Display Specification for Fossil Power Plant Digital Control System Operator Interfaces

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REPORT SUMMARY

Technical advances in control systems have resulted in major changes in the human-machine interface. In particular, operators now interact with CRT displays instead of hard control panels. This specification describes various features of graphics, controls, and computer systems needed to create displays that apply human factors design principles. Additionally, the specification offers guidance on display design and provides example displays.

Background

In 1984, EPRI first published human factors guidelines for fossil power plants entitled, Enhancing Fossil Power Plant Design, Operation, and Maintenance: Human Factors Guidelines (CS-3745). EPRI updated those guidelines in 1993, now titled, Human Factors Guidelines for Fossil Power Plants (TR-101814). This current specification provides more specific information on CRT displays and screens than was contained in the previous human factors guidelines.

Objective

To provide guidance on display hardware and graphics systems capabilities and present information on designing screens according to human factors principles.

Approach

The project team gathered information from 10 utilities on operational experience with CRT-based control systems, including screen examples. In general, utilities described problems with information clarity and ease of access. Additionally, they expressed a wide range of opinions on how to design effective screens that incorporate the most important human factors features. Because of this variation, the display specification addresses common issues, with some latitude for individual preferences.

Results

Use of human factors guidelines will enhance the clarity of information on CRT display screens and improve organization of control functions for fossil power plant operators. This specification addresses two major issues: hardware and display specifications and display examples.

Hardware specifications include CRTs, keyboards, input devices, and printers, and could involve, for example, identifying the appropriate CRT performance factors for a particular control room application. Display specifications emphasize screen content, screen organization, coding techniques, menus, windows, information format, alarms,

and integration between controls and displays. A display specification could, for example, recommend redesign of the screen to ensure appropriate brightness, resolution, and contrast for a specific work environment.

The example screens represent a wide range of digital control system displays. As mock-ups, they incorporate aspects of displays from many utilities but are not from any individual utility. This specification contains discussions of important human-machine elements of the example displays. For example, the specification illustrates various data graphic techniques to facilitate rapid scanning of information.

EPRI Perspective

Human factors considerations are essential for the successful implementation of a CRT-based operator interface. The explosion of information and capabilities available from modern control system displays in combination with a greatly reduced display area require careful design of an operator interface. This specification provides information not previously available, describing display equipment and the design of fossil power plant screens that incorporate human factors guidelines.

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Interest Categories

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Fossil steam plant systems and performance
Engineering and technical support

Keywords

Fossil fuel power plants
Control systems
Real-time systems
Human factors engineering
Computer graphics
Display devices

ABSTRACT

The introduction of digital control systems (DCS) in fossil power plant control rooms has significantly changed the human-machine interface. Now operators receive information from CRT displays and control the plant using computer input devices. Human factors principles can be applied to the human-machine interface to improve information flow and make it easier to control the plant. To that end, EPRI recently issued a general document: *Human Factors Guidelines for Fossil Power Plants (TR-101814),* which includes one chapter on the human-machine interface. The display specification contained herein provides more detailed guidance on the subjects of display hardware and screen design.

This specification describes requirements for digital control system vendors to incorporate into their designs and bids. As an example, the specification recommends graphics capability for organizing data in windows. DCS vendors typically provide hardware and software but do not build the plant-specific display screens. Those screens should be designed by a team with representatives from operations, engineering, human factors, and software areas. The specification contains a large set of screen examples based on human factors principles. These screens provide a starting point for a design team to develop plant-specific displays.

OBJECTIVES

This document has two objectives:

1. To serve as an example that can be used with little modification by utilities to develop part of the procurement specification for control system upgrade projects. This model describes the hardware requirements and graphics system capabilities required to generate displays capable of meeting current human-machine interface system display requirements.

2. To show examples of major kinds of displays meeting current human-machine interface system display guidelines. The important human-machine elements of the example displays are evaluated and discussed.

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- Alabama Electric Cooperative
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- Philadelphia Electric
- Public Service Indiana
- Southern California Edison
- Southern Company Services

The displays reproduced herein are not specific to any of the utilities listed above or otherwise, or to any digital control system vendor, but are the creation of the authors. Display examples which bear resemblance to a particular vendor's DCS system do so for illustration purposes only. Nothing in this document constitutes an evaluation or endorsement for any particular DCS design methodology. The display examples are intended to provide ideas and guidance to display designers who will wish to use the principles illustrated in these examples to create displays that suit their own utilities' specific needs and objectives.

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PART ONE:

HARDWARE AND DISPLAY SPECIFICATIONS

The CRT consoles will be the primary method of user interface with the real-time data acquisition and control functions of the digital display control system (DCS). Each console, which includes three to six CRTs, should operate independently of the other consoles and a failure at one console should not affect the operation of another console. The consoles will be made up of the following equipment:

- Colorgraphic CRTs
- Keyboards
- Other Input or Control Devices
- Printers

1.1 Colorgraphic CRTs

1. Supply CRTs that are, at a minimum, 19-inch color CRTs.
2. Ensure the CRTs meet the preferred luminance ratio for characters and background of 7:1; the minimum luminance ratio is 3:1.
3. Equip the CRTs with a circular polarizer bonded to the CRT face and a quarter-wave anti-reflection coating.
4. Equip the CRTs with anti-glare screens (optional).
5. Ensure the CRT display does not have any perceivable flicker.
6. Ensure the CRT response time accords with the following:.

A. Computer System Interpretation of Action

Computer System Interpretation of Action	*Response Time (seconds)*
Key response	0.1
Key echo	0.2
Data field entry	0.2
Pointing	0.2
Drawing or sketching	0.2
Local update	0.5
Page scroll	0.5
Next page	1.0
Function selection	2.0
Host update	2.0
Simple inquiry	2.0
Error feedback	2.0
File update	10.0

B. If response time exceeds three seconds, display a delay message indicating the control system is operating normally.

7. Ensure the CRT displays dynamic data as follows:

   A. Update rates for graphically presented real-time data does not exceed 0.5 seconds.

   B. Alphanumeric values that the operator needs to reliably read do not change more than once per second.

1.2 Keyboards

1. Use a QWERTY keyboard that provides immediate feedback (key resistance or audible click) for each keystroke.

2. Group function keys together and make them easily distinguishable from other types of keys.

3. Provide the capability to clearly label each function key.

4. Provide the capability to use colors to code functional groups of keys.

5. Select matte colors to reduce shine and glare.

6. Use a minimal number of colors consistently.

7. Design the numeric keypad as a 3 x 3 x 1 matrix with the zero digit centered on the bottom.

1.3 Other Input or Control Devices

The following are types of devices used for inputting data or controlling functions in a DCS other than a conventional keyboard:

- Membrane Keyboard
- Trackball
- Mouse (X-Y Controller)
- Light Pen
- Touch Screen

(The utility should select the devices wanted and modify this section accordingly.)

1. <u>Membrane Keyboard</u>

   A. Provide auditory or tactile feedback for each keystroke.

   B. Provide embossed borders for keys to assist placing the fingers.

2. <u>Trackball</u>

   A. Use a trackball that is at least two inches in diameter.

   B. Ensure the cursor cannot be driven off the edge of the display.

   C. Provide wrist or arm support if the trackball is used for precise or continuous adjustment.

3. Mouse (X-Y Controller)

   A. Create consoles with enough workspace on either side of the keyboard to use a mouse

   B. Ensure the cursor cannot be driven off the edge of the display.

4. <u>Light Pen</u>

   A. Use a light pen designed with a switch to activate the signal.

   B. Visually designate the screen area that can be activated by the light pen.

C. Provide a place on the workstation to hold the light pen and a retractor or trough to keep the cord from laying over the keyboard when not in use.

5. <u>Touch Screen</u>

A. Provide software control to ensure there is adequate space between poke points.

B. Ensure the touchable area of a poke point is 0.75-1.0 inch square.

C. Ensure the touch screen accepts only one command at a time, indicates the command was accepted, and responds within 0.1 seconds to the command.

D. Require two separate touches (a "select" poke point and an "operate" poke point) to enter a command that affects the control system.

E. Locate the "select" poke point and "operate" poke point in separate area of the screen to prevent accidentally activating a control.

1.4 Printer

1. Include a printer that allows a clear view of the last printed line.
2. Ensure parameters and scale units can be identified and that column headings can be printed at least once per page.
3. Code color printing according to display coding standards.

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SCREEN CONTENT

Each display screen is structured and its contents formatted to enhance usability. The font is simple and easy to read and the cursor is distinguishable and an effective locating aid. Control system messages, alphanumeric codes, and continuous text are all consistently formatted so users do not have to interpret the information. On-line help is provided so users do not have to rely on memory for information like abbreviations, symbols, and codes. The design elements structure each screen to ensure information is easy to understand and use.

2.1 Font

1. Ensure the font is readable.
2. Ensure the font has character spacing of at least 10% of character height or one pixel.
3. Ensure the following character matrices are available to create characters:
   - 5 x 7 character matrix
   - 7 x 9 character matrix
   - 4 x 5 character matrix
4. Ensure that both uppercase and lowercase lettering is available.

2.2 Cursors

1. Design a cursor that is distinct and easy to locate.
2. Include a point designation "hot spot" on the cursor that is small and obvious to enable exact pointing or positioning.
3. Program the cursor to blink at a rate of 3 HZ.
4. Ensure the cursor cannot be driven off the display.
5. Ensure the control actions for positioning the cursor correspond to the direction the cursor is moving on the screen.
6. When a selectable item is touched by the cursor "hot spot," high light the selected item.

7. If multiple screens share the same cursor, ensure the cursor appears immediately on the second screen when it exits the first.

8. If multiple screens are controlled by a single keyboard, display the cursor only on the screen interacting with the keyboard.

2.3 Messages

1. Write messages in plain English and ensure messages can be tailored to include all the necessary information (such as document references and corrective actions).

2. Provide the capability for two levels of detail for each message: a detailed message for the novice user and an abbreviated message for the experienced user.

3. Highlight critical messages that require immediate operator response.

2.4 Alphanumeric Codes

1. When an alphanumeric code is entered, ensure the control system can display an English-language description of the item.

2. Group codes into sets of three to five characters.

2.5 Continuous Text

Continuous text is a block of text in sentence format. The ability to use continuous text should comply with the following:

1. At a minimum, display four lines of continuous text at a time.

2. Display continuous text in wide columns of at least 50 characters per line.

3. Provide adequate spacing between lines of continuous text.

2.6 On-line Help

1. Create on-line help that is available at any point in the control system.

2. Provide the following types of on-line help:
   - Reference material describing control system capabilities and procedures
   - Data index to guide users in selecting what data to display

- Command or code index to guide selecting and composing commands
- Dictionary of abbreviations and acronyms
- Dictionary of symbols and icons

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SCREEN ORGANIZATION AND LAYOUT

Each display screen is organized and laid out with the goal of facilitating information retrieval. Screens are partitioned into zones, which organize the information. Information that is too great to fit entirely on one screen is organized into multiple pages and formatted to always show the location within the multiple-page display. The display hierarchy is laid out to help the user locate the desired information or controls from anywhere in the control system.

3.1 Display Partitioning

Each display shall be partitioned into zones that govern the type of information appearing in that zone. The zones shall remain consistent for all displays and comply with the following:

1. Place a field containing the display title, an alphanumeric designator, and the current time and date at the top of every display page.

2. Reserve specific areas of the screen for standard information (such as, display titles, status messages, menu bar, function key labels, and command entry).

3. Use demarcation to visually separate standard information fields from the main display area.

3.2 Multiple Page Considerations

When a display contains too much information to present in a single frame, present the information on multiple pages that comply with the following specifications:

1. Label each page to show its relation to the other pages.

2. Number separate pages to identify the currently displayed page and the total number of related pages (Page I of 3).

3. For scrollable pages, provide a scroll bar on the display to indicate the relation of the previously displayed page.

4. Provide summaries or overviews where there are several pages of similar information that require monitoring for a small set of predictable deviations.

3.3 Display Navigation

Design the display hierarchy so that it is easy to navigate among the displays and locate the necessary information and controls according to the following specifications:

1. Provide a map of the display network that is available on user request.
2. Organize display pages so that displays used in sequence can be accessed by a single action, such as paging.
3. Dedicate function keys to access displays and controls that are time-critical.
4. For menu or sequential access schemes, allow the user to randomly access displays by using command entry.
5. Provide a "type ahead" capability allowing the control system to process and act on inputs while intermediate displays are being drawn.
6. Allow the user to proceed to the next step in the selection process before an intermediate display is fully displayed.
7. Create a "return to previous display" capability, which recalls the last data display rather than the last menu.
8. Provide a direct call-up of the appropriate data display from an alarm display.

4

CODING TECHNIQUES

Information can be coded to convey the following: location, differentiation, qualitative differences, and approximate quantitative differences. Effective methods for coding information are using color, attention-getting properties, and graphic symbols. Each method has its own purpose and specifications.

4.1 Color Coding Techniques

Color coding helps the user locate specific information quickly and is not necessarily attention getting. Color coding should comply with the following specifications:

1. Ensure there are at least eight distinct colors to minimize the instances of using the same color for more than one meaning.

2. Use brighter, more saturated, colors to draw attention to the coded item.

3. Ensure color codes on the CRT do not conflict with color codes used on other displays in the control room.

4. Confine the colors used for emphasizing especially critical items to a single use or meaning.

5. Ensure color is never used as the only means for conveying information (in consideration of color-limited vision).

4.2 Enhancement Coding Techniques

Enhancement coding or highlighting is used to create attention for selected portions of a display, and can include any of the following techniques:

- Brightness
- Blinking
- Contrast Reversal or Color Padding

1. Brightness

   A. Use only two intensities when using brightness for coding information.

   B. Ensure the brighter intensity is at least two times the intensity of the dimmer.

2. Blinking

   A. Use blinking or flashing to highlight information that requires immediate attention.

   B. Use a blink rate of two to five HZ.

   C. When two blink rates are used, apply the higher rate (3 HZ) to the more critical information and the lower rate (less than 2 HZ) to less critical information.

   D. Provide a means for turning off the blinking once the user has attended to the display.

3. Contrast Reversal or Color Padding

   A. Use contrast reversal for highlighting critical items that require user attention.

   B. Ensure the borders around characters that use contrast reversal or color padding extend at least one-half character width beyond the characters.

4.3 Other Visual Coding Techniques

Other visual coding techniques, such as pictorial coding techniques, can conveyapproximate (but not exact) qualitative information. Some effective visual coding techniques are:

- Symbols and Icons
- Size Coding
- Line Coding

1. Symbols and Icons

   A. Only use symbols that are easily distinguishable from one another.

   B. If an icon is potentially ambiguous attach a textual label to the icon.

C. Ensure the symbols used on the CRT are the same or similar to symbols used in other media such as prints.

D. Ensure all symbols are simple, closed, and large enough to interpret from a reasonable viewing distance.

E. Ensure that symbols and icons have a common meaning that is identical for each usage.

2. <u>Size Coding</u>

The physical size of an object can be used as a coding technique (for example, smaller characters for labels and larger characters for real-time data). Size coding should comply with the following specifications:

A. Provide a maximum of three sizes for size coding.

B. Ensure the larger symbol is at least 1-1/2 times the height of the smaller symbol.

3. <u>Line Coding (Thickness or Width</u>)

Varying the line thickness or width can be used on mimics to discriminatebetween lines that run in parallel. Line coding should comply with the following specifications:

A. Provide a maximum of three line sizes for use in coding lines.

B. Ensure that weight-coded lines differ from each other by a factor o£ 1.5.

C. Assign weight codes to correspond to either the physical capacity of the pipe or electrical bus OR to the importance of the pipe or bus.

4. <u>Geometric Shapes</u>

Do not use arbitrary geometric shape coding. Use standard symbols or icons instead.

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MENUS

A menu is a screen, or a portion of a screen, that displays selectable items. Well organized menus can minimize training requirements because the menus lead a user through options. Items can be selected from menus by using a keyboard or pointer device and the menus need to be designed with the selection method in mind.

5.1 Menu Design

1. Provide a pointing method for selecting items from a menu.

2. If menu items are not available at certain times, show them as dimmed, outlined, or shaded to indicate they are temporarily not available.

3. Provide the capability for both single-choice and multiple-choice menus.

4. In multiple choice menus, provide a means for simultaneously highlighting each selected item (numbering or shading).

5. If window or pop-up menus do not occupy the entire screen, design them to appear in the same place on the screen, preferably in the center.

6. Design a feature on all window and pop-up menus to remove them from the screen without selecting a displayed item.

7. Provide dedicated keys to access displays or control functions that are time critical.

8. For displays that are commonly called up in a sequence, provide direct linkages via page up/down/right/left keys.

9. Allow users to bypass the menu by entering a command via the keyboard.

5.2 Keyboard Selection

1. Code menu selection items using the first letter of a key word or the first word in the menu item name. Provide a standard display area for entering the code and place the cursor in that area.

2. When using control keys (Aft, Shift, etc.) with the first letter code, group codes with similar functions together under one control key.

3. When menu items are selected by using the cursor control, tab, or return keys, design the menu screen so that the cursor appears on the first available menu item.

5.3 Pointer Selection

1. Create the following two-step selection method: first, position the pointer to designate and highlight the menu item; second, select the item for execution.

2. Design menus with sufficient pointing area to enable users to quickly select items without making an error.

3. Highlight items under the pointer.

4. To minimize "first-touch misses" on a touch screen, provide wider than normal item spacing and pointing areas.

5. When using a touch screen, provide an "execute" field on the menu rather than requiring a keyboard entry to select an item.

5.4 Hierarchical Menus

1. Design hierarchical menus so that the subordinate items are displayed when the upper-level item is pointed to.

2. On each lower-level menu, provide an option allowing the user to return to the next higher-level menu.

3. On each menu, provide an indication of where the current menu is in relation to the hierarchy or network.

6

WINDOWS

Windows are frames for viewing a functional display or a portion of a display. The contents of a window can be independently selected and manipulated. Designing a window includes some of the following considerations: visual demarcation; dedicated window space; overwriting current display information; and restoring the original display. Windows should be designed to allow user flexibility without creating a significant amount of new work for the user.

