65392

CONTRACTOR REPORT

C. 3

SAND86–8188
Unlimited Release
UC–62a

10 MWe Solar Thermal Central Receiver Pilot Plant Control System Automation Test Report

McDonnell Douglas Astronautics Company
5301 Bolsa Avenue
Huntington Beach, CA 92647

Prepared by Sandia National Laboratories, Albuquerque, New Mexico 87185
and Livermore California 94550 for the United States Department of Energy
under Contract DE-AC04-76DP00789.

Printed April 1987

Printed in the United States of America
Available from
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A05
Microfiche copy: A01

UC-62a

SAND86-8188
Unlimited Release
Printed April 1987

10 MWe SOLAR THERMAL
CENTRAL RECEIVER PILOT PLANT
CONTROL SYSTEM AUTOMATION
TEST REPORT

Contract Report Prepared
Under SNLL Contract 84-8173

McDonnell Douglas Astronautics Company

ABSTRACT

This report describes results of tests on the automatic features added to the control system for the 10 MWe Solar Thermal Central Receiver Pilot Plant located near Barstow, Ca. The plant, called Solar One, is a cooperative activity between the Department of Energy and the Associates: Southern California Edison, the Los Angeles Dept. of Water and Power and the California Energy Commission. This report provides an overview of the automation features added to the plant control system, a description of tests performed on the system, and the results of those tests.

SOLAR THERMAL TECHNOLOGY
FOREWORD

The research described in this report was conducted within the U.S. Department of Energy's Solar Thermal Technology Program. This program directs efforts to incorporate technically proven and economically competitive solar thermal options into our nation's energy supply. These efforts are carried out through a network of national laboratories that work with industry.

In a solar thermal system, mirrors or lenses focus sunlight onto a receiver where a working fluid absorbs the solar energy as heat. The system then converts the energy into electricity or uses it as process heat. There are two kinds of solar thermal systems: central receiver systems and distributed receiver systems. A central receiver system uses a field of heliostats (two-axis tracking mirrors) to focus the sun's radiant energy onto a receiver mounted on a tower. A distributed receiver system uses three types of optical arrangements--parabolic troughs, parabolic dishes, and hemispherical bowls--to focus sunlight onto either a line or point receiver. Distributed receivers may either stand alone or be grouped.

This report describes results of tests on the automatic features added to the control system for the 10 MWe Solar Thermal Central Receiver Pilot Plant (Solar One). This is part of the continuing evaluation of the pilot plant for the Solar Thermal Technology Program.

CONTENTS

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

A/M	Auto/manual station
CCM	Communication control module
CO	Control output
CRT	Cathode ray tube
CSM	Configuration storage module
DAS	Data acquisition system
DMA	Direct memory access
EH	Electro-hydraulic
EPGS	Electrical power generation subsystem
GN_2	Gaseous nitrogen
HAC	Heliostat array controller
HC	Heliostat controller
HFC	Heliostat field controller
MVCU	Multi variable control unit
NIP	Normal incident pyrheliometer
OCS	Operational control system
OSP	Operator station processor
PV	Process variable
RS	Receiver subsystem
SDPC	System distributed process control
TSS	Thermal storage subsystem

Section 1

INTRODUCTION AND SUMMARY

The goals of the plant automation effort were to increase the overall Solar One operating efficiency and to develop an automated plant capable of performing a clear day scenario and of being controlled from a single operator console. The automation effort concentrated on two main areas of achieving these goals. The first was to improve the plant output performance and the second was to improve the effectiveness of the operator in running the plant. The results of the control system evaluation can be found in Reference 9.

Improvement of plant output performance included reducing the time required to start up the plant and achieve net positive output power, increasing the maximum output power levels, extending daily operating time, reducing the parasitic loads and effectively managing the available energy resources from the receiver subsystem (RS), thermal storage subsystem (TSS), and auxiliary systems. Improvement of operator effectiveness included providing the operator with enhanced displays for operating the plant, providing direct measures of plant efficiency so the operator can effectively manage energy resources, reducing the operator interaction required for routine tasks and providing a simple, effective man-machine interface between the operator and the plant.

Figure 1-1 shows the overall architecture of the control/monitor system used at Solar One. The Subsystem Distributed Process Control (SDPC) equipment provides independent centralized control of the Receiver Subsystem (RS), the Thermal Storage Subsystem (TSS) and the Electrical Power Generation Subsystem (EPGS). Three display/control terminals provide the operator interface for the

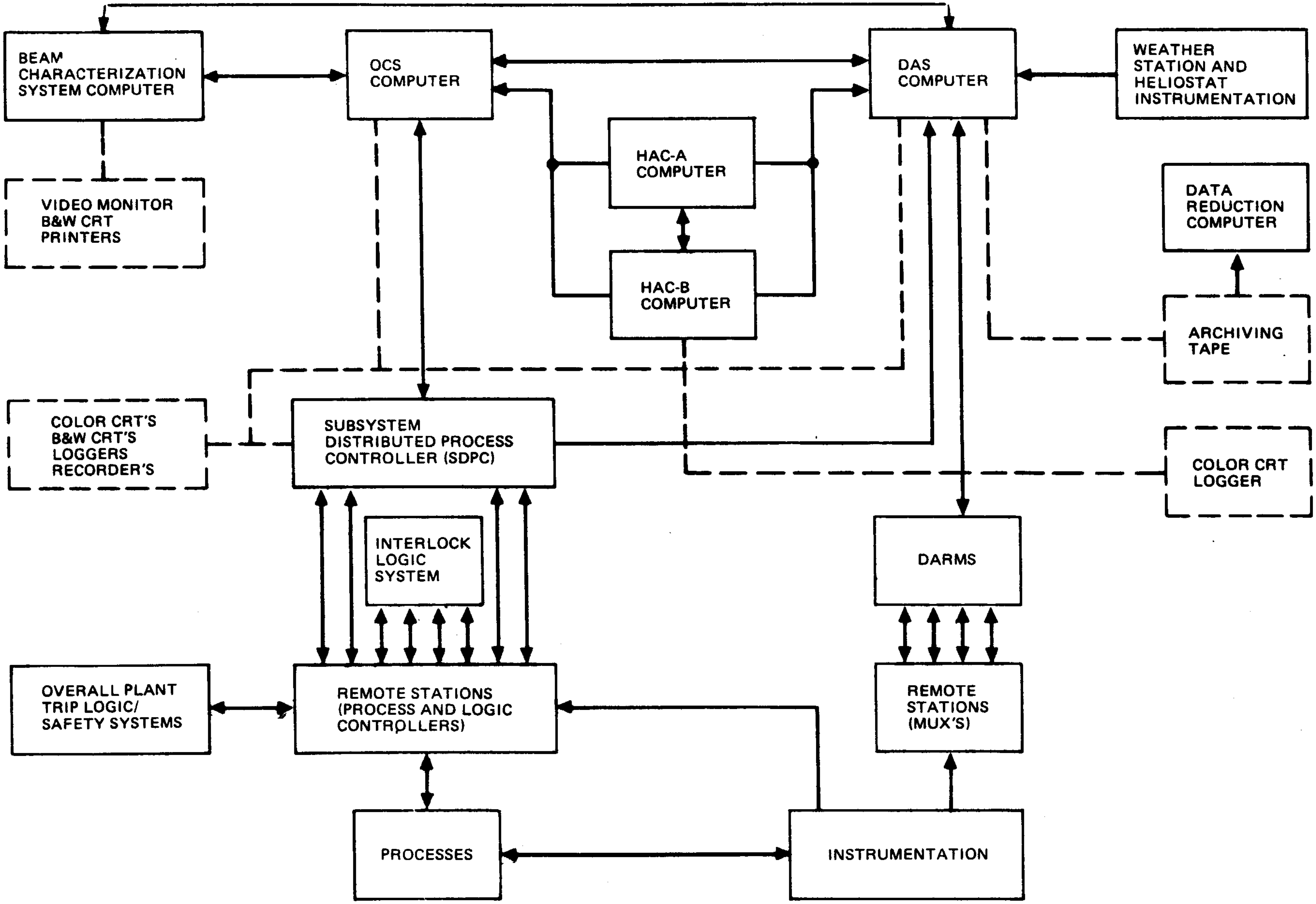

Figure 1-1. Solar One Control/Monitor Architecture

three subsystems. The SDPC system consists of functionally and physically distributed monitoring and control devices that provide manual control capability and access for automatic computer control. The Heliostat Array Controller (HAC) system provides redundant computers for control of the Collector Subsystem (CS). The collector control system is also a distributed control system with central computer control of the heliostat controllers on each heliostat and keyboard/display equipment located in the master control console. The Interlock Logic System (ILS) provides the independent interlock logic and plant permissives required to safely operate the plant. The ILS program logic control computer will verify equipment status prior to executing a command and will provide shutdown of equipment in the event established permissives are not satisfied. The Operational Control System (OCS) is the control element of the Master Control System (MCS) which provides for automated monitoring and supervision of the integrated plant subsystems during various operating modes. Plant operating commands can be initiated either by the operator or directly from plant operating software via the OCS computer interfaces to the SDPC and HAC systems. The Data Acquisition System (DAS) provides the data gathering function for Solar One.

The plant automation capability was implemented in both the SDPC and OCS. Within SDPC, hardware and software (data base) modifications were made to include the capabilities to automatically execute selected operational sequences, change control modes at the control loop level, respond to trips and disturbances, etc. A discussion of SDPC automation implementation and testing except as required to support OCS testing is beyond the scope of this report and is documented in References 2 and 8. The plant automation capabilities included in the OCS are summarized in Table 1-1. A description is given of the functional capability for each of the major automation categories implemented in OCS. Also listed are the major benefits provided by the automation over manual operation.

The balance of this report identifies and describes the tests performed with the plant automation hardware and software. Sections 2 through 7 describe the tests conducted in each of the six major automation functional areas and presents an assessment of the results and a discussion of the modifications made to correct problems. The principal test results are summarized in Table 1-2.

Table 1-1. Plant Automation Summary

Category	Description	Major Benefits
Automatic Collector Field Control	o Provides the capability to automatically regulate the collector field to achieve either startup full power, an intermediate power condition, a hot standby condition, or defocus of entire field (Section 2.0)	o Decreases the RS startup time compared to manual operation. o Maintains RS flowrate within flash tank limit during startup. o Limits incremental power increases to minimize system disturbances. o Rapidly transition back to acceptable flash tank operating power conditions in order to keep receiver on-line during disturbances. o Reduces the time and operator commands to achieve the desired power condition thereby improving output of performance.
SDPC Configuration Upload and Download	o Provides the capability to maintain the SDPC data base (Section 5.2)	o Able to store current configuration for future reference or download. o Able to quickly verify the data base in case configurations are in question. o If data base gets "scrambled" for some reason, able to quickly download data base and resume operation. o Keep track of data base changes over periods of time.

Table 1-1. Plant Automation Summary (Continued)

Category	Description	Major Benefits
Supervisory Control	o Provides the operator with the capability to automatically control and sequence the plant as desired for any one day with minimal real-time interaction by operator (Section 6.0) o There are three levels of automation and control: clear day scenario, mode transitions, and SDPC basic subsystem (Section 6.4)	o Decreases startup time of each system and plant compared to manual operation o Improves the maximum operating performance of each system and plant o Improves the net on-line operating time for each system and plant o Reduces operator interaction with the plant o Reduces operator workload. o Provides a uniform and consistent approach to plant operations.
Automatic Collector Aimpoint Control	o Provides the capability to control aimpoints in one of three modes: manual, semi-automatic, and automatic (Section 3.0)	o Establishes required aimpoint set according to time of year and day. o Three modes of operation for flexibility. o Assures proper aimpoint set such that RS performance is maintained.
Plant Surveillance Functions	o Provides the operator with information regarding the current state of plant operation and operating efficiency in the form of alarm summaries, trends, operating status displays, and performance related displays (Section 4.0)	o Provides operator visibility into all plant operations via one console o Increases operator awareness of plant operating condition. o Provides visibility of automatic sequences in terms of major steps and which step is currently in progress

Table 1-1. Plant Automation Summary (Continued)

Category	Description	Major Benefits
Plant Surveillance Functions (Continued)		o Provides high resolution trending of historical data o Provides subsystem and overall plant efficiency measures which provide operator insight into ways of increasing efficiency o Alarm summary consisting of all plant alarms which are color coded according to subsystem o Allows operator to monitor and control the plant from an energy management and efficiency standpoint
Man-Machine Interface (MMI)	o Provides the capability for the operator to monitor and control from one console all systems critical to overall plant operations (Section 7.0) o Provides the capability for the oprator to control the plant using OCS displays and application programs (supervisory control) (Section 6.4)	o Increase of display capability and display response time o Operator access to all plant controls, alarms, and data via one console

Table 1-2. Plant Automation Implementation Problems and Corrective Measures

Category	Problem	Corrective Measures
Automatic Collector Field Control	o Difficulty regulating total receiver flowrate to desired value of 35KLBH during startup (Section 2.2.1)	o Implemented control algorithm in startup task, CFUP, to adjust power on receiver panels based on total flowrate error
	o Inability to attain temperature control on some boiler panels during startup due to removing heliostats in some wedges from the receiver as insolation increases (Section 2.2.1)	o CFUP modified to not allow decrease commands to dominant wedge affecting receiver panel if panel not in temperature control mode
Plant Surveillance Functions	o Sequence of events logic and changing of graphics attributes using arithmatic/logical functions (which were programmable through the OCS console) used CPU and task control block resources aggravating an OCS computer overload problem (Section 4.0)	o Sequence of events logic "hard coded" into applications task instead of using arithmetic/logical function capability. Attribute changes for plant graphics limited in use
SDPC Configuration Data Base Operations	o Downloading configuration data from OCS disk file to the MV 8000 "wipes out" directory preventing writing onto MV 8000 floppy disk. (Problem is in MV 8000 System) (Section 5.0	o Necessary to remove floppy disks from MV 8000 when downloading from OCS
Supervisory Control	o Application programs were initially designed to execute their tasks from beginning to end which caused restrictive use by an operator (Section 6.0)	o Implemented capability to begin control execution at proper step within the sequence of control and perform status checks of each step prior to its execution.

