ELECTRIC POWER RESEARCH INSTITUTE

Operator Human Machine Interface Case Study

The Evaluation of Existing "Traditional" Operator Graphics Versus High-Performance Graphics in a Coal-Fired Power Plant Simulator

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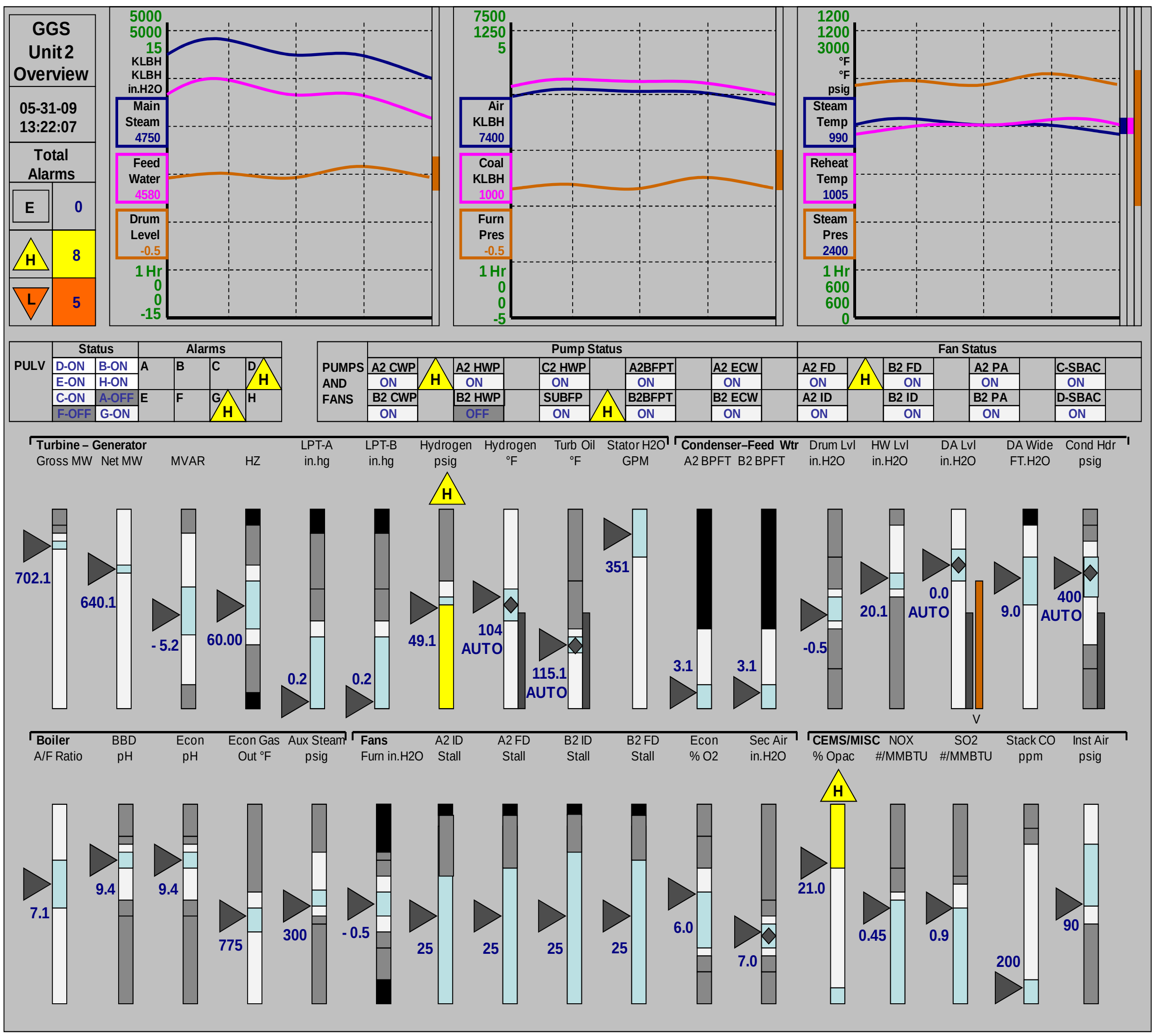

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Technical Update, December 2009

EPRI Project Manager

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PRODUCT DESCRIPTION

The content and structure of a control system's human machine interface (HMI) has become a high-profile topic in the process industries. This report documents a comparison study of graphic types used by operators to control a coal-fired power plant.

Poor HMIs (specifically, control system operator graphics) have been cited many times as contributing factors to major industrial accidents. These graphic HMIs for most power plants were generally developed in the 1980s and 1990s as older technology control systems were replaced with computer-based controls. These were generally Distributed Control Systems or DCSs. At that time, there were no guidelines constituting how to create effective HMIs.

In 2008, this situation changed with the publication of *The High Performance HMI Handbook*, a book dealing with all aspects of effective HMI creation for modern control system and plant operations.

In a power plant simulator, "traditional" graphics in use for more than 15 years are compared to "high-performance HMI" graphics developed in accordance with the latest published guidance and methodologies. Several operators ran multiple operating scenarios with both sets of graphics, and the performance differences and operator reactions were noted and summarized.

The project was identified by the Advisory Group of EPRI Operations Management and Technology, Program 108, as a need for the power generation industry.

Results and Findings

Positive differences were found in operator performance in use of the high-performance graphics. Operator comments were significantly positive. The best summary quote from an operator was "Once you got used to these new graphics, going back to the old ones would be [expletive deleted]." The trials indicate that the high-performance concepts significantly assist the operator in the following:

- Maintaining situational awareness
- Recognizing abnormal situations
- Dealing with abnormal situations
- Embedding knowledge into the control system

This project clearly illustrated a fundamental issue with industry graphics—that of inertia. People become accustomed to, accepting of, and essentially satisfied with whatever they have, regardless of its actual merits or deficiencies. Change is rarely advocated. It is quite significant that a decade of simulator training use at Gerald Gentleman Station has resulted in almost no change to the existing HMI.

Total HMI replacement, while often desirable, is not necessary for considerable improvement to be achieved. Partial implementation of the concepts in this report can provide significant incremental gains.

Challenges and Objectives

Corporate and plant management and engineers will find this report helpful if considering control system upgrades or if implementing strategies to improve operator effectiveness.

In the face of continued emphasis on the bottom line, power producers are working toward optimized plant staffing levels. Use of advanced technologies such as combustion optimizers, intelligent sootblowing systems, and advanced controls continues to improve productivity with these optimized staffing levels. Yet, most plants operate using poorly designed graphics that have not changed for more than a decade.

There is tremendous inertia associated with operator graphics, so much so that in many cases a control system might have been upgraded or replaced several times, yet in each case the existing graphics simply “migrated” from system to system without evaluation or improvement.

EPRI Perspective

This report was developed with the assistance of third-party expertise in the form of the authors of *The High Performance HMI Handbook*. This report enables readers to compare their own HMIs against best practices.

Keywords

Alarm management
Control systems
Distributed control systems (DCS)
Human machine interface (HMI)
Operator graphics

ABSTRACT

Modern power plants are controlled with computer-based control systems located in a control room. The operator interacts with the control system through a set of graphics that constitute the human machine interface (HMI). The content, structure, and the resulting performance of the HMI have become a high-profile topic among users of modern control systems.

These graphic HMIs for most power plants were generally developed in the 1980s and 1990s as older technology control systems were replaced with computer-based controls (generally distributed control systems). At this time, there were no guidelines constituting how to create effective HMIs.

Much has been learned about effective HMI in the intervening years. In 2008, PAS published an important book on the topic, *The High Performance HMI Handbook*. The book detailed proper practices and development methodologies for high-performance operator graphics. These HMI practices differ significantly from most of the practices currently in effect throughout the power generation industry.

In 2009, the Electric Power Research Institute (EPRI) commissioned a project in conjunction with PAS and the Nebraska Public Power District, Gerald Gentleman Station (GGS). GGS is a large, two-unit coal-fired power plant with a full process simulator. The project was designed to test operator effectiveness in the use of both the existing graphics and new high-performance graphics, which were designed in accordance with the modern, high-performance principles. Eight operators tested both sets of graphics in four simulated scenarios.

The trials indicate that the high-performance concepts significantly assist the operator in the following:

- Maintaining situational awareness
- Recognizing abnormal situations
- Dealing with abnormal situations
- Embedding knowledge into the control system
- Allowing for more effective training of new operations personnel

The trials also confirmed the often-found presence of great inertia regarding operator graphics. The existing HMI has been in use since the early 1990s, with operator training via a simulator in effect for more than a decade. Despite clear deficiencies, almost no change to the existing HMI has been made since inception. Total HMI replacement, while often desirable, is not necessary for considerable improvement to be achieved. Partial implementation of the concepts in this report can provide significant incremental gains.

ACKNOWLEDGMENTS

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Tim Berntson, Unit Operator/Operator Trainer
Tom Brunz, Production Consultant

Plant Operators and Shift Supervisors who supported the development and testing of the revised graphics.

EPRI also acknowledges SimGenics for their support in developing the modified graphics for the simulator and supporting the demonstration exercises for the operators.

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INTRODUCTION

1.1 The Basic Principles of High-Performance HMI

Poorly designed human machine interfaces (HMIs) are common. They are responsible for the following:

- Encouraging various poor operating techniques, such as “running by alarms”
- Actively impeding proper situation awareness
- Resulting in increased process variation and poorer quality
- Contributing to higher numbers of avoidable upsets
- Increasing the likelihood of suboptimum response to abnormal situations
- Significantly contributing as a factor in major industrial accidents

HMIs are often neglected. People become accustomed to, accepting of, and essentially satisfied with whatever they have, regardless of its actual merits or clear deficiencies. HMI change is rarely advocated. Yet, the entire plant is controlled via the HMI, and operational effectiveness, online reliability, abnormal situation response, and overall efficiency are greatly affected by the quality of the HMI.

There is now current and process-industry-specific data as to the significant potential for improved operation based on proper HMIs. A study was performed by the Abnormal Situation Management (ASM) Consortium® and Nova Chemicals. In this expensive study, 21 experienced operators were tested using traditional graphics versus graphics designed in accordance with many of the principles in a 2008 book, *The High Performance HMI Handbook*. Using a sophisticated simulator, operators had to detect and respond to identical malfunction and upset scenarios. The results were clear. With the revised graphics, more operators were able to consistently detect abnormal situations well in advance of alarms. The events were dealt with in less time and with a higher success rate. Table 1-1 outlines the benefits of high-performance HMIs.

Table 1-1
High-Performance HMI Benefits (ASM® Study)

Task	With Traditional HMI	With High-Performance HMI	Result
Detecting abnormal situations before alarms occur	10% of the time	48% of the time	A 5X increase
Success rate in handling abnormal situations	70%	96%	37% over base case
Time to complete abnormal situation tasks	18.1 min	10.6 min	41% reduction

Based on historical incident and upset rates, the anticipated annual savings by switching to a high-performance HMI were determined to be $800,000 per year for one ethylene plant. There is clearly a financial return on investment for such efforts, along with a step change in the potential capability to avoid incidents and accidents.

1.2 Redesign Displays to Emphasize the Most Important Information

Display design and style has a significant impact on the speed and accuracy of operators' interactions with a display. Common misuse of color and animation are an impediment to easy and early recognition of a significant event. Our knowledge of human factors has increased greatly since the introduction of the distributed control system (DCS), yet display design has not generally incorporated this knowledge.

Proper HMI design increases the ability of operators to distinguish different conditions, recognize important information, and respond to abnormal plant conditions. Improper design slows response times and contributes to errors in perception and comprehension.

Traditional displays usually overemphasize numeric data. The operator needs information, not just raw data.

Information is data in context made useful.

Proper presentation of information in innovative ways will significantly enhance the operator's situation awareness and ability to deal with abnormal situations.

Some characteristics and contents of high-performance displays are as follows:

- Gray backgrounds are used to minimize glare, along with a generally low-contrast depiction.
- There is no gratuitous animation, such as spinning agitators or pumps, moving conveyors, and splashing liquids and sprayers. Animation should be limited and only used to highlight abnormal situations.
- Depiction of process values is made in the context of information, rather than as simple numbers on a screen.
- Important information and key performance indicators have embedded trends in the graphics themselves.
- There is very limited use of color, and color is used consistently.
- Alarms are prominently depicted and important. Alarm colors are used only to display alarms and nothing else.
- Equipment is depicted in a simple 2-D low-contrast manner, rather than brightly colored 3-D vessels with shadowing. The piping and instrumentation diagram (P&ID) style of graphic element is used when appropriate but not overused.
- Layout is consistent with the operator's mental model of the process.
- Navigation methods are logical and consistent.
- A hierarchical structure supports progressive exposure of detailed information.
- Display access requires a minimum number of operator keystroke actions.
- Techniques are used to minimize the possibility of operator mistakes, as well as provide validation and security measures.
- Display elements have consistent visual- and color-coding.

1.3 Hierarchical, Scenario-Based Displays Improve Situation Awareness and Response

Situation awareness is an accurate and timely understanding of the condition and behavior of the process. Proper display design should support situation awareness and encourage proper operating practices.

Four distinct levels of displays should be used, incorporating the principle of progressive exposure of detailed data:

- Level 1: Process Area Overview (for situation awareness)
- Level 2: Process Unit Control (for ongoing process manipulation)
- Level 3: Process Unit Detail (for close, detailed examination)
- Level 4: Process Unit Support and Diagnostic Displays (for troubleshooting)

When P&IDs are used as the simplistic basis for graphic design, a proper graphic hierarchy will not result. P&IDs are a totally "flat" form of depicting the process (imagine a computer hard disk with only one folder for all files). For control purposes and proper abnormal situation handling, the displays should enable "drill-down" for increased level of detail.

Proper displays for running a process in a normal situation will likely not contain the right information for handling an abnormal situation. Additionally, there should be displays specifically designed to address upset conditions, as well as certain routine activities such as mode transitions.

1.4 Seven Steps for Creating a High-Performance HMI

The following steps are optimum for transforming a traditional HMI into a high-performance HMI. They are also easily adaptable for creation of a new HMI for an entirely new facility.

- Step 1: Adopt a High-Performance HMI Philosophy and Style Guide. (An abbreviated example of such a document is included in this report as Appendix C.)
- Step 2: Assess and benchmark existing graphics against the HMI philosophy.
- Step 3: Determine specific performance and goal objectives for the control of the process, for all modes of operation.
- Step 4: Perform task analysis to determine the control manipulations needed to achieve the performance and goal objectives.
- Step 5: Design and build high-performance graphics, using the design principles in the HMI philosophy and elements from the style guide, to address the identified tasks.
- Step 6: Install, commission, and provide training on the new HMI.
- Step 7: Control, maintain, and periodically reassess the HMI performance.

Enumerating the details of these steps is beyond the scope of this report. They are described in full in *The High Performance HMI Handbook* (see References in Appendix B).

2

THE EXISTING GGS CONTROL SYSTEM AND SIMULATOR

This section provides a detailed description of the Gerald Gentleman Station (GGS) control system, and the simulator used for operator training and testing of these high-performance HMI concepts.

2.1 The Existing GGS Control System

The GGS DCS is a Honeywell TotalPlant® Solution (TPS) (also known as TDC-3000), a highly capable DCS of early 1990s vintage. The graphic screens are glass CRTs, 640x480 pixel, with a significantly limited color palette, and are representative of early 1990s technology. The Honeywell terminology for the graphic display type is called "Native Window."

The displays are single or dual, vertically stacked touchscreen computer remote terminals (CRTs) with special-purpose associated membrane keyboards (known as Universal Stations or US). The console has one example of a later replacement workstation developed in the late 1990s, providing for increased graphic capability (graphic user stations or GUS). These have not been fully implemented at GGS and are used to display existing Native Window graphics. Use of the advanced capability requires development of separate GUS graphics; this has not been done.

An upgrade project to bring the control system, screens, and graphics to the latest technology (Honeywell Experion) is underway.

Here is the control console arrangement left to right (shown in Figure 2-1):

- 1-screen general purpose PC.
- 1-screen US.
- 2-screen (stacked) US.
- 2-screen (stacked) US.
- Manual panel includes a TELEX station, some large light-emitting diode numbers, three Yokogawa liquid crystal display (LCD) trend devices (vertical paper chart replacement types), and some manual buttons for synching the unit.
- Suspended above the manual panel is a 30-inch glass CRT displaying the Alarm Summary—it is really a 1-screen US with the US keyboard located in front of the manual station.
- 2-screen (stacked) US.
- 2-screen (stacked) US.
- 2-screen side-by-side GUS (usually displaying one Native Window graphic each).
- Above the two GUS screens are two other screens from separate non-DCS computers. One is the "water wall cannon system," and the other is the CIRRUS system.

Figure 2-1
GGS Unit 2 Control Room Console

2.2 The GGS Simulator

The GGS Simgenics simulator (Figure 2-2) is in a different building and looks very much like the Honeywell console, including the membrane keyboards. The displays are Simgenics emulations of the Honeywell Native Window screens, and they look and function almost identically to them.

The simulator has several limitations that became relevant to this study. It is also a 1990s design and will require an upgrade in order to work with the planned GGS replacement control system. The simulation of the high-performance graphics in this test pushed the simulator capabilities to their limit, and several functionality compromises were made.

There are significant differences in developing graphics for a DCS and creating simulated versions. Actual control system graphics can access routines and functions involving thousands of lines of built-in code supplied by the DCS manufacturer. It is impractical to replicate such functionality in the simulator environment.

The main simulator limitations include the following:

- Simulated alarm functionality is extremely limited. Most alarms are not implemented in the simulator. All alarms utilize one priority. Equipment status alarms were not implemented. Some points that need alarms do not have them.
- Trend functionality. The scales and time spans cannot be changed. The number of trend traces was limited. The trends all ran at 7 minutes left-to-right instead of the 20 minutes desired, and the solution to the problem could not be found prior to the testing.
- Standard graphic methodologies for calling up "faceplates" for manipulation of all points was impossible because each faceplate type and function had to be hand-coded in the simulator environment. Only a subset was provided, tailored only to the scenario.

- The simulator does not have all of the points that exist on the DCS.
- Keyboard functionality was not fully integrated with graphics as it would be on the actual control system. There was missing functionality.
- Physical screen resolution problems existed. The high-performance graphics had to be run in reduced physical sizes compared with how they would actually appear on the actual control system—similar to a "letterbox" effect on a conventional television.
- Touchscreens. The operators are very used to the existing Honeywell touchscreen operations, which are emulated on the simulator for the normal graphics. The early 1990s capability of touchscreens does not adapt to high-resolution displays, such as will be provided in the planned upgrade. Higher resolution displays utilize mice or trackballs. LCD displays without touchscreens were used for the testing, and the operators had to use a single mouse, manually switching it from screen to screen via a selector box. This clumsy but necessary arrangement was not totally satisfactory.
- Being a simulator, identical process values are often present in identical equipment. Trending of those values results in trend traces that are exactly on top of each other. This is not the case in the "real world."
- There were **significant** time and cost pressures in preparing the graphic designs, then the simulator versions, and in running the scenarios.

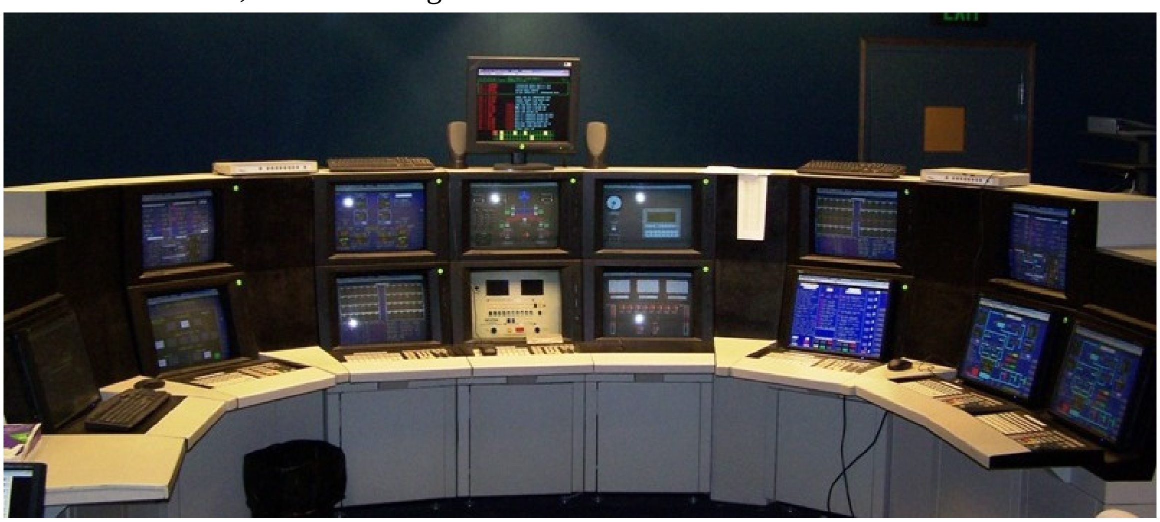

Figure 2-2
GGS Simulator Console

2.3 The Existing GGS HMI

PAS has analyzed and developed hundreds of HMIs for refineries, chemical plants, power plants, pipelines, mines, and similar processes. The existing GGS HMI has several significant issues and has not been significantly updated since the early 1990s.

Images of several GGS screens are shown later in Section 2.3.2.

2.3.1 Characteristics of the Existing GGS HMI

General Factors

- There is no existing overview display summarizing the key factors of each operator's entire span of control. The graphics are not designed with the concept of hierarchy, providing for the progressive exposure of detail as needed.
- No graphics exist, specifically designed for the support of a shutdown or runback conditions.
- Many controller elements are not shown on any graphic.
- The paradigm for the creation of the graphics is, in some cases, the emulation of the pre-1990 physical panel instruments that the DCS replaced. By making this choice, the HMI functionality has been significantly limited. The graphics have not had a significant update since their creation in the early 1990s.
- Numbers and digital states are presented inconsistently. Numbers are not shown in any sort of context to indicate whether they indicate normal or abnormal values.
- Graphic space utilization could be significantly improved. Many elements take up too much space for their functionality, and numbers and text are often crammed together.
- Some elements on the screen are "selectable" in that some action occurs if they are touched—for example, a manipulation element appears. Other elements are not selectable. There is no consistent visual differentiation of selectable and nonselectable elements.
- GGS does consistently include confirmation elements (for example, Execute/Cancel) for the commanded change of equipment run condition and similar changes.
- There are significant issues with color choice and usage. While most Honeywell TPS systems of this vintage utilize black backgrounds (this early technology does not allow for effective use of gray), GGS implemented blue backgrounds. Blue backgrounds have significant deficiencies when coupled with the use of other colors on top of the blue. The very eye-jarring combination of red and blue is frequently used.
- Interlocks are not generally shown on graphics indicating their inputs, status, and outputs. Nor can the operator easily see the actions needed to clear the interlocks. (The pulverizer screens are an exception to this general statement.)
- Color is greatly overused and inconsistent. Bright red and yellow are used excessively on most screens. The use of red and yellow can indicate several different both normal and abnormal conditions, and thus red and yellow actually have no meaning on the GGS screens.
- GGS graphics do not utilize gratuitous animation elements. Such things as spinning agitators and pumps, moving conveyors, splashing liquids and sprayers, and other such animation elements are inadvisable components.