6.1 Real-time Windows

1. Visually separate windows from the background by a border or other demarcation.

2. Clearly identify the active window and allow only one window at a time to accept inputs.

3. Provide a method of closing the window.

4. If the entire frame is not displayed in the window, provide scroll bars (or another reference device) to show what section of the frame is displayed and to allow the contents of the entire frame to be displayed within the window.

5. Provide a method for changing the size of the window. Ensure that changing the size of a window only affects the viewing area and not the format or contents of the window.

6. Ensure the methods for controlling windows are the same throughout the control system.

7. If windows will overwrite information on real-time displays, provide a method of rapidly restoring the original display.

8. If windows will overwrite time-critical information, display any important changes in the status of information that is hidden from view.

6.2 Pop-up Windows

1. Dedicate window areas (tiles) for displaying user-selected information.

2. Preformat the information available for user selection in the dedicated window areas so the user only has to select what information to display and does not have to format the information.

3. Dedicate a window area in which to display soft control or "pop-up control" stations.

4. Design the window so it is possible to change out and then recall the parent display with the same windowed information it had on it.

6.3 Dialogue Boxes

A dialogue box is a window that pops up on a portion of the screen that requires a user response and establishes a dialogue between the user and the computer.

1. Display dialogue boxes in the lower portion of the screen, close to the keyboard.

2. Use a single dialogue box to elicit as many responses or perform as many actions as possible.

3. Provide a clearly identified method of closing a dialogue box.

6.4 Alert Boxes

1. Display alert boxes in the center of the screen.

2. Design alert boxes to provide information or recommended corrective actions to the operator.

3. Provide a clearly identified method of closing an alert box.

7

INFORMATION FORMATS

In addition to the numerical or text presentation of data or information, the CRT provides opportunities to use pictures, which can allow a user to more rapidly process the data. Drawing a graphic presents data in a simple and easily interpretable form, especially when comparing numerical data. Each type of graphic has design specifications that need to be considered.

7.1 General Characteristics

1. Provide a limited number of different formats so the operator is familiar with the presented information.

2. Limit the amount of information presented to only that information necessary to perform the specified task (task, in this case, refers to control of the computer display rather than the plant per se).

3. Use the simplest format needed to reduce the amount of time needed to interpret the display and decrease the chance of an error.

4. Provide templates for simple and clear graphs.

5. Create uncluttered and simple analog displays (for example, meter scales).

6. Indicate acceptable limits or normal operating ranges on plots and other graphics.

7.2 Digital Displays

1. Change the digits slowly to ensure good readability.

2. When appropriate, provide arrows to indicate the direction of change.

3. Provide + or - signs to indicate positive and negative values.

7.3 Analog Displays (Meter Configuration)

1. Provide the capability for creating analog displays where a rapid check-reading of an approximate value is needed.

2. Orient numbers and wording upright.

3. Ensure the pointer does not cover graduation marks.

4. Vary the length of major, intermediate, and minor graduation marks.

5. Allow numbers to be placed outside the graduation marks.

7.4 Binary Indicator

Use color, intensity, flashing, or highlighting to indicate the status of a binary indicator (for example, "on" or "off").

7.5 Trends

Trend plots are used to show how one or more variables change over time. In a trend plot, one of the axes is always time. A single value line chart is a variation of a trend plot in which two variables (one not necessarily time) are plotted against each other (for example, pressure versus temperature). Both trend plots and single value line charts have similar specifications.

1. Resolution

   Provide the following capabilities for organizing and displaying the raw data:

   A. Averaging of all samples in the update interval

   B. Creating a weighted average

   C. Displaying a high resolution of both axes to show short-term fluctuations

   D. Using good temporal resolution to rapidly display feedback on how the control system is responding to control inputs

2. Length of Time History Displayed

   Enable the user to choose the length of time history shown (for example, the last few minutes for an operator predicting where the process is going or the last 12 hours for an engineer evaluating long-term trends) as appropriate.

3. Multiple-Parameter Trends

   A. Provide the capability of plotting more than a single trend line per chart.

B. Provide the capability of using coding (color, line weight) to distinguish the trend lines.

4. Size

A. Provide the capability of creating a two-panel plot, which draws the last 10 minutes with fine resolution in the right "fast speed" panel and the preceding 50 minutes (or several hours or days) is drawn with much coarser resolution in the left "slow-speed" panel.

B. Provide the capability of creating scrollable plots that can be scrolled to show any interval of time history.

5. General Characteristics

A. Use graph lines that contain at least 50 pixels per inch.

B Ensure that large fluctuations are not shown in trend plots as a result of minor fluctuations in data.

C. Provide digital readouts for the current value of each parameter.

D. Provide a cursor that will give a digital readout of the value of displayed parameters at a selected point in time.

E. Show both the current value of the data and a trail showing the movement of data over time.

7.6 Mimics

Mimic displays illustrate component relationships in a functionally Oriented diagram. Mimic displays are drawn as graphic representations of a plant system showing directional data to help operators visualize the relationships among components. Use the following specifications:

1. Provide the capability for color coding the different flowpaths.

2. Use the same colors on the CRT as used for color coding on the control panels.

3. Use arrowheads to clearly indicate flow direction.

4. Label all origin and destination points.

5. Provide the capability of using three line widths (and no more) to show volume of flow.

6. Provide symbols that are easily understood by operators, yet show a meaningful pictorial representation with minimal detail.

7.7 Graphs or Charts

Provide the capability to create the following types of graphs or charts to represent data:

- Bar or column chart
- Deviation bar
- Range bar or column chart
- Subdivided or cumulative bar chart
- Band chart

(The utility should decide which formats they want to specify.)

1. Graphs/Charts General Characteristics

   A. Provide the capability for labeling each axis.

   B. Allow up to nine graduation marks between numbered scale points.

   C. Increase the magnitude in scales from left to right, bottom to top, and clockwise.

   D. Maintain a good contrast between scale markings and the displayed values.

2. Bar or Column Graphs

   A. To compare data, provide the capability of placing bars or columns adjacent to one another.

   B. Allow bars or columns to incorporate limit markers or color coding to show normal operating conditions.

3. Deviation Bar Graphs

   A. Indicate a normal band for each parameter.

   B Ensure the bars grow outward from a "normal" central stem.

4. Range Bar

   A. Present the range of variation as a bar whose ends indicate the high and low values of a set of related data.

   B. Indicate the average by a symbol on the bar.

5. Cumulative Bar Chart

   Provide the capability of clearly distinguishing each different segment from each other.

6. Band Charts

   A. Ensure that the different bands are distinguishable from each other.

   B. Place the least variable curves at the bottom and the most variable curves at the top.

   C. Provide the capability of labeling areas of the band chart within the shaded bands as well as on an accompanying legend.

7.8 Profiles

Profiles are created by plotting points and shading the area between or beneath the points to form readily recognizable shapes. Any abnormal condition is shown as a distortion of the shape. Profiles are useful for detecting patterns, but not for determining precise values. Provide the capabilities to create the following types of profiles:

- Linear
- Circular
- Fourfold circular

1. Linear Profile

   A. Provide the capability to draw a line connecting points and shade the area under the line.

   B. Superimpose a line that illustrates normal operating conditions so that any abnormal conditions are easily distinguishable.

2. Circular Profile

   A. Place the variables radially from the center of a circle to create a closed figure with a distinctive shape.

   B. Organize the chart so it forms an easily recognizable shape.

   C. Scale the variables so the shape of the profile is radially symmetrical when the variables are normal.

   D. Provide digital readouts of the values of all parameters.

3. Fourfold Circular

   A. Divide the circle into no more than six sectors, each sector representing a variable.

   B. Indicate the value of a variable by the radius of each sector.

7.9 Data Maps

Data maps show the spatial distribution of a large number of variables that are measured in separate locations (for example, boiler tube temperatures).

1. Provide symbols that are easily understood by operators, yet show a meaningful pictorial representation with minimal detail.

2. Provide the capability for color coding the different paths and symbols.

7.10 Display Enhancements.

1. Arrows

   A. Use damping and deadbanding to eliminate meaningless arrow changes in response to normal minor fluctuations in the process or noise in instruments.

B. Use 45° up (??) and down (??) arrows or other distinctive formats (⇑) for vertical arrows to avoid confusion with the numeral "1.".

2. Limit Marks

A. Draw limit marks that are easily distinguishable from data, tic marks, or grids.

B. Use a colored fill to indicate an out-of-limits zone only when it is not immediately apparent which side of a limit line is the out-of-limits zone.

3. Grids

A. Draw grids so that the data is laying on top of the grid rather than the grid laying on top of the data.

B. Draw grid lines that are of a lower contrast than the data placed on the grids (for example, thinner lines, dimmer lines, or less conspicuous colors).

C. Make the grid lines that are numbered bolder than the grid lines that are not numbered.

4. Fills

A. Use a solid color or a shade of gray rather than cross-hatching for fills.

B. If the purpose of the fill is to differentiate rather than to emphasize data, use a muted color.

C. Use a muted color to indicate an out of limits or unacceptable zone.

D. Use a bright fill to call attention to important deviations in deviation bars and deviation trend plots.

8

ALARMS

Alarms are used to call the operators' attention to off-normal conditions that may affect the continued operation or safety of the plant. An alarm system includes alarm identification, the auditory alert, the alarm message, an alarm list, and the alarm system controls. All these features must be consistently formatted to develop an effective alarm system.

8.1 General Characteristics

1. Provide the capability for at least two levels (utility should specify) or tiers of setpoints to allow the operator adequate time to respond to the warning condition before a serious problem develops.

2. Design the alarm system to code and sort alarms according to a user-definable priority scheme of at least three levels of severity or importance.

3. Design the ringback feature as follows:

   A. Provide a ringback silence control separate from the acknowledge function.

   B. Display cleared alarms until they are manually reset.

   C Have all momentary alarms automatically ringback.

   D. Do not use an audible alert for ringback.

4. If conventional hard panel or other non-CRT-based annunciators are used with CRT-displayed warnings, repeat annunciator alarms on the CRT alarm list and other alarm displays.

5. Ensure consistency between the alarm message and alarm priority when alarms are presented on an annunciator and CRT.

6. If the majority of control actions are performed via the CRT, control the hard panel or other non-CRT-based annunciator alarms through the CRT.

7. If the controls used to respond to alarms are placed on control boards (and not on the CRT), build a set of operator controls (such as, Acknowledge, Silence, and Reset) that are distinct from the CRT controls.

8. If auxiliary equipment is shared by a facility with multiple control rooms, provide alarms for shared plant systems in all control rooms.

8.2 Auditory Alert System

1. Provide an auditory alert signal only for those alarms that require prompt attention.

2. Code the auditory alert signal, using a maximum of 8 levels, according to the alarm priority or the plant system affected. If more than 3 levels of auditory coding are desired, ensure the signals differ in two or more characteristics.

3. Ensure the auditory alert signal for the highest priority alarms remains on until silenced by the operator.

4. Have the auditory alert signal for alarms not requiring immediate response self-terminate after a brief interval.

5. Use an auditory alert signal for the CRT-based alarms that is discriminably different from auditory alerts used for other purposes (such as the Fire Alarm System).

6. In a multiple-unit control room, use the following methods for distinguishing each units' alerts:

   A. Assign auditory alert signals that aid in distinguishing which unit the alarm is associated with.

   B. When different tones are used for differing priorities, use separate speaker systems for each unit and place the speakers over each unit's console.

7. To ensure the intensity of the auditory alert signal can be reliably heard above the ambient control room noise, amplify the alert signal above the average ambient noise.

8.3 Alarm Message Content

1. Include the following in each alarm message content:

   - Plant system or component affected

- Parameter in an off-normal state
- Nature and severity of the deviation
- Indication of severity of problem or priority of corrective action (color coding or redundant symbols)
- Value of setpoint violated
- Reference to additional information for the affected plant system or component

2. If the time of the alarm or ringback is included in the message, present it last in the message line.

3. On color CRTs, indicate alarm severity or priority by color codes.

4. On monochrome CRTs and printers, use a redundant symbolic code to indicate alarm severity or priority.

5. Use the following alarm message syntax:

   A. Parameter Alarms:
   <priority><parameter><nature/severity><current value & associated engineering units><violated setpoint><reference><time of alarm> * MAIN STEAM PRESS HI 2453#(2440) A 15:36:27

   B. Component Alarms:
   <priority><component><status><reference> <time of alarm> ** FEEDWATER PUMP A TRIP A 15:36:28

   C. Ringback:
   <priority><plant system/parameter><nature/severity> <current value & units><cleared setpoint> <reference><time of return to normal> /MAIN STEAM PRESS NOR1M 2412#(2440) A 15:41:10

6. Write specific and unambiguous alarm messages.

8.4 Alarm Lists

1. Create a multiple-paged alarm list display.

2. Provide and print a separate sequence of events list, which tracks all alarms and ringbacks in chronological order. Time stamp each entry on the list to the finest detail possible (for example: mm/dd hh:mm:ss:ddd).

3. Use visual coding to distinctly indicate a new and unacknowledged alarm (for example, blinking or brightness).

4. In alarm message lists, separate alarms by priority with the highest priority alarms listed first. Within each alarm category, list the alarm messages in chronological order with the most recent alarms at the top.

5. Allow the operator to choose which alarm priority to display and indicate on the screen the alarm priority displayed.

6. Keep alarm messages that overflow the first page on subsequent alarm pages.

7. Number each page of an alarm list with "Page X of Y" where "Y" is the number of pages currently displaying alarms.

8. List alarms with the most recent alarms entered at the top of the page and the oldest alarms moving from the bottom of the page to the next alarm page.

9. Use paging to access subsequent pages of an alarm stack if only one method is available. If more than one method is available, use both paging and scrolling.

10. Alert the operator to an unacknowledged alarm on a page that is not displayed (for example, a blinking page number or a blinking up and down arrow in the margin or next to the page number).

11. Indicate a ringback by changing the appearance of the formerly active alarm message. Do not indicate a ringback by writing another alarm message on the alarm list.

12. Require an explicit reset action to remove the cleared alarm from the screen.

8.5 Alarm System Controls

1. Provide a dedicated and labeled function key to call up the alarm lists.

2. Provide the following control capabilities for each work station capable of receiving and displaying alarms:

   A. Silence Control

      Design the silence control to extinguish all audible alarms within the operating area. For multi-unit control rooms, ensure the silence control only affects alarms for the work station's unit. Hardwire the control so that alarms can be silenced without having to change displays to access the controls.

B. Acknowledge Control

Design the acknowledge control to change the state of a displayed alarm from the ALERT state (typically blinking) to a STEADY-ON state. Ensure the acknowledge control only affects alarms that are currently displayed to the operator and does not affect alarms that the operator cannot see. Have the acknowledge control change the state of an acknowledged alarm throughout the control system. Design the acknowledge control function to acknowledge all alarms on a display instead of requiring each alarm to be selected and acknowledged individually.

C. Reset Control

Design the reset control to change cleared alarms from the RINGBACK to the OFF state and erase cleared alarms from an active alarm list. Ensure the reset control only applies to alarms that are visible to the operator when the control is activated.

D. Paging

Design each work station with the capability of paging through alarm lists.

3. Ensure that alarm system controls have identical functionality and layout on all consoles.

4. Distinctly identify each alarm system control.

8.6 Reducing and Prioritizing Alarms

1. Develop a separate means of displaying advisory messages for conditions not affecting plant system operation.

2. Do not implement alarms that need to be acknowledged for conditions that will be automatically corrected.

3. Avoid alarms that are activated as a part of a normal operating sequence.

4. Design the alarm system to suppress logically redundant alarms.

5. Design the alarm system to suppress alarms that are the logical consequences of trips or isolations.

6. To avoid nuisance alarms, allow alarm messages to be removed from the active alarm list and stored, with re-alarming being prevented.

7. Provide operators with the capability of disabling or suppressing alarm points. Provide a list, on request, of all suppressed alarms.

8.7 Functions Supporting Alarm Response

1. Design into all displays the capabilities for rapidly identifying, evaluating, and responding to alarmed conditions.

2. For mimic and other non-alarm list displays, highlight components or parameters in an alarm condition by color coding, blinking, or brightening.

3. Ensure the coding used for alarm information on non-alarm list displays is compatible with the coding used on the alarm lists.

4. When alarm information is displayed by coding components or parameter values, provide a means of displaying the associated alarm message on the same screen. (For example: reserve a two-three line area at the bottom of the screen designed to display the two or three highest priority alarms on the current display.)

5. Design the control system to allow for ready access to trend plots of affected parameters.

9

CONTROL/DISPLAY INTEGRATION

Controls and displays need to be integrated with the user in mind. Consider what is easiest for the user when establishing the method of user dialogue and control system feedback and creating manual/auto stations and controls on mimic displays. The objectives of control and display integration are to create a control system compatible with task requirements, minimize control actions, minimize memory load on the user, develop consistent control actions, and allow maximum control system and user flexibility.

9.1 User Dialogue

User dialogue is the means by which users interact with and control the computer system. User dialogue is designed to meet the following objectives:

- Compatible with task requirements
- Minimal number of control actions by the user
- Minimal memory load on the user
- Consistent control actions
- Flexibility of sequence control

1. Ensure that control actions are simple.

2. Assign frequent or time-critical control actions to function keys.

3. Ensure that sequence control actions are consistent in form and consequence from one transaction to another, from one task to another, and throughout the user interface.

4. Ensure the control system immediately acknowledges every controlling action: for every action by the user, ensure there is an immediate reaction by the control system.

5. Design the control system so that a controlling entry by one user does not interfere with another user who is simultaneously working on the control system.

6. Allow users to make control entries as needed; a sequence of control entries should not be delayed by control system response.

7. If a control entry must be delayed while a prior entry is being processed, indicate the delay to the user.

8. When control lockout occurs, provide the user with a means of overriding it, such as a special function key that will interrupt or abort the processing that causes a lockout.

9. Provide the capability for creating the following types of dialogues:
   - Question and answer dialogue
   - Form-filling dialogue
   - Menu-driven dialogue
   - Command language
   - Query language
   - Natural language

9.2 Control System Feedback

1. Continuously display an indication that the control system is functioning normally (for example, a blinking cursor, a ticking clock).

2. Ensure that every user input produces an immediate control system response.

3. If a function requires the user to standby while processing, provide periodic feedback to the user to indicate the control system is operating normally.