Table 1-2. Plant Automation Test Results (Continued)

Category	Description	Major Benefits
Supervisory Control (Continued)	o Limitations of the OCS computer's machine resources were reached (Section 6.2)	o Three items were implemented: - Time spacing which temporarily alleviates machine resource usage . - Minimized SDPC data required for decisions and control which minimized input data transfer time - Limited number of programs executing simultaneously to three
	o Inadequate automatic abort structure which caused the operator spend precious time aborting each porgram instead of taking care of the problem (Section 6.2)	o Implemented a bottom-up automatic abort structure. When the operator aborts a program, only those programs which depend upon the completion of the aborted program are in turn aborted
	o Inadequate information was displayed to the operator concerning the current step a particular program was executing as well as a list of all the steps to be taken (Section 6.2)	o Sequence-of-events graphics pages were generated to provide the information
Man-Machine Interface	o Update rate of a graphics display was in the range of seven to ten seconds which was inadequate for effective operator interaction with the plant (Section 7.2.2)	o Replaced RS232C link with a display processor which used direct memory access. Update rate was reduced to two-four seconds
	o Limitations of the OCS computer's machine resources were reached (Section 6.2)	o Some MMI programs were subdivided, such that one subtask was integrated into another program while a new program was created for another subtask

Section 2

AUTOMATIC COLLECTOR FIELD CONTROL THROUGH THE OCS

The Collector Field Control requirements for OCS were originally released in April 1983 and were subsequently updated in June 1983. The Test Plan Outline for testing of the OCS Collector Field Control Software was documented and released in July 1983 (Reference 1). Testing of the OCS software at the site was initiated in late July 1983.

The Collector Subsystem (CS) control equipment and software are described in Reference 2. The system is a distributed computer control system with two redundant central computers (Heliostat Array Controllers (HAC)) for overall control. The HAC software processes operator commands, communicates with the Heliostat Controller (HC) through the Heliostat Field Controllers (HFC), displays status of the field, commands the field and provides a printout of alarm and status messages.

The HAC computes the sun position and transmits it to all heliostats once per second. Status is received from each heliostat once every eight seconds and displayed on the color CRT terminal showing status. Changes in status and alarms are printed on the Message/Alarm logger in the control room. The status can be viewed for an individual heliostat, a ring or segment or the entire field.

The OCS can command the collector field through the HAC by activating HAC command files on specific heliostat increase/decrease commands. It requests HAC status periodically to maintain a data base of the collector field status for use by a various applications programs. For automation, separate tasks were generated to support the four phase of OCS/CS operation: startup, intermediate power, full power, and hot standby. There are only two modes of CS operation: Manual or OCS automatic.

2.1 COLLECTOR FIELD CONTROL TESTS

The test plan for Collector Field Control checkout required testing in four steps which are summarized below:

1. Stand Alone Testing of Collector Field Control in OCS at the Solar One Site. The purpose of this test was to check out the OCS software without affecting any other systems. The links with SDPC and the HAC were not connected, and all required OCS input data were artificially loaded. Representative data for the four phases (startup, intermediate power, full power, and hot standby) were entered and the OCS outputs were compared to the off-line digital simulation program results.

2. HAC Command File Startup with OCS Linked to SDPC. The purpose of this test was to check the SDPC/OCS interface under actual startup conditions. A HAC command file, which was generated off-line by the OCS program and contained wedge commands in incremental steps, was used to command the collector field. The resultant SDPC outputs for total RS flowrate, RS water inlet temperature, RS outlet pressure, and status of receiver panel controllers in temperature control (TSP flag=1) were used by OCS to generate new HAC commands. These commands were not passed on to the HAC but were checked for correctness by comparison of an off-line digital program used to compute the new HAC commands using the same SDPC outputs.

3. Night Testing of Collector Field with Simulated HAC Responses and Representative SDPC Inputs. The purpose of this test was to checkout the OCS/HAC interface. Representative SDPC data (RS flowrate, inlet temperature, outlet temperature and temperature controller status) were entered into the OCS and the OCS generated commands which were transmitted to the HAC to control the collector field. The resulting HAC commands sent to the field were as pre- dicted by the off-line digital program thus proving proper operation of this interface.

4. Testing of OCS with SDPC and HAC Links Under Actual Plant Operating Conditions. The purpose of these tests was to exercise the full operational capability of the OCS Collector Field Control software. The OCS was linked to both the SDPC and HAC and exercised under actual operating conditions. The following types of tests were conducted:

A. Late startups (clear day) - from one hour after sunrise to late after- noon.

B. Early morning (sunrise) startups (clear day).

C. Transitions from startup power conditions to intermediate power levels ranging from 50K LBH to 90K LBH total flow rates.

D. Transitions from intermediate power to full power for all conditions in 4(c).

E. Transitions from a collector field full power condition to a hot standby power condition during midmorning, solar noon, and late afternoon.

In addition to these planned tests, the OCS Collector Field Control software was regularly tested under a variety of other operating conditions which normally occurred during plant operations.

2.2 TEST RESULTS

During testing and development of the OCS Collector Field Control software, numerous changes were made to either correct problems, improve performance, and/or reduce operator interaction with control of the collector field. The major software changes, the reasons for the changes, and the OCS tasks affected are discussed below.

2.2.1 Startup Test Results

The startup phase of the automated collector field control mode is implemented in the OCS task CFUP. This phase is the most critical and consequently the most complex of the four phases implemented. Power must be sequenced onto the receiver with the proper magnitude and rate to assure that each of the boiler panels achieves temperature control without the total flow rate exceeding the receiver flash tank flow limit (40K-44K LBH). Sequencing of power is done in an "open loop" fashion in which the power required to achieve a desired flow rate is computed using models of the system components: the field effectiveness, receiver absorptivity, heat losses, etc. During testing, initial errors in these models resulted in total startup flow rates which were too low or too high depending on the time of day, time of year, the cleanliness of the heliostats, etc. When the total flow rate was too low, problems with low subcool temperatures at the preheater panels outlet occurred. If high total flow rates (above 40K LBH) occurred while the startup task was being executed, the CFUP task would determine if the number of heliostats in track was being reduced. If a reduction was being processed, normal operation would continue. If the reduction was zero or an increase was being processed, the CFUP task would abort. Aborting was necessary so that collector field control could be returned to the operator.

A control scheme was implemented for the startup task (CFUP) to provide a means of maintaining a nominal total flow rate of 35K LBH. The amount of power on each boiler panel is adjusted during each execution of CFUP by multiplying the present power on a panel by a scale factor. The scale factor is equal to the desired flow rate of 35K LBH divided by the actual flow rate. The scale factor is computed only when the total flow rate is outside a % 3K LBH deadband (i.e. above 38K LBH or below 32K LBH). Thus, if the total actual flow rate is 40K LBH, the scale factor would be 35K LBH/40K LBH or 0.875. This would result in a reduction in power on the panels by removing heliostats from tracking the receiver. A flow rate of 30K LBH would be a 1.167 scale factor and result in a power increase by the addition of heliostats. In addition, the capability to change the value of the heliostat reflectivity, in terms of percent clean, was provided through the OCS console so that a better match between the model and the actual field conditions could be obtained.

Another problem was encountered early in the test program in which power was allowed to be reduced on individual boiler panels that had not reached the temperature control mode threshold temperature of 600°F. A change was implemented in the CFUP task to examine the auto/manual status of the panel temperature controllers in the SDPC. If the panel temperature controller was still in manual, i.e., the panel was not in the temperature control mode, decrease commands to the HAC for the dominant wedge affecting the panel were not allowed by CFUP. This change allowed power to continually increase on an individual panel as the insolation increased during startup to eventually achieve temperature control of the panel.

The total flow rate algorithm now also provides the capability to adjust power on the receiver when the temperature setpoint is ramped from 600°F to 775°. This occurs after all panels have their temperature controllers in AUTO (temperature control). These changes and subsequent refinements have resulted in much better control of the total flow rate during startup and have eliminated the problems discussed previously.

2.2.2 Intermediate Power Test Results

The Intermediate Power OCS task, INTPWR, increases the power from the startup power level in steps by the ratio of the desired intermediate power total flow rate (50K, 60K, 70K, 80K, or 90K LBH) to the actual total flow rate. During initial testing of this phase, it was found that it was not possible to put all available heliostats in track regardless of the flow rate requested. This problem was caused by scaling power up in the task on a wedge by wedge basis. When the desired power exceeded the capability of wedge, it was not redistributed to a wedge with available heliostats. Changes were made to the "INTPWR" task to obtain the additional power required from wedges with heliostats available. This modification allowed the entire field to be put in track when the requested total flow rate equalled or exceeded the total flow rate capability for the current power level.

2.2.3 Full Power Test Results

The OCS task FULPWR increases the number of heliostats in track by 25% until all heliostats are in track if the system pressure is at least 1100 psia. This pressure limit is to insure that the steam dump valve or turbine main steam valve has the capability to handle the maximum flow achievable with the full field in track. This pressure limit was originally set to 1350 psia but was found to be overly conservative and was reduced. No problems were found during testing of the full power collector field control phase.

2.2.4 Hot Standby Test Results

The purpose of the Hot Standby phase is to modulate the collector field to a receiver power level compatible with flash tank operating conditions (flow < 40K LBH, pressure Ç 500 psia) such that flow can be diverted from the steam downcomer due to cloud transients, plant equipment problems, etc. The HOTSTA OCS task is designed to distribute power among receiver panels to achieve a desired flow rate on each boiler panel. The summation of the desired boiler panel flow rates equals 35K LBH. The power distribution is calculated based on nominal rather than actual insolation to prevent the field from responding to clouds.

Initial tests of the HOTSTA task resulted in total flow rates achieved which were consistently below 35K LBH. When the known sources of error were accounted for, e.g., actual output of the Normal Incidence Pyrheliometer (NIP) less than the nominal insolation and the test outlet temperature and pressure different than assumed in the task, the adjusted flow was still 10 to 15% low. This error was subsequently found to be the result of power limiting on one side of the receiver caused by operating in the early morning or late afternoon and as a result of a mismatch between the actual field effectiveness and the OCS model value. Subsequent testing without power limiting, with the percent clean adjusted to match the field and with all known errors accounted for, resulted in total flow rates much closer to the desired value of 35K LBH and acceptable operation of the hot standby task.

Section 3

AUTOMATIC AIMPOINT CONTROL THROUGH THE OCS

The OCS aimpoint control task determines where each heliostat aims on the receiver, when in track, by commanding the HAC to execute various aimpoint files which have been established as a function of time of day and time of year. Three modes of operation for aimpoint control are available: manual, semi-automatic and automatic. In the manual mode, the operator sends change commands to the HAC without any prompts or messages from the software. In the semi-automatic mode, messages are printed when aimpoint changes are required, but the aimpoint change commands are not sent unless operator permission is granted. In the controlled automatic modes, messages are printed out when aimpoint changes are required. The aimpoint commands will be sent unless they are inhibited by the operator.

Testing of the aimpoint control task was done on a non-interface basis when the plant was in operation. The following paragraphs describe the test activity. No major functional problems were encountered.

The data base files for this task were checked to verify proper installations in the HAC and OCS. In the OCS this included the data base for manual, semi-automatic and automatic operations. Proper operation of the aimpoint control functions were verified by operating in each mode. First, the transition between modes was tested by starting in manual (M), switching to semi-automatic (S), then to automatic (C), etc. The test mode sequence was M→S→C→M→C→S→M. Proper operation was observed in all cases by the aimpoint status display on the OCS control console CRT.

The manual mode was tested by assigning an aimpoint command through the OCS console and observing printout of the command and HAC response on the OCS mes- sage printer. A test aimpoint was entered in error also and the proper error message and HAC error response was again printed on the OCS message printer.

With the OCS switched to the semi-automatic mode, the time for aimpoint change was set up to accommodate the test. At the proper time the OCS displayed a request for an aimpoint change on the CRT every 30 seconds. After proper operator response (GO), the OCS logged the commands and HAC responses correctly and the aimpoints were properly processed by the HAC. An operator response of "NO" was also tested and the OCS disconnected the aimpoint processing at that point.