Alarm System Factors

- At the time of the simulator test, the GGS system had not yet undergone any aspects of alarm management. GGS has begun a major alarm improvement effort. These comments apply to the alarm system at the time of this test.
- Alarms are generally not indicated on graphics. That is, when a depicted measurement goes into alarm, there is generally no indication of that condition on the graphic. Alarms are only shown on a scrolling-list "Alarm Summary Screen" where, during high alarm rate conditions,

the missing of important alarms is a likely situation. In some cases, graphic numbers change to red to indicate an alarm condition. This is not consistently implemented, and the use of color alone to differentiate an important status condition is an inadvisable practice.

- Alarms are inconsistently applied. In most cases, you cannot tell by looking at a GGS graphic if a particular value is in alarm. This is true even on signals that are precursors to automated shutdowns.
- While three alarm priorities are available on the system (Emergency, High, and Low), GGS does not use the priority attribute in a consistent way and most alarms are configured as "High" priority. This is inconsistent with documented best practices of alarm management.
- Alarm rates are high. A recent baseline report indicated an average of almost 500 annunciated alarms a day with peaks past 1,000. Maximum acceptable and manageable alarm rates are 150 to 300 alarms per day.
- There are many nuisance alarms and usually multiple screen pages of standing alarms.
- Alarms have been placed on sensor points rather than properly on controller points.
- Some important alarms (such as shutdown precursors) are not implemented. Operators indicate that they get high alarm rates when operating the unit at high rates.
- Alarms are undocumented regarding their causes, consequences, corrective action, and similar information.
- The Honeywell TPS system has the built-in ability to navigate from an alarm selected on the alarm summary to a screen predetermined to be the correct screen to analyze that alarm. This feature is not implemented at GGS.
- "Blinking" of unacknowledged alarms on graphics is a desirable use of animation (an exception to the general rule), but GGS graphics do not use this functionality.

Note: For further information about proper alarm management practices, see the *EPRI Alarm Management and Annunciator Application Guidelines*, product ID 1014316, as well as *The Alarm Management Handbook* listed in the references section.

Use of Trends

- The existing Native Window graphics are capable of incorporating embedded trends (dedicated trends that are part of the graphic itself and appear whenever the screen is brought up). Embedded trends are highly desirable elements. Only one GGS graphic incorporates such a trend.
- GGS relies on the ability of operators to use Honeywell functionality to "trend on demand" any values that "need trending." This capability is highly overrated, limited, and underused by the GGS operators. This is a typical condition throughout industry, regardless of the type of control system. Comments by operators made in the simulator testing indicate that in situations when they are needed most, there is no time to build trends from scratch. In several visits to the control room, PAS noted that DCS trends were not evident on any of the screens.

Navigation

- It is easy to call up any GGS graphic screen. The Honeywell system has a large number of programmable and labeled buttons at each station to which graphics can be assigned and called up in a single keypress. GGS has made effective use of this functionality and of supporting graphic menus.
- However, GGS graphics do not incorporate a highly desirable and standard Honeywell Native Window feature called the “change zone.” When a graphic element (such as a depicted measurement) is selected (touched), the change zone area at the bottom of the screen dynamically swaps to show details about the point involved. This includes showing the point name and description and allowing for keyboard-integrated manipulation of such things as controller modes and setpoints. A single touch in the change zone navigates to the point detail screens, where diagnostics and additional point information is available. Instead of using this functionality back in the early 1990s when the screens were designed, GGS implemented partial access to similar functionality via custom code in the graphics. By failing to utilize the standard change zone functionality, GGS operators have extremely limited access to the standard Honeywell screens for diagnosing problems.

2.3.2 Existing GGS Screens Used in the Testing Scenarios

Figures 2-3 through 2-11 are images of the existing GGS screens that were used in the scenario testing. Note the differences between the first screen below (Figure 2-3) and the high-performance unit overview screen shown later in Figure 3-4.

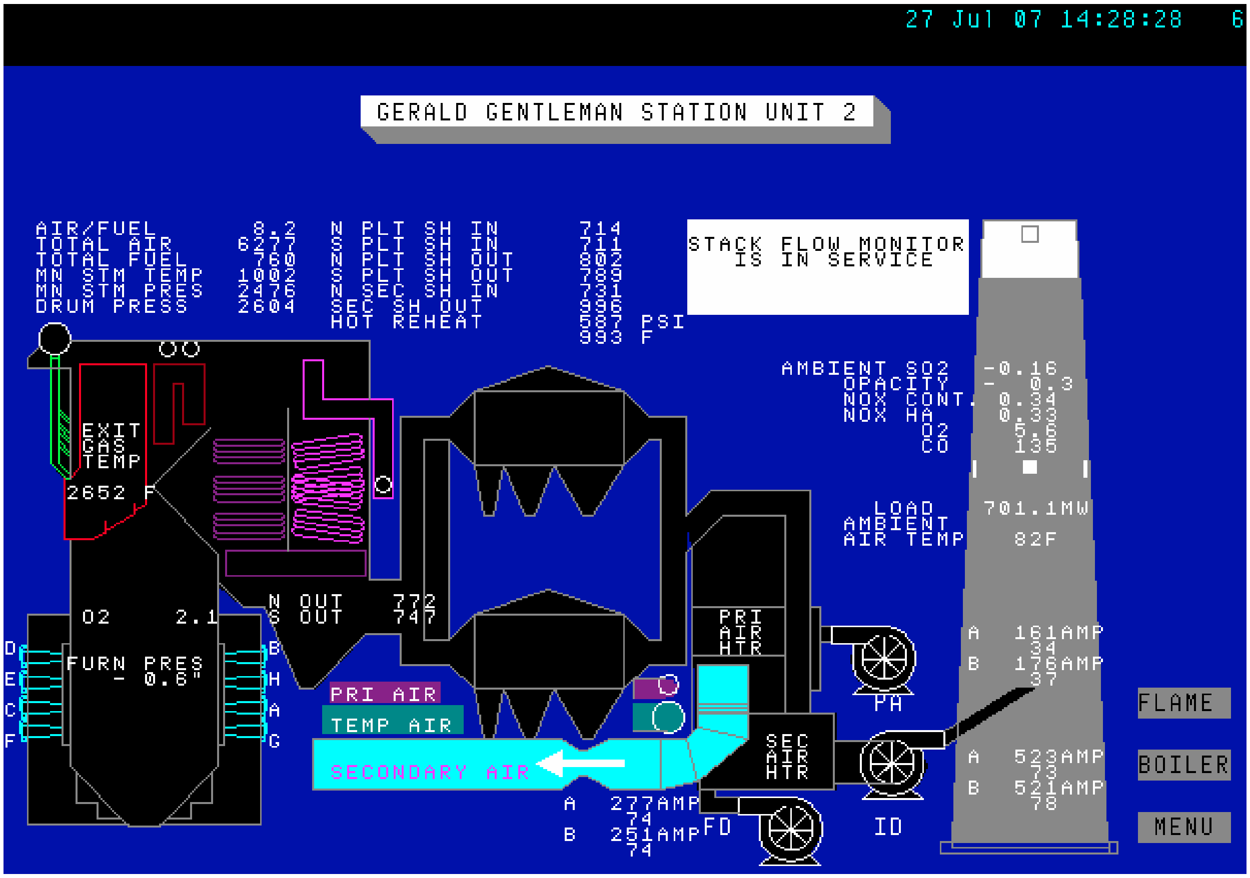

Figure 2-3
Existing GGS Unit Overview

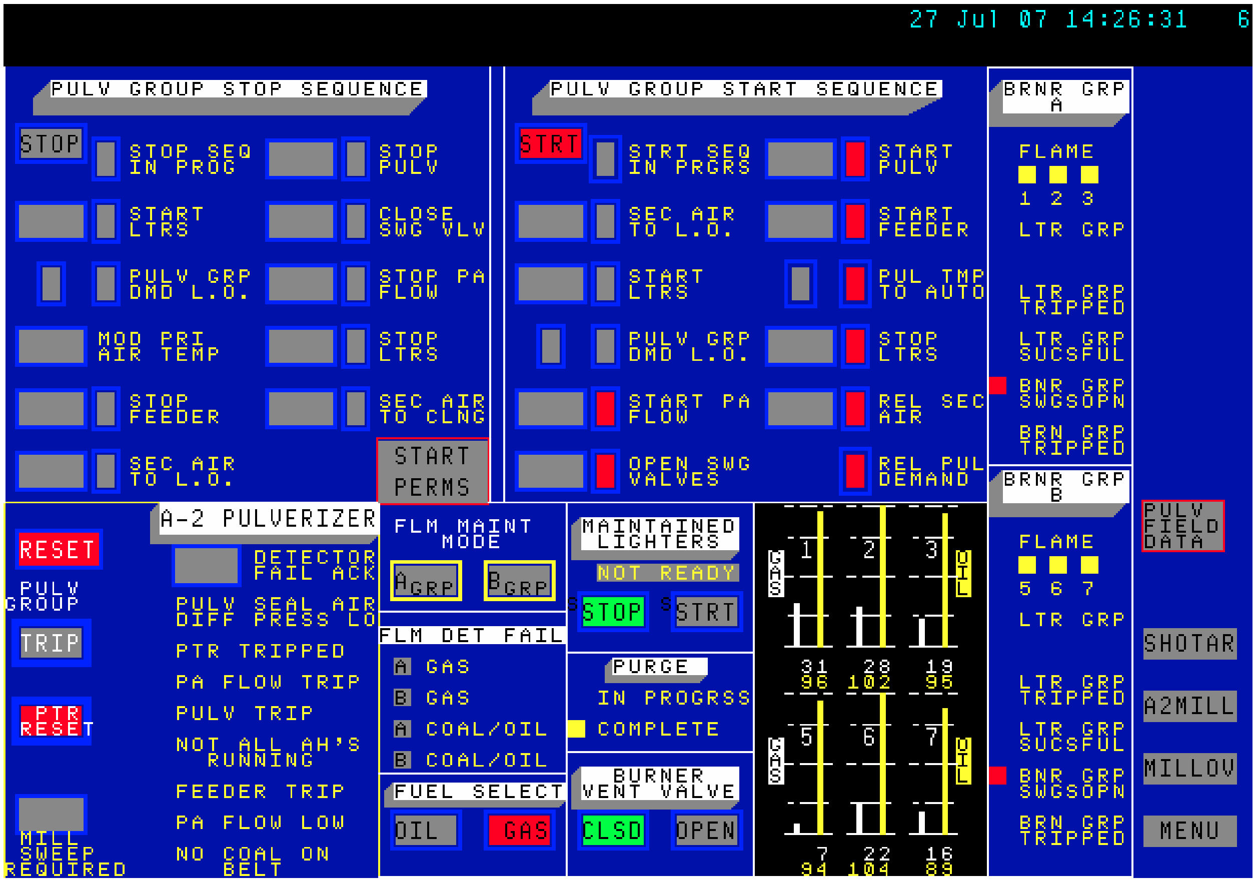

Figure 2-4
Existing GGS Pulverizer Control Graphic (1 of 2)

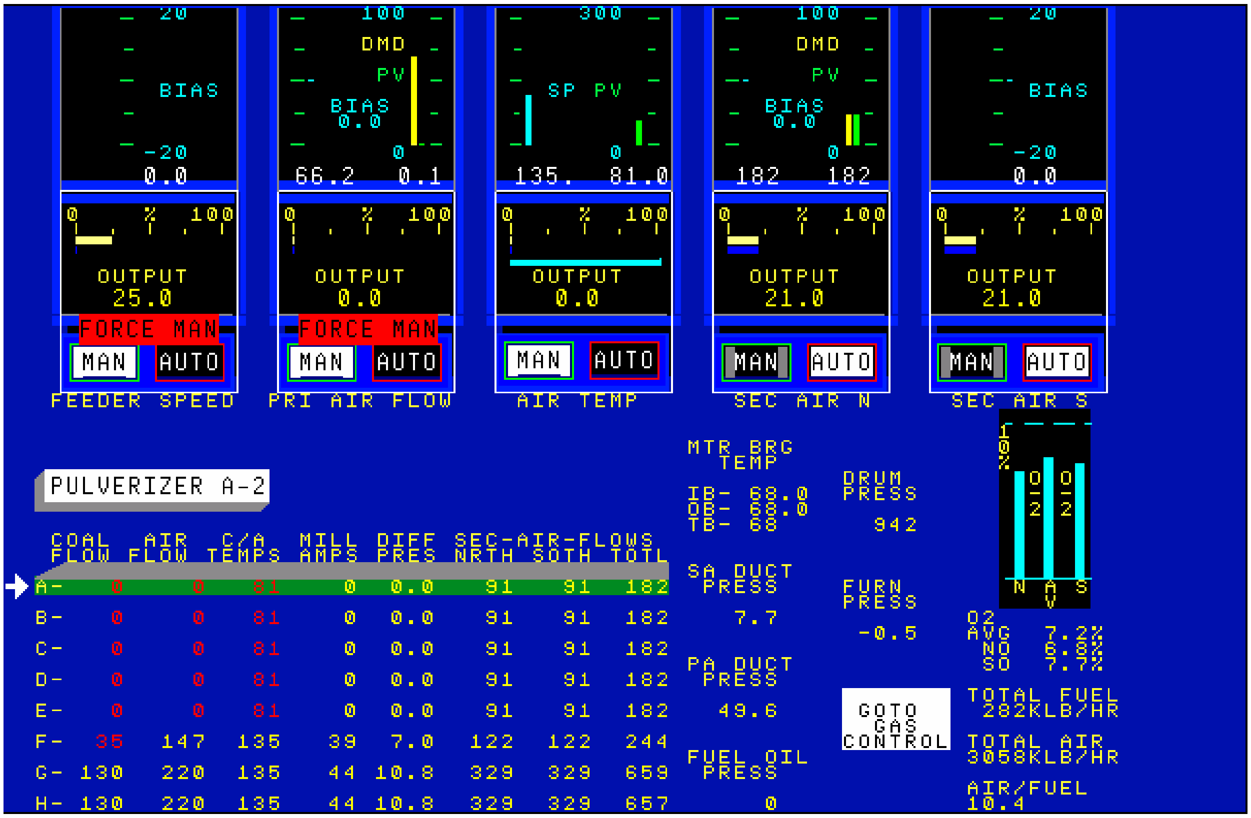

Figure 2-5
Existing GGS Pulverizer Control Graphic (2 of 2)