4. If the result of a transaction process is not displayed on the terminal (for example, printing a report), provide a feedback message indicating the transaction is complete.

5. When a command will irreversibly alter data or control system processing (for example, deleting a file), require a second, confirming input before executing the command.

6. Ensure that indications of control system status reflect actual, rather than demand, status.

7. Ensure the control system provides a "positive" indication that the computer, datalink, sensor, or control element has failed. Control systems that simply stop updating and fail as-is are not acceptable.

8. If the keyboard locks up or the terminal is disabled, signal the user by removing the cursor from the display. If disability problems are very infrequent, signal the user by a more prominent indicator such as an auditory signal or message.

9.3 Manual/Auto Stations

1. Design the different types of soft control stations so they appear distinctly different (such as, continuously variable controls versus discrete controls).

2. When an array of soft control stations are presented, highlight the one selected for operation.

3. Indicate which soft control stations are not available due to tagouts or unsatisfied permissives.

4. Label control stations to clearly identify the controlled component or process.

5. Label each indicator to identify its function or the parameters displayed.

6. Display the actual status of the controlled component.

9.4 Displaying Controls on Mimic Displays

1. When letters or numbers are used to identify components that may be operated, code identifiers in a distinctive fashion (for example, by color) and place them in a consistent location in relation to the component symbol.

2. Use one of the following methods to visually distinguish those symbols that can be operated from those that cannot:

   - Size coding
   - Brightness coding
   - Placing an "L" next to the symbols for locally operated components Displaying the valve/breaker number for locally operated valves/breakers, but not for remotely operated ones. Or, as an alternative to distinctly coding non-operable components, indicate these components cannot be operated by not highlighting them when the user attempts to select them. If selecting a component requires an explicit action such as pointing and clicking with a mouse, present an advisory message when the user attempts to select a non-operable component.
   - Using a background color for non-operable components that is different than for operable components.

3. Distinctly highlight a selected component (for example, by changing the color padding) on the mimic display.

4. When soft stations are controllable through a touch screen, display the soft control station for the selected control.

5. To prevent unintentionally activating a control on a touch screen, do not allow a procedure where the first touch of a point selects a component for operation and the second touch to the same location or a closely adjacent location executes the operation (for example, toggling a component on and off).

6. On mimic displays, if controls will be operated through the screen, reserve an area for soft control stations so the soft control stations will not overwrite other information.

7. When pop-up control stations overwrite portions of the main display, program the stations to disappear after they have been operated. Allow at least a 3-second interval for displaying and assimilating feedback before erasing the station.

8. When pop-up control stations overwrite portions of the main display, provide the user with a means for removing the station without operating the control.

9.5 Permissives and Tagouts

1. Indicate on the display if a control or plant system is not available.

2. Reduce clutter on mimics by using a selectable overlay or presenting an unsatisfied permissive symbol when the control is selected.

3. Provide information explaining why the permissive is not satisfied.

4. Indicate the status of all tagged-out components.

5. Ensure the control system is capable of completely disabling controls that are tagged.

6. Indicate all tagged components on mimics.

7. Provide access to pertinent tag information on demand.

9.6 Single Keyboard Controlling Multiple CRTs

1. Ensure the keyboard has a legend switch that illuminates to indicate the selected CRT. Lay out the legend switch with the same spatial layout as the CRTs (for example, one above the other for stacked CRTs).

2. Provide each CRT with some obvious indication, such as a pilot light that illuminates, when the keyboard is selected to interact with that CRT.

3. In control systems where the CRT for interaction is selected by driving the cursor from one screen to the other or by touching the screen, ensure the screen pilot light and keyboard legend switch illuminate to indicate the active display.

4. Ensure the CRT selected to interact with the keyboard displays a cursor (if appropriate) and the other CRTs do not.

A

APPENDIX: DISPLAY EXAMPLES

INTRODUCTION TO DISPLAY EXAMPLES

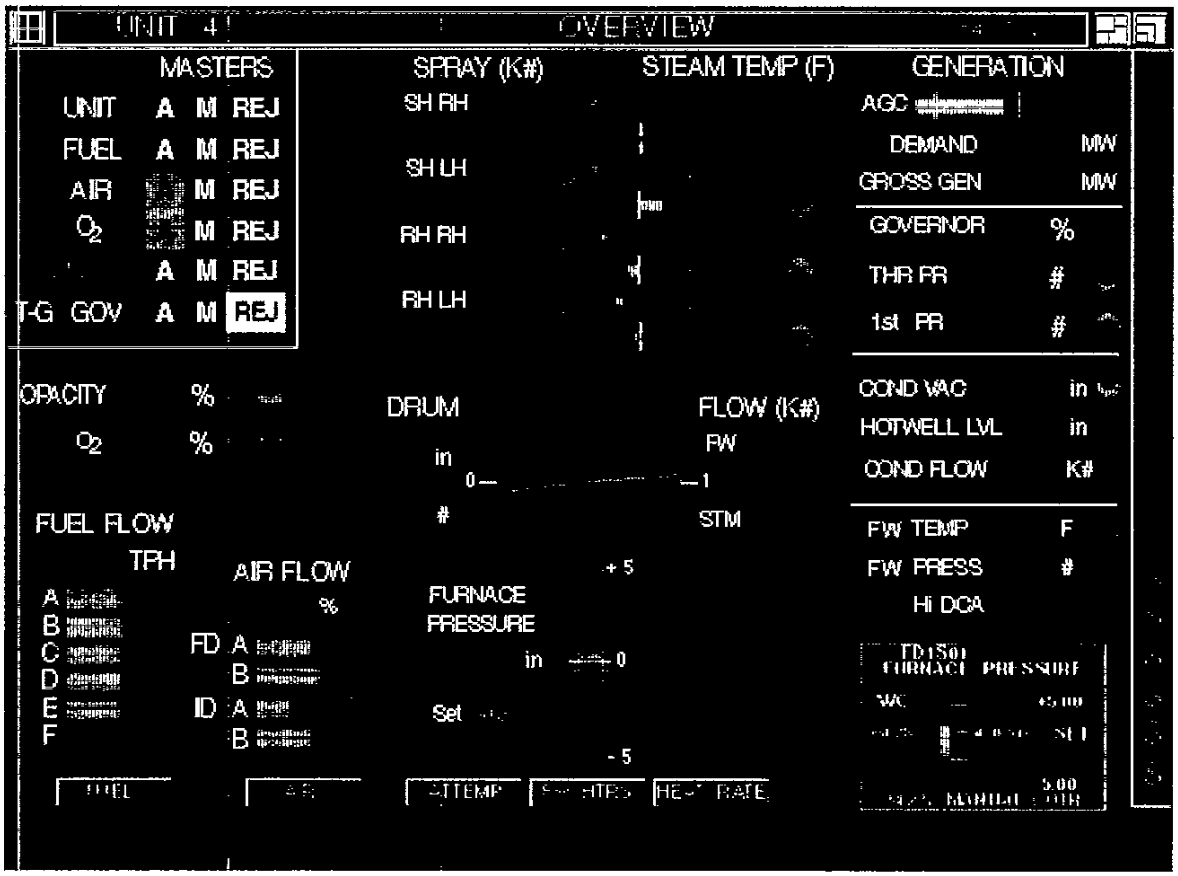
The display examples in this section are representative of the range of displays found on most digital control systems (DCS). They are display mock-ups rather than actual displays, although many are based on display examples provided by member utilities for a variety of different plants and DCS. The displays have been drawn on a number of "frames" representing the reserved areas found on systems from ABB, Bailey, Leeds & Northrup, and Westinghouse. The use of these "frames" does not constitute an endorsement of the particular vendor's system or graphic conventions, but rather serves the purpose of aiding the viewere in visualizing how a display fits in a frame. All displays assume a graphical user interface in which objects on the screen may be selected for operation by pointing (and selecting) via a cursor or touch screen.

The mock-ups in this report were drawn at approximately full scale for 13-inch monitors, or about 3/4 scale for 19-inch monitors. The display area has been scaled to represent a VGA screen 640 pixels wide by 480 pixels high. In the drawings, all lines have been drawn to be one, two, or four pixels in width.

All of the examples have been drawn to follow the display design guidelines presented in *Human Factors Guidelines for Fossil Power Plant Control Rooms and Remote Control Stations*, EPRI TR-101814. Color and size coding are used to differentiate labels, which are unchanging, from data, which is potentially variable. The coding scheme is intended to emphasize live data and de-emphasize the unvarying background information. Labels are written in light gray, and data values are written in bright green (or yellow, or white on red if they exceed alarm thresholds). Light gray is used for the labels rather than white to reduce their brightness, in order to make the data more conspicuous. The size of the lettering for labels was set to a nominal 12 points (for printing on standard letter size paper), with the data values in 16 or 18 point lettering. Note that the actual size of lettering on the screen, rather than its nominal point size, is what is important. Note also that different fonts of the same nominal point size may differ in height by 10-15%.

One single font has been used on the displays in the series. In general, font selection will be limited to those provided by display system vendors; more recently designed systems may provide a greater variety of fonts than those whose design is a few years old.

Data graphics such as bar graphs have been used to facilitate rapid scanning of information where appropriate, and where comparisons of related data or patterns of values may be important. Some of the displays also incorporate additional graphics in the form of schematics, which are used to provide a natural organization for plant data and (especially) controls. In these we have generally opted for symbols or simple boxes rather than the elaborately detailed drawings found on many displays.



Unit 4 Overview Screen

Two versions of this screen are provided. The first version has three unique graphics that may exceed the capabilities of some DCS graphics packages. On the second version, these unique graphics are replaced with bar graphs that essentially perform the same function. The first display was the original conceptual design: the second is an alternative design that eliminates the more complex graphic elements of the first design, **while retaining the same functionality**.

The intent of this screen is to provide an integrated overview of the plant in at-power operation. It incorporates information from an on-line performance monitor, presenting the deviation from calculated performance targets as "bulls eyes" located to the right of their respective parameter readouts. The screen allows monitoring of parameters affecting thermal efficiency during at-power operation and provides enough detail to allow the operator to detect developing problems before an alarm is triggered.

Labels, frames for graphics, and demarcation lines are light gray, and live data is green when within limits, red when out of limits, and red on yellow when immediate operator attention is required. Numerical values (the live data) are 30% larger than labels, presented in the brightest green (or other color), and in bold type so as to better convey the color/brightness.

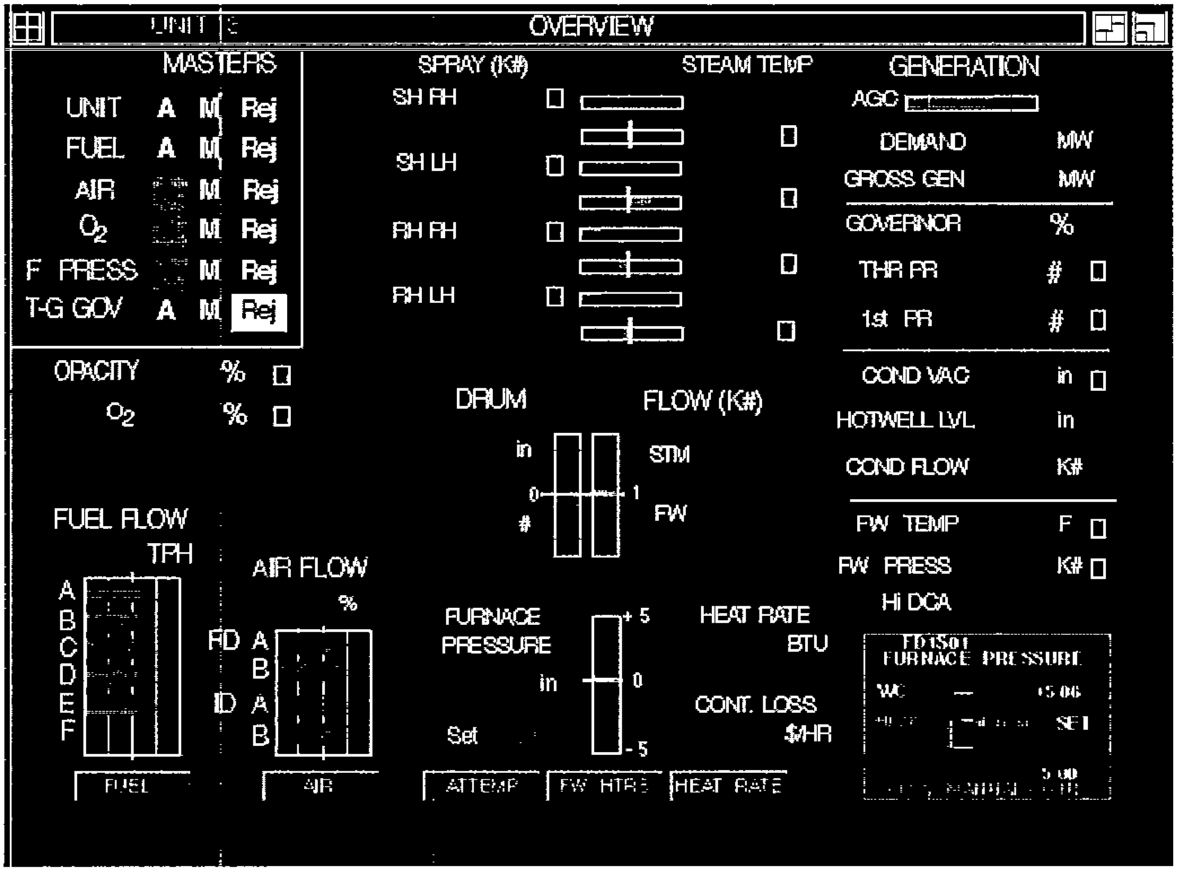
The status of the master controllers is summarized in the matrix at the upper left corner of the display. Selecting a controller with the cursor will cause the associated control to appear in the reserved pop-up window at the lower right.

Opacity and 02 readouts are located in the area below the controller status block. The accompanying "performance targets" show a centered "bulls eye" when values of the parameter are optimum or "on target". The "bulls eye" moves up or down within the target if the parameter's current value is more or less than the calculated target value. On the second screen the "bulls eyes" are replaced by small bar graphs which are essentially hollow squares when the parameter is on target and show red bars that grow larger as the parameter strays farther from its optimum value.

Below the Opacity and 02 readouts are summary graphics for air and fuel. The numerical values shown for these are total fuel flow and total air flow. The added graphics below the readouts show the relative values for the four fans (air) or the six mills (fuel — pulverizer F is not running). If one of the monitored components trips, a TRIP message is shown in place of the bar on the appropriate graphic. Alarms associated with the monitored equipment are indicated by the appropriate label and bar turning red.

Center screen, at the top: superheat right hand and left hand (SH RH & SH LH) and reheat right hand and left hand (RH RH & RH LH) steam temperatures are shown on four deviation bar graphs. The reference point is 1000°E Associated readouts and performance targets are on the same line as the deviation bars in the column labeled "STEAM TEMP (°F)".

Directly above each temperature bar is a graphic showing attemperating spray flow as a "pip" moving in an outlined slot (on the second display the moving pip is replaced by a conventional bar graph). The pip (or bar) shows the instantaneous (current) position of the spray valve: the range of the bar is 0-100%. The readouts to the left, in the column labeled "SPRAY (K#)" show the total flow in the past hour. The pips above the superheater temperatures are "parked" at the left of the outline, indicating no superheat spray flow at the moment.



In the center of the first display, the "butterfly" is an integrated display composed of 2 back-to-back analog meters. The left side shows Drum Level. There is a gray tick at the O-point, and readouts of drum level and pressure. The right side shows Feed Flow/Steam Flow ratio (irrespective of the actual values, which are given digitally), with a tick at equality. The pointer above the tick represents feed flow in excess of steam flow: below the tick steam flow is in excess of feed flow. With this display, "wings straight & level" is nominal, a banked attitude for the wings indicates a state that is returning to equilibrium, but "wings up" or "wings down" indicates a departure from equilibrium. As drawn, drum level is low but feed flow is greater than steam flow, and the low drum level will be corrected shortly.

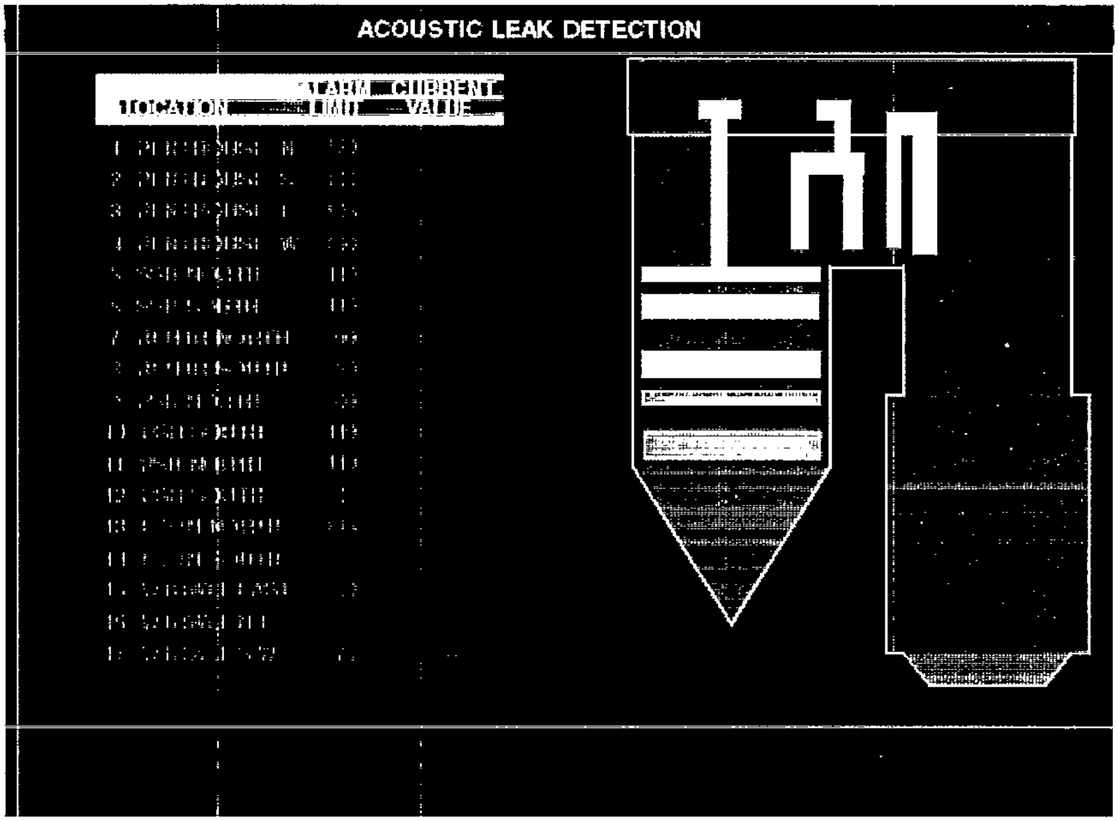
On the second version of the display, the butterfly is replaced by a pair of deviation bar graphs. The bar for drum level is an exact analog of the left wing of the butterfly, but the one on the right shows the ratio of Steam Flow to Feed Flow, so departure from equilibrium is indicated by the bars on the paired graphs being on opposite sides of the center point.