When the OCS was switched to automatic mode, and the time for aimpoint change setup to accommodate the test, the following were verified. OCS display and logger notifies the operator two minutes prior to and every 30 seconds thereafter, that an aimpoint change is about to occur. First, the operator did not inhibit the change, and the OCS message printer logged the command and HAC response as they occurred. When the operator did inhibit the change the "Operator Inhibiting Aimpoint Change" message was printed and the HAC did not receive a command.

Several other tests were conducted to insure proper response in the automatic mode and when the plant was not ready for a change (e.g. plant in start-up). All tests showed proper commands, operation and responses.

Section 4

PLANT SURVEILLANCE FUNCTIONS

The original requirements for plant surveillance functions called for five major categories: Mode Status and Sequencing, Monitor and Alarm, Performance Calculations, Diagnostic Testing, and Report Generation. The purpose of the Mode Status and Sequencing function is to display to the operator the operating mode status of the plant or one of the system. If a startup, shutdown, or transition is occurring, the function displays the current sequence step. The Monitor and Alarm function displays monitored data on X-Y formats which may be either raw data or the result of a calculation. Alarm messages are displayed on the bottom of the OCS console (last two alarms) and on the alarm summary page (up to 252 alarms). Performance calculations are displays of the results of calculations or mathematical operations performed on monitored data. Diagnostic testing is to compare monitored data values against data base values and flagging only those which were outside a given tolerance. Report generation is to produce periodic and/or event driven hardcopy reports summarizing plant operation. The
requirements for each category were implemented and tested in the following order:

1. Monitor and Alarm
2. Mode Status and Sequencing
3. Performance Calculations
4. Diagnostic Testing & Report Generation

As the development of the OCS automation progressed, the limits of the computer resources were reached. There were too many tasks running at one time and those which did run took too much time to execute. On some occasions the OCS computer would halt due to the overloaded condition. Several modifications were made to avoid the "halt" problem and to improve performance. First, major OCS tasks which required a large amount of machine resources to execute were made "mutually exclusive" which meant that the major OCS tasks could not execute concurrently or that only one task could execute at any one time. The major tasks are listed as follows:

1. Application program tasks (OCS command files) for supervisory control
2. SDPC upload/download
3. Format generation
4. OCS data base generation

Second, the monitoring and sequencing requirements that were implemented were "hard-coded" like the performance calculations. (Originally they were programmable through the operations console to allow changes in sequencing or monitoring by the operator if desired).

4.1 MONITOR AND ALARM FUNCTION

The function of Monitor and Alarm was implemented and tested first because the function was a basic necessity for operator interaction with the plant. Also, some of the other functions required data from Monitor and/or Alarm for input to their calculations. The following paragraphs discuss the operating status displays and five special X-Y plots included in this function.

4.1.1 X-Y Plots

All of the specified X-Y plots were implemented per the requirements. These plots were:

1. Panel Gradients
2. Flux Distribution
3. Temperature Distribution
4. Receiver Panel Power
5. TSU Charge Status

Testing of these plots showed the data to be as expected; thus the plots are useful to SCE operations. The plots are made up of from 3 to 24 discrete data points in the X directions. An option, which could be added at a future date might be to include the use of curve-fit software on some of the plots to provide a more continuous curve.

4.1.2 Operating Status Displays

The OCS graphics display system has the capability to display up to 150 dynamic data points. The attributes of these points can be line data variables (i.e., pressure, temperature, etc.), control tags (i.e., change set points or control modes, auto/manual), or blink and/or change color of a symbol or area of the display based on various plant conditions. When a display is generated each data point is assigned the applicable attributes (live data, change color, etc.) until the display is complete or the 150 dynamic point maximum is reached.

As OCS automation testing progressed more and more OCS graphic displays were generated. It was observed that the line data and control attributes were more important, from an operator viewpoint, than the picture changing attributes (color, etc.). This is partly due to the ability of the OCS to display data from any plant system on one graphic page. The SDPC is limited to 32 dynamic points per display for only one plant system (RS, TSS, or EPGS). Therefore, while the SDPC displays continue to be used for interaction with the system equipment and process controllers for each system on initial startup or shutdown, the OCS displays are used for normal plant operation which includes interaction with supervisory control and automation in general.

4.2 MODE STATUS AND SEQUENCING FUNCTION

The mode status and sequencing function provides a direct display of the current plant and/or system operating mode. As described in paragraph 6.0, the supervisory control was designed using application program tasks (OCS command files) to provide the sequencing functions for the various mode transitions and/or clear day scenarios. To monitor these operations and display the status to the operator a graphic display was generated for each of the sequence-of-events. The live status data on each display was generated by "hard-coding" OCS discrete identifier (ID) tags into the command files which are set as each step of the sequence is executing. The display is setup so that each discrete tag, when on, "backlites" an area on the screen which is annotated to show the current step. This operation is further described in Reference 5.

4.3 PERFORMANCE CALCULATIONS

To obtain data on each system and overall plant performance, a set of calculations were developed to monitor operating efficiencies. The calculations were "hard-coded" in application programs which execute continually. The fol- lowing paragraphs briefly describe each of the calculations while the actual equations are shown in Reference 6:

1. The Collector Field performance calculates the incident power on the receiver as a function of the current insolation, collector field configuration and operating conditions.
2. The Receiver efficiency is the absorbed total power (enthalpy rise in the receiver times the mass flow rate) divided by the incident power calculated in item 1.
3. TS Charging efficiency is the increase in enthalpy of the oil divided by the decrease in enthalpy of the steam times the ratio of the oil to steam weight flow rates.
4. TS Extraction efficiency is the increase in enthalpy of the water/steam divided by the decrease in enthalpy of the oil times the ratio of the steam to oil weight flow rates.
5. Turbine efficiency is the sum of the gross heat rate due to main steam plus the gross heat rate from extraction steam.
6. Plant efficiency is the net power to the grid divided by the receiver total absorbed power plus the TS extraction total power output minus the TS Charging total power used.

A separate graphic display page was generated for the efficiency of each system and the overall plant. The equations required for the calculation of the efficiency are also shown on each display page.

4.4 DIAGNOSTIC TESTING AND REPORT GENERATION

The purpose of diagnostic testing was to provide the capability to compare monitored data values against a set of data base values and flag or alarm only those which were outside a given tolerance. This capability does exist within the OCS but was only implemented on the receiver panel lateral temperature gradient displays. If any panel which is instrumented to provide gradient data has a gradient higher than a tolerance value, an alarm will sound and that gradient will blink when the display is called up. All gradient calculations and the alarming functions are "hard-coded" in an OCS appliction program.

The report generation capability is available as part of the SGM RCS-7 software in the OCS. It can be programmed through the OCS operator consoles if desired. Due to manpower and schedule constraints MDAC did not develop any displays to utilize this function.

Section 5

SDPC CONFIGURATION DATA BASE OPERATIONS

The System Distributed Process Controller (SDPC) is the primary control system for Solar I. As shown in Figure 5-1 it consists of an operator console with a CRT and keyboard, a Configuration Control Module (CCM) and several Multivariable Control Units (MVCU) distributed among the various remote stations. There are three CCM's and a total of 21 MVCU's. The CCM's and MVCU's contain a data base which must be correct to assure proper plant operation. Normal operation results in the storage of these data bases on a floppy disk by the Configuration Storage Module (CSM).

Early in the test program it was observed that there was a need to have a simple method of comparing the large data base (3 CCM's, 21 MVCU's) with a known baseline. A program was developed on the DAS computer to compare the actual data base with a stored file of the desired data base. This program could only be run when the DAS was offline and was primarily used by MDAC engineering personnel. As the OCS automation testing progressed it became apparent that this program could be included in the OCS for use by SCE maintenance personnel. In addition, since the floppy disk storage was not too reliable, the program would be setup to upload the data base to a file for the baseline or download this baseline file to the CCM or MVCU if desired. Figure 5-1 shows the program software and the various peripheral equipment used to store, print or display the data base. Operation of this program is described in Reference 3. The following paragraphs include a description of the functional interfaces and the development and operational tests performed.

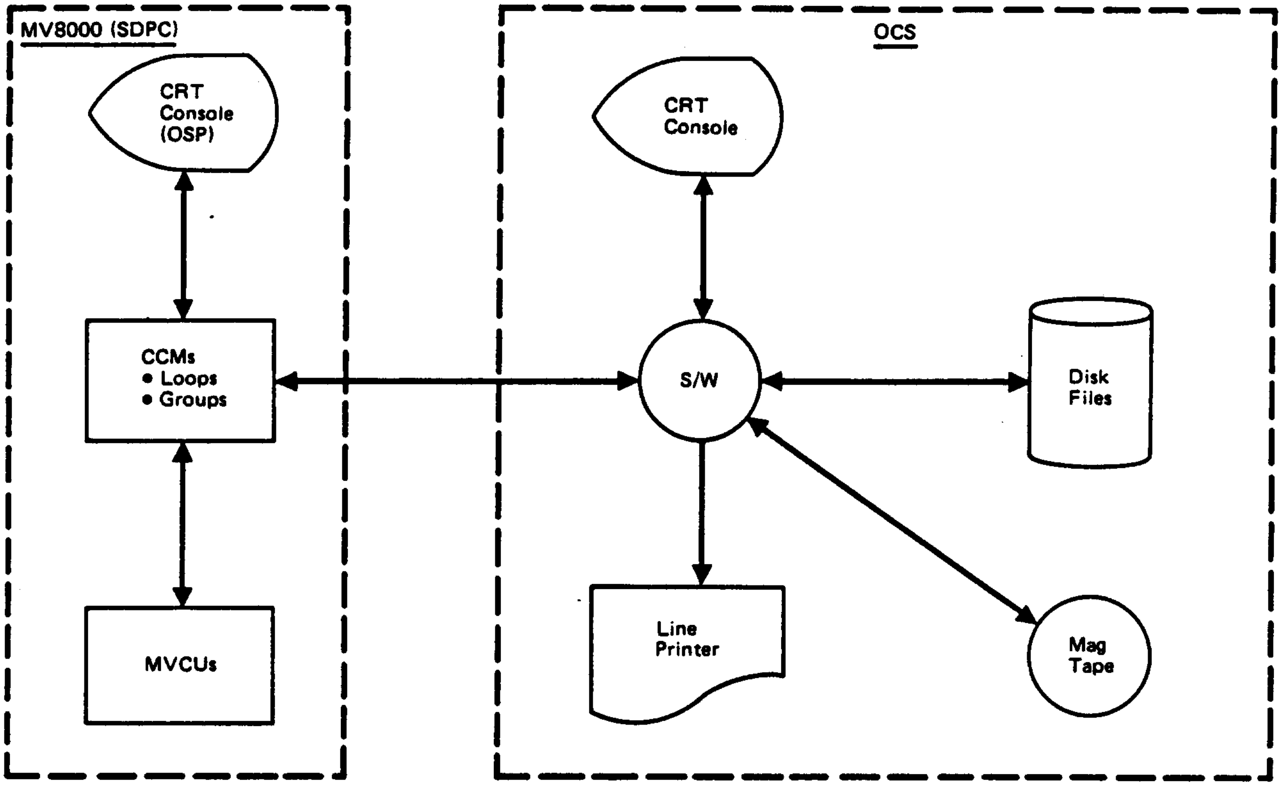

Figure 5-1. SDPC Configuration Upload and Download Interfaces

5.1 FUNCTIONAL INTERFACES

The interfaces used in performing the SDPC configuration upload and download functions are shown in Figure 5-1. Operation of the basic menu functions tested is summarized as follows:

A. Function Control. All functions are selected and executed by using one of the OCS operator consoles via a sequence of formatted menu's and displays. Execution status information is also provided on the display.

B. Print System. To print the system data base configuration, read configuration commands are sent to the CCM's and the returned configuration messages are decoded and printed on the line printer.

C. Store. To store the current configuration, read configuration commands are sent to the CCM's and the returned configuration messages are written to an OSC disk file.

D. Print Save File. To print a save file (system configuration data base stored on disk), the stored configuration messages are read from the OCS disk file, decoded and printed on the line printer.

E. Compare. To compare the current SDPC configuration to a stored configuration, read configuration commands are sent to the CCM's and the returned configuration messages are compared to the stored configuration messages read from the OCS disk files. Any differences detected are printed on the line printer.

F. Download. To download a stored configuration, the stored configuration messages are read from the disk file, converted to download commands and sent to the CCM's.

G. Tape Backup. To create a backup magnetic tape, the stored configuration messages are read from the disk files and written to a magnetic tape.

H. Tape Restore. To restore the stored configuration disk files on a tape, the configuration messages are read from the backup magnetic tape and written to the disk files.

I. Reference Configuration. The actual current SDPC configuration for evaluation of functions B-H is obtained from the MV8000 CRT console. This console is also used to insert known configuration changes for testing the compare and download functions.

5.2 DEVELOPMENT TESTS

The order in which development and testing of the SDPC configuration upload and download functions was performed is shown in Table 5-1.