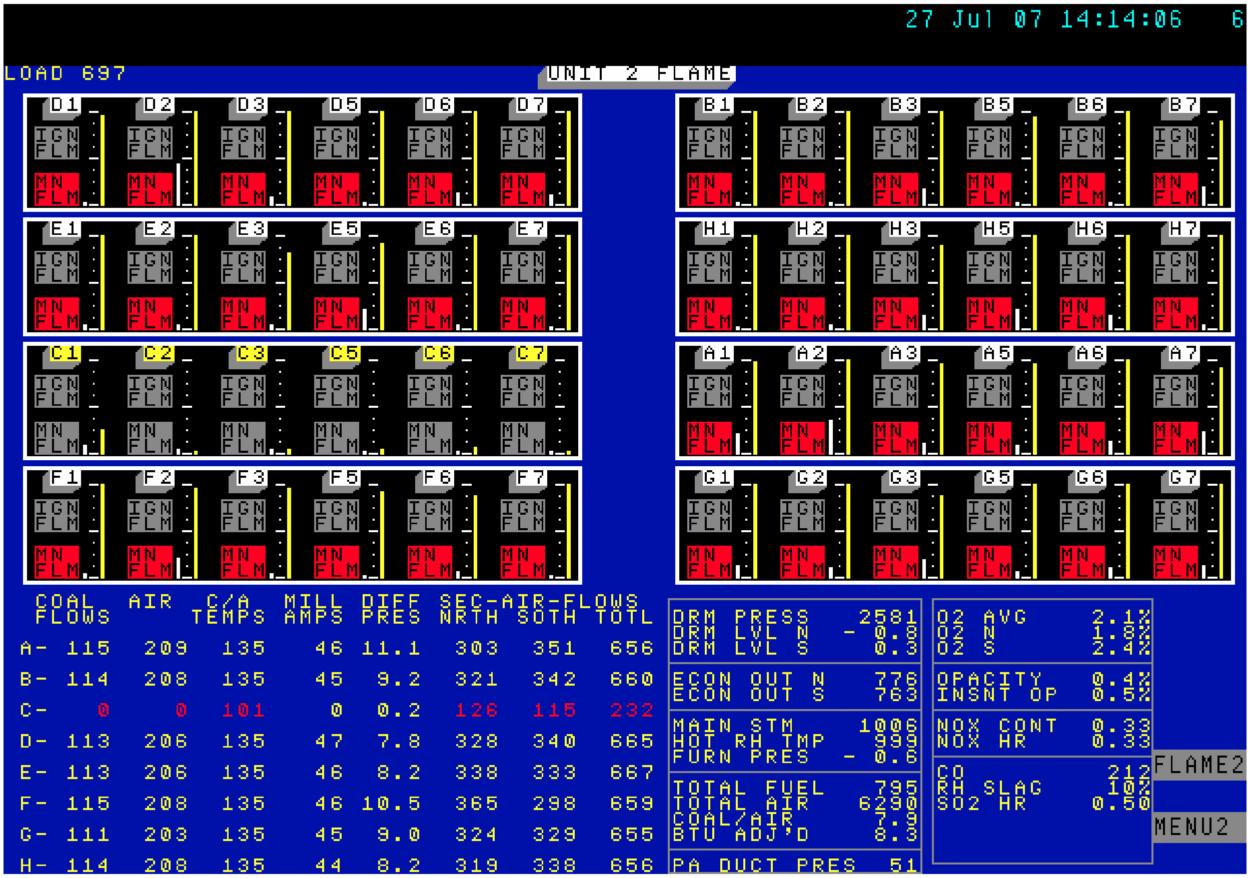

Figure 2-6
Existing GGS Pulverizer Flame Graphic

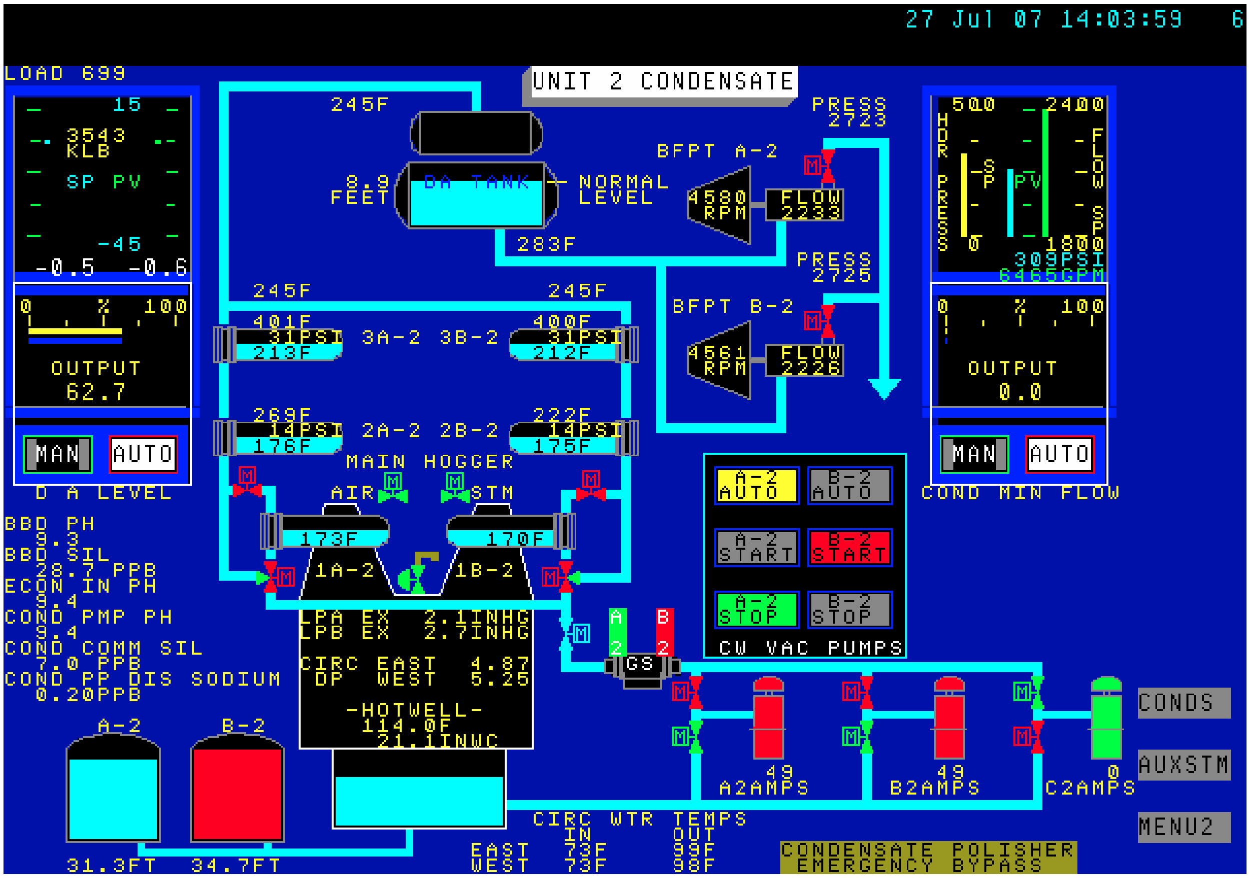

Figure 2-7
Existing GGS Condensate and Deaerator Graphic

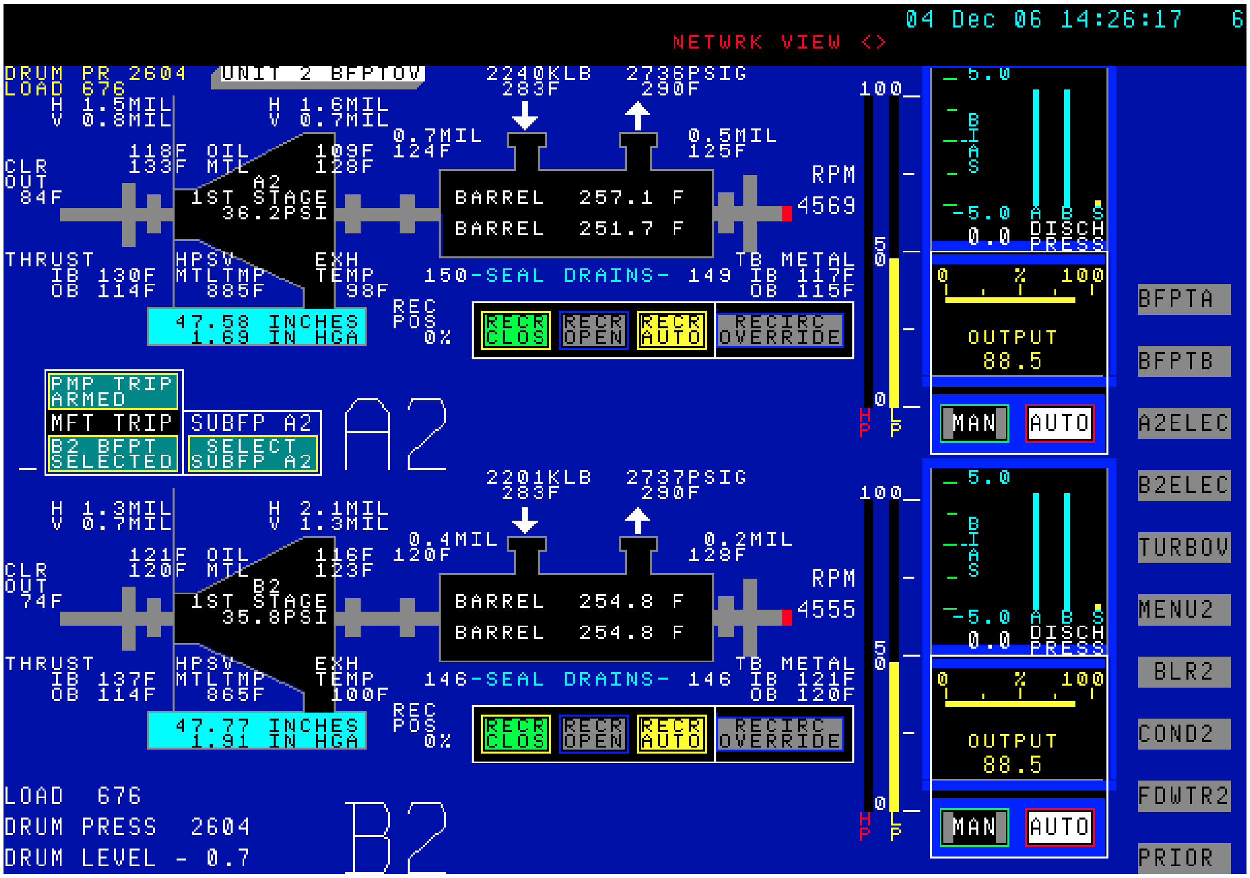

Figure 2-8
Existing GGS BFPT Overview

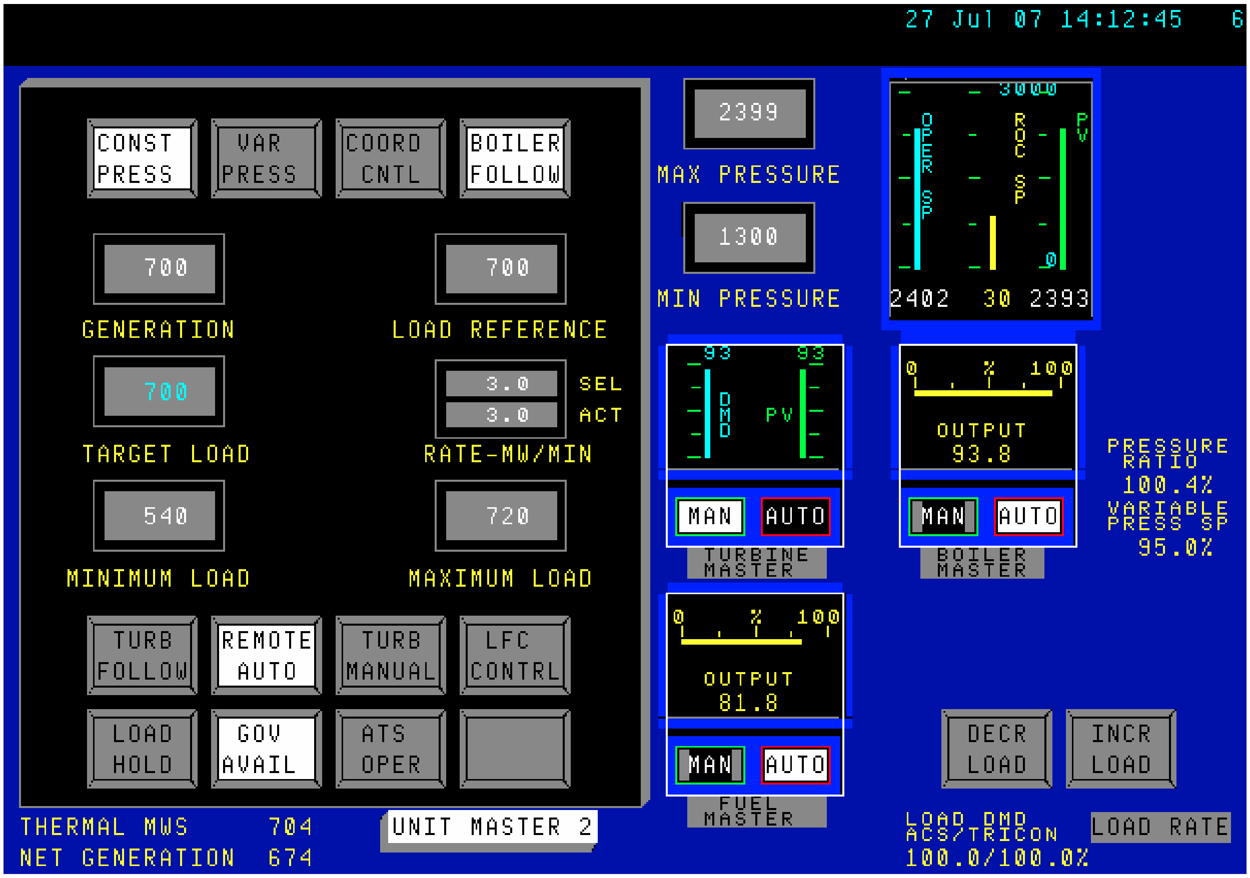

Figure 2-9
Existing GGS Unit Master

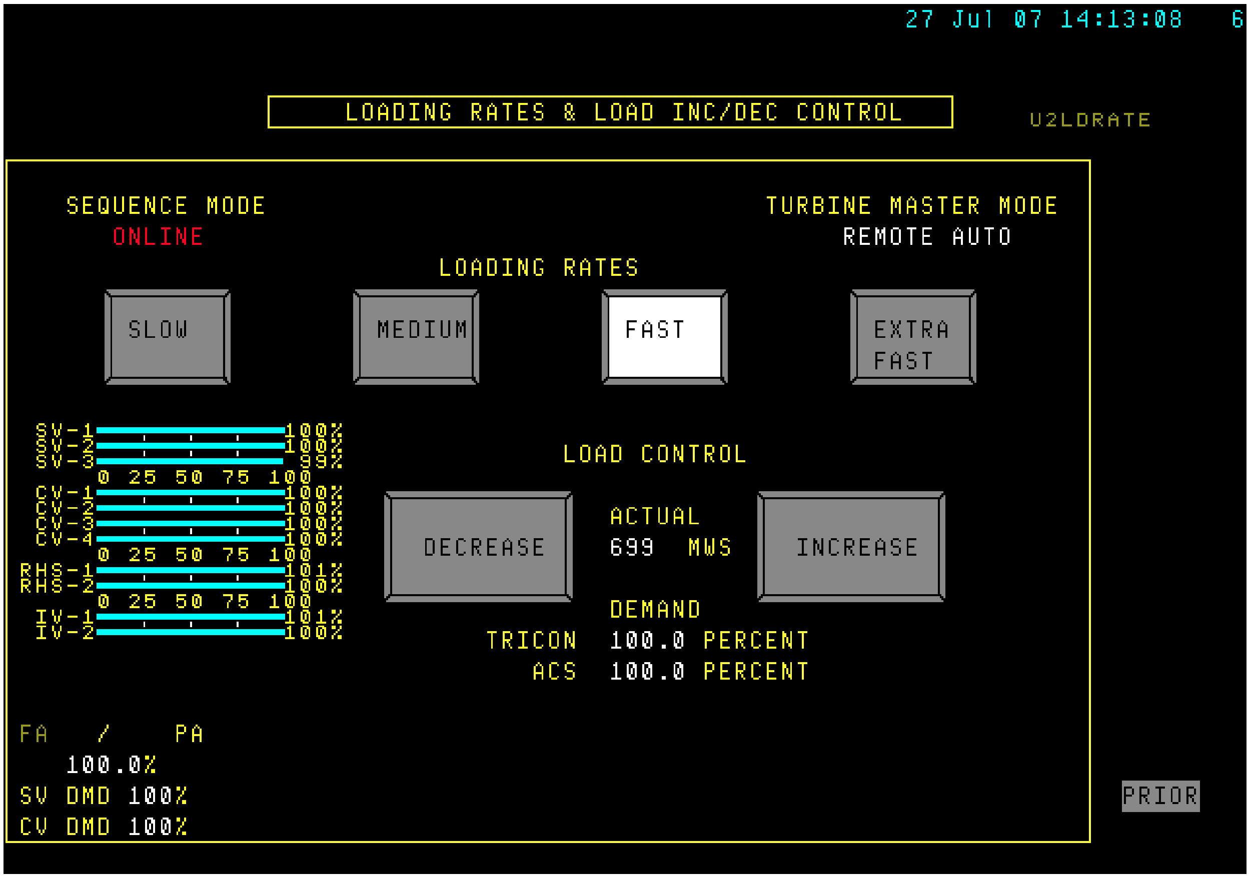

Figure 2-10
Existing GGS Load Graphic

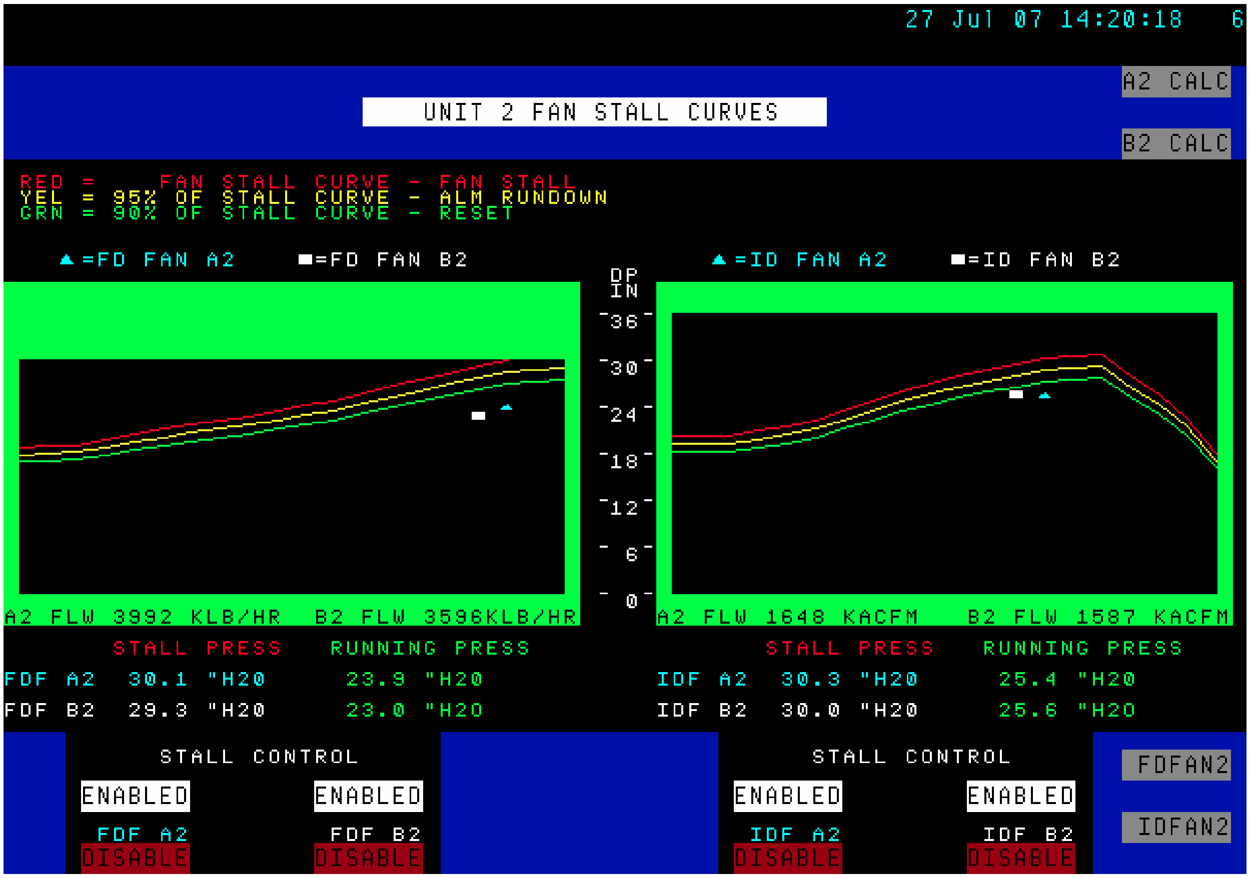

Figure 2-11
Existing GGS Fan Stall Graphic

This is the only GGS graphic with an embedded trend.

3
HIGH-PERFORMANCE GRAPHIC DESIGN

The time and budget limitations on the project required that the focus of the graphic design and simulator testing be limited to only certain conceptual elements of high-performance graphics. These were chosen to be the following:

- Analog depiction of numbers, including the indication of "good" versus "abnormal" ranges, alarm ranges, and interlock ranges
- Significant use of embedded trends
- Limitation of color usage
- High-visibility depiction of alarms
- The use of an always-visible overview display, depicting the most important aspects of the overall process
- The use of an always-visible pulverizer overview display, depicting the high-level performance functioning of all eight pulverizers on one screen
- The use of special-purpose graphics to assist in the abnormal situation of a significant unit runback, by providing all controls necessary to manage the situation in one place along with dedicated display elements to indicate the runback performance
- The creation of a control graphic containing all of the items needed for effective startup, operation, and shutdown of an individual pulverizer on one screen (The existing graphics use two screens per pulverizer for this.)

High-performance graphics concepts not included in this test include:

- Implementation of a full graphic hierarchy, including provision of a full complement of Level 2 control graphics, as well as Level 3 and 4 graphics
- Full alarm functionality on depicted values, with proper alarm prioritization and rationalization
- Navigational connection from the alarm summary screen to the appropriate graphics
- Access to alarm documentation from within the operator's HMI
- Access to equipment and operations procedural information from within the HMI
- Proper faceplate design
- Detailed interlock depiction
- Multiple navigation methodologies
- Trend timebase and scaling functionality
- Display "yoking"—the ability to call up several displays on multiple screens in a predefined arrangement for a given situation
- Ergonomic layout of the display hardware

3.1 GGS High-Performance Graphic Development

The work process for high-performance graphic development followed the applicable steps (see Section 1.4) of process performance and goal development, and task analysis, in determining the screen content. Much time was spent discussing a question that had never been asked about any item depicted on any GGS screen: “For the depiction of this measurement, what constitutes the good or normal range, the abnormal range, and the alarm range or ranges?” The intent of a high-performance graphic is to display **information** rather than raw data.

- Several Electric Power Research Institute (EPRI) engineers were consulted for ideas about which process measurements for a coal-fired power plant should be depicted on the overview screen. The list was further developed with GGS and PAS personnel. There were three rounds of review and comment in coming up with the content and design used for this project.
- For the runback situation, GGS demonstrated manual runback scenarios on the simulator using the existing graphics. The items manipulated were noted, and it was also noted that many different screens were needed to accomplish a manual runback. Much time was spent answering, “How do you tell the difference between a good runback and a bad one? What measurements are involved? What rates of change for these measurements are desirable versus undesirable? What measurements show potential trouble?” The answers were used to create the two runback graphics, also with multiple content reviews.
- Pulverizer functionality and operation was similarly questioned, determined, and reviewed. A pulverizer overview screen showing the combined comparative functioning of all eight pulverizers was created, as were individual pulverizer control graphics. Each of the latter was a single-screen version of the existing two-screen graphics.
- In some cases the high-performance graphics intentionally replicated an existing arrangement and input mechanism because of operator familiarity, even if a modified arrangement or mechanism might be more desirable or consistent with high-performance principles.

3.2 The Moving Analog Indicator

Analog indication of important process values is accomplished through the use of the moving analog indicator (MAI; Figure 3-1). This graphic element has several significant features.

The MAI displays not only the process value (number), but also its proximity to a normal or expected range, a high and low alarm range (if configured), a hi-hi and lo-lo alarm range (if configured), and the presence of automatic interlock actions at high and/or low values (if configured). At a single glance, an entire bank of such indicators can be evaluated. Values outside of normal range are easily detected, and values in alarm stand out strongly.

Not all process measurements will have all such alarms and interlocks mentioned, and the MAI dynamically reflects the point’s actual configuration. On actual graphics (as opposed to the simulator), a control toggle is provided to cause the numbers to appear/disappear under operator control.

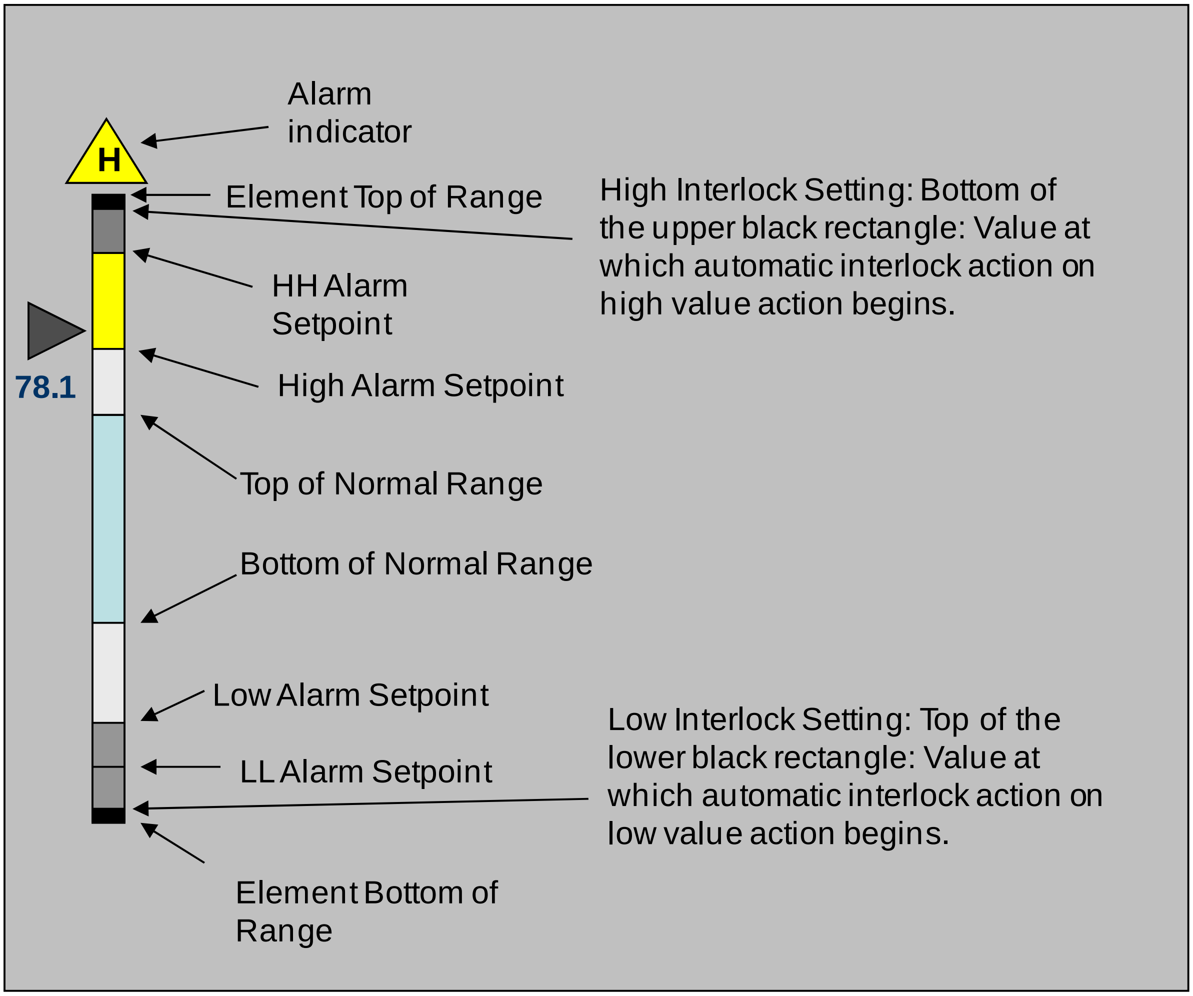

Figure 3-1
Moving Analog Indicator

3.3 The Controller Element

Proportional-derivative-integral (PID) controllers have the additional elements of setpoint, mode, and output. They are shown as follows (Figure 3-2) on the original simulator graphics.

The testing indicated some desirable changes in the controller depiction, which are discussed later in Section 5.2.1.

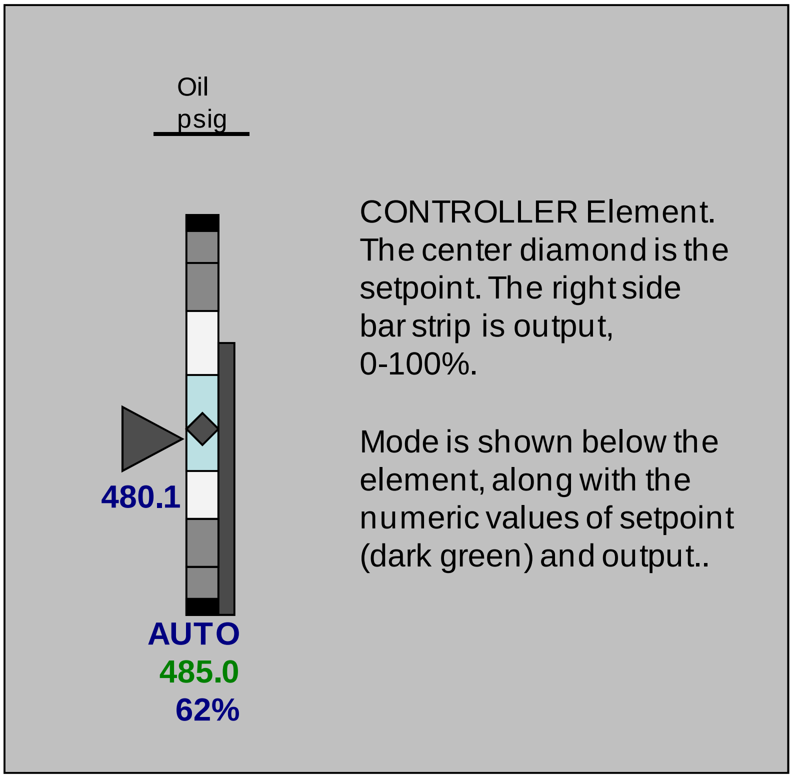

Figure 3-2
PID Controller Element Before Improvements

3.4 The Embedded Trend Element

The embedded depiction of trends within graphics is fundamental to high-performance graphics. Even in trends, it is important to indicate the boundaries of normal and abnormal operation. Various DCS types have differing abilities in this regard. Generally the background of the trend area itself cannot be manipulated. It may be possible to plot dotted lines indicating boundaries. The GGS graphics used elements at the right side of the trend, indicating the boundaries of normal operation and color-coded with the trend trace line. Such elements should be dynamic and work with the trend ranges currently in effect; Figure 3-3 shows one trend element.