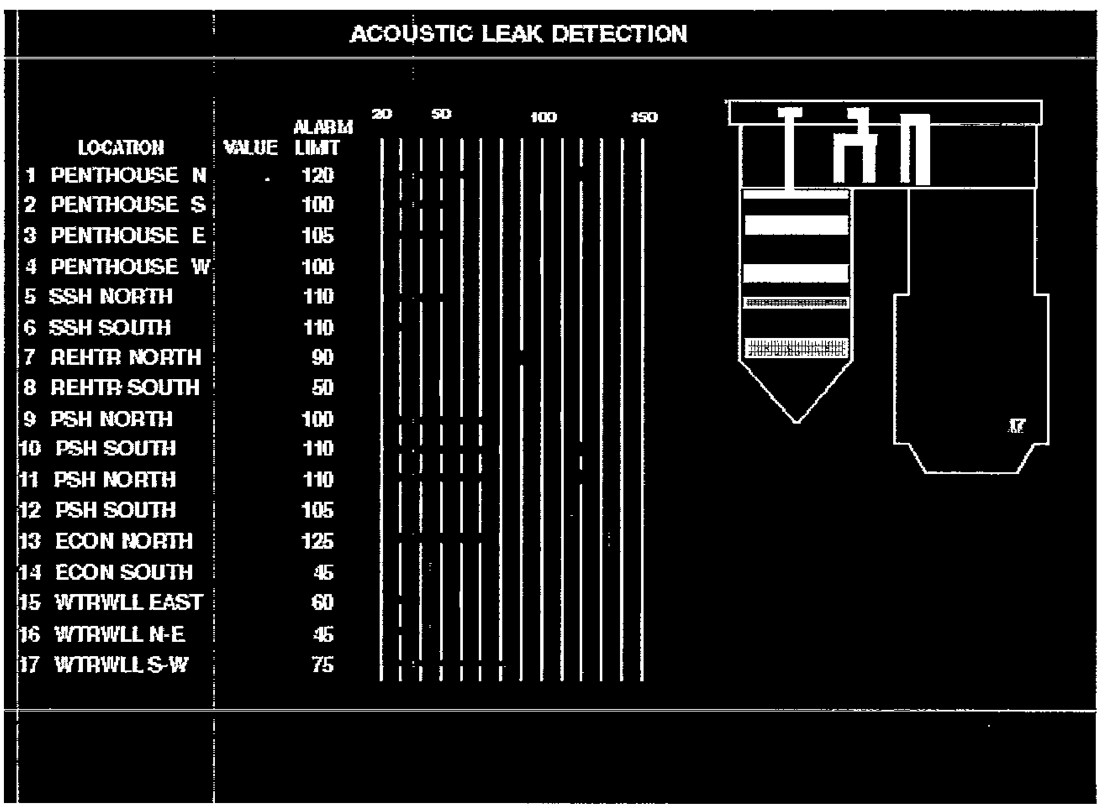
Below the "butterfly" (or corresponding bar graphs), Furnace Pressure is shown as a conventional deviation bar graph. The readouts indicate current pressure and the setpoint, which is written in cyan and shown on the pressure bar by a cyan line.

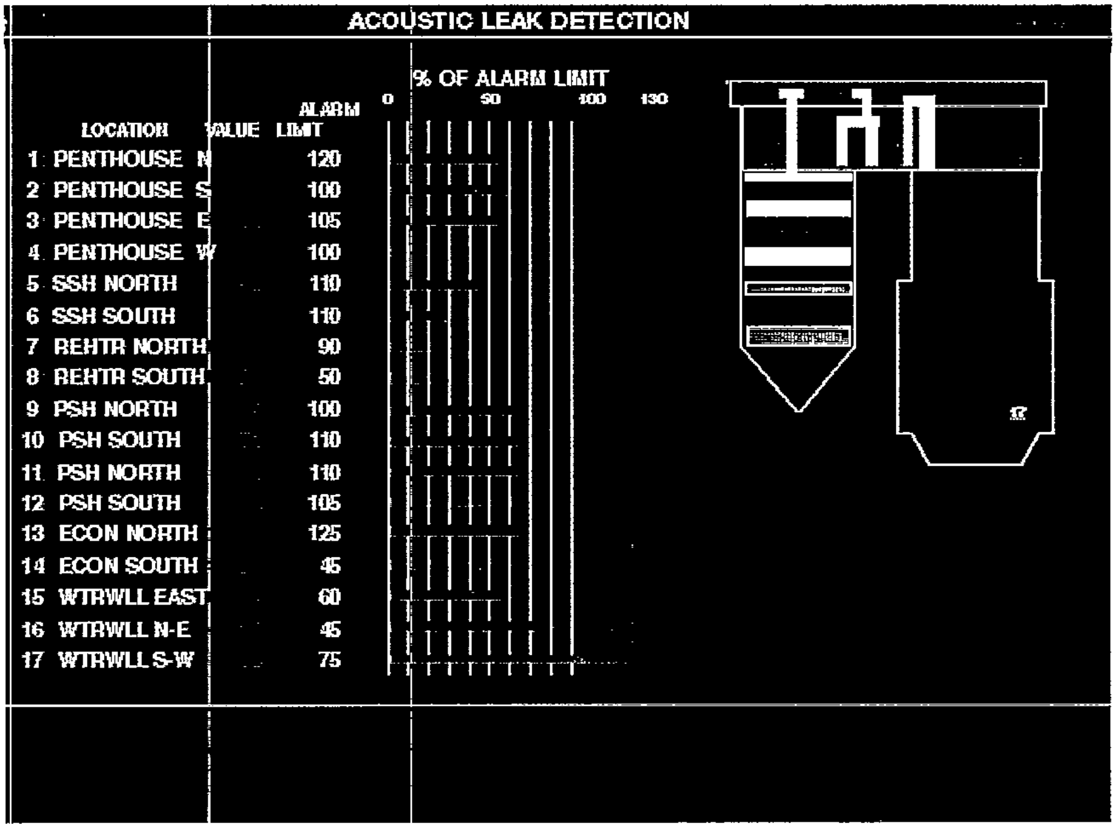
In a column on the right side of the display are grouped readouts for generation, turbine parameters (with performance targets) hotwell and feedwater parameters (also with targets). The Generation graphic shows the Automatic Generation Control (AGC) mode and a bar graph showing the current generation in relation to the 20 MW AGC band. Minimal demarcation lines are used to partition this column of readouts into smaller groups of related parameters.

As an overview of feedwater heater performance, the auctioneered high DCA (Drain Cooler Approach) value from all seven feedwater heaters is displayed. Although this summary value cannot be used for diagnosing the nature of the problem or attempting to correct it, it provides a very compact high level overview that directs the operators attention to the feedwater heater performance before an alarm is generated. The gray rectangle at the lower right is the reserved pop-up area for controls.

At the right edge of the first display is a column of dollar signs that serves as the summary graphic for the on-line performance monitor. Each red-illuminated $ symbol represents $10/hour "out the stack". In the second display, the graphic has been replaced by digital readouts of heat rate and the hourly cost of controllable losses.


ACOUSTIC LEAK DETECTION
LOCATION
ALARM LIMIT
CURRENT VALUE


ACOUSTIC LEAK DETECTION
LOCATION
VALUE
ALARM LIMIT
20
50
100
150
1 PENTHOUSE N 120
2 PENTHOUSE S 100
3 PENTHOUSE E 105
4 PENTHOUSE W 100
5 SSH NORTH 110
6 SSH SOUTH 110
7 REHTR NORTH 90
8 REHTR SOUTH 50
9 PSH NORTH 100
10 PSH SOUTH 110
11 PSH NORTH 110
12 PSH SOUTH 105
13 ECON NORTH 125
14 ECON SOUTH 45
15 WTRWLL EAST 60
16 WTRWLL N-E 45
17 WTRWLL S-W 75
17

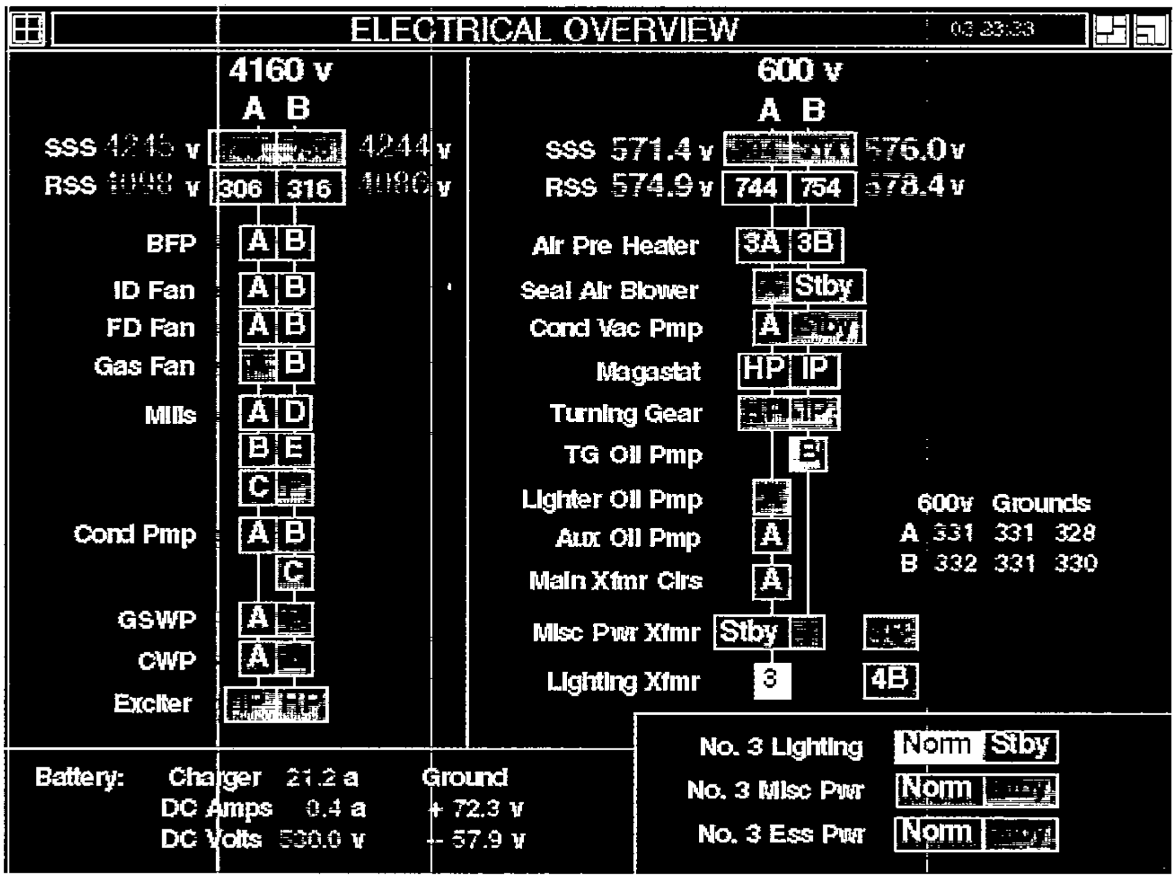


Acoustic Leak Detection

There are three versions of this display. The first is similar to a prototype obtained from a utility. It is dominated by a large yellow diagram which shows the locations of the acoustic monitors, whose outputs are listed in the column headed CURRENT VALUE. The alarm limits for each monitor are shown in the ALARM LIMIT column.

The second version of the display provides bar graphs of the displayed values, and reduces the size and brightness of the reference diagram so as to distract less from the data. The alarm limits are different for every individual monitor. In the bar graphs, the alarm limits for the individual monitors are shown by the red bars. The resulting bar graphs are odd in appearance, and must still be processed individually. In this case simply displaying the data graphically has made it only slightly easier for the operator to process the information presented.

In the third version of the display, the data has been rescaled and presented as a percentage the alarm limit (the actual values are still presented digitally). The rescaled bar graphs are easier to scan for high values. On the bar chart, lines representing 100% of alarm limit and higher are drawn in red, and the bar and data value for any monitor reporting values in excess of alarm limits are also in red.



Electrical Overview

This display combines information from four separate displays for the 4160, 575/600, and 208v systems, showing the status of the major breakers, feeder voltages, and the station batteries. The display is intended as an overview only, and no control capability is provided.

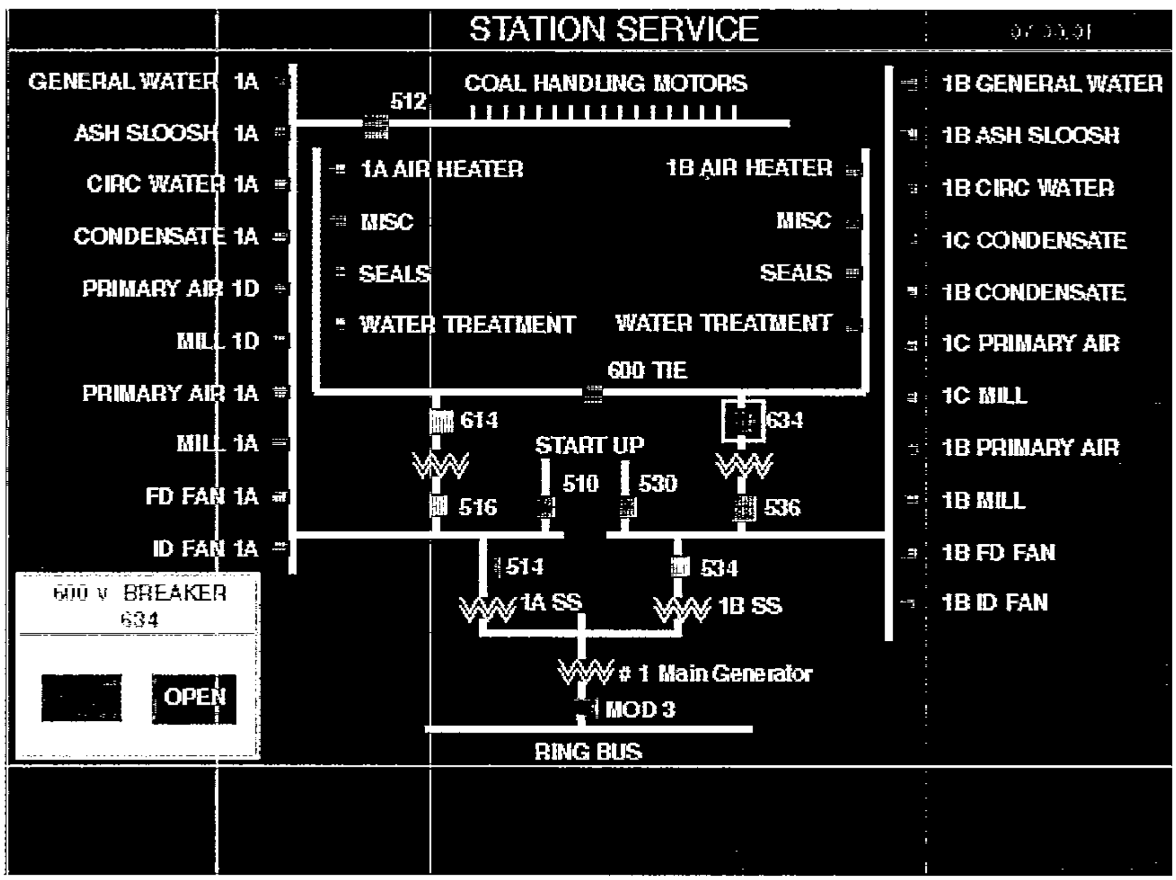
This schematic does not attempt to show the layout of the buses, and includes only those loads for which remote indication is available. Although there are breakers connecting the two intermediate sections of the 4160v bus, they are not shown on the display because they are always closed.

The left side of the display shows the 4160v bus, with its feeders at the top. To save space, the display shows only the last 3 digits of the 5 digit breaker number, as the first 2 are all the same: the boxed 746 on the display represents breaker 90746. The voltages of the feeders are shown next to the breaker numbers. Battery status is shown in the bottom left, set off by demarcation lines.

The right side of the display shows the status of the loads on the 600v bus, again with the feeders and their voltages at the top. Again the display includes only those loads for which remote indication is available. The "4B" boxes to the right of the indications for the Misc. Power Transformer and the Lighting Transformer show the status of the Unit 4 breakers that supply standby power to the 208v loads.

