
$P_{tt}(t)$:	PTT:	thermal power from the turbine from receiver at time t (MW_{th})

$\varepsilon_r\ (T_{wb}, X)$: EPSR: gross EPGS conversion efficiency from receiver power at wet bulb temperature T_{wb} and mass flow fraction X.

$\varepsilon_s\ (T_{wb}, X)$: EPSS: gross EPGS conversion efficiency from storage power at wet bulb temperature T_{wb} and mass flow fraction X.

$T_{wb}(t)$: WBT: wet bulb temperature at time t (°F)

$X(t)$: FMF: mass flow fraction at time t

$P_{ta}(t)$: AXTE: auxiliary electric power required by the EPGS at time t (MW)

P_{tsb}: AUXP: constant standby power requirements (MW)

α_r, α_s: ALPHR, ALPHS: scale factors (MW_e/MW_{th})

Appendix B Program Logical Unit Assignments

LUN 2 - A binary file of insolation and weather data read in INPUT2.

LUN 5 - Input Card.

LUN 6 - Output of detailed data for plotting and/or analysis.

LUN 7 - Output for use in BUCKS (2).

LUN 8 - NAMELIST input file.

Appendix C External Library Routines

Documentation is self contained in the FORTRAN versions of the library routines that are included with this program package and this documentation should suffice. However, the basic library documentary references are also provided.

C.1 International Mathematical and Statistics Library (IMSL)

The following FORTRAN versions of IMSL routines are proprietary and are included in this code through the courtesy of IMSL with the understanding that they will not be extracted from the code. Documentation is in IMSL Library, Edition 6, 1977, Volume I.

IBCICU

IBCEVU

IBCIEU

ICSEVU

ICSICU

UERTST

C.2 Sandia Mathematical Library

The following FORTRAN versions of Sandia Mathematical Library routines are included in this code. Documentation is available from Sandia Livermore Laboratories. It is User's Guide to the Sandia Mathematical Program Library at Livermore, SAND77-8274, October, 1977.

SPLIFT

SPLINT

Appendix D Sample Problem Description and Input

D.1 Sample Problem Discussion

To illustrate STEAEC output and provide a reference check on program operation, the output from three sample runs has been included with this report on microfiche. The plant model used for these runs is representative of a 100 MW central receiver solar thermal electric power plant with a solar multiple of 1.67 and six hours of storage. Each run consists of ten days using hypothetical insolation and weather data. The runs illustrate receivers with and without a derated operating mode, turbine and storage priority dispatching strategies and storage sytems with and without packed bed units. Table D.2 summarizes the options selected for each run.

D.2 Summary of Run Options

Run No.	Derated Receiver Mode	Dispatch Strategy	Packed Bed Storage
1	Yes	Turbine Priority	Yes
2	No	Turbine Priority	No
3	Yes	Storage Priority	Yes

D.3 Insolation and Weather Data Input

Ten days of data is appended to the program source tape as file two. For transmittal purposes, the data file was converted from binary to BCD. Format of the first record is (27X, I5, 4A10). Format of all subsequent records is (6F12.6). INPUT2 requires a binary file so reconversion will be necessary.

D.4 Card Input

Run No.	MFLAG	NDAF	NDAL
1	5	1	10
2	3	1	10
3	3	6	10

D.5 NAMELIST Input

D.5.1 Run One

```
$CONCOEF
$END
$CONCOLF
$END
$CONRCVR
$END
$CONPIPE
$END
$CONTRBN
$END
$CONSTRG
$END
```

D.5.2 Run Two

The NAMELIST file is the same as D.5.1 except as follows.

```
$CONRCVR
MODPO = 1,
$END
$CONSTRG
```

```
LS = 1,

$END
```

D.5.3 Run Three

The NAMELIST file is the same as D.5.1 except as follows.

```
$CONTRBN

MOPMF = 2,

$END
```

References

1. P. Leary and J. D. Hankins, User's Guide for MIRVAL - A Computer Code For Comparing Designs Of Heliostat - Receiver Optics For Central Receiver Solar Power Plants, Sandia Laboratories. SAND77-8280.

2. J. M. Brune, BUCKS -- Economic Analysis Model For Solar Electric Power Plants, Sandia Laboratories. SAND77-8279.

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