Trends should be implemented with several capabilities and characteristics:

When the graphic is called up, the trend's *y*-axis span should automatically range itself to a predetermined scale or a predetermined amount relative to the current value of the reading, such as ± 2% or ± 5% engineering units. This should be a tight scale where meaningful change of the value is immediately detectable.

The trend should come up with a default timebase appropriate for the process condition (for example, to show the last 10 minutes, 2 hours, or the last 24 hours). This choice will vary based on the particular process value being trended.

Normal process bounds, quality limits, or desirable operating range should be indicated based on the state of the process.

Manual alteration by the operator of the ranges and timebase should be possible and should persist to the next invocation of the display.

The operator should not have to manipulate any keys to make the trend usable.

The display of multiple traces should be consistently implemented.

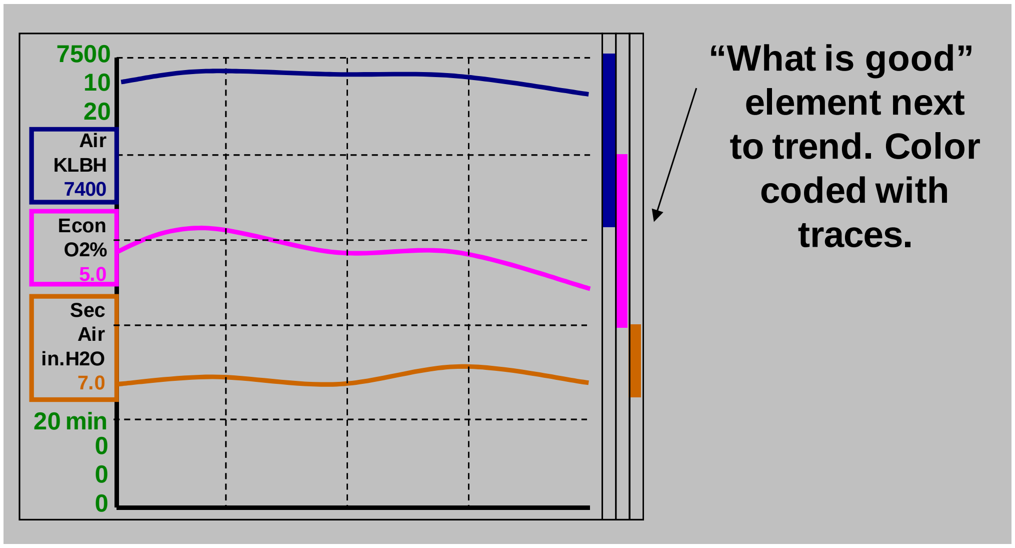

Figure 3-3
Trend Element

Full descriptions of the functionality of high-performance graphic elements are found in the Abbreviated High-Performance HMI Philosophy and Style Guide (Appendix C).

3.5 The GGS High-Performance Graphics Used for Scenario Testing

The following graphics were used in the simulator testing.

3.5.1 Unit Overview

The overview display will show the broadest available view of the facilities under a single operator's control. It is a "big picture" at-a-glance view of the process unit. It provides a clear indication of the current performance of the process by tracking the key performance indications (Figure 3-4).

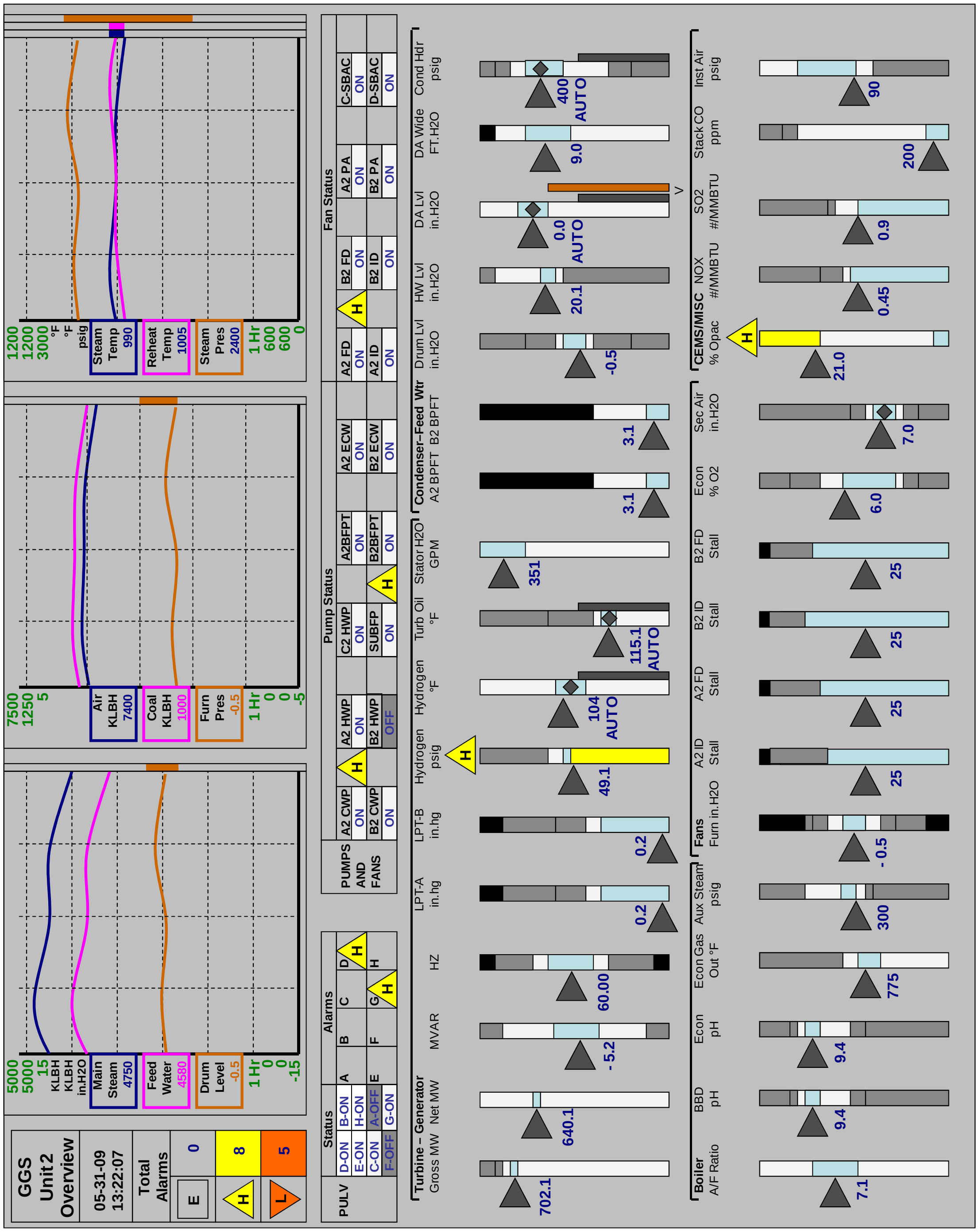

Figure 3-4
GGS Overview Graphic

The overview display is often properly placed on a large screen off of the console. In many facilities, operating areas are closely coupled through feed and product streams, heat integration, and dependant utilities, so the overview of any given area may be useful to adjacent operators.

In the GGS simulated overview graphic, the four fan stall indicators (bottom row, middle) were left off because of the dynamic complexity embedded in their depiction and the simulator limitations.

3.5.2 Pulverizer Overview

Pulverizers are complex, highly instrumented equipment items. A single operator controls eight pulverizers. In such cases, it is useful to have an overview screen showing the overall functioning of the pulverizers as a group, with each individual pulverizer having a more detailed (Level 2) graphic designed for control manipulation (Figure 3-5).

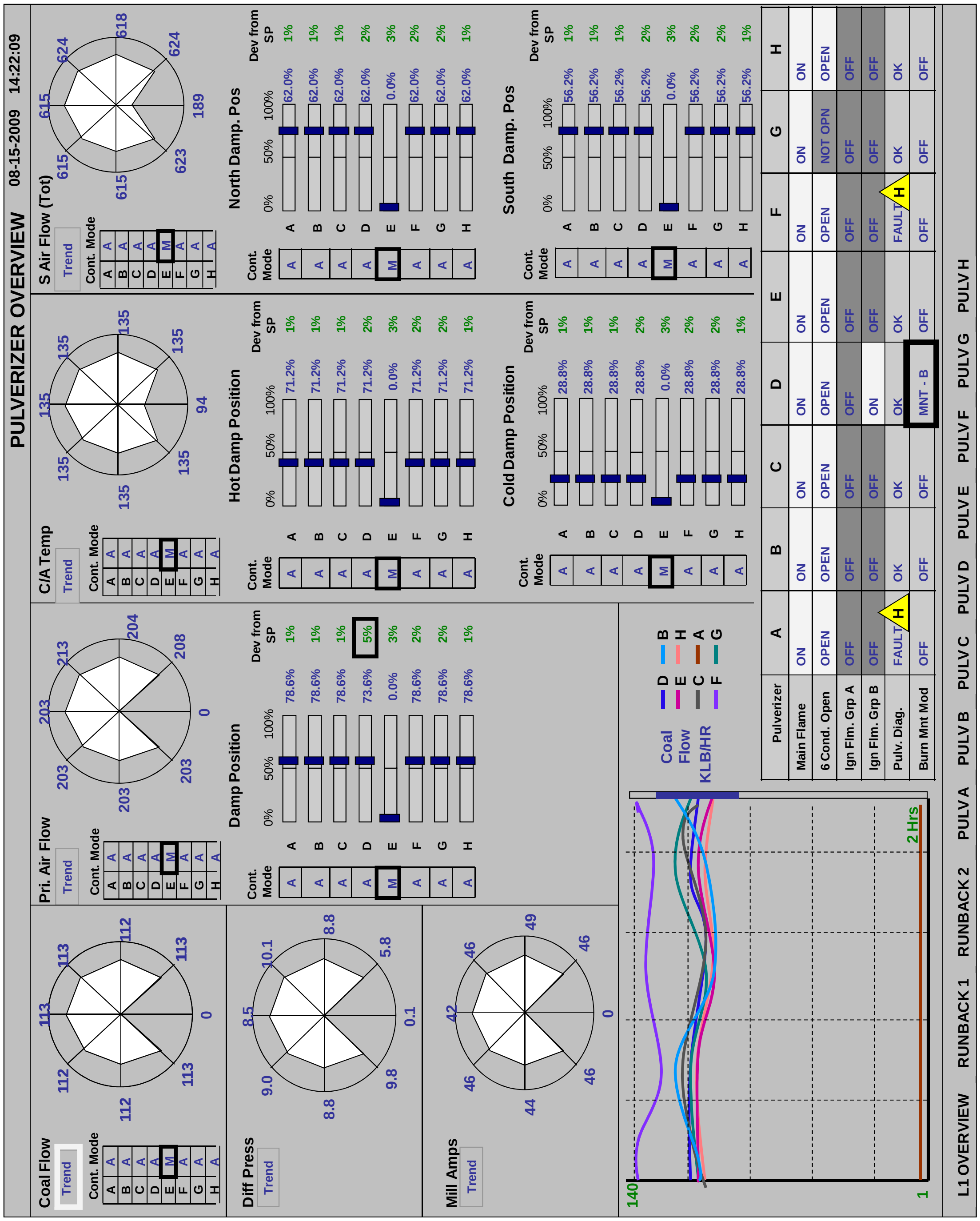

Figure 3-5
GGS Pulverizer Overview Graphic

A primary purpose of the pulverizer overview is to depict any differences in pulverizer operation. The radar plots were intended for this purpose, indicating the same measurement for each different pulverizer. This proved to be less than satisfactory. The reasons and a revised depiction are shown in Section 5.2.2.

The trend element shows all eight of the same readings for the pulverizer selected by the operator.

3.5.3 Pulverizer Level 2 Control Graphic

Figure 3-6 is the Level 2 graphic for detailed control of an individual pulverizer. There were eight identical graphics prepared, one for each pulverizer.

Elements are manipulated by first "selecting" via a click. This causes a standard "popup faceplate" element to appear in a reserved space on the right side (the element shown as Inlet Feed). The faceplates vary by point type and are supplied by the control system manufacturer for use. Manipulation of the element is done via the faceplate.

Custom faceplates can also be prepared, as the standard functionality supplied by the vendor may be lacking. For the primary purposes of this project, faceplate design and functionality was relatively unimportant, although it did garner operator comments.

3.5.4 Runback Screens

Discussions were held to determine what abnormal situation scenarios would provide for a good test of high-performance graphic contents. Many different abnormal situations at GGS require the operator to perform a manual runback of the unit to a significantly decreased load. That requires the operator to access many separate screens and is a stressful operation to successfully accomplish. GGS has no existing graphics specifically designed to assist in this common situation, and it was decided to include such graphics as part of this project. Two graphics were created—runback 1 and runback 2.

Runback 1 is a monitoring screen that provides an overview of the process and the important parameters that must be observed to accomplish a successful runback (Figure 3-7). Runback 2 is the screen designed for control manipulation (Figure 3-8).

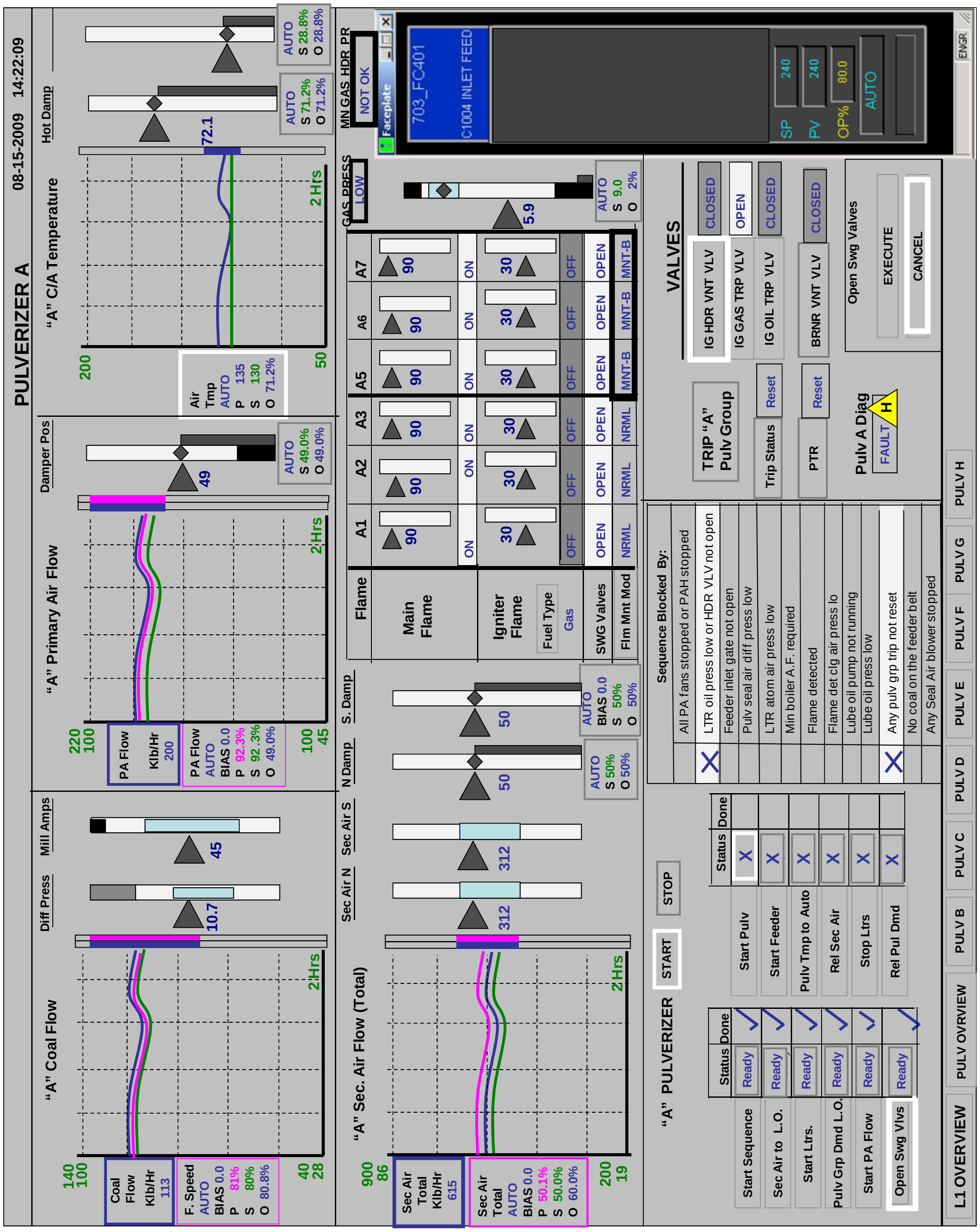

Figure 3-6
GGS Pulverizer Level 2 Control Graphic

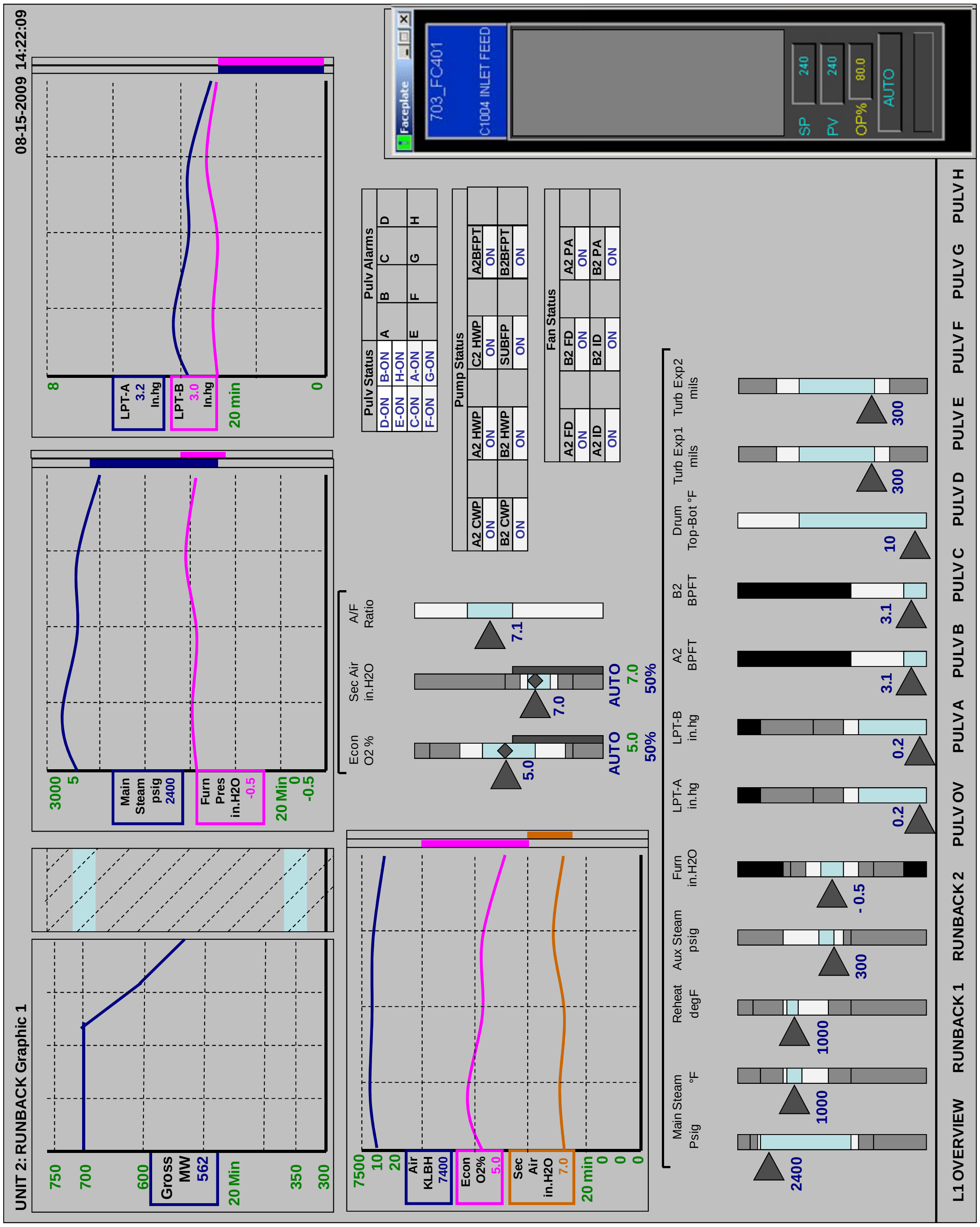

Figure 3-7
GGS Runback 1 Graphic

Note in particular the megawatt trend in the upper left. It is desirable that load reduction be carried out at a certain rate. The element to the right of the trend has slanted lines that represent this proper rate. These provide a visual cue for the operator for monitoring the load reduction progress. It would be more desirable if these lines were part of the background of the trend itself, but this is not possible on either the simulator or the DCS itself. The graphic also has the reserved space for the popup faceplates for manipulation.