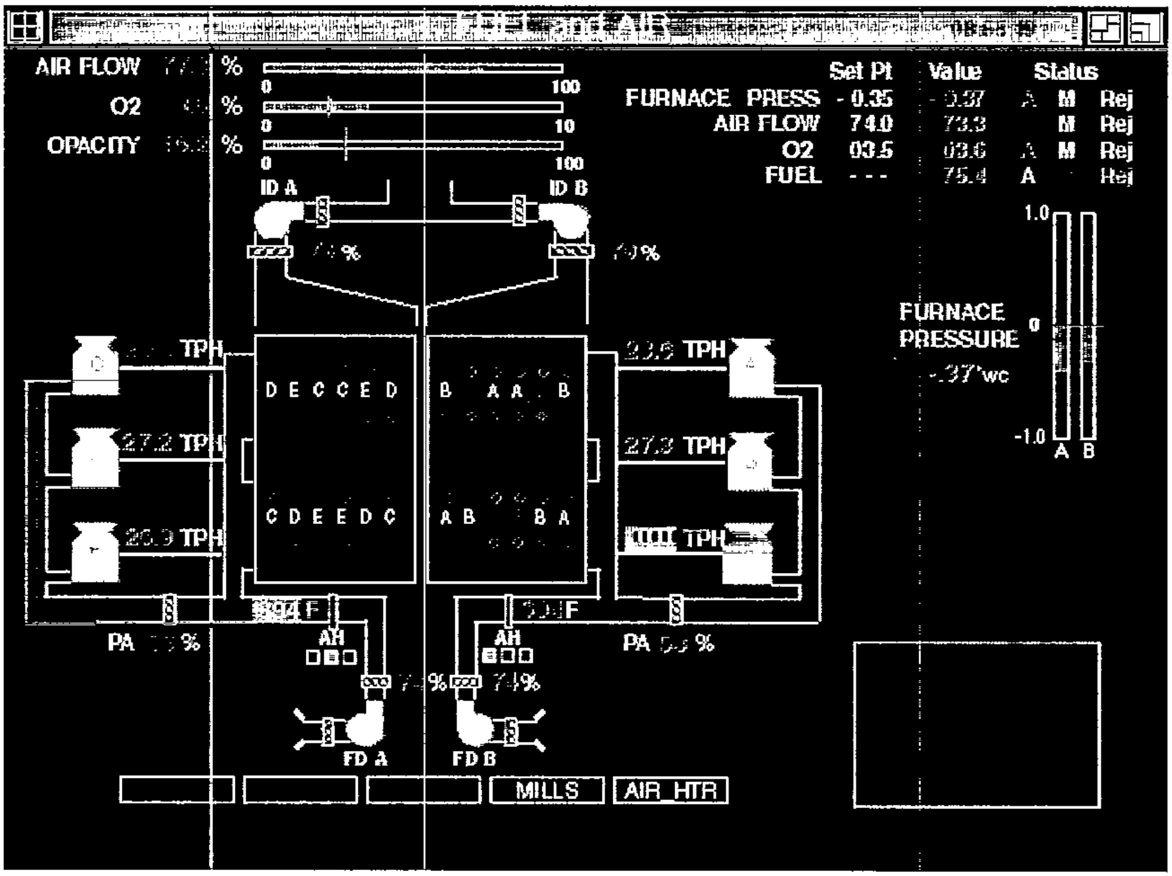
The 600v bus grounds are shown in a table to the right of the bus. The 208v breakers are shown in the demarcated area at the lower right.

In the display, the breaker status is shown by color coding of the boxes: red with white lettering if closed, green with black lettering if open, and yellow with black lettering if tripped.
The display background is black and the labels are light gray. Gray is used instead of white for the labels so that they would not be brighter than the data, which is represented by the colors of the breaker boxes and the voltage and amperage readouts. Numerical data (voltages and amperages) are bright green.



Station Service

This is a conventional electrical one-line diagram, showing the 4160 and 600 volt systems, and their interconnections. The status of breakers is indicated by color coded squares, with the conventional coding of red for closed (energized) and green for open (de-energized). Any of the breakers represented by the large square indicators may be selected and operated from this display. Selection if a breaker for operation may be made by pointing with the cursor or via touch screen. Selected components are highlighted by a cyan box (as shown around breaker 634) and the control for the selected breaker appears in the pop-up area. The status of breakers for major 4160 and 600 volt components is shown by the smaller colored rectangles, but these breakers are not operable from this display.



Fuel and Air

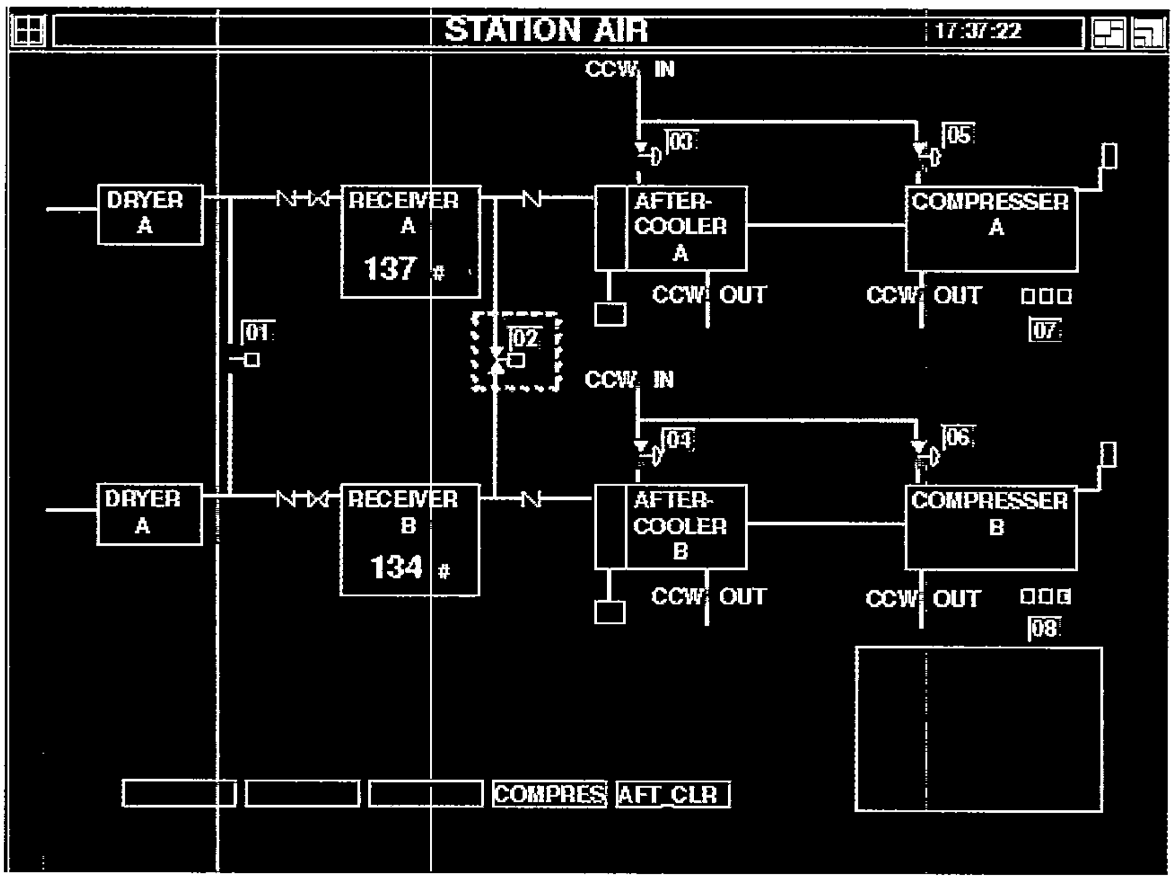
This graphic shows the status of FD and ID fans, six mills, and 24 burners. Bar graphs are provided for Furnace Pressure (2 channels), total air flow, opacity, and 02. Fuel flow in tons per hour is shown for each pulverizer. Air temperature exiting the air heaters is shown, along with the position of the FD, ID and primary air dampers. A table at the upper right shows the status of the Furnace Pressure, Air Flow, 02, and fuel master controllers.

Fan and mill status is indicated in two (redundant) ways: the color of the outline of the component (red for run, green for off, yellow for trip) and the shading of the component (light gray for on and darker gray for off). Controls for the fans, dampers, and mills appear in the shaded pop-up area when the outline of the component is selected.

Additional controls for mills and feeders are provided on a separate screen. Likewise, the four controllers in the table at the top of the page may be displayed in the pop-up area by selecting the appropriate line of the table.

The status of the air heaters is shown by three small status lights (on-trip-off), but no controls are accessed through this display. Status of the 48 burners (from the flame scanners) is shown by the array of circles in the center of the display, color coded red for on and green for off.

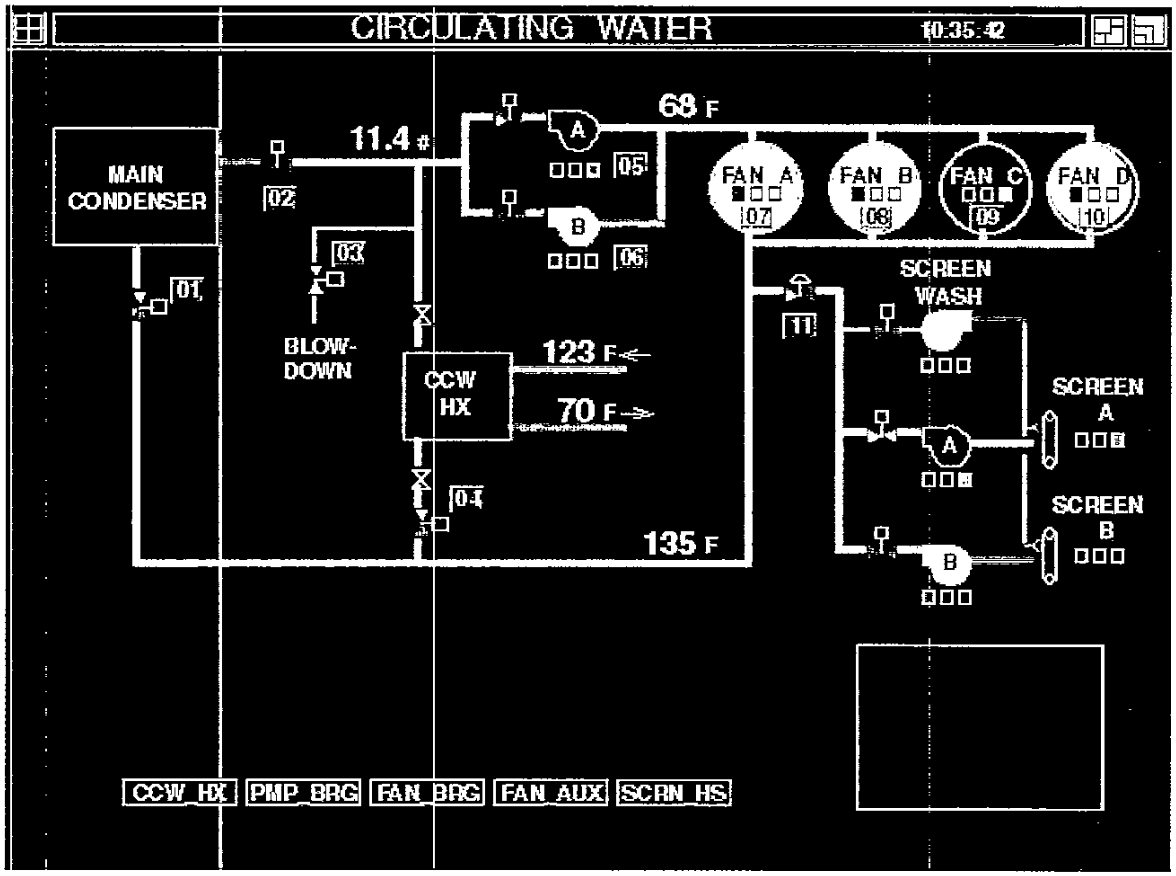
Use of color is conventional and restrained. Live data values within an acceptable range are shown in green for both numerical readouts and bar graphs. The red = on; green = off convention is followed for status indicators. To avoid large patches of distracting color on the display, the outlines of component symbols are colored rather than the entire symbol. Neutral values such as setpoints are indicated in cyan.



Station Air

This display shows the station air compressors and associated component cooling water (CCW). Air lines are drawn in gray, and CCW lines in dark cyan. For simplicity, and also minimum interference with the labels, components are drawn in outline rather than filled. Components that may be operated by controls that pop up in the shaded control area in the lower right hand corner of the screen are indicated by the numbered buttons. For these selectable components, the display is drawn to allow consistent placement of the buttons to the right and slightly above the valve symbols, while the buttons for the compressor motors are centered below the status indicators.

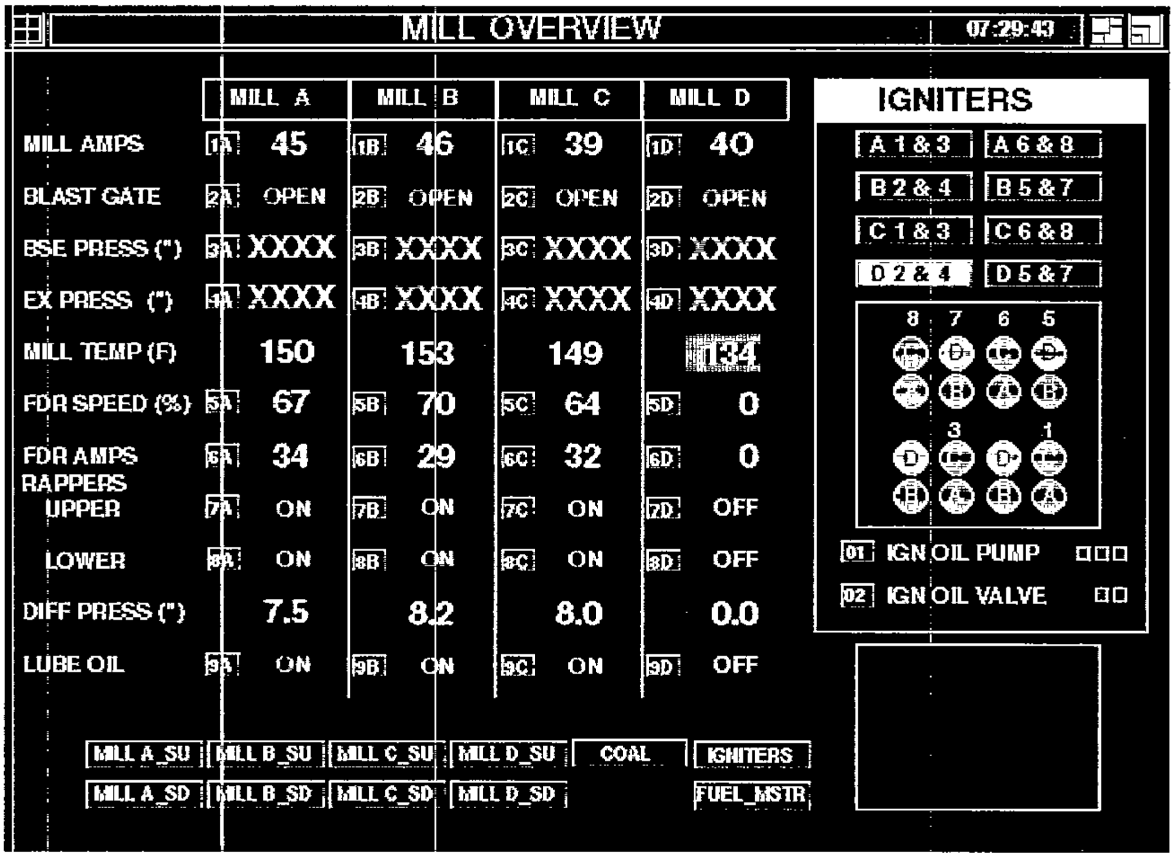
Labeling is in a nominal 12 point font. Aside from the system status and lineup, which is conveyed by the system graphic, there are only two items of data on the display, the air pressure values for each receiver. These values are written in 18 point type, and colored bright green.



Circulating Water

This display is a conventional schematic, with components shown in their approximate physical relations. Pumps and fans are shown filled if on and outlined if off. Status is indicated redundantly by the associated three-part indicator lights, red for on/open, yellow for trip and green for off/closed. Selectable components are indicated by the numbered "buttons": selecting the button or entering its number via the keyboard will cause the appropriate control to appear in the shaded pop-up area at the bottom right of the screen.

In this display the positions of remotely operated valves are indicated by color coding of the valve symbol, red for open, green for closed, and half red and half green for intermediate positions (throttled or traveling). The isolation valves for the Component Cooling Water heat exchanger are shown in gray outline, a coding that indicates that they are manually operated.

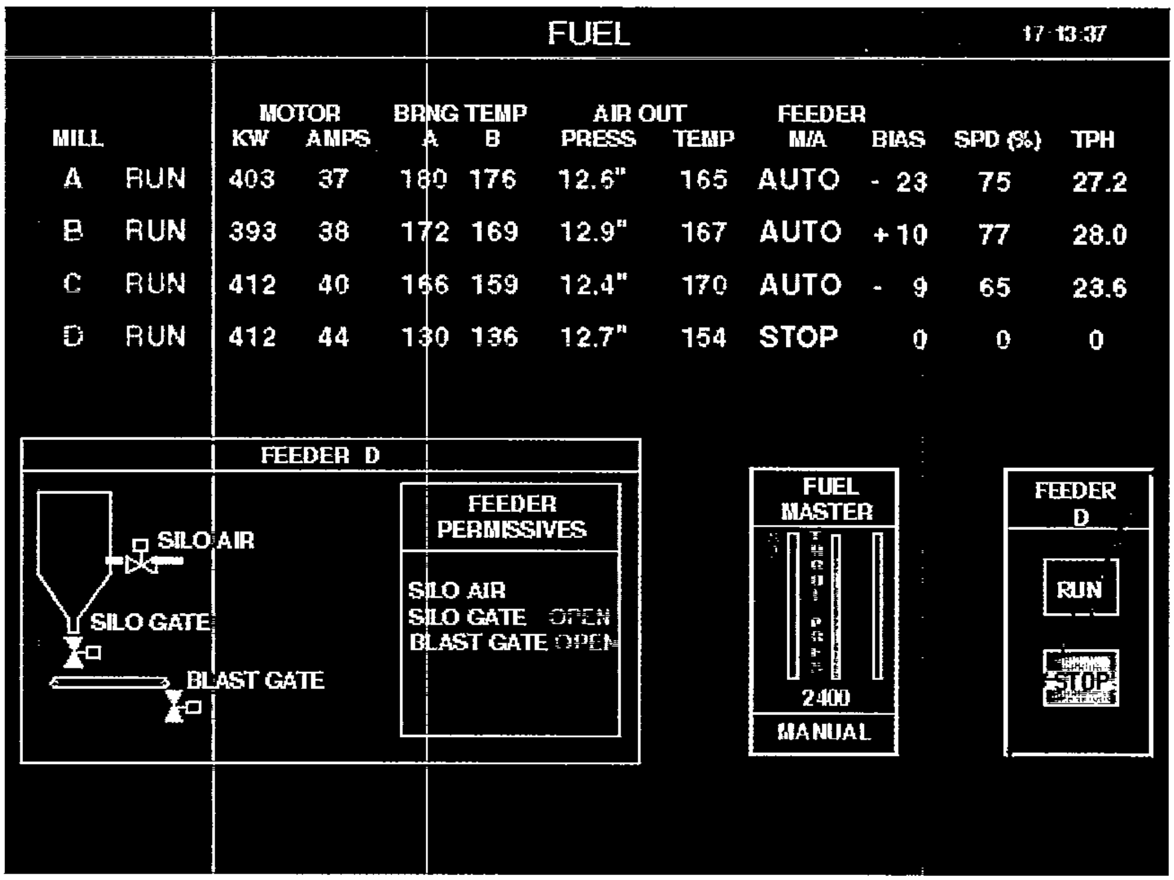


Mill Overview

This display is based on a design by Rovisys Engineering for Centerior Energy's Eastlake station. The main feature is a summary table showing critical parameters for all four pulverizers, and allowing call-up and operation of controls for all components from this single display. In the conceptual design shown, the large window at the right of the display shows burner status and allows call up and operation of paired igniters via the series of buttons at the top of the window. This window also allows operation of the ignition oil pump and ignition oil valve, and shows their status via color coded status indicators. The buttons at the bottom of the display provide direct access to a variety of other sub-displays for the window, including shutdown and startup displays for each of the mills.