The basic software for the print system configuration data base, store, and compare functions for CCM loops and MVCU's was originally developed and operated on the DAS computer. This software was adapted to the OCS computer and extended to include the printout of a save file (baseline system configuration data base previously stored on disk), download, tape backup, and restore functions. The scope was extended to include the processing of CCM group configurations and a single MVCU configuration. The use of the OCS operator consoles with linked graphic pages (displays) as the man-machine interface was another extension.

The following briefly describes the development and test steps performed (see Table 5-1). The code was modified to correct anomalies or changed to improve performance as the testing progressed.

Table 5-1. Development and Test Sequence

Function	Configuration Type			
	CCM Loops	CCM Groups	MVCUs (One or More Systems)	Single MVCU
Print System (System Data Base)	①	⑥	⑩	⑭
Store	②	⑦	⑪	☒
Print Save File	③	⑧	⑫	☒
Compare	④	⑨	⑬	⑮
Print Loop Index	⑤	☒	☒	☒
Download	⑯	⑰	⑲	⑱
Tape Backup	⑳			
Tape Restore	㉑			
Console Display Interface	㉒			

ⓝ = Order of development and test

Step 1 - The code for reading and printing-out the current CCM loop configurations was moved from DAS to the OCS computer and modified to be compatible with the OCS/SDPC interface.

The function was executed and the printed configuration compared to the actual configuration as found in the system by using a MV8000 Operator Console. This was done first for one CCM, followed by two CCM's concurrently and then all three CCM's concurrently.

Steps 2 & 3 - The code for reading and storing the CCM loop configurations on a disk file was moved from the DAS to the OCS computer and modified to be compatible with the OCS, SDPC interface and the OCS disk file structure. The software for reading and printing out prior CCM loop configurations stored on a disk file was developed.

The store function was executed followed by the print save file function. The print-out of the stored configuration was compared to the actual configuration found in the system by using a MV8000 operator console.

Step 4 - The code for comparing current CCM loop configurations to prior loop configurations stored on a disk file was moved from the DAS to the OCS computer and modified to be compatible with the OCS/SDPC interface and the OCS disk file structure.

The current loop configurations were stored, known additions, deletions, and changes were made to the CCM loops, then the compare function was executed. The print-out of the miscompares was compared to the known alterations.

Step 5 - The code for printing-out an index (an alphanumerically ordered list of CCM loop ID names) was moved from DAS to the OCS computer and modified to be compatible with the OCS/SDPC interface. The index function was executed and the printout was compared to the actual configuration as displayed on a MV8000 Operator Console.

Step 6 - The software for reading and printing the current CCM group configurations was developed. The function was executed and the print-out was compared to the actual configuration found in the system by using a MV8000 Operator Console.

Steps 7 & 8 - The software for reading and storing the CCM group configurations on a disk file and for reading and printing prior CCM group configurations stored on a disk file was developed.

The store function was executed followed by the print save file function. The print-out of the stored configuration was compared to the actual configuration found in the system by using the MV8000 Operator Console.

Step 9 - The software for comparing current CCM group configurations to prior group configurations stored on a disk file was developed. The current group configurations were stored, known additions, deletions, and changes were made to different CCM groups, then the compare function was executed. The print-out of miscompares were compared to the known alterations.

Steps 10 thru 13 - The development and test activities in steps 10 through 13 for MVCU configurations were identical to Steps 1 through 4 for CCM loops.

Step 14 - The code for reading and printing the MVCU configurations was modified to allow selection and processing of a single MVCU. The function was executed and the printed configuration compared to the actual configuration found in the system by using a MV8000 Operator Console.

Step 15 - The code for comparing the actual MVCU configurations to prior MVCU configurations stored on a disk file was modified to allow selection and processing of a single MVCU. The current MVCU configurations (were stored, known additions, deletions, and changes made to a selected MVCU, and the single MVCU compare function executed. The printed changed configurations were compared to the known changes.

Steps 16 & 17 - The software for downloading stored CCM loop and group configurations from a disk file to the CCMs was developed.

The current CCM configuration (loops and groups) was first uploaded to the MV8000 floppy disk and the disk removed from the CSM drive and replaced with a new formatted disk. The current CCM configuration was stored on a disk file, known additions, deletions, and changes were made to selected loops and groups, then the download function executed. The compare function was then executed for both loops and groups.

The above was first performed for a single CCM and subsequently for two and three CCM's concurrently.

Step 18 - The development and test activities for Step 18 were identical to Steps 16 and 17 for the single MVCU configuration.

Step 19 - The development and test activities for Step 19 were identical to Steps 16 and 17 with the exception that first all MVCUs and CCMs and then all MVCUs, CCMs, and groups were tested collectively.

Steps 20 & 21 - The software for writing the stored configurations disk files to a backup magnetic tape and restoring them from the tape to the disk was developed.

The store and print save file functions were executed for CCM loops and groups and for MVCU configurations. The tape backup and restore functions were then executed followed by the execution of the compare and print save file functions for CCM loops and groups and for MVCU configurations.

Step 22 - The OCS software to allow control and monitoring of the SDPC Configuration Upload and Download functions from an OCS Operator Console was developed. Appropriate displays were generated using the RCS-7 format generation function.

Each of the major functions shown in Table 5-1 was then executed from a OCS Operator Console and the results monitored.

5.3 OPERATIONAL TESTING

After completion of the development testing, the SDPC Configuration Upload and Download functions were operated on a daily basis by SCE operations and maintenance personnel and by MDAC control engineers. Any anomalies observed were analyzed and code modifications made as necessary to achieve the desired operation.

5.4 RESULTS

All SDPC Configuration Upload and Download functions performed correctly except for one unresolved side effect caused by a limitation in the MV8000 system.

When downloading the configuration from an OCS disk file to the MV8000 the configuration data will only be written into the memory of the CCM or MVCU; it will not be written onto the floppy disk. This is because a directory has to be created in the CCM and on the disk which directs the location where the particular MVCU data will be stored. The problem is internal to the MV8000 system and cannot be corrected in the OCS computer.

To preserve a means of restoring CCM and MVCU memories from the MV8000 Configuration Storage Modules (CSM), it is necessary to remove the floppy disks from the CSM's prior to performing a configuration download from the OCS computer. The floppy disks can be replaced after the download from the OCS computer is completed. The method of making a new floppy disk after a download is described in Reference 3.

Section 6

SUPERVISORY CONTROLS TESTS

The initial requirements for plant supervisory control were generated in the third quarter of CY 83 then released on October 6, 1983 (Reference 7). These initial requirements were intentionally conservative because of uncertainty in OCS's functionality and failure modes, and the degree of operator interaction necessary for safe and reliable operation of the plant. Therefore, from the beginning, development of the supervisory control capability was known to be an iterative process where the initial requirements and control algorithms would be modified and tuned as the design and its implementation were tested. This evolution impacted both plant surveillance and man-machine interface requirements causing their requirements to be modified as well. The ultimate goal for supervisory control was to provide a simple, reliable, and effective means for SCE operations personnel to operate Solar One in a safe, consistent, and efficient manner.

6.1 IMPLEMENTATION METHODOLOGY AND STRUCTURE

The development of supervisory control was structured by design to be done in three distinct phases: SDPC automation, OCS mode transitions and collector field automation, and OCS clear day operation. Each phase represents a particular type of supervisory control task. Also, each phase ascends to a higher level of control, or automation, forming a hierarchy as illustrated by the hierarchical pyramid in Figure 6-1.

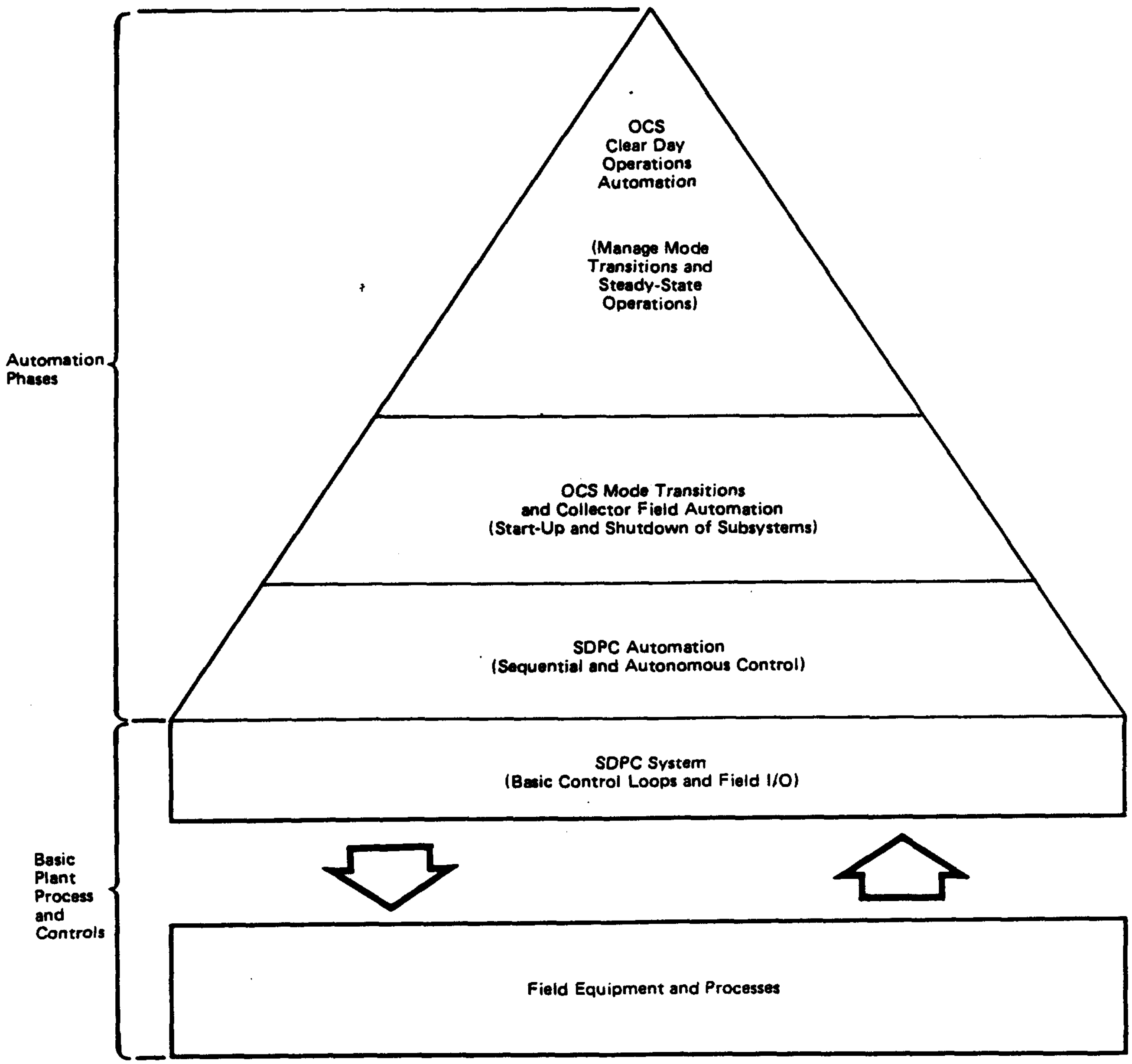

Figure 6-1. Hierarchical Pyramid of Automation

Phase one of supervisory control was implemented completely within the SDPC (MVCUs and Modicon 584s). The philosophy was to automate as much as reasonably possible within the SDPC because of proven reliability due mainly to redundant hardware and data highways which the OCS would not have. Ideally, all of supervisory control would have been configured within the SDPC but the SDPC had hardware and firmware constraints which limited automation. SDPC automation was implemented in discrete automation packages which covered particular portions of the existing manual operating procedures according to function and SDPC capability. Phase two and three of supervisory control were implemented within the OCS, providing control of the whole plant from a single console.

The data base in the SDPC used for display and control is identified and stored by alpha-numeric numbers called "TAG ID's". The OCS computer accesses and manipulates these tag IDs as the only means of interacting with the process. Thus, a common data base of all systems process information is maintained in the OCS to provide the data necessary for the supervisory control functions.

Supervisory control was implemented within the OCS computer in the form of FORTRAN programs called Application Program Tasks (OCS command files). Before development of these programs began, supporting subroutines were coded for common, basic internal, and external functions such as reading or setting a value of an SDPC tag ID, writing a message to the printer, waiting a certain number of seconds before continuing, etc. These supporting subroutines helped accelerate the development process of application programs by allowing the control engineer to concentrate more on the operation of the plant than on the configuration of the software.

Phase two application programs required the capability to transfer the plant from one steady-state operating mode to another and establish known optimum operating setpoints for each power producing mode of operation. Optimum setpoints were determined from individual mode tests conducted prior to, or in conjunction with, automation testing. The transition from one mode to another required the ability to startup and shutdown each of the four major subsystems (CS, RS, TSS, EPGS) which make-up the entire plant. The startup of a system is a far more involved process than shutdown of a system. Therefore, the application programs involving startup procedures required considerably more effort and code than those involving shutdown. SDPC automation was quite comprehensive and was completely utilized by phase two application programs. Since the SDPC automation had matured, gained acceptance, and proved reliable prior to OCS supervisory control implementation, the approach was taken not to duplicate or modify any of the SDPC automation via OCS. Also, the high confidence level in SDPC automation provided initial confidence in OCS automation resulting in a stable and predictable automation base to begin implementation and testing of phase two application programs in OCS.