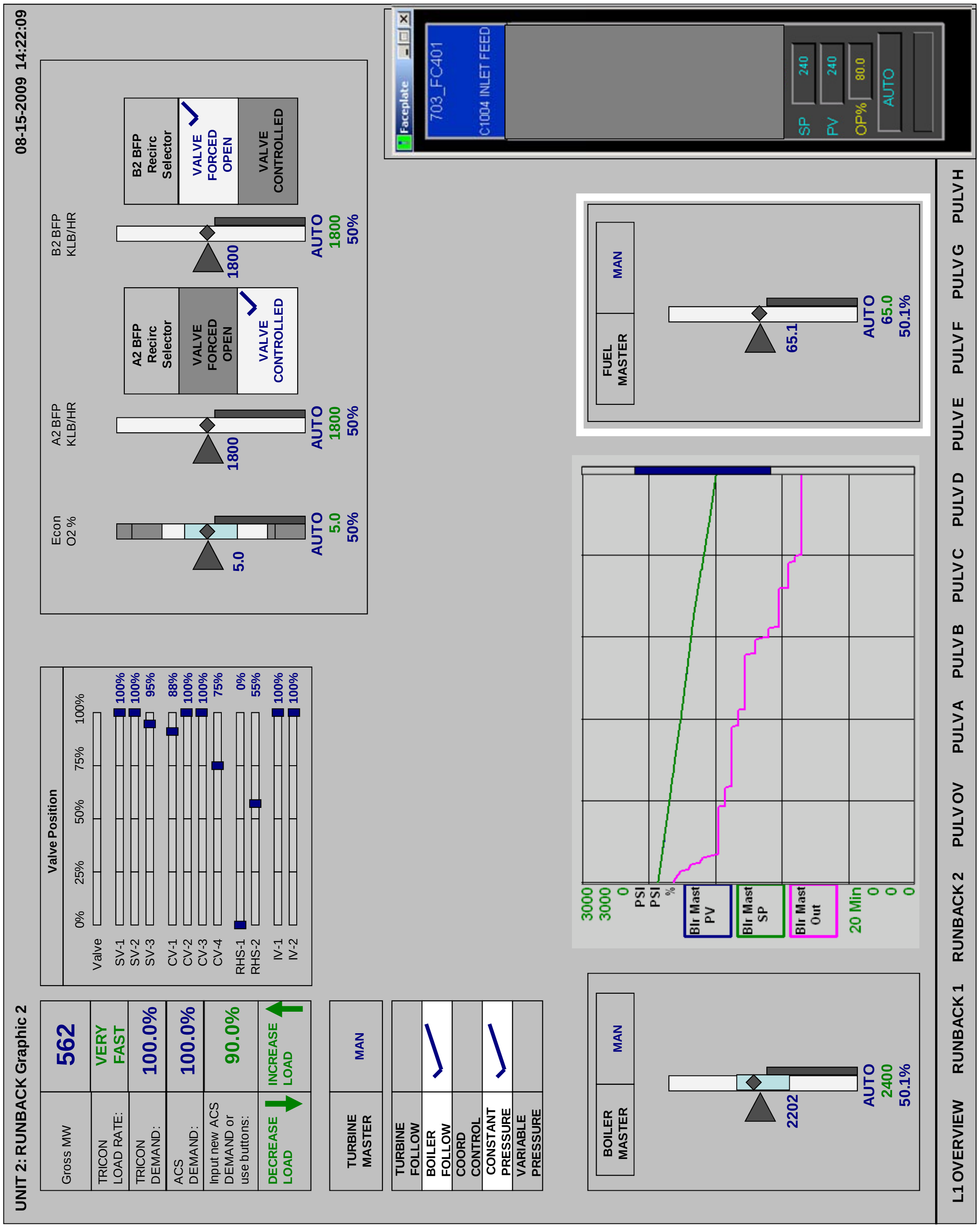

Figure 3-8
GGS Runback 2 Graphic

3.6 Changes and Modifications

During the scenario testing, deficiencies were identified in some elements of these graphics. Valuable operator comments were also captured suggesting modifications and improvements. Section 5 shows the comments, modifications, and resulting improved versions of some of the high-performance graphics.

4
SIMULATOR TESTING

4.1 Simulator Testing Methodology and Results Summary

There are issues with any measurement of human performance, and this project is no exception. The project was limited to the utilization of eight different operators for half a day each plus a GGS staffer that operates the simulator.

Four increasingly complex scenarios were developed for each operator to run.

In the half-day period, each operator performed the four identical scenarios twice: once with the original graphics and once with the high-performance graphics. Obviously, after performing the scenario set the first time, the operator had knowledge as to "what was coming" for the second test. To mitigate this effect, four operators ran the original graphics first and the other four ran the high-performance graphics first. This latter arrangement was the toughest test of the new graphics.

The operators did not use written reference procedures, memory aids, or checklists in the performance of these scenarios. Rather, they were managed by memorized action steps based on prior training and experience. Without guidance, operator performance variation should be expected to be larger than when governed by procedure. Fully implemented high-performance graphics should include embedded access to proper procedures and automated checklists.

As an example, pulverizer startup and shutdown operations were not governed by procedure or checklists other than those provided by interlocks built into the DCS. When swapping a pulverizer, no load reduction standard was set, no margin on furnace draft was specified, and each operator did what was "comfortable" for him.

The detailed results for each scenario are discussed in detail in Sections 4.2 through 4.5. A brief summary of these results is as follows:

- The operators had years of experience with the existing graphics and less than a few hours total with the new ones. However, the operators encountered few difficulties in operating the unit with the new graphics, despite this unfamiliarity. The high-performance graphics are designed to have intuitive depictions.
- Some significant improvements in scenario performance and accomplishment were noted in use of the high-performance graphics.
- Operator comments on the high-performance graphics were significantly positive, particularly regarding the analog depictions, the alarm depictions, and the embedded trends. There were consistent comments regarding how "obvious" they made the process situations, compared to the existing graphics.
- The capabilities of the overview screen were highly rated by the operators, with agreement that it provided highly useful "big picture" situation awareness.

- Malfunctions were detected earlier and more easily with the new graphics.
- Values moving toward a unit trip were clearly shown and noticed by the operators with the new graphics.
- Negative operator comments generally had to do with lack of familiarity, radar plot depiction on the pulverizer overview, depiction of controller output versus device position (mismatch), and certain aspects of specific faceplate functionality. These areas are addressed in detail in Section 5.

4.1.1 Operator Experience

The eight participating operators have significant amounts of experience (Table 4-1).

Table 4-1
Average Years of Operator Experience

Operator	Years of Overall Power Industry Experience	Years of Station Operator Experience	Years of Console Operator Experience	Days of Exposure to High-Performance Graphic Concepts
OP1	5.5	2.5	3	2
OP2	9	2	7	0.5
OP3	16	8	8	0.5
OP4	21	5	4	0.1
OP5	8	2	4	0.2
OP6	8	4	4	0.2
OP7	11	3	8	0.1
OP8	29	3	25	0.1
Average	**13.4 years**	**3.7 years**	**7.9 years**	**0.5 days**

Console operator: Runs the unit via the control system and HMI, and directs some activities of the station operator.

Station operator: Performs rounds and equipment-related duties, takes direction from the console operator, and does not control the unit via the control system and HMI.

4.1.2 Familiarization with High-Performance Graphics

Every operator had years of experience working with the existing graphics. Some of the operators had participated in prior brief reviews of some of the new high-performance graphics in a PowerPoint format. None had worked with them on the simulator prior to these tests.

Each operator received a 90-minute introduction to the graphics in which the elements were reviewed and the layout, intent, and capabilities of each high-performance graphic were reviewed. During this time, the operators had about an hour to manipulate the graphic functions and generally familiarize themselves with measurement placement and content prior to the beginning of the test.

The operators indicated that the comparative unfamiliarity with the new graphics (for example, content, location of each measurement, and control manipulation) was always a factor in the scenario performance.

4.1.3 Data Obtained from the Scenario Testing

Both quantitative (objective) and qualitative (subjective) measurements were incorporated in the testing, as described in the results for each scenario. With only eight test subjects in two groups of four, it is easy to try to draw too many conclusions from such a small data set.

The data indicated that the effect of already knowing the scenarios for the second set of trials could have as much impact on the results as did the different graphics. Even so, some interesting and consistent results were seen. The subjective data is perhaps more enlightening for this project than the objective data.

Each scenario was followed by a discussion with the operator. Questions included, “What aspects of the graphics either helped you in this scenario or made it more difficult? What changes would have made this easier?”

An interesting response was observed. Remember that these operators have years of experience using the existing graphics. When the scenario was first performed using the existing graphics, and the above questions asked immediately thereafter, there would be almost no suggestions or graphic improvement ideas mentioned. This is an indication of the inertia associated with graphic change—operators will get used to using whatever they are given.

But when the high-performance graphics were used first, a very different response was observed. When the existing graphics were used after the high-performance graphics, operators would make many comments about desirable changes or improvements, or elements that were missing that would have made the task easier. This is due to having then experienced a different data presentation.

This dichotomy reinforces a typical observation about HMI—that people become accustomed to, accepting of, and essentially satisfied with whatever they have, regardless of its actual merits or deficiencies. Change is rarely advocated. It is quite significant that a decade of simulator training use at GGS has resulted in almost no change to this early 1990s designed HMI.

4.2 Scenario 1: Pulverizer Swap Under Load

The unit is at full load (700 MW). The operator is informed that an oil leak is detected on one pulverizer by the outside operator. The operator task is to take that pulverizer offline and bring the spare online. A minimum loss of capacity during the swap was desired. No extraneous malfunctions were included in the scenario.

This first scenario helps the operator obtain familiarity with the overview screen, the pulverizer overview screen, and the individual pulverizer control graphics.

4.2.1 Scenario 1: Objective Measurements

- Overall scenario duration
- Amount of time to start the idle pulverizer
- Amount of time to stop the malfunctioning pulverizer

4.2.2 Scenario 1: Objective Results

No significant differences in any of the durations measured resulted from the use of the original versus high-performance graphics.

The act of bringing down or starting up a pulverizer is a multistep process involving a lot of rote actions such as “Select the first item, hit ‘Enter,’ wait for the status indication, select the next item, hit ‘Enter’…” and so forth. That methodology was not changed. The process could be significantly automated but such a revision in control logic was not a practical task for this testing of high-performance graphics.

It was observed that the normal wait times (such as for purges) involved with the various stages of pulverizer startup and shutdown were a large percentage of any theoretical improvement that could be accomplished by revised graphics of any sort.

4.2.3 Scenario 1: Subjective Results

An interesting phenomenon was observed. Some operators dropped load intentionally and significantly (up to a 40 MW drop) prior to beginning the pulverizer swap, to provide margin for error. Others intentionally managed the swap with no capacity loss at all.

4.2.4 Scenario 1: Operator Comments on the High-Performance Graphics

- The trends were very useful when making the swap (a consistent comment).
- Navigation was easy.
- The pulverizer overview made it easy to track what was going on.
- These graphics make things pretty obvious. I can see the dampers moving together—or not moving together.
- The things I needed were on the same graphic.
- If I was very far from the overview screen, I might not be able to read it. But when things go into alarm, it really stands out and is visible. I know at a glance that something significant is wrong.
- I liked the damper position depiction and the highlighting of what was in MANUAL that is normally in AUTO.
- It was really handy having the important items on the overview—I could keep track of them much easier. Without it, I have to look at many different graphics and compare a lot of numbers.
- I liked having only one pulverizer graphic rather than two to do what I need to do.
- I like the horizontal position indicators as separate tic marks on the screen rather than solid bars.

4.2.5 Scenario 1: Operator Comments on the Existing Graphics

- Not having the overview graphic was a detriment. "When you are busy with something, you are totally relying on all the automatic controls to keep everything else right. You don't have time to also be going through several other screens and checking a lot of numbers. But with the overview screen, I could glance at it and see how all the important things were doing."
- I missed having the trends.
- The things I needed to do were spread out over a lot of different graphics.

4.3 Scenario 2: Pulverizer Trip and Load Reduction

Unit is at full load. A coal feeder on one pulverizer is tripped off. There is no spare available and the operator is informed that the tripped pulverizer will require full lockout for repair. Therefore, the operator must effectively drop load to match the capacity of the remaining pulverizers.

This second scenario familiarizes the operator with dropping overall load and observing the performance indicators and trends. The runback 1 and runback 2 graphics come into play.

4.3.1 Scenario 2: Objective Measurements

- Overall scenario time
- Successful load drop

4.3.2 Scenario 2: Objective Results

This is a short scenario. There was no difference in the average time (7 minutes) for the use of the existing versus high-performance graphics, and all operators were successful in accomplishing the load drop. However, there was an unusual situation observed as indicated in Table 4-2.

Table 4-2
Existing Graphics Versus High-Performance Graphics

Graphics Used FIRST	Scenario Time Variation Using Existing Graphics	Scenario Time Variation Using High-Performance Graphics
Original graphics used first	Duration minutes: 8, 5, 4, 3 (Average: 5)	Duration minutes: 7, 6, 4, 3 (Average: 5)
High-performance graphics used first	Duration minutes: 21, 13, 5, 4 (Average: 10)	Duration minutes: 15, 12, 7, 4 (Average: 9)

If you used the high-performance graphics first, your average scenario time was five minutes for them, then five minutes running the same scenario using the existing graphics. The times were tightly clustered together.

But if you used the existing graphics first, your average time was 10 minutes with the existing graphics, and also 10 minutes when you repeated the scenario with the new high-performance graphics. The times varied much more among those four participants. Of those four, two were faster with the existing graphics and two were slower.

The conclusion is that this is likely an artifact of the small sample size and not significant.

4.3.3 Scenario 2: Subjective Results

In this scenario using the high-performance graphics, two of the operators picked up on the initial malfunction before the coal feeder trip occurred. The consensus was that this malfunction would never be noticed in such a way with the existing graphics.

4.3.4 Scenario 2: Operator Comments on the High-Performance Graphics

- I had a better understanding of the big picture.
- It was good to see all of the feeder and air-flow trends.
- This is much better than just having a bunch of numbers on the screen.
- It was good to see the damper positions reacting.
- Everything is right in front of you.
- The items are on the right screens—I don’t have to use as many different screens to accomplish the same task as when I use the old graphics. I like not having to switch back and forth.
- I don’t “miss” having all the color on the screens.
- I picked up the damper position problem really easily on the pulverizer overview. To spot it with the old graphics, I would have had to look at eight different screens and remembers the numbers involved.
- I saw things on the trends moving toward a trip condition. I do not normally notice that on the old graphics.
- I saw that the feeder was going to trip before it did!
- The damper positions draw your attention.
- Having the trends there whenever I call up the graphic really helps. When a situation comes up, we just don’t have time to manually build trends.

4.3.5 Scenario 2: Operator Comments on the Existing Graphics

- I missed having the overview screen.
- I did not notice several numbers changing, that I did notice on the high-performance graphics. They were easier to see.
- The information I need is spread out on several different screens.

4.4 Scenario 3: Manual Load Drop with Malfunctions

Unit is at 580 MW. The operator is told by dispatch to quickly drop load to 520 MW and be prepared for further load drop after that. During the load drop, the instructor causes the south secondary air damper and a single pulverizer primary air-flow damper to fail in its current position.

The operator must drop load, remove one additional pulverizer from service, and detect and resolve the damper failure. If the operator does not detect the damper failure, there will be consequences with emissions and a probable boiler upset. This scenario combines fast load drop, pulverizer manipulation, and equipment malfunction detection.

4.4.1 Scenario 3: Objective Measurements

- Overall scenario duration
- Amount of time to recognize the secondary air damper failure
- Amount of time to recognize the pulverizer primary air-flow control damper failure

4.4.2 Scenario 3: Objective Results

There was no significant difference in overall scenario duration. The average was the same for both sets of graphics. In both cases, an average time improvement of about five minutes occurred for the second set of simulations compared to the first. (If you ran the original graphics first, you would be faster on the high-performance graphics, and vice versa.) This illustrates the significant "learning effect" of running the same scenarios twice within a short time period.

This scenario did exhibit some significant differences in abnormal situation detection (see Table 4-3).

Table 4-3
Comparison of Graphics in Detection of SEC Air Damper Failure

Order of Graphics	**Detection of the SEC Air Damper Failure**
Original graphics run first	ZERO of four operators detect the failure using the original graphics
High-performance graphics run first	ALL FOUR operators detect the failure using the high-performance graphics
Overall Detection of SEC Air Damper Failure	**Number of Operators Successfully Detecting the Failure**
Using original graphics	Three of eight
Using high-performance graphics	Six of eight

This is a highly significant difference, even though it is noted later in this report that the method of depicting damper position/command mismatch should be significantly improved over the method used in the test. The far improved method is shown later in Section 5.2.1, an improvement that would depict such mismatches clearly and make them very difficult to miss in the future.

The pulverizer damper mismatch was depicted differently on both the existing and new graphics, and was consistently picked up faster on the existing graphics. This sort of specific malfunction detection was not part of the scenario design that the high-performance graphics were created for; rather, it was added as a factor later. The revision mentioned in the paragraph above addresses this issue fully as well.

4.4.3 Scenario 3: Subjective Results

In this scenario, several more comments on specific potential improvements to the high-performance graphics were made. Those are covered in Sections 5 and Appendix A.

4.4.4 Scenario 3: Operator Comments on the High-Performance Graphics

- I had a better understanding of how the total unit was responding to the load reduction.
- The "not normal" highlighting on the pulverizer overview helped me notice those conditions. The mismatch should be alarmed.
- The trends of megawatts, air-flow, air temp, and feeder rate really helped in performing this scenario. The O2 controller depiction is good.
- I caught both damper failures, but it was from looking at the numbers, not the analog positions.
- I spotted the secondary air mismatch, but I am still just getting used to knowing where things are on these new graphics.
- The pulverizer overview radar plots do not work well when multiple pulverizers are removed from service (a consistent comment covered more fully in Section 5.2.2).
- It was easier to catch the secondary air problem with the new screens.
- The depiction of output versus position of valves and dampers isn't clear enough (a consistent comment covered more fully in Section 5.2.1).

4.4.5 Scenario 3: Operator Comments on the Existing Graphics

- I was more comfortable with the control manipulations on the existing screens I've used for years.

4.5 Scenario 4: Circulating Water Pump Failure and Load Runback

This is a high-consequence/high-pressure scenario. Unit is at full load. The operator is informed that a leak exists on the seal system of the main circulating water pump. Almost immediately after that, the circulating pump itself is failed, and the operator is informed that it cannot be brought online without mechanical repair.

The operator must perform a manual runback and drop load by half to approximately 350 MW. This involves quickly shutting down up to four pulverizers. The response and load adjustment must happen quickly or the entire unit will trip offline.

During the runback the simulator instructor also fails the following:

- Deaerator level control valve—“sticks” in its current position
- #3 Turbine control valve on the steam flow to the main turbine, also “sticks” in its current position
- Primary air-flow control damper failure on “G” pulverizer

These malfunctions cause the following:

- Significant problems in deaerator level control, causing a possible unit trip.
- Increase of the main condenser backpressure, taking it up to the trip point if not promptly detected and resolved.
- A minor pulverizer control problem, making it difficult to drop load. However, resolving this problem is not necessary for a successful scenario resolution, and as shown below, most operators missed this malfunction using either set of graphics.

4.5.1 Scenario 4: Objective Measurements

- Overall scenario duration
- Successful load drop without unit trip
- Amount of time to recognize the DA level valve failure
- Amount of time to recognize the #3 turbine control valve failure
- Amount of time to recognize the pulverizer damper failure

4.5.2 Scenario 4: Objective Results

This was a fascinating, high-stress scenario to observe. Fast decision-making, action, and control manipulation are needed for success. Seven of eight times we watched the vacuum trends rise steeply toward the unit trip point, then curve over and recover before the trip occurred. (Once, we watched them go all the way to the trip.) The tension resembled a scene from a movie. The original graphics provided no such clear visual indication of the unit path toward a trip, instead having only numbers changing on the screen. See Section 4.5.6 for how the high-performance graphics looked during this scenario.

Again note that the operators used no procedures, checklists, or other memory aids in their response.

- There was no difference in the overall scenario duration from the different graphic sets. This was expected, as any delay in resolving the various issues would result in a unit trip.
- Two different operators lost the unit all the way to zero load. One of these was using the original graphics (run first), and the other was with the high-performance graphics (run first).
- Malfunction detection is described in the Table 4-4.

Table 4-4
Malfunction Detection by Operators

Malfunction	Detection by Operators
Deaerator level control valve sticking	Two of the eight operators failed to spot this sticking valve, using the high-performance graphics, when those graphics were run first.
#3 Turbine control valve sticking	Two operators failed to detect this sticking valve, using the high-performance graphics, and one operator failed to detect it on the original graphics.
Pulverizer damper sticking	Only two operators spotted this malfunction, one on the high-performance graphics and one on the original graphics. Spotting this malfunction was not essential to successful scenario completion.
These situations fed the planned improved depiction of such output versus position mismatches (see Section 5.2.1).	

4.5.3 Scenario 4: Subjective Results

The skill level and response methodology of different operators was very evident in this scenario. Some were assertive, fast, and confident, and others were slower and more tentative with the steps needed to deal with this situation.

In this scenario, a proper high-performance graphic depicting the deaerator would have been helpful but was precluded by time and budget considerations.

4.5.4 Scenario 4: Operator Comments on the High-Performance Graphics

- The embedded trends were really useful in this situation, and there is no way we would have time to create them on the fly if this happened.
- After three hours now, I have come to really like the moving analog indicators. I like that they show the “normal” range and my eye tracks that well. I like it that I don’t have to rely on my memory for so many numbers. I can see the problems developing even before the alarms come in, and I usually can’t with the regular graphics.
- I am very experienced with the old graphics—I know where everything is. But with very little experience with these new graphics, I can see how you can pick up important changes much easier. Once you got used to these new graphics, going back to the old ones would be hell.

- Remembering the numbers under stress is difficult. Your time sense changes. Having the trends right where I need them on the new graphics made this much easier.
- I really liked the overview screen. It showed what was going wrong very clearly.
- I can diagnose problems faster, before the alarm comes in.
- I caught the vacuum going up on the trends and resolved it well before the trip point. Those trends helped a lot in this scenario for knowing when the "tide had turned" and seeing the rate of change and the direction.
- The diagonal load reduction lines on the runback megawatt trend were a really useful guide.
- The alarm indicators made the alarms very prominent, which was important. Particularly on the overview, they drew my attention.
- It will take a while to learn where everything is—I'm still getting used to these.
- In these partial load situations, the radar plots on the pulverizer overview become a mess and don't make sense! (See planned revisions in Section 5.2.2.)
- The runback graphics were really helpful—everything I needed to accomplish this was in one place. Normally what I would need to handle this is spread out over many different graphics.
- A new guy would be much more likely to handle this case successfully with the new graphics than with the old ones.

4.5.5 Scenario 4: Operator Comments on the Existing Graphics

- All of the numbers on the existing graphics can be overwhelming.
- I did not see the DA level problem until the alarm occurred. There are a lot fewer alarms on the simulator than in the real plant, and it is much easier to miss an alarm in the real plant.
- I really missed having the trends.

4.5.6 Graphic Screenshots

Screenshots of the overview graphic and the runback graphics during this scenario are shown in Figures 4-1 through 4-3. Note the alarms in effect.