Most labels are 12 point gray lettering, with 18 point lettering used for the numerical data. Alphanumeric data (e.g., rapper status) is written in 12 point lettering to conserve space. The live data contained in the columns of the table is color coded bright green, with out-of-tolerance values written in white against a red background. A "green board" coding is used for the other tabled entries, where green represents expected status (e.g., the rappers are expected to be open and the lube oil pump on if the mill is running), red is an abnormal status, and cyan indicates a neutral status (eg, closed rappers for Mill D, which is not running. Conventional red/green color coding for an/off and open/closed is used for the ignition oil pump and ignition oil valve indicators.

The burner status is coded red for flame present and green for flame absent.



Fuel

This display is a variation of the Mill Overview display presented previously. However, the selection of data displayed is different, reflecting differences in plant configuration. The display is organized into three main sections: a summary data table at the top of the display, a window providing more detail for selected systems, and a reserved area for pop-up controls.

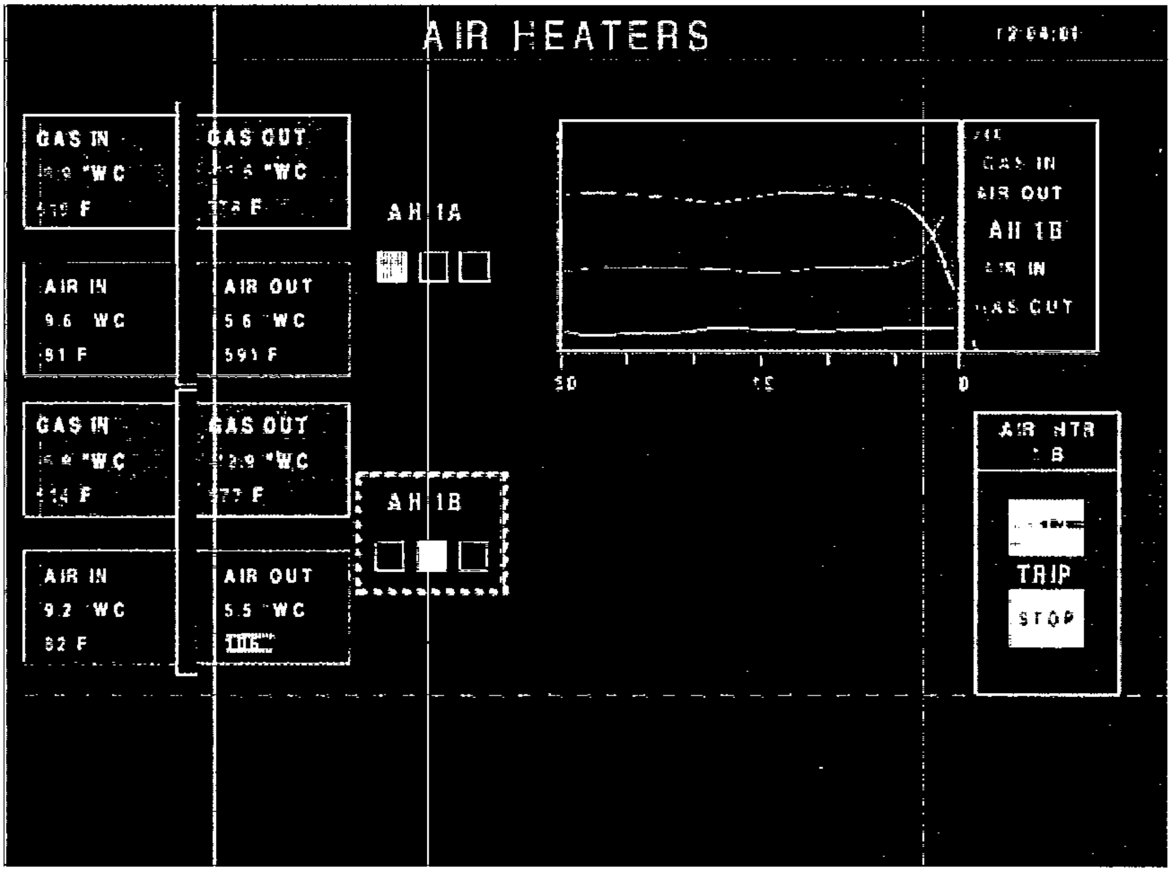
The table at the top shows status and major parameters for four pulverizers and their associated feeders. Again data are emphasized by color coding and a large font. It is marginally easier to compare values across components when the values to be compared are presented one above the other than side by side.

A large window in the lower left quadrant of the display shows schematics of any of the selected mills or feeders, and a listing of permissives for the operation of the displayed component. The contents of the window automatically change to match the component (mill or feeder) selected from the table. Components displayed on the schematic in the window may be selected for operation via pop-up controls. The window in effect turns the single display into a whole series of displays. On the schematics in the window, a solid/outlined convention is used in place of color coding to convey component status. A solid or filled valve symbol indicated that the valve is open; an outlined symbol indicates the valve is shut.

Pop-up controls appear in the reserved area at the bottom right of the screen. These controls may be selected via cursor or touch screen from the table or from the window. From the table, controls are called up by selecting any of the mill RUN/STOP or the FEEDER M/A fields. From the window, controls may be accessed by selecting a displayed component symbol with the cursor or touchscreen. The field from which the last selection of a control was made is highlighted by a dashed cyan line.

In the example display, the operator has selected the "D" feeder control. This has caused the "D" feeder breaker to appear in the pop-up control window (if the feeder was already running, the feeder M/A station would appear), and the feeder "D" schematic to appear in the window. However, the feeder start permissives have not been satisfied, as indicated by the magenta "P" superimposed on the breaker control. Inspection of the list of feeder permissives shows that the silo air damper has not been opened. To open it the operator will next select the SILO AIR valve symbol in the window, which will present the damper control in the pop-up space now occupied by the feeder breaker

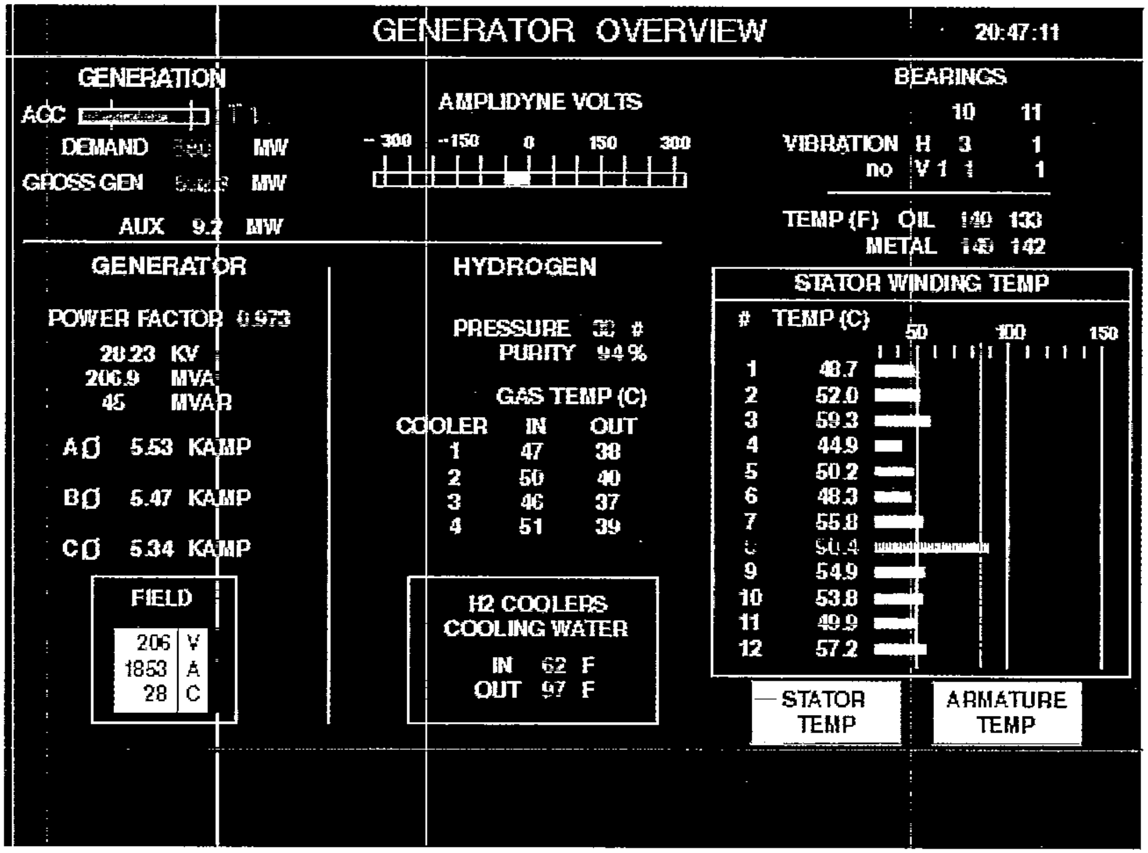
In addition to a large number available of pop-ups, the fuel master display is permanently displayed and may also be selected for operation in the same manner as any of the other controls



Air Heaters

This display shows temperatures and pressures for flue gases and air on the input and output sides of the two Air Heaters. The data are organized on an abstract schematic of the air heaters. This schematic has been rearranged so that the input values are shown on the left and the output values are on the right, instead of the more realistic arrangement where air in and gas out are measured on the same side of the rotating heating element. The background for flue gas data is dark red: air data are presented against a blue background.

A 30 minute trend of gas and air temperatures for an individual heater is displayed automatically when the control for that heater is selected.



Generator Overview

This display is a summary of data related to the generator, with no control capability. The model display is based on display examples from Southern California Edison's E1 Segundo and Carolina Power and Light's Roxboro plants.

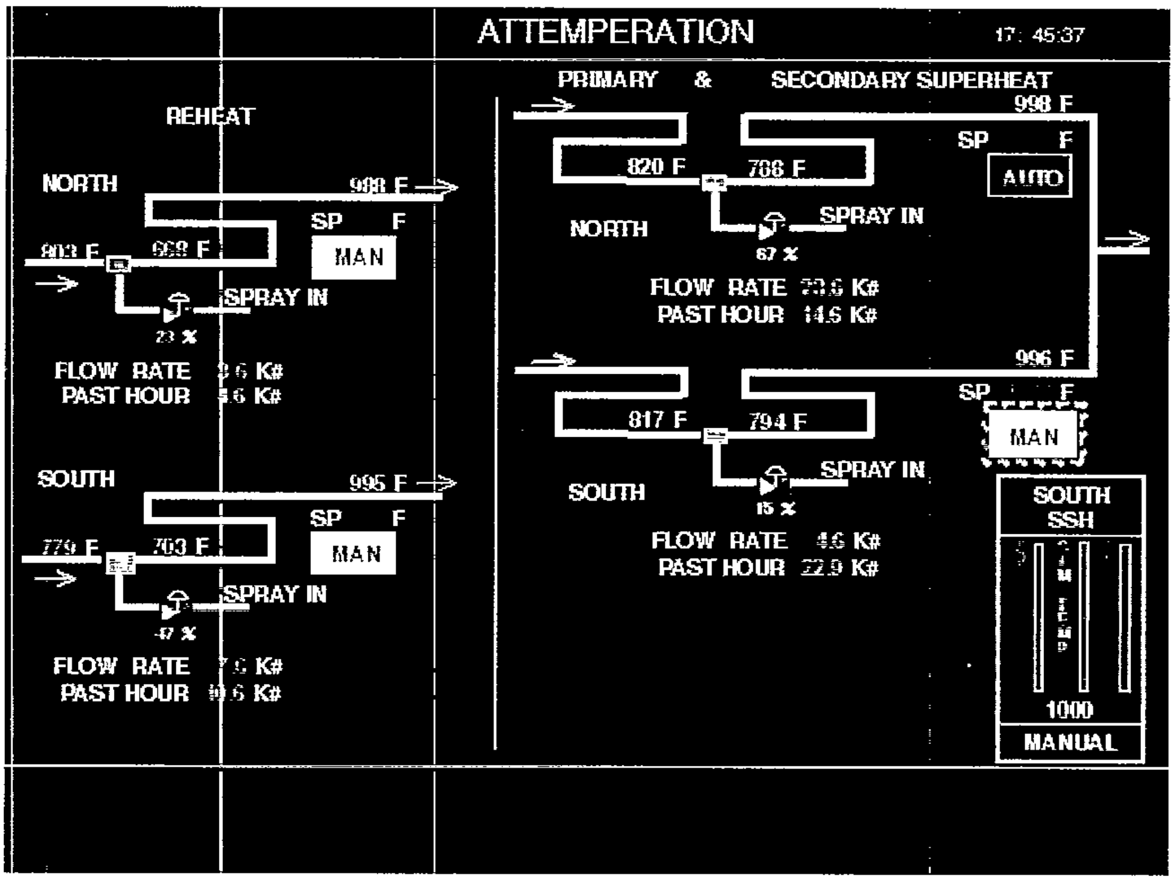
The block in the upper left hand corner is a generation summary, showing demand and gross generation, with a graphic showing current output in relation to the 20 MW Automatic Generation Control (AGC) band. The AGC mode, T1, is shown next to the graphic.

Generator parameters are shown in the block below the generation summary. These include voltage, MVA, MVAR, and current for each of the three phases. The block concludes with field voltage, current, and temperature (in degrees Celsius).

Amplidyne voltage is shown graphically at the top of the center section. In the center of the display, hydrogen pressure and purity, and the hydrogen temperatures at the inlets and outlets of the four hydrogen coolers are shown in tabular form. At the bottom center is a table showing cooling water temperatures entering and exiting the hydrogen coolers.

At the upper right corner of the display is a table of vibrations and oil and metal temperatures for the two generator bearings, which are numbered 10 and 11 on the turbine generator diagram (not shown).

The window in the lower right quadrant of the display shows the auctioneered high temperature in each of 12 groups of stator winding thermocouples. These are shown numerically and as bar graphs to facilitate comparison. The graphic spans the range of temperatures from 30 to 150°C, with the operating limit of 85°C indicated by a red line. The window can also show armature temperatures in a similar format: what is displayed is selected by the two buttons below the window.

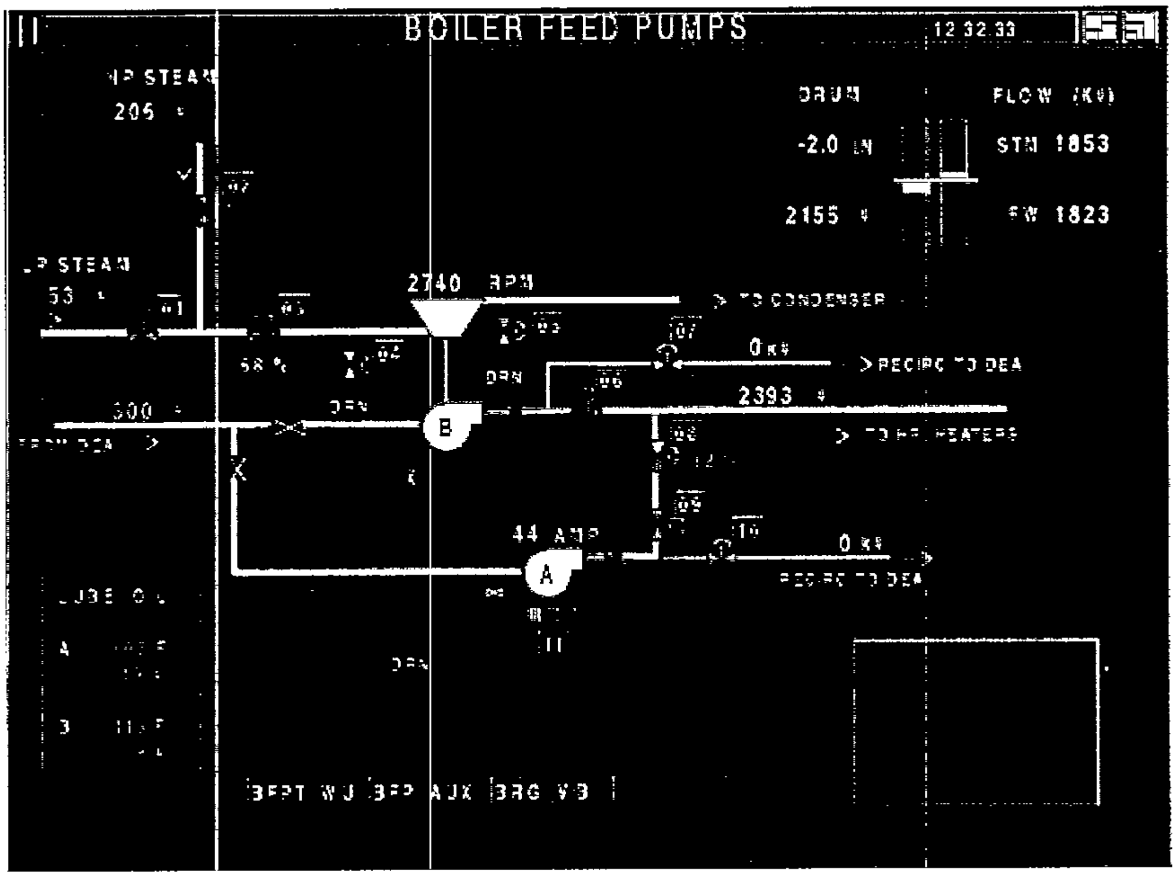


Attemperation

This is a conventional mimic display showing superheat and reheat steam temperatures and their setpoints, and attemperation spray flow. Steam lines are drawn in gray and the spray lines in dark cyan. The display shows the instantaneous spray flow rate and the throttle position (% open) of the spray valves, as well as the total spray flow in the past hour for the two reheat and two superheat sections. The direction of steam flow is indicated by arrows next to the steam lines.