The startup software was implemented, tested, and modified as individual tasks and later was integrated into mode transition software as subroutines. However, there are exceptions. The startup and shutdown software for both the RS and CS are stand alone application program tasks. This is because TSS-Extraction and transitioning from/to Mode 8 (inactive) was not to be automated via OCS such that a mode transition did not exist into which the software could be integrated. Integrating startup software as subroutines provided an efficient means of locating problems and making corrections or adding additional code as phase two of supervisory control was tested and modified.

Automatic collector field control is covered in a separate section because of its interface with the HAC computer and its unique functioning. However, automatic collector field control is technically a supervisory control task and is an integral part of phase two application program tasks. See Section 2 for details concerning this task.

The mode transitions, including system startup/shutdown and collector field control, make up phase two of supervisory control. The main effort of phase two implementation consisted of four major items: (1) fill-in areas not covered by the SDPC automation, (2) proper integration of the SDPC automation, (3) minimization of the number of data points required, and (4) response to SCE operator requests.

Implementation of a clear day scenario was the ultimate goal of supervisory control for plant operations throughout any one day. The development of phase three application programs (clear day scenario software) was a natural extension of phase two application programs, since clear day programs utilize phase two programs to accomplish their tasks. Clear day programs essentially manage phase two programs by initiating activation (start their execution) once certain process and/or environmental conditions are realized, waiting until they complete (execution terminates), then checking them to make certain they accomplish their task. Three different clear day scenario programs were developed, implemented, and tested: Clear day 1, Clear day 2 and Clear day 5. Clear day 1 starts up the collector field (CS), receiver (RS) and turbine generator (EPGS) providing maximum power generation throughout the day. Clear day 2 starts up the CS, RS and EPGS and, when the gross generator power output is greater than 7.5 MW, starts up the TS charging system. Clear day 5 starts up the TS charging system only providing the maximum charging rate of the thermal storage unit throughout the day.

The major effort in implementation and testing of the phase three programs was determining the proper timing and system conditions for activation. Since OCS had the capability to execute only three application programs at any one time, a clear day program had the added dimension of governing two "phase two" files at any one time. This required close coordination between the two programs.

In summary, the structure of supervisory control is comprised of three phases. The first phase consists of basic automation packages within the SDPC system. The second and third phase are implemented within the OCS where phase two consists of mode transitions, stand alone startup/shutdown, and any other special application programs subtasks, while phase three consists of clear day scenario application tasks. Phase two tasks were structured to utilize process data and SDPC automation to accomplish their specific automation function such that OCS would not duplicate any SDPC automation functions. Phase three tasks were structured to utilize process data and phase two tasks to accomplish their specific automation functions where phase three files would not duplicate any SDPC or phase two automation functions. This structure is best illustrated by the hierarchial pyramid (see Figure 6-1). Each phase depends on the lower phase in order to perform its task. The structure was implemented methodically phase by phase, program by program, and task by task. Each of these was implemented in a manner such that each one was a reliable stand-alone task and could be utilized reliably and effectively by another higher level task.

6.2 BASIC FUNCTIONAL TESTS AND RESULTS

Several basic functional tests were conducted once the OCS hardware and executive software became operational. These initial tests provided important information regarding the OCS interface with the SDPC. This interface was crucial for reliable operation of the OCS in all areas of automation, particularly for supervisory control. Therefore, the following tests were conducted.

6.2.1 Integrated Update Cycle Time

The time required for the OCS to retrieve an input process value from the field, do a computation, and return an output value to the field is considered the integrated update cycle time (see Figure 6-2). This update time was particularly important for effective, reliable, and safe utilization of supervisory control because of the need for timely information and control capability. As specified in the supervisory control requirements document, the overall update time requirement was four seconds or less. This amount of time was rather lenient because closed-loop control was not to be effected with supervisory control. Only managerial type control was to be effected such as establishing setpoints, enabling SDPC automation sequences, monitoring the process variables, etc. This was mainly because of the lack of a redundant interface between the OCS and SDPC and the inherent potential of a variable update time. The likelihood of communication failures was why SDPC automation was so important to the success and safe operation of supervisory control via the OCS. Being able to read, compute, and output every four seconds was considered adequate according to engineering judgement and control experience.

A simple test was conducted to determine the integrated update cycle time. The system configuration for this test is illustrated by Figure 6-3. A voltage sinusoid of low frequency (ν = .05 Hz) with a positive DC component was used as the driving input signal which was connected to a MVCU input terminal. The MVCU was configured with an Auto/Manual (A/M) station where its input was configured with the input terminal number and its output was configured to drive one of the output terminals on the MVCU. An SDPC CCM was

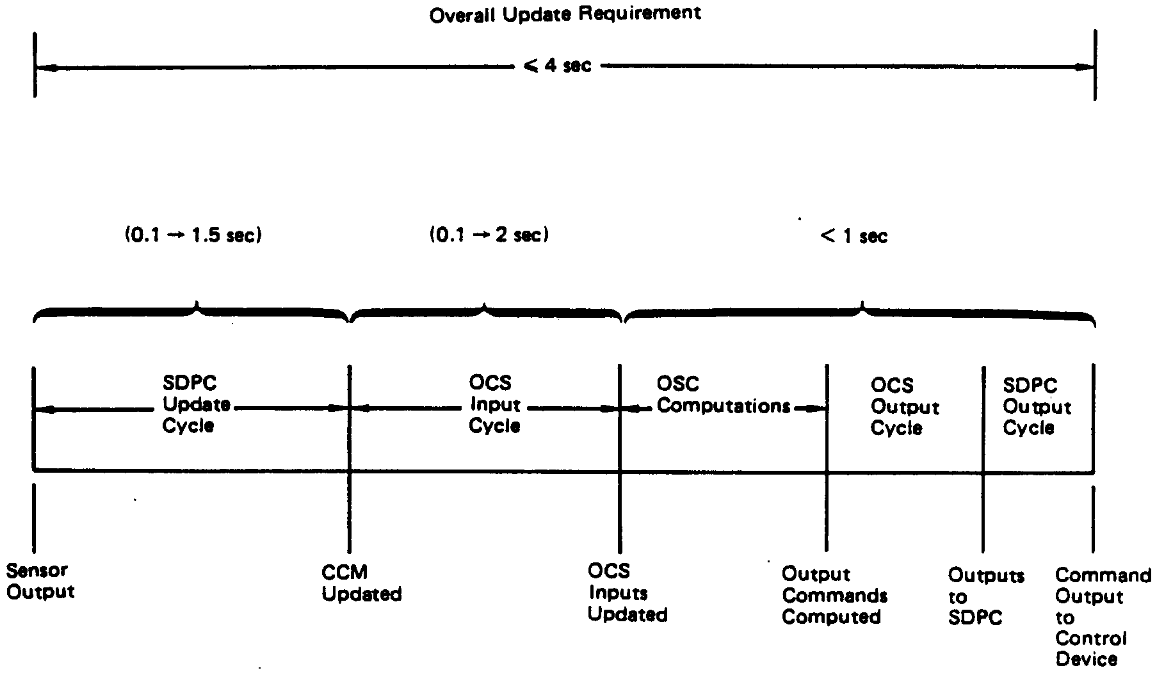

Figure 6-2. Integrated Supervisory Control Update Cycle

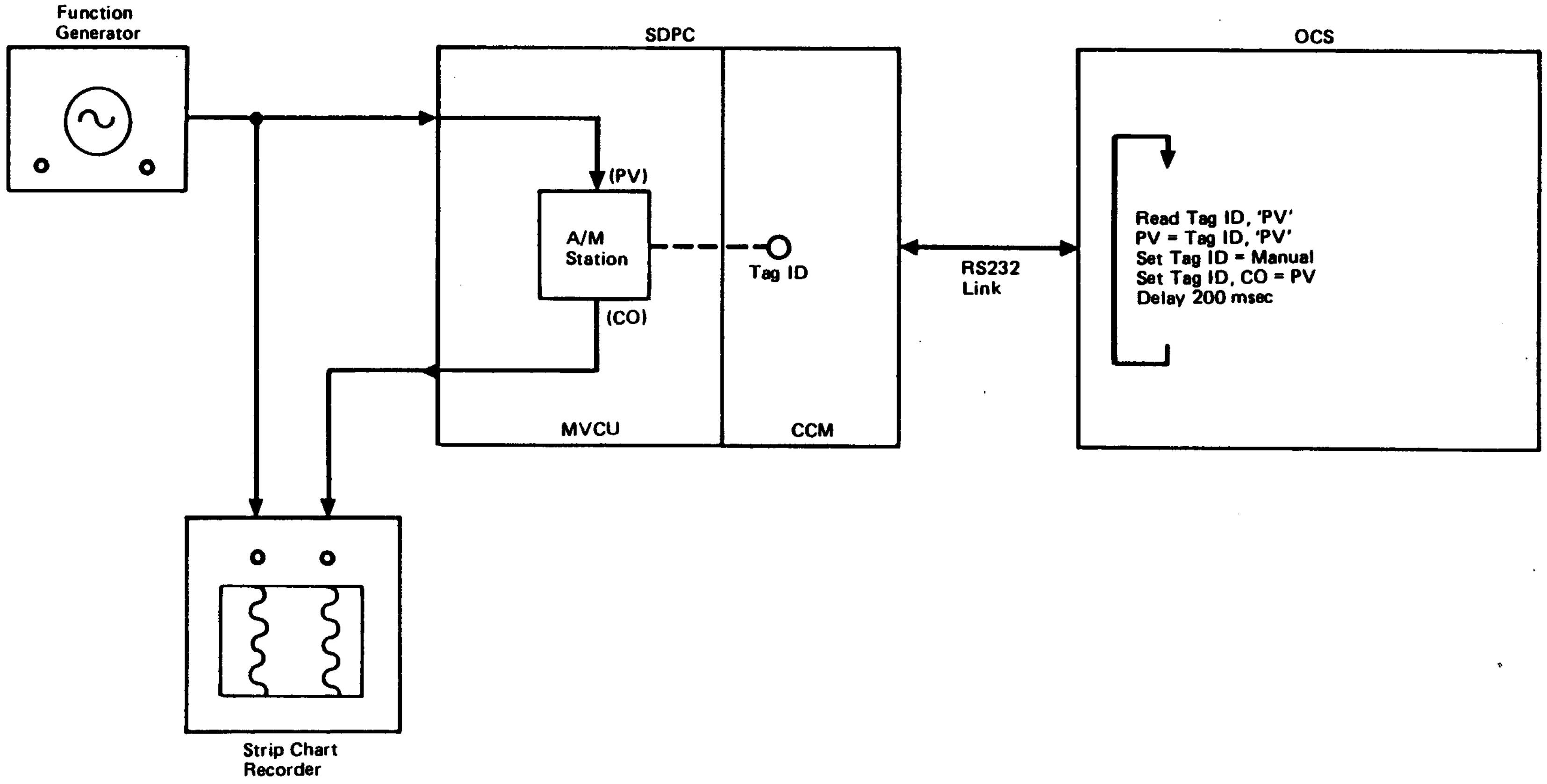

Figure 6-3. System Configuration to Determine the Integrated Update Cycle Time

configured with a tag ID connected to the Auto/Manual station so that the OCS could have access to both the input and output channels of the MVCU. A task was programmed within the OCS to read the input process variable (PV) of the tag ID and then command the tag ID to MANUAL with a commanded controller output (CO) equal to the PV value which was read. The sequence would be delayed 200 msec, then looped back and be continuously repeated. Both the input and output voltage signals were recorded on a strip chart recorder for evaluation.