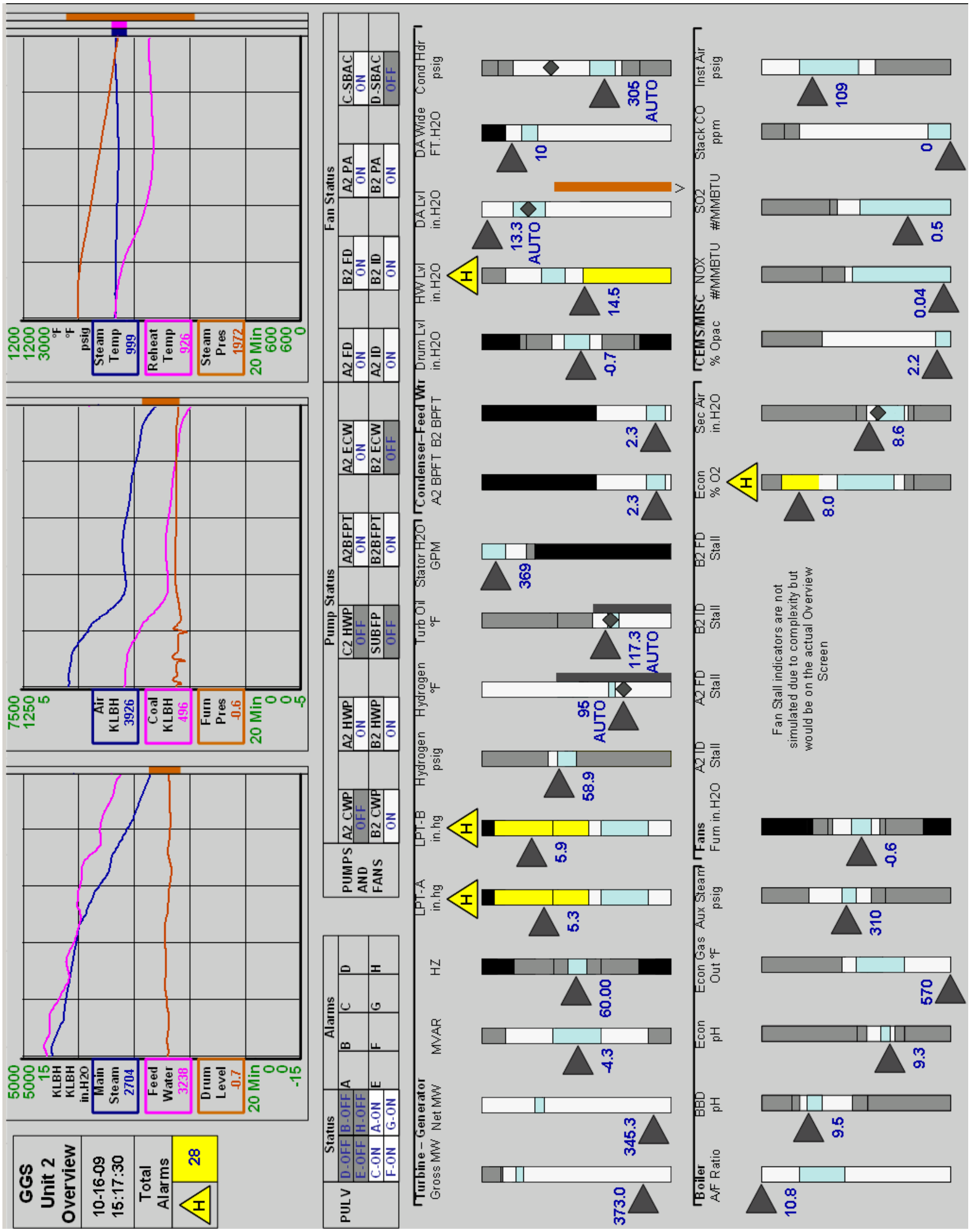

Figure 4-1
Screenshot of Overview Display During Scenario 4

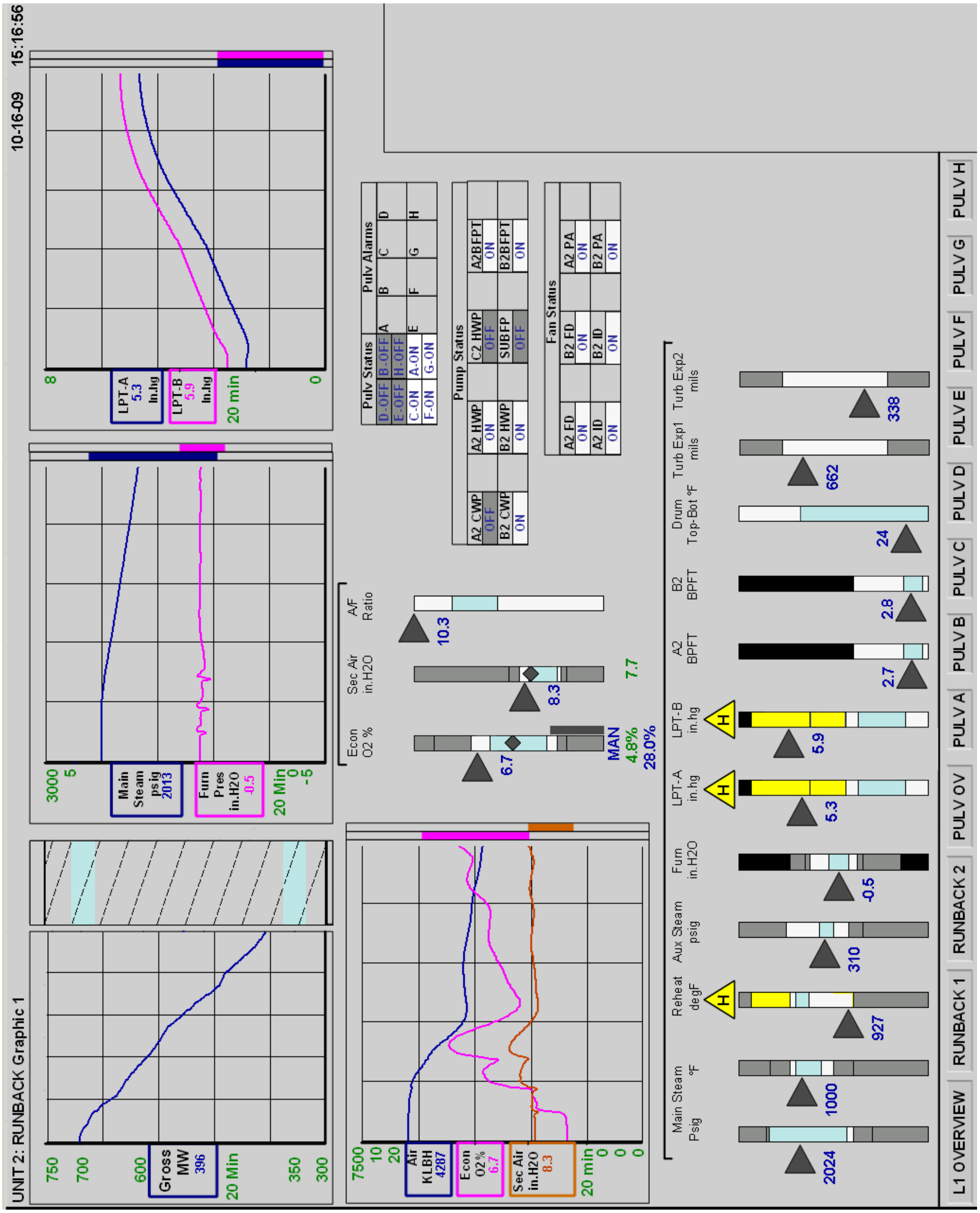

Figure 4-2
Screenshot of Runback 1 Display During Scenario 4

Note the trend on the upper right of runback 1. If these values reached the top of the trend, the full unit trip occurred. MAIs for these values depicting the situation are in the bottom row, middle (labeled LPT-A and LPT-B).

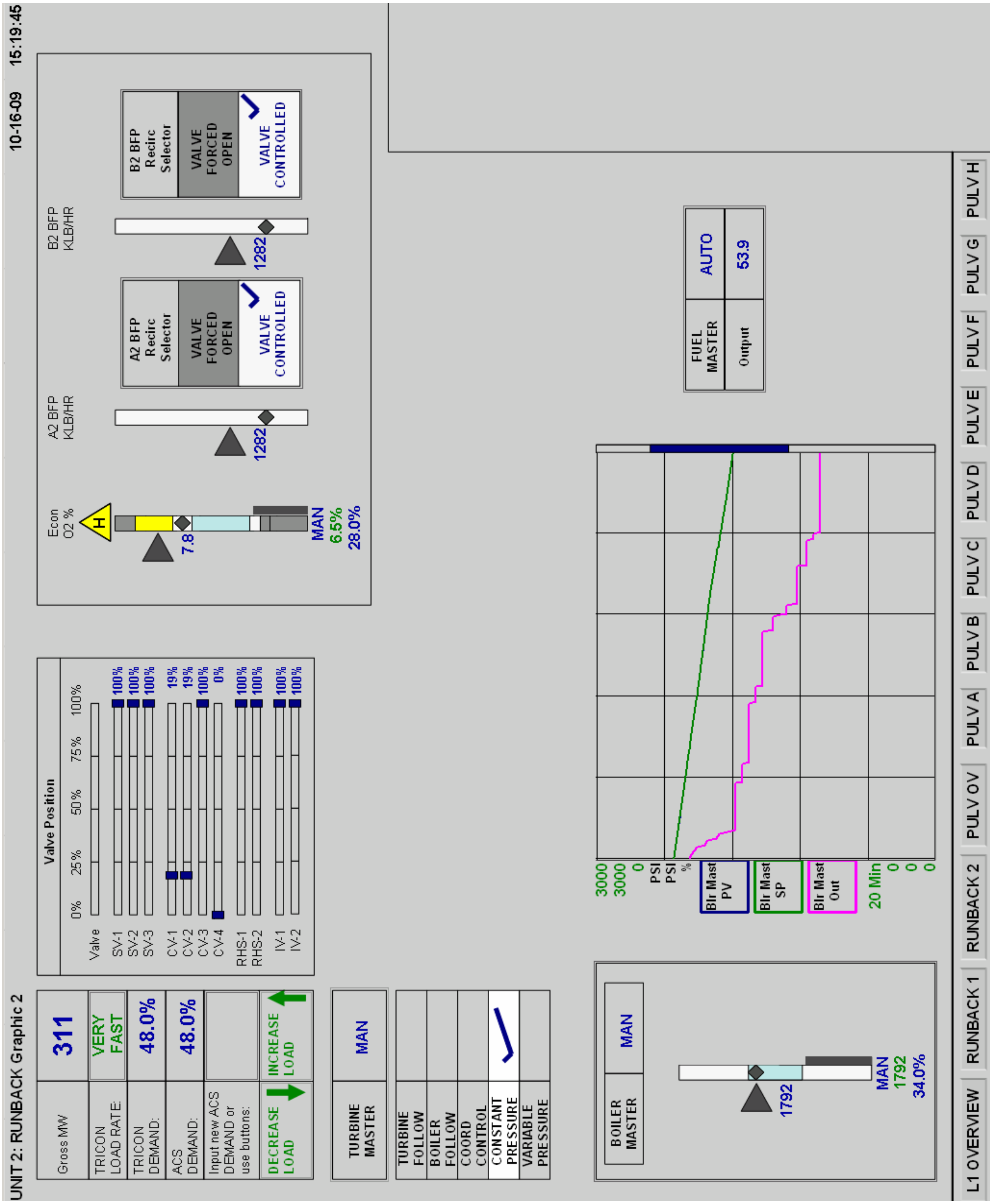

Figure 4-3
Screenshot of Runback 2 Display During Scenario 4

5
HIGH-PERFORMANCE GRAPHIC COMMENTS AND ISSUES

5.1 HMI and the Training of New Operators

Most companies have a large "bubble" of experienced personnel that will be retiring in the next decade. Their experience will walk out the door, necessitating the training of new personnel.

Each operator was asked about the training of new operators to run the process with the old versus new graphics. All agreed that much training time is involved with new operators having to memorize hundreds of measurements, spread out inconsistently over dozens of graphics. The new operator must build a mental model as to what values, and combinations of values, constitute "normal." All operators also agreed that the high-performance depiction of normal range, abnormal range, alarm ranges, and interlock presence would make it far easier for a new person to learn to operate the unit. These depictions are actually embedding experience into the HMI.

Extra time was spent with some of the operators, and some nonscripted malfunctions were "thrown" at them. One spotted a vacuum leak directly from a trend on the high-performance graphics and remarked, "I would have never seen that with the old graphics until some alarms happened."

5.2 Specific Comments and Identified Changes to the High-Performance Graphics

The testing uncovered several specific desirable modifications of the high-performance graphics, described in this section.

5.2.1 Controller Depiction and Output Vs. Actual Position Mismatch

The controllers used a bar graph strip to indicate output from 0% to 100%. The problem with a bar graph is that it disappears when the value is zero. This is the major reason that the moving analog indicators use pointers rather than such bar graphs. Zero values for output are commonplace, resulting in a disappearing indicator. Human perception is much better at detecting the presence of something rather than the absence. A pointer-type depiction is thus better but takes up more horizontal space and can look too "busy" if designed incorrectly.

The graphics inadequately depicted failure of final control elements (for example, valves and dampers) to follow the output commands to them. Such failures are commonplace. It is desirable to show commanded position versus actual depiction and alarm a mismatch above a certain amount. It is also desirable that this depiction be compact because banks of several such elements will be desirable. Several revised depictions were evaluated for visibility, compactness, and consistency. The following revisions shown in Figure 5-2 resulted.

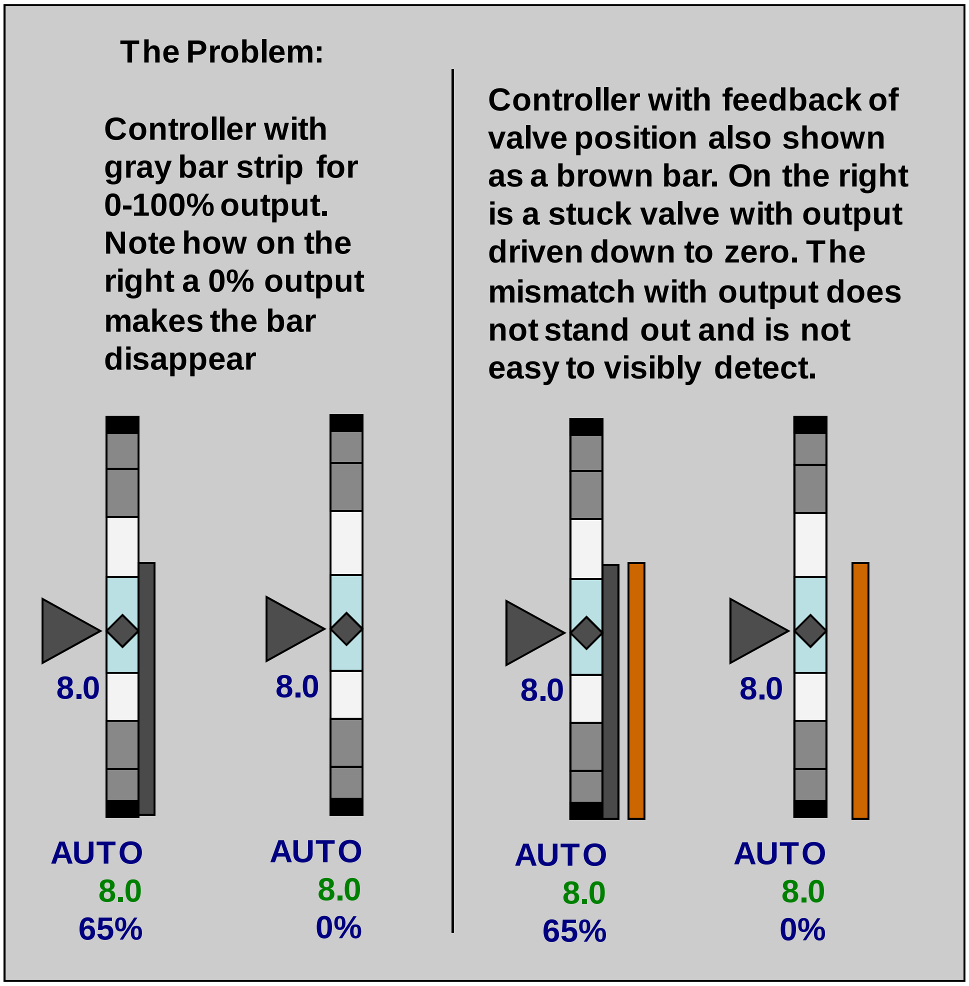

Figure 5-1
Problematic Depiction of Controller Output and Device Feedback

The improved depiction is shown in Figure 5-2.

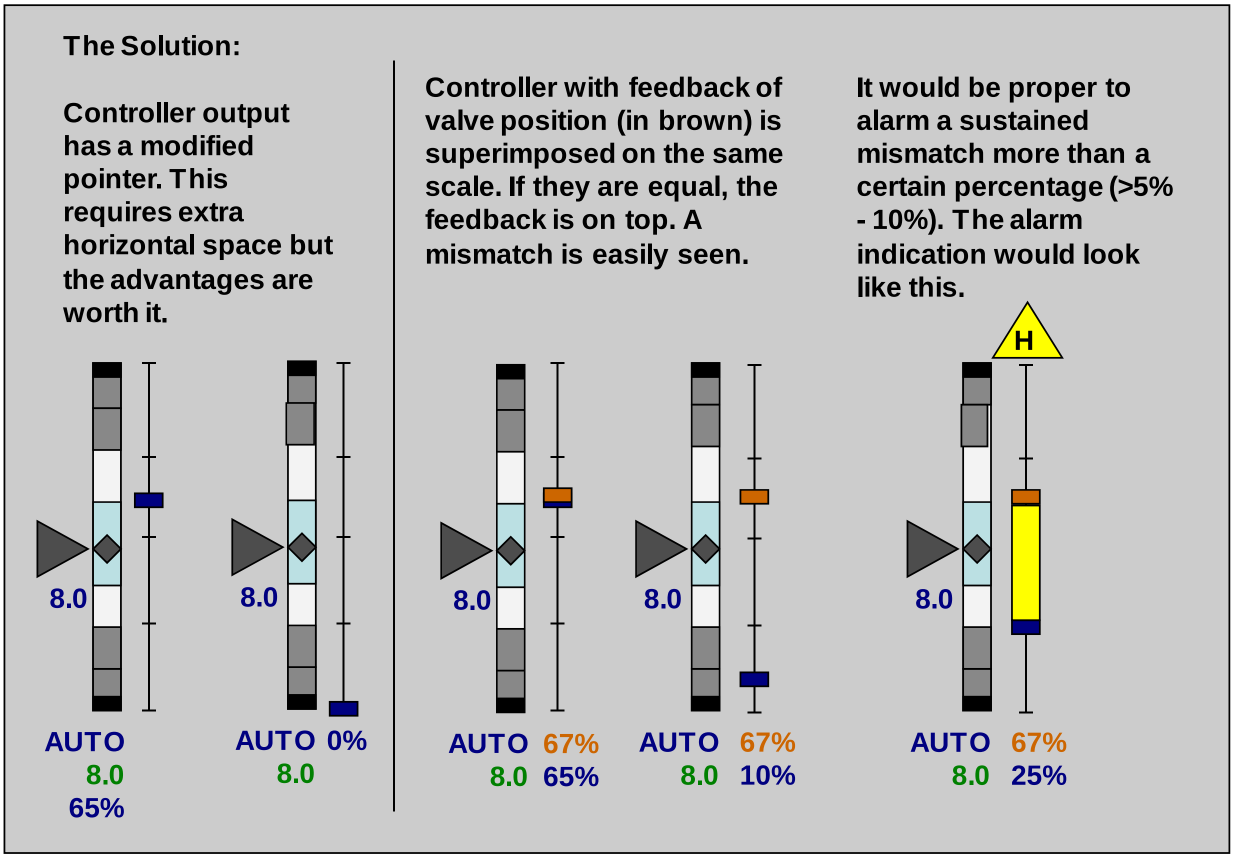

Figure 5-2
Improved Depiction of Controller Output and Device Feedback

Banks of position indicators following these principles are compact and possible. See Figure 5-5 as an example.

5.2.2 Radar Plots

Radar plots can be powerful depictions of several measurements in a compact area. There are two basic implementations of radar plots. In the first, a single radar plot is used to depict disparate measurements on a single piece of equipment (for example, various flows, pressures, and temperatures). The resulting polygon can become a recognizable "shape" that differs under various operating loads and conditions. It is possible to "normalize" such a depiction at a given point in time to a circle, thus making later deviation stand out. It was noted that such an object would be a good addition to an individual Level 2 pulverizer control graphic.

The other implementation is to use a single radar plot to show a certain identical measurement (such as inlet flow) from multiple pieces of similar equipment. This can make visible small differences in performance from equipment that is supposed to be running more-or-less identically. This was the intended implementation for the pulverizer overview radar plots of eight identical pulverizers.

The problem with the GGS radar plots is that under full load only seven of eight pulverizers are being operated. So, rather than starting out as a circle, each radar plot begins as a "Pac-Man."

(See Figure 5-3.) In reduced load conditions, the radar plot loses its shape and become unclear. (One operator said it looks like a "squashed bug.") It was decided that compact analog indicators on the pulverizer overview would make for a better depiction.

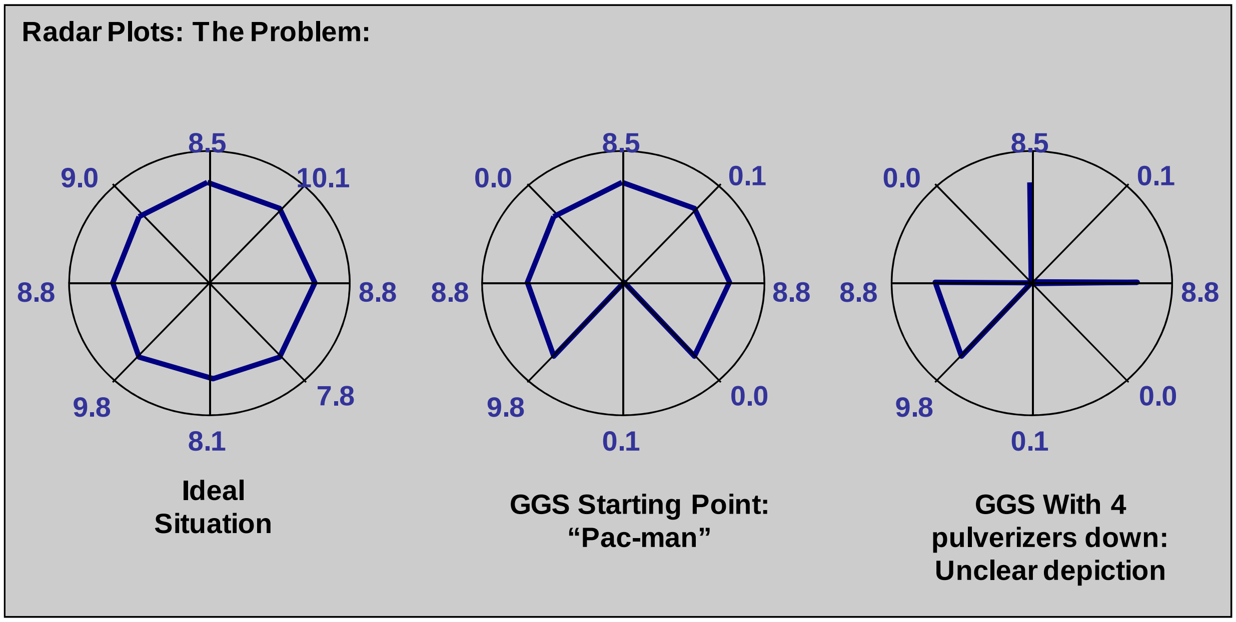

Figure 5-3
Problematic Radar Plots

5.2.3 Other Comments

- Scaling: Many comments were received about rescaling of certain indicators and trends.
- Trends: The feedback on embedded trends was highly positive. It was suggested that the "what is good" element to the right of the trend should not only show the "good" range but also the alarm and interlock ranges as well. Such a modification would be easy to accomplish.
- Faceplates: Several comments were received about specific faceplate functionality. Time and budget constraints prevented detailed functionality incorporation in faceplates, and such functionality was not necessary for the testing objectives. Faceplate review during the actual GGS upgrade to their next control system will be important.