The setpoint for each section is displayed below the steam exit temperature as

"SP XXXX F", along with the status (AUTOmatic or MANual) of the four spray controllers. Each controller may be selected for operation by selecting its status box. The selected button is highlighted by a cyan box and the controller appears in the pop-up area at the lower right corner of the screen.



Boiler Feed Pumps

This display is a conventional mimic display showing two boiler feed pumps, the "A" motor-driven start-up pump and the "B" turbine driven pump and associated valves. The display is used for starting both pumps and for transferring from the motor-driven to the turbine driven feed pump when sufficient steam is available.

The display has a pair of bar graphs showing drum level and the ratio of steam flow to feedwater flow, and digital readouts of drum level, drum pressure steam flow and feedwater flow. Note that feedwater flow is shown in this summary figure and not presented redundantly on the P&ID portion of the display. A small table at the lower left shows Lube Oil temperature and pressure for both feed pumps.

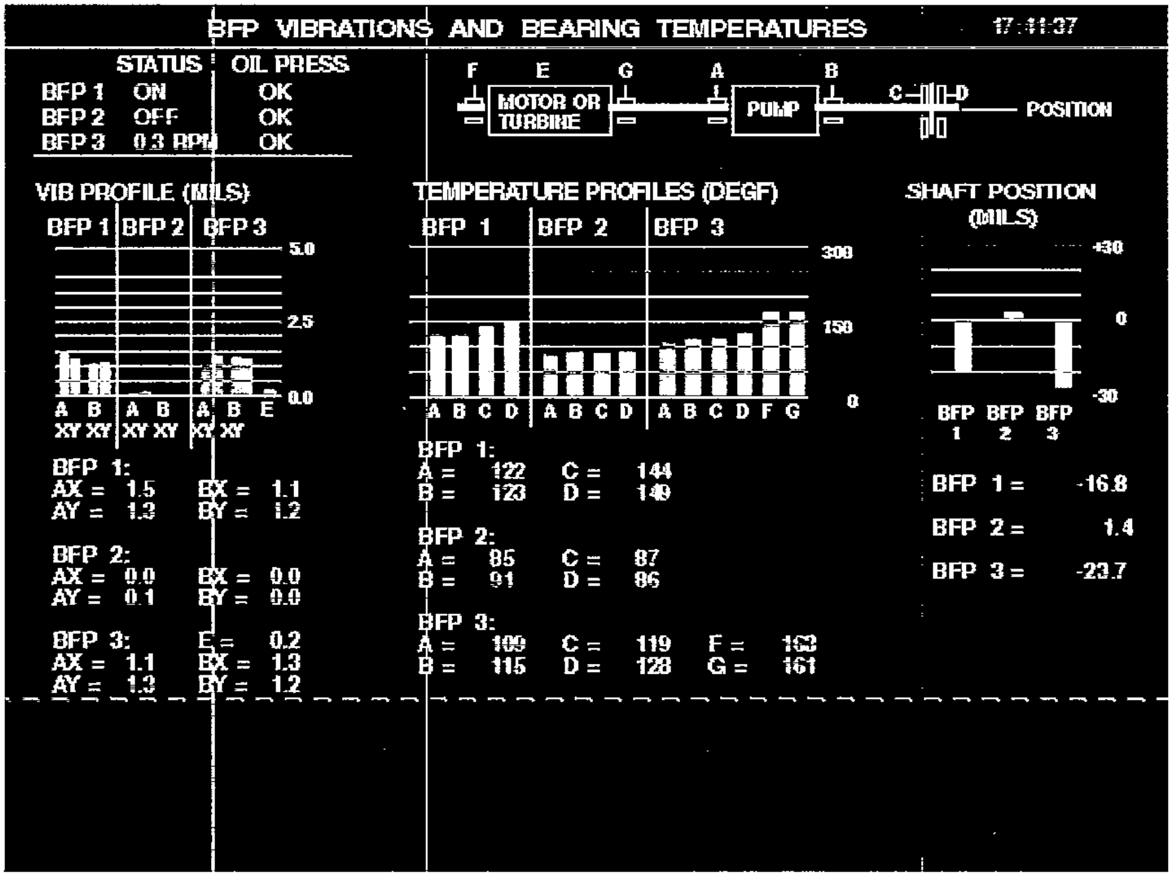
Additional parameters are presented on the diagram itself: steam pressure and BFP turbine RPM, feedwater pressure entering and exiting the feed pumps, flow (in thousands of pounds mass per hour) in the recirculation lines, and current for the motor-driven feed pump. In addition, the valve position (percent open) is shown for throttle valves 3 and 8.

In the diagram, the steam supply lines for the BFPT are gray and the feedwater lines are a dark cyan. The piping in this display is drawn in darker values of the basic colors (white and cyan) so as not to be unnecessarily distracting. The relative capacities of the lines depicted are coded by line weight.

The positions of the remotely operated valves are indicated by color coding: red for open, green for closed, and half red and half green for partially open or throttled. Manually operated valves and check valves are shown in gray.

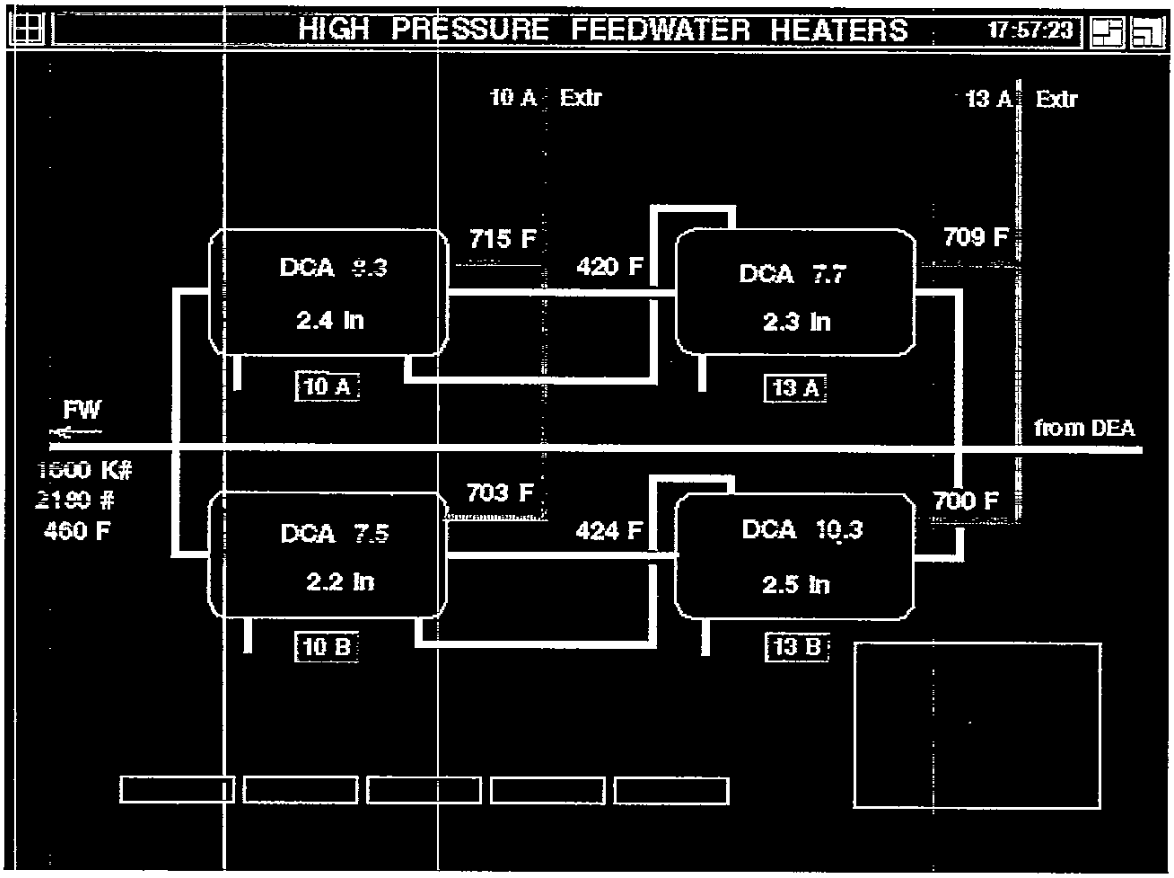
The controls for the "A" pump motor and the 10 remotely operated valves in the diagram may be presented in the shaded pop-up area by selecting the numbered buttons next to the desired component. The diagram is laid out so that the buttons for accessing components are placed in a consistent location in relation to the component. For the valves, this location is above and to the right of the valve symbol. For the "A" BFP the button is located directly below the status lights for the pump motor.

The large buttons at the bottom of the display provide access to additional related displays: Boiler Feed Pump Turbine Warm-Up; Boiler Feed Pump Auxiliaries, and Bearing Vibrations and temperatures.



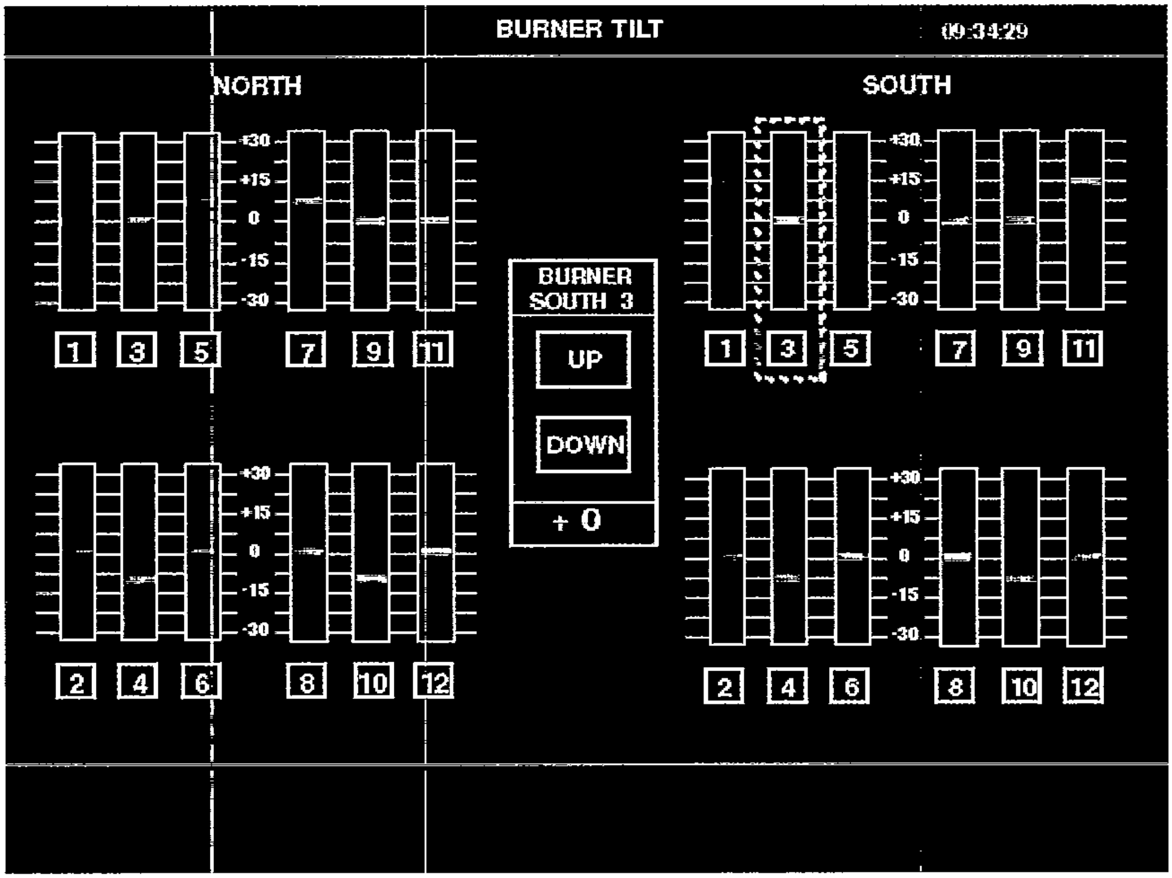
Boiler Feed Pump Vibrations and Bearing Temperatures

This display is for a plant with two motor-driven and one turbine-driven feed pumps. It is a close copy of a display developed by Southern Company Services for a Westinghouse WDPF™ control system for a small co-generation plant. The display is characterized by a simple diagram that provides orientation as to the locations of the monitored bearings and the grouped vertical bars that create "profiles" of temperature and vibration. The data are primarily displayed graphically, with numerical readouts available below the graphics if additional information is needed.



High Pressure Feedwater Heaters

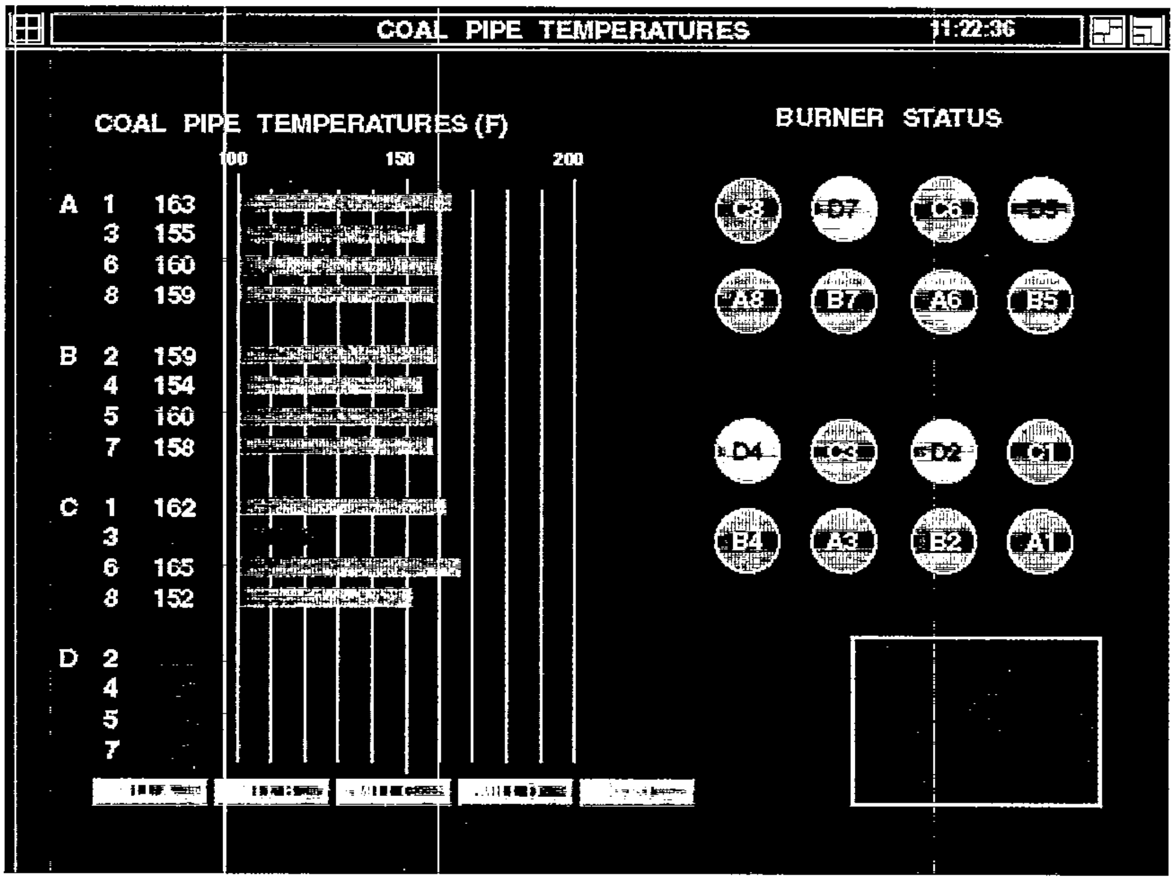
This display provides an overview of the performance of the four high pressure feedwater heaters in a conventional schematic format. Extraction steam lines are shown in red, and feedwater in a dark cyan. The level in each heater is shown superimposed on its blue lower half. Blue is used because it provides a better contrast with the green readout for heater level than does cyan. An overall measure of heater performance, DCA (Drain Cooler Approach), is presented in the upper half of each heater.



Burner Tilt

This display shows the orientation of four banks of six burners each. The display is

a series of analog position indicators. Burner tilt is indicated by the position of the green horizontal bar or "pip" for each burner. Individual burners may be selected for adjustment by means of the numbered buttons below each position indicator. The position indicator for the selected burner is highlighted by being outlined in cyan, and the control is placed in the center of the display. The control provides a digital readout of the commanded burner tilt. The display is drawn in gray, with live data in bright green.