The test was conducted during the evening hours after the plant had been shutdown so as not to interfere with normal operations during the day. This condition provided test data when the CCM was essentially free of other tasks (i.e., alarms, operator command, etc.) such that conditions were ideal for communication with SDPC and the SDPC update cycle time was at a minimum. The receiver system (RS) CCM was chosen for the test since it had the largest data base (most tag IDs and MVCUs configured within it). Also, MVCU C1-9 was chosen because its data base configuration was near capacity and it had the largest number of tag IDs related to it. Also, MVCU C1-9 had a more busy data highway due to three MVCUs communicating over the same highway; most highways typically handle only two MVCUs at Solar One. Therefore, using the RS CCM and MVCU C1-9 provided the most busy and adverse configuration for communicating data within the SDPC hardware. Overall, the configuration (see Figure 6-3) and conditions were deemed sufficient to provide meaningful and representative data of the overall integrated update cycle time. The evaluation of the strip chart (see Figure 6-4) revealed a very consistent update time of two seconds. However, the time from execution of the OCS application task until the initial

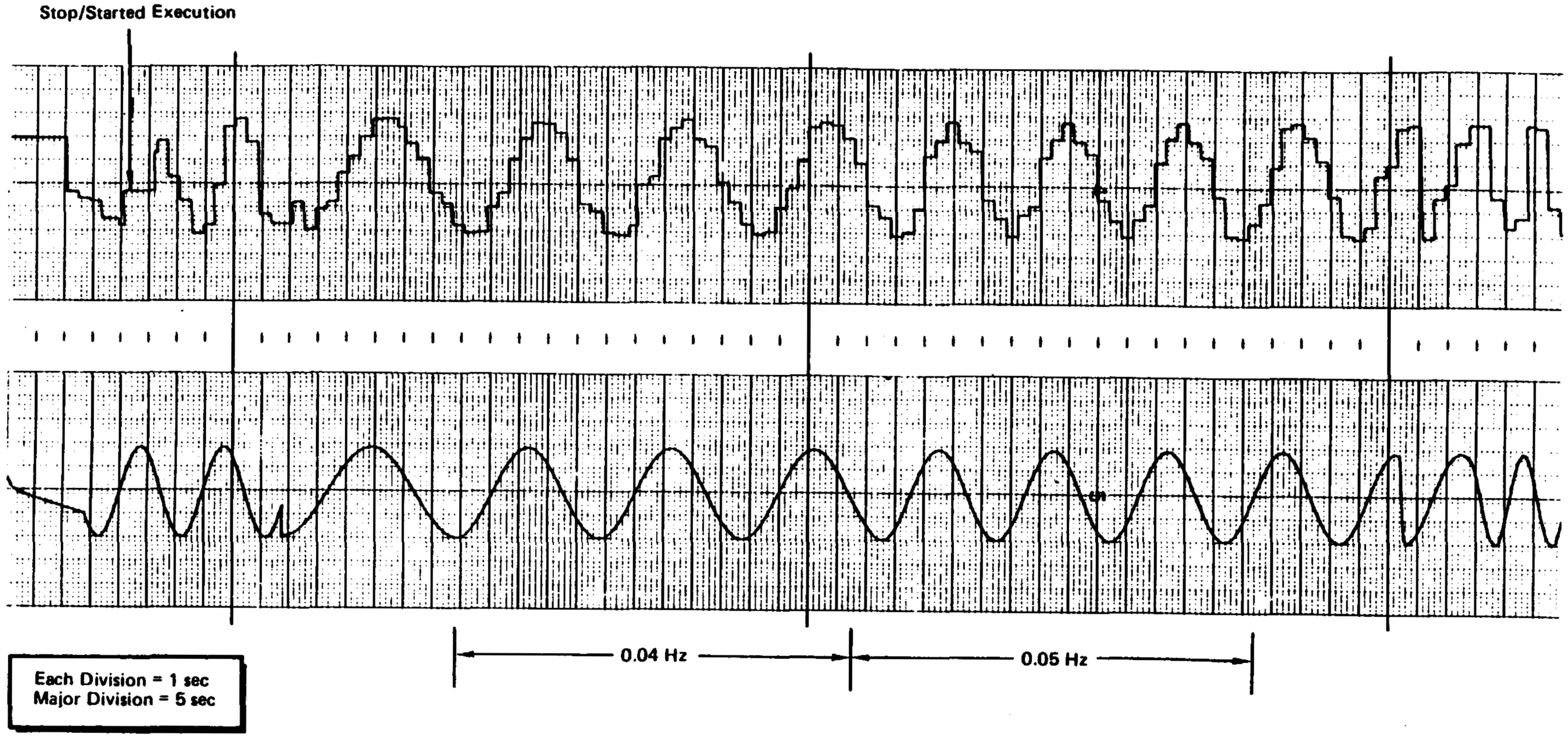

Figure 6.4. Results of Through-put Tests

output was received revealed an initial delay of four to five seconds. This initial delay was attributed to the necessity of the executive software to establish a new scan list of tag IDs, notify the SDPC, and begin receiving data following the initiation of an application program task. The consistent update time of two seconds was very encouraging and met the four seconds or less requirement. The four to five second initial delay posed no problems and was acceptable also.

6.2.2 OCS to SDPC Command Test

The OCS communicates with the SDPC over three RS232 (serial) links; one for communication with each of the three SDPC subsystems (RS, TSS, EPGS). Each link performs data transmission in both directions (data retrieval and commands), in a serial fashion, with each SDPC communication control module (CCM). Transmitting and receiving data serially was not a problem in itself since the speed of the link was much greater than the update and processing time of a CCM. The problem was that the OCS could potentially overwhelm a CCM with too many commands at one time. Commands are received by a CCM and placed into a buffer chronologically. A CCM scans its command buffer and transmits as many commands to the appropriate MVCU and tag ID as time permits in chronological order. If a CCM has to spend more time handling other functions (i.e., sending data to the OCS & DAS, alarm handling, provide live-data for graphic pages, etc.), then the buffer could become full and not be able to accept any more commands temporarily. Therefore, a command test was conducted to determine the realistic likelihood of such an event.

An application program was generated which would send a set of ten commands, a combination of both analog and digital, to each of the three CCMs. The program was coded such that the RS, the TSS, then the EPGS were sent a set of ten sequential commands. The program looped back and started with the RS again until the program was terminated. The initial test showed that the EPGS CCM would cause an error to occur and the command file would abort automatically. The error was generated by the EPGS CCM because of the command buffer problem as expected. What was unusual about this buffer problem was that it occurred within the EPGS CCM which was the least busy and had fewer tag IDs configured within it than any of the others. There is no explanation for this occurrance to date. Another result of the initial test was that the command file continued to abort because it was unable to execute a command to the SDPC after only trying once. This software configuration was not acceptable. Therefore, the executive OCS software which handles commands to the SDPC CCMs was modified to send the same command again if an error message returned from a CCM due to that command. The command is sent again after a 200 msec delay and with a limit of five tries before the file is aborted. After the modifications were coded, the above application program was executed again. The EPGS CCM was the only one to cause an error again and was of the same type. However, the executive software modification was successful since the program did not abort and the command was finally executed.

The overall results of this command test indicated that the likelihood of a command buffer problem was relatively low. However, minimizing this type of problem was desirable. Therefore, the executive software was modified to circumvent this problem in order to reduce the likelihood of aborting an application program task. The modification improved the integrity of the OCS supervisory control capability, both operationally and functionally.

6.3 APPLICATION PROGRAM (OCS COMMAND FILE) TESTS

Testing of application software followed the implementation methodology discussed in Section 6.1. The actual order in which these OCS command files were tested is shown by Table 6-1. The table does not include collector field control command files since they were tested concurrently with the programs listed (no specific order). The table also provides a description of the primary function for each application program.

Testing began in December 1983 and officially ended in July 1984. Initially, basic functional tests were conducted to determine basic OCS functional characteristics concerning supervisory control, then application program testing began. Unusually clear skies prevailed for the first two or three months of testing which provided more testing time than anticipated. This additional time facilitated the known need for software modifications and algorithm fine tuning. Consequently, the schedule was moved up but allowed time to implement all three clear day scenario application programs.

Mode transition application programs are the real work horses of OCS supervisory control. Consequently, approximately 70% of testing was conducted on mode transition files. Testing consisted of three major items: (1) finding and resolving deficiencies in process/operational control, (2) integrating the SDPC automation and (3) implementing reasonable operator requests. Supervisory control design problems which surfaced during automation testing were resolved as they appeared.

Table 6-1. Order of Application Program (OCS Command File) Testing

Test Order	Application Program (OCS Command File)	Functional Description
1	RUNMOD	Determines Steady-State Operating Mode
2	MX95	Mode 9 to Mode 5 Transition
3	MXT9	Mode 1, 2, or 5 to Mode 9 Transition
4	RSUP	RS Startup
5	MX91	Mode 9 to Mode 1 Transition
6	MX12	Mode 1 to Mode 2 Transition
7	RSDRAT	RS Derated
8	MX21	Mode 2 to Mode 1 Transition
9	RSSHUT	RS Shutdown
10	MX25	Mode 2 to Mode 5 Transition
11	CLRDY2	Clear Day Scenario With Noontime Mode 2 Operation
12	CLRDY1	Clear Day Scenario With All Day Mode 1 Operation
13	CLRDY5	Clear Day Scenario With All Day Mode 5 Operation

Clear day scenario testing began by manually activating mode transition tasks in order to determine the basic activation criterion, anomalies in sequencing or simultaneous execution of mode transition programs, and management type control actions. The manual results were coded and actual clear day scenario program testing began. Three such application programs were generated and tested.

6.4 APPLICATION PROGRAM (OCS COMMAND FILE) TEST RESULTS

The results are divided into four main program categories: mode transitions, clear day scenarios, special functions, and OCS displays. The results of the mode transitions affected the results of the clear day scenarios while the results of the special functions affected the results of the other categories.

All of the initial supervisory control requirements were met. However, as expected, implementation of additional requirements became necessary as the overall OCS capability matured and testing progressed. These additional requirements were a result of the OCS computer's hardware and software limitations, operator awareness and control capability inadequacies, and detailed operational control deficiencies.

6.4.1 Mode Transition Test Results

Application Program Tasks,in general, were initially designed to be executed from beginning to end only. During implementation and testing of the initial programs, it was determined that this design feature was unreasonably restrictive. If a task sequence had to be aborted because of problems, the operator had to return the plant operating condition to its original state (once the problem had been corrected) in order to restart the program for a retest. Usually the problems were of a simple nature that could be corrected within a short time; therefore the need to completely recycle was considered unacceptable. The programs were subsequently modified to allow initiation of control execution at the proper location, or step, within its sequence and to perform "status checks" at each step prior to the start of its execution. This provided a much smoother operator/OCS interface and reduces the chances for operator error.

The capability to begin control execution at the proper step within an application program 's sequence increased the use and importance of the "mode finder" software. The knowledge of the current operating mode of the plant provided the general initiation location for control execution while the "status check" capability for each step determined the specific initiation step. Also, status checks allowed some degree of concurrent operator/program control because the check would determine if an operator-commanded step had already been executed by the program and, if it had, the program would automatically cycle to the next step.

The gains in the overall performance of supervisory control, produced by the above modifications to program design, were demonstrated during testing. Specifically, reliability was improved since sequential execution of each step within a program was assured (manually or automatically). Also, program usability was improved because of the removal of the conditional start criterion and the allowance for concurrent operator/program control.

As the overall OCS capability matured, machine resources became more and more of a concern (see Section 4 for details). Three features were implemented within the application programs to improve OCS performance. A summary of these features follows:

1. Time Spacing. The subroutine WEIGHT(X) was used extensively to break up the executable code, where appropriate, without causing any functional problems. When WEIGHT(X) is called, the program essentially stops execution for "X" number of seconds. Thus, machine resources are utilized more efficiently.

2. Minimize Data Required. Each application program requires data from SDPC tag IDs in order to make decisions and to provide control. When a program first begins to execute, the SDPC is commanded to begin sending data for every tag ID required by the file independent of the current needs of the file. Machine resources are required to process the data for each tag ID. Therefore, the number of tag IDs required by each application were minimized.

3. Limit Number of Command Files Executing Simultaneously. The number of tasks which could execute simultaneously was limited to three. Three tasks were sufficient to operate the plant in the planned operating modes.

6.4.2 Clear Day Scenario Test Results

The necessity for each application program task (e.g. clear day program) to have execution status information from other programs was established during initial testing. This information was important for three reasons: (1) to prevent one application program from attempting to activate another program which was already active, (2) to perform checks to determine whether or not a program had completed its task following task termination (transition from an active to an inactive state) and (3) to prevent a program from waiting indefinitely on process conditions to be established when the required program, which would provide operations to establish those conditions, was no longer active. A 16-bit word, called "task bits" (TSKBITS), was established and implemented; each bit represents the active/inactive state of a particular application program.

The capability of the OCS to execute three application programs simultaneously caused some problems, or confusion, from an operators point-of-view. Since three tasks were only active simultaenously during clear day scenario operation, the focus of the problem was on the operator's use of clear day programs. The majority of the problem dealt with providing the operator with adequate information on the present state of overall supervisory control; a discussion of this portion of the problem is provided in Subsection 6.5. The remainder of the problem dealt with the issue of supervisory control "abort structure". When an operational problem occurred (i.e., equipment failure, control loop troubles, etc.), the operator's desire was to terminate supervisory control. This decision required the operator to abort each application program which was not conducive to safe operation of the plant. Therefore, an "abort structure" was required to facilitate operations.

There was a choice of two principle automatic abort structures:

1. Top-Down Automatic Abort Structure. When the operator aborted a clear day program, any other active program would be automatically aborted.

2. Bottom-Up Automatic Abort Structure. When the operator aborted an application program, only those programs which depended on the aborted program completion would be automatically aborted.

These two structures refer to the hierarchical pyramid of automation illustrated by Figure 6-1. The bottom-up automatic abort structure was chosen for two main reasons: (1) this structure was generally implemented within the separate programs themselves and (2) aborting a clear day program did not always necessitate the need to abort all other programs.

Another key test result regarded the handling of automatic trips by the application programs. There are three trip-related program actions required: (1) determination of whether or not the system is moving towards a safe status, (2) determination of the cause of the trip and (3) resolution of the problem. Trip handling is a very delicate and safety conscious task. When a trip occurs, the operator is often inundated with alarms; one alarm condition causes another one, etc. Sometimes manual inspection of equipment is necessary. Consequently, determination of the cause of a trip is a formidable task, automatically or manually.