5.3 Revised High-Performance Overview Display

Comments were received regarding scaling of some elements and other choices for "what specific measurements should be on the screen." Different operators want different measurements, and space is always limited. The choice for the simulator version was the result of three rounds of review, with each round making alterations. This is a typical situation; in our experience an additional 10 rounds of review would produce different choices each time! That is why an ongoing program of graphics review and modification (step 7 of the high-performance HMI work process) is needed for actual production graphics.

Resizing of the trends, and the addition of a fourth trend with gross and net megawatts was suggested. It is preferred that normal ranges and normal values tend to line up in a combined depiction.

Note that the current alarm rationalization project will alter many of the GGS alarm choices and settings; these changes would need to be reflected in the depiction elements. This is easier on the real control system than the simulator because the actual graphic elements (such as the MAIs) should dynamically adapt to a changed alarm configuration. On the simulator, all such elements must be individually coded.

A revised overview incorporating better scaling, revised controller depiction, and a few other modifications (although not a fourth trend) is shown here in Figure 5-4.

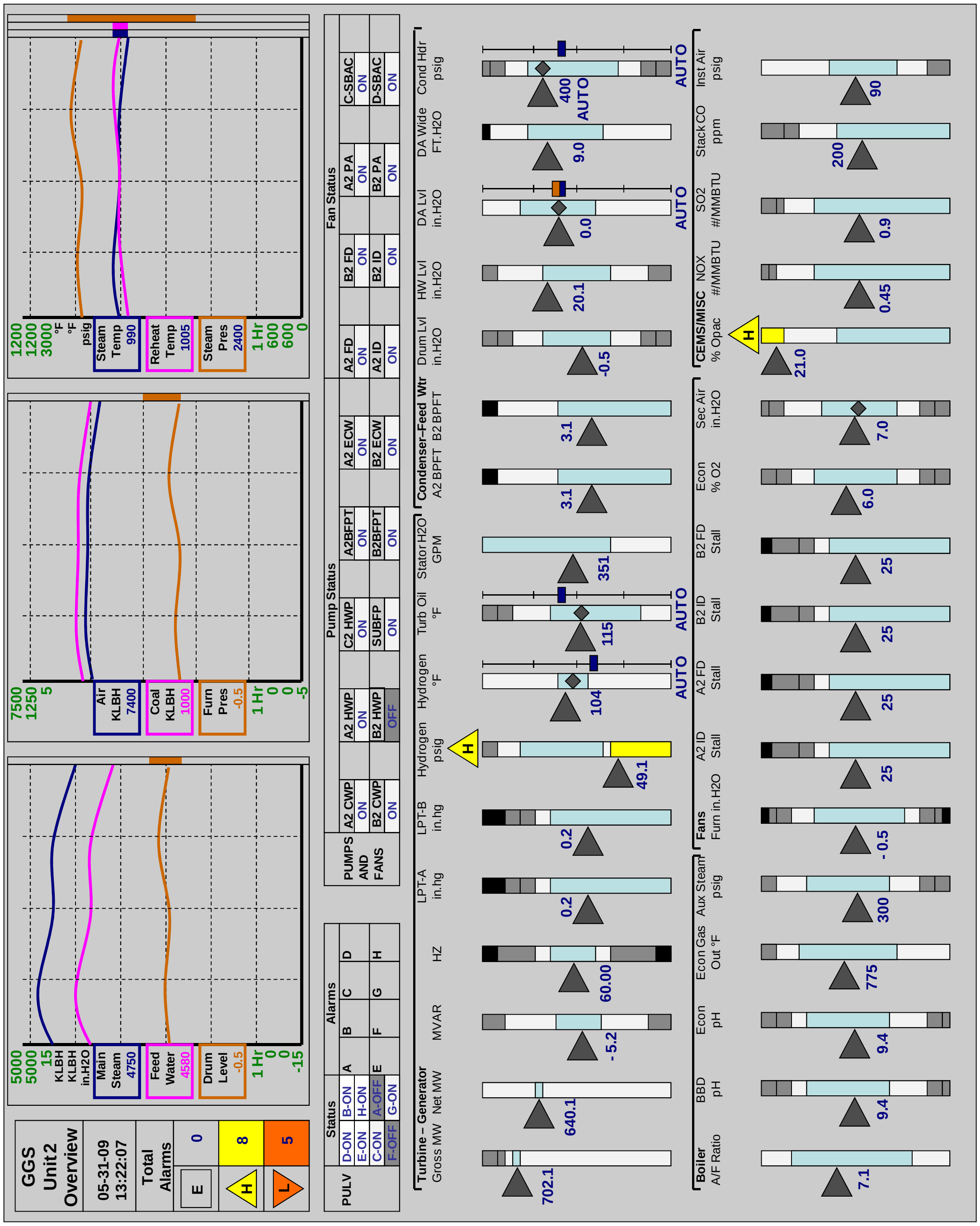

Figure 5-4
Revised Post-Review Unit 2 Overview Display

5.4 Revised Pulverizer Overview Display

The following revised pulverizer overview is a substantial change. It eliminates the radar plots and shows banks of improved feedback position devices. Many operators wanted the functionality of the existing GGS “Flame” graphic incorporated into the overview. (This original graphic is shown in Figure 2-4.) “Flame” shows flame intensity and igniter status in a geographically related layout. This complex element was added at the lower left.

The resulting graphic is shown with numbers enabled; this would be a toggle selectable by the operator to make the numbers appear or not. The graphic, at first glance, looks very busy (Figure 5-5). It is simultaneously showing the performance of eight complexly instrumented devices. But each section can be scanned “at a glance,” and abnormal conditions will stand out. The operator can tell where to drill down for further information about a particular problem.

Note the banks of position indicators with mismatch functionality (and alarms).

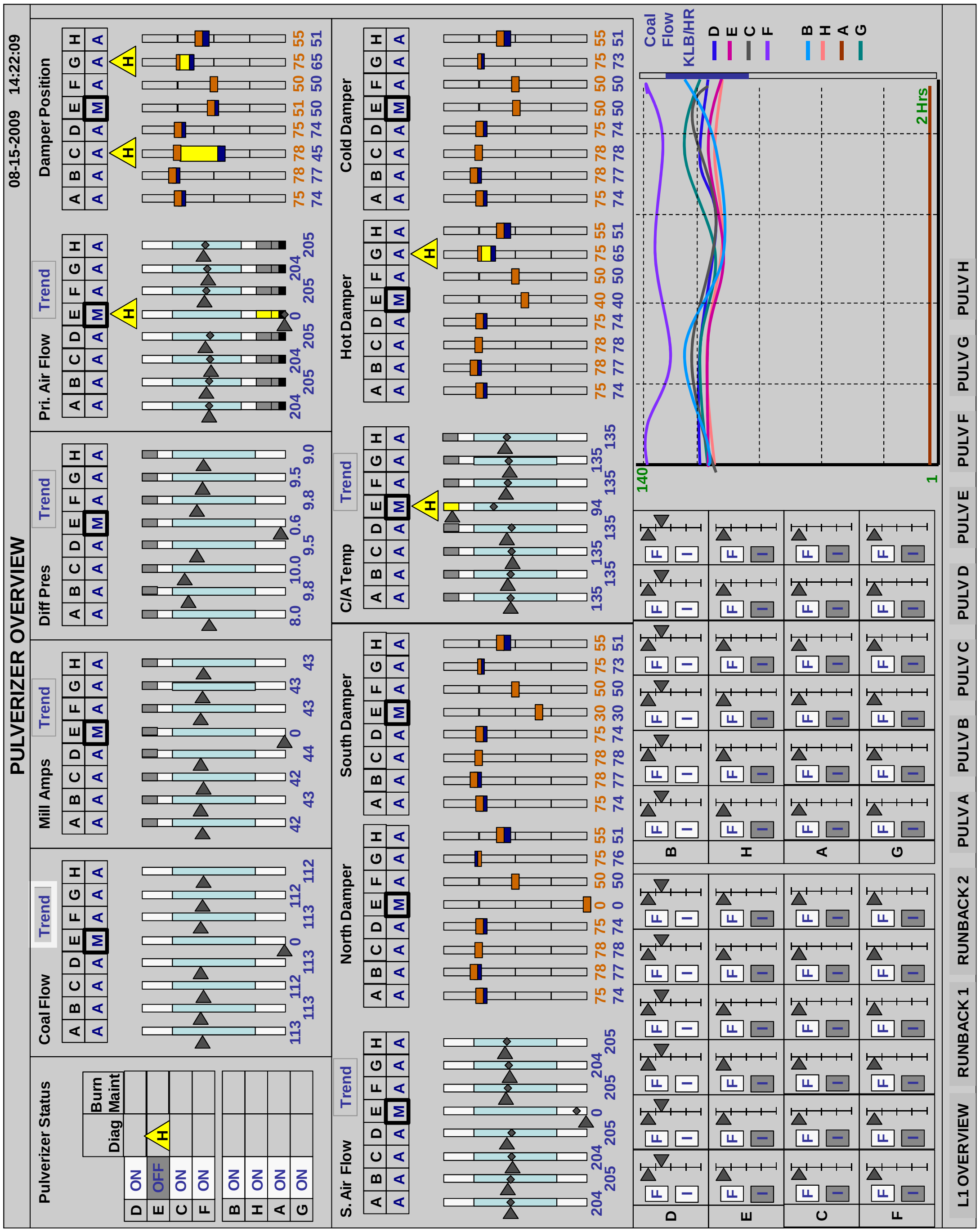

Figure 5-5
Revised Post-Review Pulverizer Overview Display

5.5 Pulverizer Level 2 Control Graphics

It was noted that each of these Level 2 graphics should more prominently identify “which” pulverizer they are because all look identical. This could be easily accomplished in a variety of ways. Additional trending of items such as differential pressure and amps was desired.

The diagnostic interlock conditions were left off of the start-stop functions on the simulator graphics (again, time constraints); these should be added to the production graphics.

A revised pulverizer Level 2 graphic is not shown.

5.6 Runback 1 and 2

Additional functionality should be added to indicate the fully automatic turbine control actions as well as the manual ones. This was not part of the simulator scenario, but such an addition to the production graphics would result in a highly useful display that would likely be left up most of the time.

Revised runback graphics are not shown.

A
OPERATOR POST-SCENARIO QUESTIONNAIRES

The operators filled out a lengthy questionnaire after the scenarios were complete. The topics covered the existing graphics, existing alarm management, existing control room operating practices, and finally the high-performance graphics. The operators ranked their agreement or disagreement with statements about the HMI.

The response to most of the questions indicated high levels of agreement by the eight operators. Some of these are shown below, paraphrased for easier readability and to indicate the direction of operator agreement.

A.1 Questions on Existing Graphics, Alarm Management, and Control Room Operating Practices

- There is NO existing overview display summarizing the key factors of each operator's entire span of control.
- Interlock functions are NOT consistently shown on graphics, nor is the information needed to clear the interlock.
- Alarm colors are NOT designated by priority and are used for many purposes other than depicting alarms.
- Graphics do NOT utilize embedded trends of important parameters.
- Color is NOT used consistently.
- Techniques ARE used to minimize the possibility of operator data entry mistakes and inadvertent trip actuation.
- It IS possible to navigate to any screen, within 5 seconds, using minimum pushbutton and/or mouse-click actions.
- The Control room is NOT kept free of distractions and unauthorized personnel, and it is often used as a hangout or meeting place.
- During an abnormal situation, there IS often distraction by having to provide status information to staff personnel.
- During abnormal situations, it IS common that staff will crowd around the operator's console.
- Alarms are NOT consistently shown on graphics.
- Alarms are NOT consistently configured so they indicate situations for which specific and known operator action is required.
- Alarms are NOT configured to occur only for abnormal situations and not for expected, normal situations.
- The alarm system is NOT kept free of miscellaneous status indication.
- Alarm priority is NOT set in a meaningful and consistent manner.

- Alarms are often NOT unique, and the same situation may generate multiple alarms.
- There is NOT a monitoring system or work process to detect and deal with nuisance alarms (chattering, fleeting, long-standing, and so forth).
- The rationale for the selection and priority of each alarm is NOT documented.
- The HMI does NOT have the ability to display any and all alarm suppression currently in effect in one easy-to-get-at list.
- The alarm system configuration IS protected from inadvertent and inappropriate change.

A.2 High-Performance Graphic Questions

The questionnaire continued and covered the general aspects of the high-performance displays, followed by questions for each display and the opportunity to give any design feedback that wasn't captured during the testing. Design feedback and planned changes are noted in Section 5 and Appendix A.

The response to the questions indicated high levels of agreement by the eight operators. These are shown below, paraphrased for easier readability.

A.2.1 General High-Performance Graphic Considerations

- The graphics ARE effective in depicting not only what the values are, but also whether they are normal or abnormal.
- The embedded trends in the graphics DO enhance understanding of the plant situation.
- Alarms DO stand out and are easily detected.
- Color IS used consistently.
- Bright colors ARE reserved only for display of abnormal conditions and alarms.

A.2.2 High-Performance Overview Graphic

- The overview graphic DOES display the most important parameters about the operation of the unit.
- The overview graphic DOES trend the appropriate things.
- You CAN tell from the overview graphic when items leave their normal operating conditions and begin to go to an abnormal state.
- The indicators ARE effective in showing the current process measurement.
- The indicators ARE effective in showing the measurement's value relative to the desirable range, the abnormal range, the alarm range, the alarm condition, and the presence of a potential interlock condition at the end of the range.

A.2.3 High-Performance Pulverizer Overview Graphic

- You CAN tell from the pulverizer overview when any individual pulverizer begins to operate differently than the others.
- You CAN tell from the pulverizer overview the general operating condition of each individual one.
- The appropriate items ARE trended.
- The damper position indications ARE effective in showing position and differences.

A.2.4 Individual Pulverizer Level 2 High-Performance Graphic

- The pulverizer Level 2 graphic DOES enable you to operate the pulverizer effectively.
- It DOES show both normal conditions and indicate when those conditions go into an abnormal state.
- The appropriate items ARE trended.
- You CAN tell from the pulverizer overview when any individual pulverizer begins to operate differently than the others.
- You CAN tell from the pulverizer overview the general operating condition of each individual one.
- The status and progress of a start/stop operation IS shown in a clear and effective manner.

A.2.5 High-Performance Runback Graphic 1

- Runback 1 DOES show the things you need to see to monitor the progress of a runback.
- The appropriate items ARE trended that help in the runback situation.
- The upper left trend DOES help in adjusting the rate of load decrease compared to the optimal rate.

A.2.6 High-Performance Runback Graphic 2

- Runback 2 DOES provide access to the correct controls to manipulate to accomplish a runback effectively.
- The appropriate items ARE trended that help in the runback situation.
- It IS easy to manipulate the variables that are needed to accomplish runback.

B
REFERENCES

The following are useful references on HMI and operator graphics:

ASM Consortium Guidelines: Effective Operator Display Design. Honeywell, Morristown, NJ, 2008.

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Ergonomic Design of Control Centres – Part 3: Control Room Layout. International Organization for Standardization, Geneva, 1999.

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Ergonomic Design of Control Centres – Part 7: Principles for the Evaluation of Control Centres. International Organization for Standardization, Geneva, 2005.

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Edward Tufte. *The Visual Display of Quantitative Information*. Graphics Press, Cheshire, CT, 2001.

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C
ABBREVIATED HIGH-PERFORMANCE HMI PHILOSOPHY AND STYLE GUIDE

Limitations

This document is an abbreviated version of a High-Performance HMI Philosophy and Style Guide and is specifically associated with the EPRI Program 108 project, *Operator HMI Case Study: The Evaluation of Existing "Traditional" Operator Graphics Vs. High-Performance Graphics in a Coal-Fired Power Plant Simulator*

It differs from a "normal" HMI Philosophy and Style Guide in the following ways:

The usual development process of these documents includes extensive collaboration and customization with the company and site for which it applies. The scope of this EPRI project excluded this step, as its purpose was to test principles advocated in current best practice literature, such as *The High Performance HMI Handbook.* The collaboration step generally modifies these principles to meet individual company preferences and accommodate certain established practices. For further information on each topic in this document, readers are directed to the *Handbook* previously mentioned.

There is less detail in this abbreviated version, and some sections are not included in detail, particularly if they deal with highly specific individual company practices.

While the philosophy section is designed to be generic and apply to several different control systems, the style guide section must reflect the specific abilities and limitations of a target control system. If a company uses several different control systems, style guides for each are generally prepared, although there will be some commonality between them. Some aspects of elements described in this style guide may not be possible on some control systems. The normal development process would customize these elements to maximize their effectiveness given a particular set of limitations.

1.0 High-Performance Human Machine Interface (HMI) Philosophy and Style Guide Introduction

This High-Performance HMI Philosophy and Style Guide is a comprehensive guideline for the development, implementation, and modification of operator interface graphics. This document contains best practice design principles and guidelines that are grounded in human factors research and practices. Standardization of displays ensures consistent assimilation and utilization of information from all process units in a facility. These principles shall be applied during the HMI development process and for ongoing utilization and modification.

The philosophy sections set forth the principles and practices associated with best practices for operator graphics. The philosophy document addresses the life cycle of the HMI, including design, implementation, performance monitoring, ongoing modification, and management of change. It is for both in-house use and for the use of contractors hired to work on the control system.

The style guide sections contain functional specifications for specific display elements used in high-performance displays. This document presumes users are familiar with creating operator graphics and with the specific features of the control system in use.

The following is a basic outline of the development sequence for a high-performance HMI (HP-HMI):

Step 1: Adopt a High-Performance HMI Philosophy and Style Guide.
Step 2: Assess and benchmark existing graphics against the HMI philosophy.
Step 3: Determine specific performance and goal objectives for the control of the process, for all modes of operation.
Step 4: Perform task analysis to determine the control manipulations needed to achieve the performance and goal objectives.
Step 5: Design and build high-performance graphics, using the design principles in the HMI philosophy and elements from the style guide, to address the identified tasks.
Step 6: Install, commission, and provide training on the new HMI.
Step 7: Control, maintain, and periodically reassess the HMI performance.

1.1 Purpose and Function of the Operator HMI

The goal of this HMI philosophy document is to ensure that the control system operator graphics are an effective tool for the safe and efficient control of the process, in both normal and abnormal situations.

Poor HMIs have been specifically cited as significant contributing factors in major industrial accidents. They are contributing factors to ongoing poor performance. In many industry cases, the HMI impedes rather than assists an operator in handling a process upset or abnormal condition. Instead, the HMI should assist in the early detection, diagnosis, and proper response to abnormal situations.

The HMI is designed for the use of the operator in running the process. Proper design is therefore not compromised for any special-use purposes of maintenance, engineering, staff, or training. If needed, graphics specifically designed for such other users/functions can be created for their use.

This document uses the terms “DCS” (distributed control system) and “control system” to refer to the instrumentation and displays used for process control. The HMI principles are the same and equally apply to SCADA systems or any other type of computerized control/display systems.

1.2 Common but Improper HMI Practices

To understand the HP-HMI concepts, it is necessary to be aware of the common but poor practices in process graphic creation. This document will provide extensive detail of proper practices.

Poorly designed HMIs are common. They are responsible for the following:

- Encouraging various poor operating techniques, such as “running by alarms”
- Actively impeding proper situation awareness
- Resulting in increased process variation and poorer quality
- Contributing to higher numbers of avoidable upsets
- Increasing the likelihood of suboptimum response to abnormal situations
- Significantly contributing as a factor in major industrial accidents

Poorly designed graphics have the following:

- No embedded trends
- A lack of display methodologies showing the operator the state of the process compared to the desired conditions
- An overuse and emphasis on a P&ID type of process representation
- Poor and inconsistent color coding of various elements, and in general an excessive use of color
- Animated elements such as spinning agitators and pumps, moving conveyors, splashing liquids and sprayers, and flashing flames
- Brightly colored process vessels rendered with 3-D shadowing, as well as 3D process lines and pumps depicting such items as impellers and flanges
- Detailed depiction of nonchanging internal elements of equipment
- Attempted color coding of process piping with its contents
- Measurement units (for example, psig and gpm) spelled out in large, prominent text
- Liquid levels in vessels displayed in bright colors the full width of the vessel
- Inconsistent process flow direction with many crossing lines
- Improper alarm depiction
- Alarm-related colors used for nonalarm related elements
- Limited, haphazard navigation from screen to screen
- Equipment depiction with excessive, distracting detail

- Hard-to-read numbers and status information, and an emphasis on the display of numbers without context
- A lack of status information
- A lack of hierarchical content and structure (the progressive display of detail)

These practices shall be avoided in the creation of a high-performance HMI.

1.3 Display Content

An important statement to graphics designers: Most of the graphics in the world consist of little more than a P&ID view of the process sprinkled with "live numbers" from the control system. A high-performance HMI **rarely** looks like a P&ID or an equipment drawing, particularly at the Level 1 and 2 hierarchies.

Proper graphics have the following characteristics:

- Display content supports monitoring, control, and troubleshooting activities.
- Important information and key performance indicators (KPIs) are appropriately trended, using embedded trends with proper functionality contained within the graphics themselves.
- A hierarchical graphic content structure supports progressive exposure of detailed information.
- Depiction of process values is made in the context of information, rather than as simply depicting numbers on a screen.
- Values are presented in analog or digital formats as appropriate. Analog formats allow operators to quickly and easily perceive the suitability of the value relative to desirable limits. Properly presented analog information typically reduces an operator's cognitive processing workload, especially in an abnormal situation. Digital formats (display of numbers only) convey precise data but can lack context.
- Techniques are used to minimize the possibility of operator data entry mistakes, as well as provide validation and security measures.
- Display elements have consistent visual and color coding.
- Color is used sparingly and is never the sole differentiator if important status conditions.
- Color is used to bring attention to abnormal, not normal, situations.
- Alarms are depicted consistently and prominently.
- Visual clutter and unneeded data are avoided.
- Symbols and process connections are depicted in a simple, meaningful, and consistent manner.
- There is no gratuitous animation. Limited and specifically allowable animation is used only to highlight abnormal situations.
- Equipment is depicted in a simple 2-D low-contrast manner.
- Objects that have an associated user interaction (for example, selectable objects and navigation buttons) are distinguishable from those that are static.