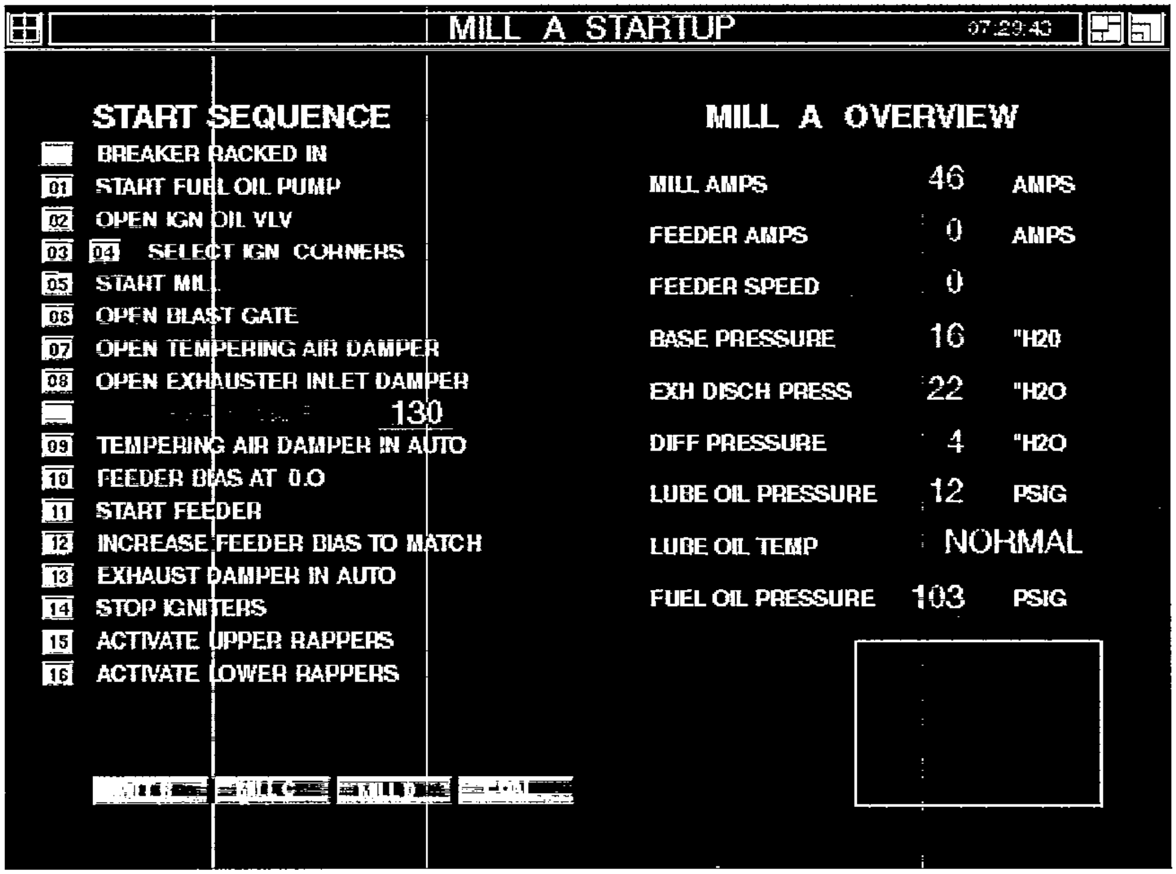


Coal Pipe Temperatures

This display shows burner status and associated coal pipe temperatures. The burner status display on the right shows flame scanner output in a binary coding of red for on (scanner output above a defined threshold value) and green for off (scanner output below the threshold). On the left, coal pipe temperatures are displayed in conventional bar graphs. These graphs are grouped by pulverizer rather than the spatial distribution of the burners they feed. The bar graphs have red limit lines at 125°F and 185°F that define the expected range of pipe temperatures in normal operation.

Both the digital temperature and the associated bar are green if the pipe temperature is within this range. For temperatures outside of the normal range, the bar is drawn in red and the data value is written in white on a red background.

Pulverizers may be tripped from this display by selecting the appropriate group (A, B, C, or D) from the temperature display, which causes the Pulverizer Run/Stop control to appear in the shaded pop-up area. The labeled buttons at the bottom of the display provide access to dedicated displays for each mill.



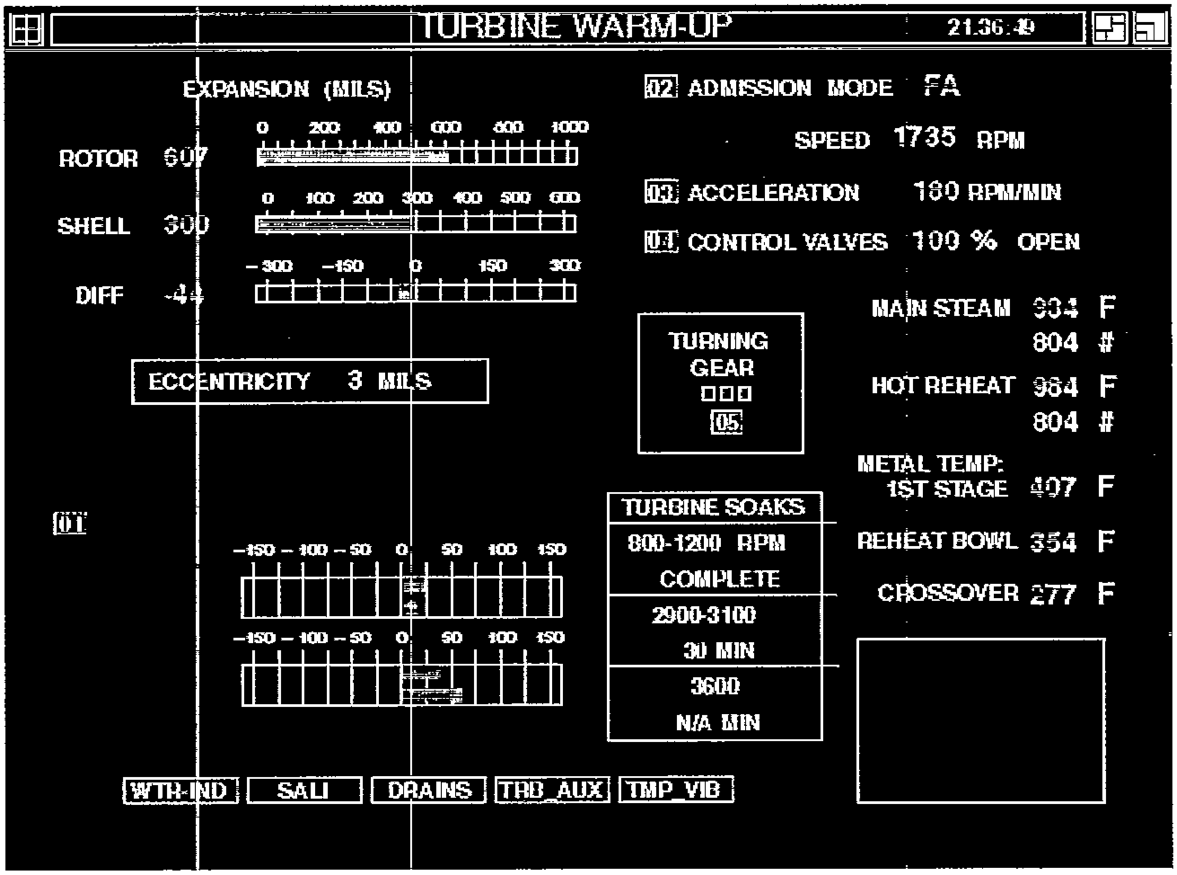
Mill A Startup

This display is a slight modification of a design by Rovisys Engineering for Centerior Energy's Eastlake station. The display is divided into two halves. The actions required to start up the mill are presented in the column at the left, in the same manner as a startup checklist that an operator might find in a procedure. The numbered buttons to the left of each step call up the control required, which appears in the gray reserved pop-up area at the lower right. Buttons that are not numbered represent either an action that must be performed by an operator in the plant (e.g., racking the breaker in) or a hold point at which the operator must wait until the desired condition is achieved (e.g., mill temperature greater than 150°F). The startup checklist is color coded according to the following scheme:

Gray = status not monitored
Green = completed Cyan = pending
Red = condition not satisfied

The table at the right provides an overview of critical mill parameters. The data values are written in 18 point lettering, and color coded green if within acceptable limits or white against a red background if they are out of limits.

This Rovisys design represents an application of task analysis data to provide a display that is custom tailored to a particular task. The information contained in the Mill A Overview table on this display is repeated in the MILL OVERVIEW display, which presents similar information for all four mills.



Turbine Warm-up

This display provides an overview of turbine expansion and warm-up for use during startup. The display does not have the turbine diagram common on many turbine graphics, as such diagrams serve mostly to remind the operators of the locations at which various parameters are measured. The turbine diagram would be useful on some of the others accessed from this display via the buttons at the bottom (e.g., Water Induction, where it would show the locations of bearings and water induction thermocouples.

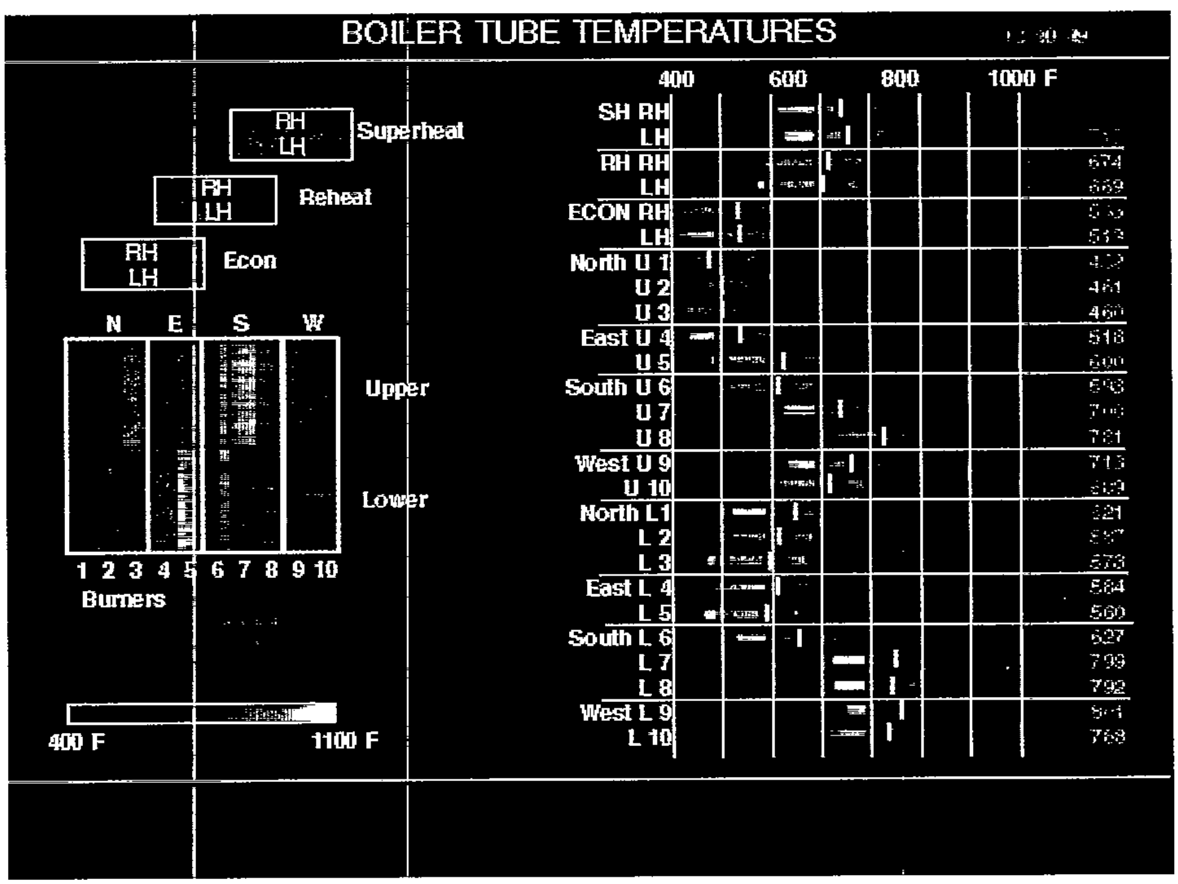
In the left upper quadrant o£ the display, rotor, shell and differential expansion are shown graphically. The digital eccentricity indicator is boxed to set it off from the turbine expansion section. Rotor stress indicators are shown graphically in the lower left quadrant, using double bar graphs. The numbered button allows the operator to select the duty cycle (percent of turbine life) which changes the acceptable stress limits.

In the center o£ the display is a box showing turning gear status via a set of three indicator lights, and a numbered button providing access to the turning gear control. In the lower center of the display, the table labeled TURBINE SOAKS shows the duration and status of any required holds during warm up. The display is fairly dense, and the demarcation of these elements is used to indicate that they are separate from the other data groups.

The column on the right side of the display shows the selected steam admission mode, current turbine speed and acceleration, and the position of the control valves. In the ADMISSION MODE readout, the selected mode, FA (full arc) or PA (partial arc) is presented in green and the other option is dimmed out to a dark gray against the display's back background. The numbered buttons provide access to pop-up controls for admission mode, acceleration, and control valve position.

At the middle right of the display are readouts of main and reheat steam temperature and pressure, and metal temperatures at three locations.

As with other displays in this series, labels and other markings are light gray, with live data that are within acceptable limits presented in green, and numerical values of critical data are also presented in a larger font than the labels.



Boiler Tube Temperatures

The display summarizes data from several hundred boiler tube thermocouples. The thermocouples are partitioned into 26 groups on the basis of their location, and the average and extreme temperatures in each group are shown as a range bar in the large plot at the right side of the display. In addition, the average temperature in each group is shown digitally at the right side of the figure.

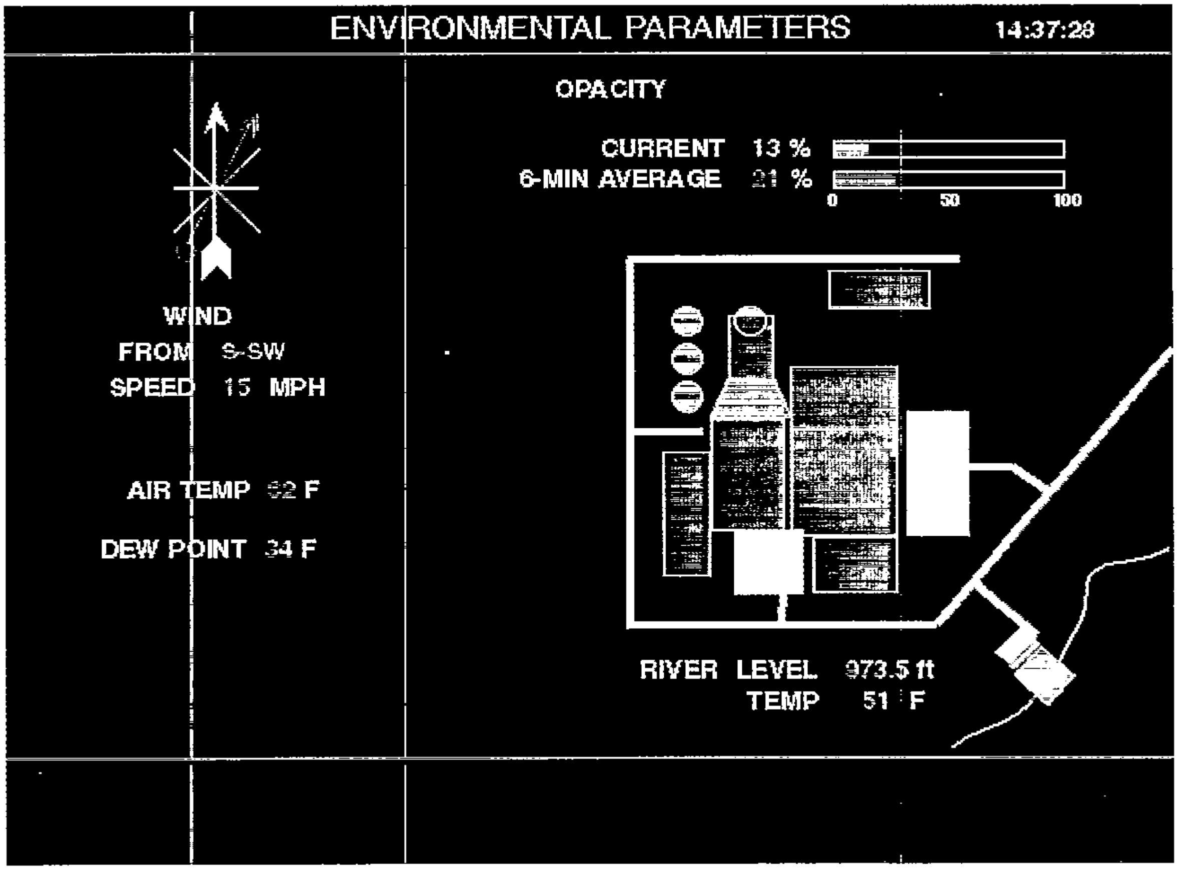
As an aid in visualizing the temperature distribution, an unfolded schematic representation of the furnace is presented on the left half of the display. This "data map" is partitioned into 20 panels in 10 columns, with labels identifying the upper and lower portions of the north, east, south and west walls. The left and right sections of the superheater, reheater, and economizer are shown in echelon above the unfolded furnace. Although the data map could be programmed to show the temperature of every individual thermocouple as a separate color coded spot, this kind of detail is not necessary, as the range bars will call attention to radically out-of-line values in their respective groups, and show the value quantitatively.

In the data map, the 26 panels representing the grouped thermocouples are color coded according to their average temperature, with the scale below the furnace showing the mapping of temperature onto the colors.

The circles below the furnace schematic are flame scanners for the burners located in the north and south walls. These are coded red for on and blue for off.

As with other displays, the labels are gray, and the bars and the digital readouts are colored green when their values are within normal limits and red when they exceed the limits. A red limit line is superimposed on the scale at 1025° F.

This display can serve as the top level of a series of display pages that presents the temperature of every monitored point: by selecting any range bar or label, the operator could access a listing or bar chart of every temperature in the selected group.



Environmental Parameters

This display shows monitored emissions (opacity only in this case), atmospheric conditions (wind speed, temperature, direction, and dew point), and river level and water temperature at the intake. Aside from the instantaneous and 6 minute running average opacity values, the display presents data that is monitored but not controllable. The plant plan, while not essential to understanding the data, is included to provide geographical orientation.