Automatic trip handling would have required an independent alarm processor or an improved SDPC alarm processor to provide cause determination. An extensive amount of OCS deterministic software would have been necessary to effectively and reliably accomplish automatic trip handling via the OCS. Determination of the alarm which represented the actual cause of a trip is best handled on the SDPC control level since an operator requires this system information when operating in a manual mode without any supervisory control. Therefore, due to system imitations, automatic trip handling within application programs was reduced to the point where the programs simply abort themselves when a subsystem trip is detected such that supervisory control terminates automatically without operator initiation.

6.4.3 Special Functions

The capability to determine the current steady-state operating mode of the plant is deemed a special function. The "mode finder" software is used by every application program, except those which control the collector field, in the form of a subroutine. The individual mode finder capability was implemented for initial testing purposes and for operator use.

Several special functions were required in many tasks and these functions were implemented as subroutines for use by each of the tasks. These functions are described below.

1. RSTFLW - RS Total Flowrate.

The receiver total flowrate is calculated in the SDPC as the sum of the three preheater flowrates (Tag ID = FI2233). Since this calculated total flow is used in many of the application programs it was important to be assured that the value was correct. This routine compares the values of the three preheater panels to determine if all three are within a specified tolerance. If they are within tolerance, the routine allows the SDPC calculated total flowrate to be used by the application programs. If one panel flowrate is out of tolerance, this routine sets an error flag and calculates the RS total flowrate using the sum of the two "good" panel flowrates multiplied by 3/2. When all three are out-of-tolerance, the error flag is set to a failure setting and uses the largest panel flowrate that is not reading a full scale (100%) value, to calculate the total RS flowrate (multiply this value by 3).

2. TSSFTK - TSS Flash Tank. This subroutine essentially controls the pressure and level of the TSS flash tank, during subsystem startups, until steam is provided by the charging subsystem. This is accomplished by determination of the source of auxilary steam (TS extraction train 1 or 2 or electric steam boiler) and setting up the appropriate controllers for this source.

3. TSUTNK - TSU Tank. The thermal storage unit (TSU) has four possible valve alignments for the inlet, outlet and bypass lines connected to the tank. The four alignment sets are TSS charging startup bypass, TSS charging, TSS extraction, and TSS extraction for auxilary steam (using the middle manifold). This subroutine checks to see that the thermal storage unit valves are set correctly to one of four different sets. A flag is set to indicate if the valves are correctly set.

4. DAVENT - Deaerator Vent. The subroutine controls the deaerator vent during RS startup to vent GN_2 from the deaerator.

5. DEACTL - Deaerator Control. The techniques for deaerator control are operating mode-dependent. Consequently, this subroutine is only used by the clear day 1 (CLRDY1) application program. The subroutine controls deaerator level and "pegging" steam pressure, mainly during RS startup, to heat-up the deaerator as quickly as possible. The sooner the deaerator is up to temperature, the sooner the actual deaeration process begins. Thus, less axuiliary steam is required once the plant is on-line.

6. TRBALD - Turbine Average Load. The subroutine calculates a running 60 second average of the load, or gross output, of the generator. This subroutine is used by the clear day programs to determine when to provide automatic turbine/generator shutdown in the evening.

7. TRBEHS - Turbine Electro-Hydrolic (EH) System. The subroutine starts the EH system. On even days of the month side "A" is started and side "B" is set for automatic failover. On odd days the opposite is accomplished.

8. TRIPS - Master and Subsystem Trips. The subroutine scans all major trip tag IDs and sets a flag for each major subsystem (RS, TSS-CHG, EPGS, SDS) accordingly.

These special function subroutines were integrated into the application programs as required. Testing was accomplished concurrently with each application program.

6.4.4 OCS Displays

OCS graphics displays are required to support operations of the plant in the automatic supervisory control mode. The operator must have available direct visibility into each automatic sequence in order to assess the conditions of the plant as well as any anomalous behavior. To provide this capability displays were developed during automatic testing which are in three levels: an Operations Menu, Application Program Status and sub-program or task status. In addition, some of the displays used on the SDPC were combined to allow manual operation of more than one system (RS + TSS, etc.) from a single console, if desired. The following paragraphs give a brief overview of each type of display. More details on their use may be found in References 3 and 5.

The overall screen layout for the OCS display is shown in Figure 6-5. Two important display zones should be pointed out here: the command file status and command line zones. The command file status fields show the current status of the application programs which are being used at any particular time. There are three fields since only three applications programs can execute at any one time. The command line zone is used for controlling the application programs (start, stop, etc.) as well as entering commands to the SDPC or HAC or for data acquisition. The remainder of the screen contains the OCS displays. The detailed descriptions of the other display zones are given in Reference 3.

The Operations Menu display is selected and displayed by depressing the function key "Operations Menu" on the OCS console. It provides a list of all application programs used to operate the plant. It shows the program name, a brief description, and any operator input labels required to run the program. The menu contains the three basic clear day programs (CLRDY1, CLRDY2, CLRDY5) as well as the different mode transition programs and system startup/shutdown programs available to the operator (see Reference 5).

The operator can select the application program desired which will cause the operations menu display to be replaced by the applications program display. This display shows an overview of the sequence of events for the selected program, related live process data and related process graphic pages and other sequence of events pages which may be executing simultaneously.

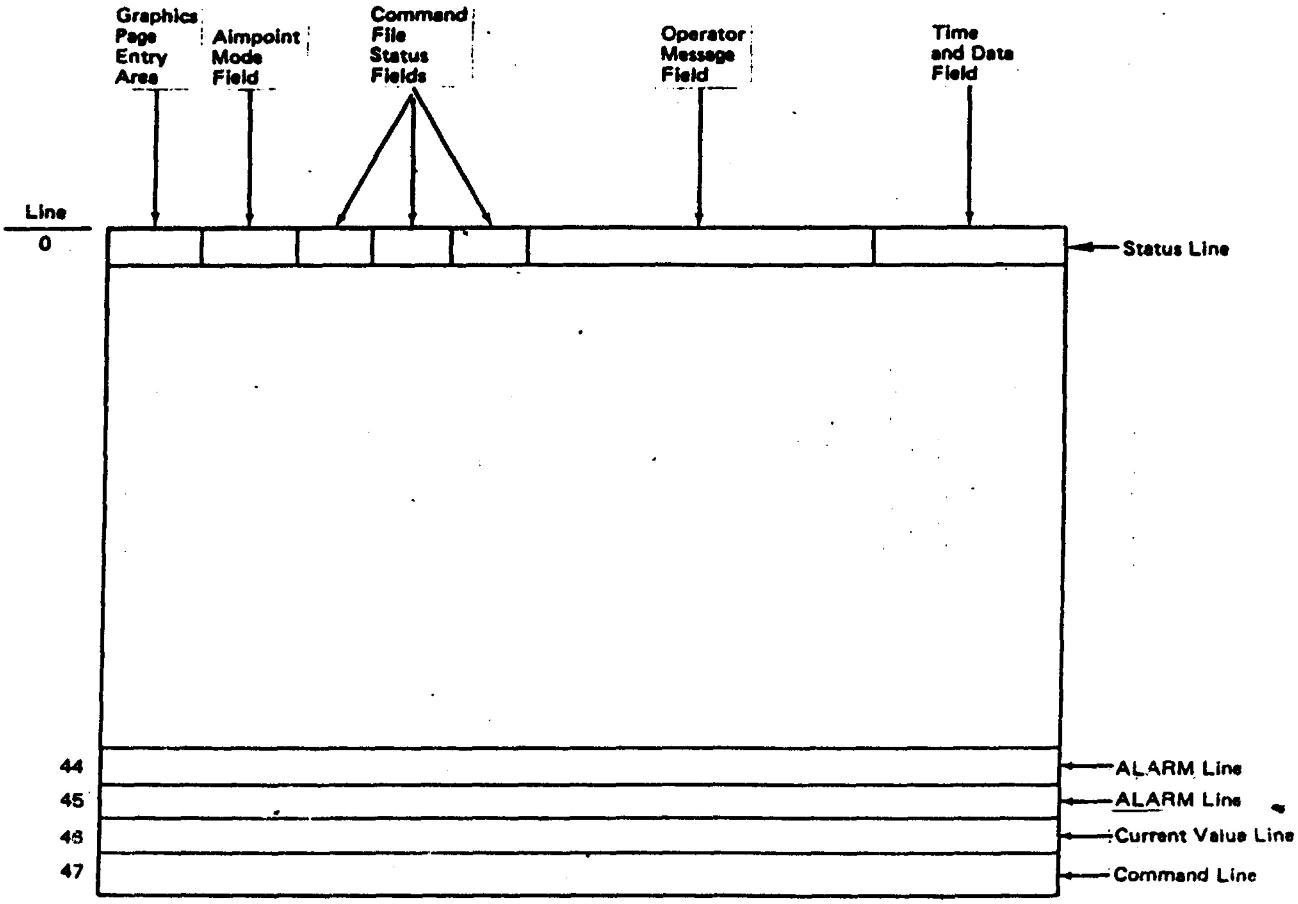

Figure 6-5 OCS DISPLAY SCREEN LAYOUT

These related displays may be accessed directly from the application program display. This allows the operator to view the status of sub-programs which may be used by the primary program.

When the application program display is called up from the Operations Menu, the means to start, stop, hold or resume the execution of the program is shown at the bottom of the display on the command line. This gives the operator immediate control over the program.

Some of the SDPC displays were duplicated on the OCS to provide manual control through a single console. Since OCS has access to the data and controllers of all three systems (RS, TSS, EPGS) it is possible to combine several SDPC displays on one OCS display. This gives the operator much more information and control from one console. These displays may be used for strictly manual (SDPC) control but are usually used by the operator to monitor startup and shutdown along with the application program display during OCS automatic control.

Section 7

MAN-MACHINE INTERFACE

The man-machine interface for the OCS can be stated as an information exchange between the OCS computer and the operator through two Aydin 19-inch color graphic CRT's, operator keyboards, function keys, light pens and printers. The hardware, software and operation are described in Reference 2 and 3. The Plant Operational Display System (PODS) is the portion of the OCS software which supports the Man-Machine Interface function. PODS also provides the software for display format generation, alarming, logging, trending, data acquisition from the SDPC, DAS and HAC, and operator manual control.

The OCS man-machine interface was tested for functional capability throughout the period of development implementation of the automation tasks. The intent was to insure that the OCS hardware and PODS software did meet the requirements as stated in Reference 4. The next two subparagraphs discuss testing on the PODS and on the OCS hardware and the changes required to improve the performance.

7.1 PODS SOFTWARE

PODS makes use of SGM's RCS-7 system to store and/or display data and communicate with the operator via the Aydin color CRT terminals. Initial testing pointed out several areas where RCS-7 needed to be modified or adapted to fit the needs of Solar One. The most important functions were alarm processing, plant graphics display processing, and trend and X-Y plot processing.

7.1.1 Alarm Processing Software

The original software stored alarm data on disk when an alarm was first received from either the SDPC or an OCS task. Having to access the disk in order to process an alarm required CPU time. At first glance, the access time seemed small. However, when multiple alarms occurred at one time, the time to access the data and process it one after another was prohibitively long. The solution was to place incoming alarm data into an input queue using a common block in memory which eliminated most of the disk access time required.

The performance was further improved by removing the alarm display software from the alarm processing software by creating its own independent task. Also, the new alarm processing software was integrated into an existing task (which was usually executed concurrently) for the sake of Task Control Block (TCB) space. TCB space is limited and is required to allow a task to begin and continue execution.

7.1.2 Plant Graphics Display Software

Early in the OCS automation test program it was observed that the update rate for graphic displays was in the range of seven to ten seconds. Investigation determined that the update rate could be improved by using a different technique to transfer the display data from the OCS to the Aydin CRT's. The original design used an RS232C link which provided serial data transfer. A decision was made to change to a system with a display processor using direct memory access (DMA) as described in paragraph 7.2.2. The graphics display software was modified to support the DMA process after the new hardware was installed.

As part of this upgrade, the display update tasks were reviewed and the code was optimized to obtain the best possible update rate. The anticipated result of these changes was to reduce the update rate to a range of two to four seconds. SCE Operations determined this rate would be adequate for plant operation even though it did not meet the original stated requirement of once per second.

7.1.3 Trends and X-Y Plots

The SGM RCS-7 system included software which would provide trend and X-Y plot display data to the Aydin CRT's. However, the maximum resolution possible of the plots on the displays was only 80 characters wide by 48 characters high (no resolution to the "pixel" level). This did not meet the man-machine interface requirements in Reference 4 which specified trend/X-Y plots of the same quality as available on the Data Acquisition System (DAS). It was determined that the cost effective approach was to adapt the DAS software to provide the trend and X-Y plot capability. The DAS routines were modified to fit within the OCS man-machine interface software. Improvements were made in scaling, the ability to generate historical trends was added, a trend menu was added and plot generation for frequently used trends was simplified. An ISC terminal was added to the OCS hardware in order to obtain the desired plot resolution. The final resolution of the displays is 340 pixels wide by 240 pixels high (RCS-7 display equivalent, 50 characters wide by 30 characters high). The revised trend routine runs faster and is more "user friendly".

7.2 HARDWARE MODIFICATIONS

7.2.1 OCS Keyboards

The SGM RCS-7 sysem provided 24 function keys for use with OCS software for any application needing operator/OCS interaction. Only 8 or 10 of these keys had been tentatively assigned by SGM when the program arrived at Solar I. Lacking any operational experience with the system the key assignments were not changed at once. Also, the keys were not engraved at this time pending identification of other key assignments.

As the OCS keyboards and functions keys were used during automation testing, other functions were identified. It became apparent that a new function key layout would be desirable from an operator standpoint.

During the final key assignment, Chris Koch, Honeywell, Inc. provided human factors-related comments and suggestions on key configuration. These suggestions are summarized as follows:

Layout

1. Place frequently used and important keys in or near corners.
2. Place programmer used and low priority operational keys in the middle.
3. Stereotyping on the same row is stronger than in a column.
4. Place the "Control Input" key in the second row to help avoid accidental activation.
5. Place keys which must be reached frequently and/or rapidly to the right side of the keyboard This suggestion assumes most operators are right-handed.

Colors

1. Use red for alarm-related keys; the color red is logically associated with alarms and is considered "attention-getting".

2. Use orange for control function keys; the color range is considered "attention-getting".

3. Use green for page accessing keys; the color green is "non-attention-getting" but effectively demarcates without over emphasizing.

4. Use cyan/blue for informational keys; the color cyan/blue is neutral which provides demarcation from and promotes visual emphasis to surrounding keys.

Legends

1. Use all capital letters.
2. Use a letter color which contrasts well with the key cap colors.
3. Use simple and clear legends.

The final function key configuration is shown in Figure 7-1. This configuration was selected after reviewing comments from SCE operating personnel and MDAC system engineers. The above suggestions by Mr. Koch were reviewed and included where possible. After this final selection function keys of the appropriate color were engraved and installed on the OCS keyboards at Solar One.

7.2.2 Display of Live-Data

The man-machine interface requirements (Reference 4) specified that the update rate for the OCS graphics display CRT's be once per second for 150 live data points. Initial OCS testing revealed an update rate of seven to ten

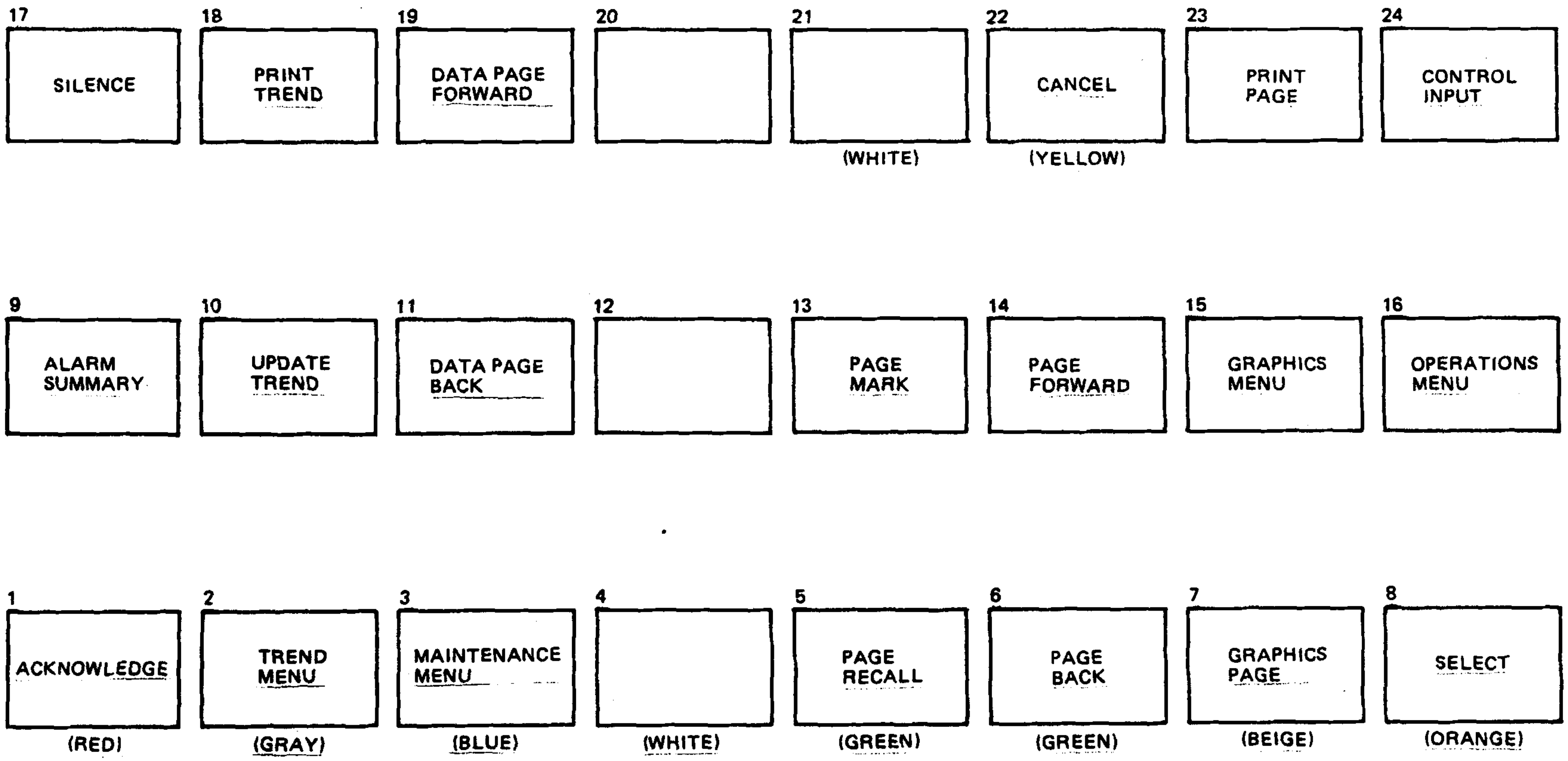

Figure 7-1. OCS Special Function Keys Layout

seconds, depending on which OCS tasks were running at that time. Investigation showed that a serial, RS232C link was being used to transmit the display data to each CRT. This technique transfers each character (consisting of 8 bits) one character at a time. Thus the display update task was using an inordinate amount of CPU time thereby slowing down all OCS processing.

To alleviate this problem the RS232C link was replaced with a display processor using direct memory access (DMA). This allows the transfer of large quantities of display data from the CPU to the Aydin CRT when a graphic page is generated or updated. The display update rate was reduced to a range of two to four seconds which was found acceptable to the SCE operators even though it was not within the original requirements.

REFERENCES

1. Test Plan Outline - OCS Collector Field Control Software, July 1983

2. Control System Description Document, March 1985

3. OCS Operating Instructions, September 1984

4. OCS Man/Machine Interface Requirements, A3-234-EP-ABS-1275, 21 November 1983

5. Supervisory Control Instructions for Plant Operations

6. Plant Surveillance Requirements, A3-234-EP-ESR-1031, dated 6 October 1983

7. Plant Supervisory Control Requirements, A3-234-EP/ESR-1041, dated 7 October 1983

8. Solar I Plant Control System Design Requirements, Drawing No. 1D44755, Revision C.

9. 10 MWe Solar Thermal Central Receiver Pilot Plant Control System Evaluation, SAND 86-8239, September 1986.

APRIL 1, 1987
UNLIMITED RELEASE
INITIAL DISTRIBUTION

U.S. Department of Energy (5)
Forrestal Building
Code CE-314
1000 Independence Avenue, S.W.
Washington, D.C. 20585
Attn: H. Coleman
S. Gronich
F. Morse
M. Scheve
R. Shivers

U.S. Department of Energy
Forrestal Building, Room 5H021C
Code CE-33
1000 Independence Avenue, S.W.
Washington, D.C. 20585
Attn: C. Carwile

U.S. Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, NM 87115
Attn: D. Graves

U.S. Department of Energy
San Francisco Operations Office
1333 Broadway
Oakland, CA 94612
Attn: R. Hughey

University of California
Environmental Science and Engineering
Los Angeles, CA 90024
Attn: R. G. Lindberg

University of Houston (2)
Solar Energy Laboratory
4800 Calhoun
Houston, TX 77704
Attn: A. F. Hildebrandt
L. Vant-Hull

Analysis Review & Critique
6503 81st Street
Cabin John, MD 20818
Attn: C. LaPorta

Arizona Public Service Company
P.O. Box 21666
Phoenix, AZ 85036
Attn: E. Weber

Babcock and Wilcox
91 Stirling Avenue
Barberton, OH 44203
Attn: D. Young

Bechtel Group, Inc.
P.O. Box 3965
San Francisco, CA 94119
Attn: P. DeLaquil
S. Fleming

Black & Veatch Consulting Engineers (2)
P.O. Box 8405
Kansas City, MO 64114
Attn: J. C. Grosskreutz
J. E. Harder

Boeing Aerospace
Mailstop JA-83
P.O. Box 1470
Huntsville, AL 35807
Attn: W. D. Beverly

California Energy Commission
1516 Ninth St., M/S 40
Sacramento, CA 95814
Attn: A. Jenkins

California Public Utilities Com.
Resource Branch, Room 5198
455 Golden Gate Ave.
San Francisco, CA 94102
Attn: T. Thompson

Centro Investigations Energetica
Medroansental Technologie (CIEMAT)
Avda. Complutense, 22
28040 Madrid
Spain
Attn: F. Sanchez

DFVLR RF-ET
Linder Hohe
D - 5000 Koln 90
West Germany
Attn: Dr. Manfred Becker

El Paso Electric Company
P.O. Box 982
El Paso, TX 79946
Attn: J. E. Brown

Electric Power Research Institute (2)
P.O. Box 10412
Palo Alto, CA 94303
Attn: J. Bigger
E. DeMeo

Foster Wheeler Solar Development Corp.
12 Peach Tree Hill Road
Livingston, NJ 07039
Attn: S. F. Wu

Georgia Institute of Technology
GTRI/EMSL Solar Site
Atlanta, GA 30332

D. Gorman
5031 W. Red Rock Drive
Larkspur, CO 80118

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91103
Attn: M. Alper

Los Angeles Department of Water and Power
Alternate Energy Systems
Room 661A
111 North Hope St.
Los Angeles, CA 90012
Attn: Hung Ben Chu

Martin Marietta Aerospace
P.O. Box 179, MS L0450
Denver, CO 80201
Attn: H. Wroton

McDonnell Douglas (2)
MS 49-2
5301 Bolsa Avenue
Huntington Beach, CA 92647
Attn: R. L. Gervais
J. E. Raetz

Meridian Corporation
5113 Leesburg Pike
Falls Church, VA 22041
Attn: D. Kumar

Public Service Company of New Mexico
M/S 0160
Alvarado Square
Albuquerque, NM 87158
Attn: T. Ussery
A. Martinez

Olin Chemicals Group (2)
120 Long Ridge Road
Stamford, CT 06904
Attn: J. Floyd
D. A. Csejka

Pacific Gas and Electric Company
77 Beale Street
San Francisco, CA 94106
Attn: J. Laszlo

Pacific Gas and Electric Company (4)
3400 Crow Canyon Road
San Ramon, CA 94526
Attn: G. Braun
T. Hillesland, Jr.
B. Norris
C. Weinberg

Public Service Company of Colorado
System Planning
5909 E. 38th Avenue
Denver, CO 80207
Attn: D. Smith

Rockwell International
Rocketdyne Division
6633 Canoga Avenue
Canoga Park, CA 91304
Attn: J. Friefeld

Sandia Solar One Office
P.O. Box 366
Daggett, CA 92327
Attn: A. Snedeker

Science Applications International Corp.
10401 Roselle Street
San Diego, CA 92121
Attn: B. Butler

Solar Energy Research Institute (3)
1617 Cole Boulevard
Golden, CO 80401
Attn: B. Gupta
D. Hawkins
L. M. Murphy

Solar Kinetics Inc.
P.O. Box 47045
Dallas, TX 75247
Attn: J. A. Hutchison

Southern California Edison
P.O. Box 325
Daggett, CA 92327
Attn: C. Lopez

Stearns Catalytic Corp.
P.O. Box 5888
Denver, CO 80217
Attn: T. E. Olson

Stone and Webster Engineering Corporation
P.O. Box 1214
Boston, MA 02107
Attn: R. W. Kuhr

6000	D. L. Hartley; Attn: V. L. Dugan, 6200
6220	D. G. Schueler
6222	J. V. Otts
6226	J. T. Holmes (10)
8000	R. S. Claassen; Attn: R. J. Detry, 8200
	P. Mattern, 8300
	R. C. Wayne, 8400
8100	E. E. Ives; Attn: J. B. Wright, 8150
	D. J. Bohrer, 8160
	R. A. Baroody, 8180
8130	J. D. Gilson
8133	L. G. Radosevich
8133	A. C. Skinrood (3)
8133	D. N. Tanner
8244	C. Hartwig
8245	R. J. Kee
8265	Publications Division for OSTI (30)
8265	Publications Division/Technical Library Processes Division, 3141
3141	Technical Library Processes Division (3)
8024	Central Technical Files (3)