- Graphics shall include mechanisms to hide and show detailed information.
- The prominence of the appearance of a screen object is associated with its importance.
- Design features are applied consistently for all types of displays and graphical objects.

1.4 Display Layout

Graphic layout should result in the following display characteristics:

- Displays are designed to maximize overall readability without causing eye-strain or fatigue over time.
- Displays are not visually complex or cluttered due to inappropriate use of graphical details.
- The arrangement of objects and information is consistent across similar displays and appropriate to process behaviors.
- Layout is generally consistent with the operator's mental model of the process.
- When a process pictorial view (P&ID-type) is used, the process flow is from left to right whenever possible. In mixed situations, gas should flow up and liquids flow down. Proper layout minimizes crossing lines.

1.5 Display Navigation

Multiple navigation methods should be provided to facilitate quick, direct, and consistent access to primary displays.

- Display access should require a minimum of operator keystroke-equivalent actions.
- Logical and consistent navigation methods utilize a hierarchy for the progressive exposure of process detail.
- It should never be necessary for an operator to type in a graphic name or a point identification.

1.6 Color Usage

Proper, effective, and consistent use of color is essential to a high-performance HMI:

- Gray backgrounds are used to minimize glare, along with a generally color-neutral depiction.
- There shall be very limited use of color. Colors facilitate the discrimination of the most important information, such as abnormal situations, and are applied consistently throughout the system.
- Color alone is not used as a differentiator of important status information. (As a test, if an operating graphic is printed in grayscale, all indications and statuses should still be easily distinguishable.)
- Alarm colors are used only to display alarm-related functionality and nothing else. If yellow is an alarm color, then yellow is never used as a text label, line color, border, or any other nonalarm-related element.

Color perception deficiencies are common in the general population, particularly red/green, green/yellow, and white/cyan. Redundant coding of important information addresses this problem. The style guide sections on alarm indications and equipment status indications contain good examples of redundant coding.

1.7 Display Hierarchy

A concept of hierarchy (Levels) should be followed in constructing control system displays. The primary purpose of these levels is to provide different amounts of operating detail to aid the operator in performing different tasks. A secondary purpose of these levels is to allow easier navigation.

Four levels are optimum:

- Level 1: Process Area Overview Display
- Level 2: Process Unit Control Displays
- Level 3: Process Unit Detail Displays
- Level 4: Process Unit Support Displays

The four levels of displays represent increasing levels of complexity and/or detail—"zooming in" on the process. The hierarchy operates like a tree structure or computer folder structure wherein lower-level displays are associated with specific higher-level displays. Proper display hierarchy has been shown to make abnormal situation response easier and more effective.

The majority of operator actions should be taken in Level 2 and Level 3 graphics, as shown in Figure 1-1.

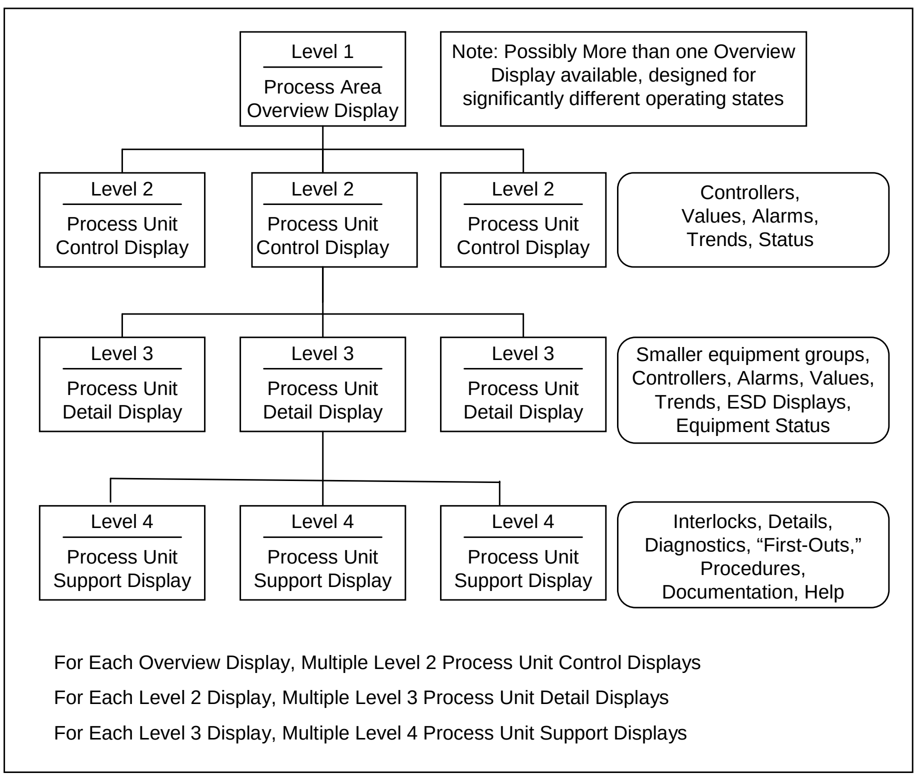

Figure 1-1
High-Performance HMI Display Hierarchy

1.8 Level 1 Process Area Overview Display

The overview display will show the broadest available view of all of the facilities under a single operator's control. It is a "big picture" at-a-glance view of the process unit. It provides clear indication of the current performance of the process by tracking the KPIs.

The overview screen is normally shown on a large format off-console display. It should also be possible to call up the overview display on one of the console screens if there is a problem with the large display screen or if one is not yet installed.

The overview screen is used for monitoring. Control moves are not expected to be made from the overview display, and that functionality need not be incorporated.

The overview screen depicts elements and features such as the following:

- High-level KPIs such as safety, environmental, production, efficiency, and quality. Chosen for display are KPIs that are influenced by the actions and performance of the control system and the operator.
- Values, trends, calculated process conditions, and deviations of KPIs.
- Alarms of the top two of three highest priorities, including acknowledgement status.
- Key process controllers.
- Important calculated parameters and conditions, such as mass balance.
- Important information from upstream and downstream units.
- Advanced control mechanisms performance and status.
- Major equipment status.
- Appropriate trends of important process parameters.
- Indications of abnormal situations, denoting severity.

All units that are controlled by an operator shall be included in the process overview. The process overview shall be useable for all operating conditions. However, more than one process overview may be needed to support certain operating conditions, such as startup or transition.

1.9 Level 2 Process Unit Control Display

The Level 2 graphics should contain all the information and controls required to perform most operator tasks associated with a specific plant unit, from a single graphic. Both routine changes and some abnormal situation interventions should be possible.

All controllers and important indicators are shown on the various Level 2 graphics. The graphics are used for routine tasks such as manipulating controllers, operating pumps, starting blowers, and opening valves. All alarms relevant to the depicted process are displayed.

Level 2 graphics include embedded trends of important process conditions and equipment performance associated with the unit depicted.

Multiple Type 2 displays may be needed to cover the same equipment. These would be purpose-built for specific situations such as startup, normal operation, state or product transitions, and shutdown. (In some control systems, graphic "overlay" methodologies might be adaptable to this purpose.) The task analysis for the abnormal situations will likely require information on the screen not useful for the normal operations case, and would therefore be distracting or cause visual clutter. In complex situations, checklist elements should be displayed to help guide the operator through the proper response.

1.10 Level 3 Process Unit Detail Display

All control elements should somewhere be shown on the appropriate graphic(s). Elements (controllers, indicators, alarms, status switches) not shown on Level 2 graphics should be shown on Level 3. Level 3 graphics are also used for detailed investigations and interventions that are not time-critical. Level 3 displays include the following:

- Detailed views of subunits, individual equipment items, components, and their related controls and indications
- Custom prebuilt trend displays for specific diagnostics
- Shutdown system diagnostic displays
- Interlock diagnostics, initiator and action tables, and similar troubleshooting displays

These detailed displays are mainly intended for troubleshooting or manipulating items not accessible from the Level 2 displays. Indicators, controllers, and alarms of all priority levels are shown on these screens. There may be several Level 3 displays for each Level 2.

1.11 Level 4 Process Unit Support Display

Level 4 displays provide extensive detail of subsystems, individual sensors (points/tags), or components. They show the most detailed possible diagnostic or miscellaneous information. The dividing line between Level 3 and Level 4 display can be somewhat gray.

Level 4 Support displays include the following:

- DCS System-supplied displays such as point detail, system diagnostics, and alarm summary
- “Common Alarm” displays with details of individual sensor status
- Detailed information about equipment and instrumentation
- Detailed status of advanced process control (APC) functionality
- Help displays

Other displays at Level 4 not associated with the display of live process information can include the integration of the following into the operator’s HMI:

- Easy access to operating procedures
- Alarm documentation and response guidance
- Abnormal situation response guidance
- APC documentation and operational procedures
- Other system or program-related documentation and procedures

1.12 Alarm Depiction and Alarm Management

The implementation of alarm functionality on process graphics shall follow the principles set forth in the site's Alarm Philosophy Document. The steps involved in the overall operator response to an alarm include the following, and the HMI should facilitate these interactions:

- Detecting the alarm
- Assessing the process situation to determine the alarm's cause
- Deciding on the proper action(s) to take in response to the alarm
- Implementing the chosen action(s)
- Continuing system monitoring to ensure that the action(s) performed correct the situation that caused the alarm.

Consistency in the presentation of alarms to the operator, as well as straightforward, uniform steps to verify and assess the potential impact of the alarm, will result in the minimal time and maximum effectiveness of response. Note that for truly high performance, the HMI should assist the operator in detecting abnormal situations before alarms occur.

Any value in alarm must be shown clearly and consistently. The following principles apply, and the style guide section provides the detailed depiction:

- Alarm indication is made by the proper display of alarm objects that are redundantly coded (shape, color, text).
- Color is related to alarm priority, and not the "type" of alarm. Every alarm priority has its own reserved color.
- Alarm colors are used only to display alarm-related functionality and nothing else. If yellow is an alarm color, then yellow is never used as a text label, line color, border, mode indicator, or any other nonalarm-related element.
- Unacknowledged alarms should be distinguished from acknowledged alarms. The most common method is the flashing (blinking) of the alarm indicator for the unacknowledged condition. This is important because color change alone is not very noticeable in peripheral vision, whereas movement is.
- All alarms should be acknowledged only once; it should never be required to acknowledge the same alarm using more than one methodology.
- If more than one alarm is in effect on a value, the highest priority alarm should be indicated.
- Every alarm priority should have its own unique alarm sound.
- Graphics should not be "hard-coded" with alarm behavior for specific alarms; the behavior should be consistent based on the current configuration of a point's alarm and should change if the configuration changes.

- A process graphic must visually and consistently identify tags in alarm, whether the alarm is acknowledged, and the priority of the alarm.
- Tags with alarms that are suppressed should be indicated on the graphics. The HMI must supply functionality for the operator to easily identify all suppressed alarms in their area of responsibility.
- Every point with a configured alarm should have an associated Level 2 or 3 graphic display on the control system. This associated display should aid the operator in the proper diagnosis and mitigation of the event causing the alarm. Methods by which the operator is quickly directed with a single keystroke or button-click (that is, one-touch access) to the associated display should be used. Most control systems have this capability, but it must be configured.

A single alarm interface should be used, namely, the control system and not separate “lightbox” style annunciators. Compared to a properly functioning DCS alarm system, lightboxes are expensive to implement, maintain, and modify. They provide little guidance or assistance to the operator in handling the abnormal situation—far less than can be configured with a graphic display of the information.

(Further information about proper lightbox implementation omitted.)

2.0 HMI Design Process

The design of a high-performance HMI begins with the documented HMI Philosophy and Style Guide (this document). The work process to then implement the philosophy principles is straightforward.

High-performance displays require a thorough understanding of the process and the necessary operator actions in controlling it in various scenarios. The process engineer, control engineer, operations engineer, and operators should be involved in defining information to be used by the HMI designer.

Note that having exceptional ability to design or operate a process does not necessarily translate into the ability to design a good HMI.

2.1 Performance and Goal Objectives

High-performance display design involves:

- Determination of the proper process operational bounds
- Depiction of the current process performance relative to those bounds
- Provision of easy and effective access to control functions and actions that adjust the process performance

This cannot be accomplished by simply replicating P&IDs onto a control screen. Therefore the first step in the design of a high-performance HMI is to:

Determine specific performance and goal objectives for the control of the process, for all modes of operation.

Performance and goal objectives should be determined all factors that are influenced by the performance of the operator and the control system, such as:

- Safety
- Efficiency
- Generation cost
- Reliability
- Generation rate
- Equipment health
- Quality
- Environment (for example, emission control)

Monthly operations reports are a good source for KPIs that are important to the business, influenced by the operator, yet often not displayed to the operator.

Many of the performance goals will have different values depending on the process mode. Most processes have different possible operating modes. Each of these must be defined. Examples of modes of operation include:

- Starting up
- Normal operation
- Partial rate operation
- Shutting down
- Utilizing alternative feedstocks (such as grades of coal)
- Expected abnormal situations
- Operation after the activation of a safety shutdown system

For each of the identified modes of operation, determine the specific control performance goals in each category. These goals for each mode are documented for the overall process and for each subsystem the operator controls, which will generally constitute a Level 2 display each.

(Further details, figures, and tables omitted.)

2.2 Task Analysis

Operator control tasks needed to achieve the process objectives must be determined. This is task analysis, and it is simple and straightforward. From the Tables produced in the prior step, and with the identified goals and variables involved, determine the operator tasks necessary to accomplish effective control. Typical tasks include:

- Controller setpoint and mode manipulation
- Digital (on-off) point manipulation (pumps, fin-fan banks, compressor loading, valve switching)
- Activation and monitoring of advanced control schemes or programmatic controls
- Observation of lab results

- Direction of outside operators to perform nonautomated tasks
- Interaction with daily production planning goals and changes
- Troubleshooting
- Abnormal situation response

Control manipulation begins with Level 2 graphics. For each Level 2 subsystem and for each mode, list the control system elements that must be manipulated by the operator in order to perform the tasks. List the elements to be observed and trended to meet the performance and goal objectives.

(Further details, figures, and tables omitted.)

2.3 Design and Build

Based on the objectives, goals, and task analyses, design graphics that facilitate both the observation of the performance goal variables and provide access to all of the system manipulations associated with control of those variables. Perform proper grouping so control is not spread out across several graphics.

For example, if a certain important parameter is to be maintained between values of *X* and *Y*, then the graphics should show the parameter, a properly scaled and time-spanned trend of it, and the associated part of the process and manipulation controls used to affect the parameter. When graphics are produced based on P&IDs as the starting point, often the result will not provide the proper controls on the right graphic.

Participation in this step should include the same people as in the preceding steps, although the DCS HMI designer (in-house or outside services) will be doing most of the work at this point. It is a good idea to post life-size printed versions of the new graphics as they are developed, in the control room for operator familiarization and comment. Operators participating in the HMI design effort should regularly report back to their peers.

Perform testing of the prototype graphics. Allow more users than those assigned to the design effort to review and participate in the testing. A final testing check should be made to ensure the changes have not affected important functionality.

Ideally, the tests should involve certain key simulated situations with the operators performing relevant tasks. This will uncover issues with the interface that might not be detected in a casual examination. The cohesiveness of the HMI as a whole should be assessed, and any necessary adjustments to the graphics are determined.

(Further details, figures, and tables omitted.)

2.4 Installation, Commissioning, and Training

Ensure the installed graphic versions run correctly compared to the test environment (if used). It is not uncommon for points to be added or modified in a parallel project effort of DCS configuration, which can affect the graphics.

Provide operator training in the following areas as part of introducing the new graphics:

- DCS operating procedures and methods—a refresher is usually a good idea
- Aspects of the high-performance HMI philosophy relevant to operations
- The reasons the HMI was changed, and the expected benefits
- Features of the DCS and HMI alarm presentation, annunciation, and management
- Navigation in the high-performance HMI
- Use of trends
- The HMI navigation system and the progressive hierarchy
- Graphics for specific situations (such as rate changes, product changes, and shutdowns)
- Changes in depiction compared to the old graphics, and proper use of the new graphics
- Ongoing HMI review, feedback, and continuous improvement

2.5 HMI Management of Change Control and Maintenance

Only authorized and trained personnel will be allowed to make changes to graphics.

A graphics change MOC process will be followed that ensures the following:

- Backup and retention of prior graphic versions
- Proper design, in accordance with the HMI Philosophy and Style Guide
- Proper functionality review and checkout
- Proper notification of all affected parties on the details of the change
- Update of applicable procedures, menu paths, links to/from other graphics, and any other documentation

(Further details omitted.)

3.0 HMI Performance Monitoring and Ongoing Assessment

After several weeks of initial usage, operators should be surveyed for necessary or beneficial HMI changes. An ongoing system of operator feedback on graphic effectiveness should be provided. A logbook or e-mail “inbox” specifically for recommended graphic changes is recommended. Operators should be encouraged to print screen snapshots of the graphics and make notes on those for suggested improvements. This comment method should be retained long-term.

Production upsets, incidents, and accidents should receive an internal company review. Part of the review of such events should be a specific assessment of the effectiveness and performance of the HMI before, during, and after the event.

4.0 Control Room Factors and Work Practices

Control room design and operating practices should create a work environment promoting high levels of vigilance and situation awareness. While control room design is beyond the scope of this document, some important principles are detailed.

4.1 Control Room Lighting

(Details omitted.)

4.2 Noise

(Details omitted.)

4.3 Console Design

(Details omitted.)

4.4 Distractions

(Details omitted.)

5.0 High-Performance HMI Style Guide and Object Library

There are aspects of an HMI that are very specific to the abilities and paradigms embedded in a particular DCS. The HMI style guide is therefore a detailed document specific to a particular type of DCS. It covers the methodologies by which the principles contained in the high-performance HMI philosophy are embodied within the capabilities of the subject DCS. Separate style guide sections are needed for each type of DCS.

Graphic object creation is generally DCS-specific as well, even if identical appearance, behavior, and capability are being implemented. The object library is therefore the collection of individual screen objects. High-performance HMIs reuse properly created objects to the maximum extent possible. (Note: Actual coded functional objects are not included in this abbreviated document, only descriptions.)

It is not recommended for a single operator to use multiple types of DCS systems. However, a site's evolution and capital constraints may have resulted in this situation. In such cases, the HMI designer should bring commonality to the systems to minimize confusion, as this scenario is a high risk for human error.

5.1 Control System Specificity

(Details omitted.)

5.2 Basic Principles of Process Depiction

Several basic principles should be embodied in high-performance graphics:

- The presentation of information follows explicit, consistent visual coding, navigation and layout schemes.
- Consistency decreases the time and error in locating critical information.
- The prominence/size of objects shall typically be appropriate to their importance in the process.
- Information that is related shall be grouped together in a way that shows the association or relationship.
- Display arrangements should be neat, clean, aligned, and uncluttered.
- Text should not overlap other elements.
- Similar processes in parallel trains shall be distinguishable with clear visual and text coding.
- Operator actions shall provide feedback. Selected items clearly indicate that condition.

The “P&ID” or “process pictorial” representation is a far overused and underperforming paradigm in process graphic creation. High-performance Level 1 and 2 graphics will rarely resemble a P&ID, although they may contain some elements with a simplified P&ID depiction. Level 3 graphics often have a more P&ID appearance as part of their content. When appropriate, proper use of the P&ID representation is the following:

- Process flow shall be laid out in a left to right and top to bottom arrangement.
- An effort shall be made to minimize the number of bends in lines.
- Crossing lines shall be avoided.
- In some cases, geographic layout is important (see the special purpose graphics section).

5.3 Global System Display Defaults

(Details omitted.)

5.4 Color Palette and Usage

Color shall be used sparingly and primarily to indicate abnormal rather than normal conditions:

- Normal operating conditions are less conspicuous than alarm conditions.
- Grayscale is used for equipment and instrumentation.
- Color alone should not be the only distinguishing characteristic of important status information.
- Alarm colors are used only for the depiction of alarm-related functionality.

The following color palette in Figure 5-1 is used in this style guide. The color choices and combinations should be verified to be distinguishable and of adequate contrast, when displayed on the actual control room hardware in real lighting conditions. Any needed adjustments should update this table.

Color	RGB Values	Hue, Saturation & Luminosity	Sample Color	Defined Uses
Background Grey	204,204,204	160,0,192		Overall graphic background
White	255,255,255	170,0,255		Highlighting of some small items, such as poor or bad quality indications
Light Grey	243,243,243	170,0,243		On indication for pumps, motors, equipment
Grey	136,136,136	160,0,128		Non-navigation button color, Off indication for pumps, motors
Dark Grey	74,74,74	160,0,70		Tag name EU descriptions, process lines, process vessel outlines. Black can also be used.
Black	0,0,0	170,0,0		Text and labels
Dark Blue	0,0,128	160,240,60		Process values, controller modes and outputs, similar special purposes
Dark Green	0,128,0	80,240,60		Controller setpoints and other operator inputs, trend trace of setpoints
Light Green	153,255,102	71,255,179		Possible “faint green” for some specific highlighting
Light Blue	187,224,227	131,106,207		Desired operating ranges or conditions
Cyan	0,255,255	127,255,128		Vessel level strips, trend lines
Brown	204,102,0	21,255,102		Trend lines, misc.
Red	255,0,0	0,240,120		Top level, priority one alarm
Yellow	255,255,0	42,255,128		Priority-two alarm
Orange	255,102,0	17,255,128		Priority-three alarm
Magenta	255,0,255	213,255,128		Priority-four alarm for diagnostics
Dark Magenta	204,0,102	234,255,102		Trend trace

Figure 5-1
Color Palette

5.5 Display of Text

The display of static text on-screen should follow several principles:

- The amount of text should be minimized but not eliminated. A graphic screen is not an instruction manual or a training document, nor should it be a puzzle. Use text to identify different items when their placement or shape does not make their identity obvious to the operator.
- Text should generally be a dark gray or black based on testing samples for legibility in the actual control room environment and hardware.
- All display screen lettering should be in nonserif fonts (Arial is a proper choice).

- Use larger, highly visible text to identify duplicated equipment, such as multiple reactors, furnaces, compressors, and so forth. When a screen shows only one system out of several identical ones, it is important to be clear on which system is being depicted.
- For isolated words, titles, short labels, and equipment designations (particularly for a “nonword” term like HYDRO SEP), all uppercase lettering is preferred. For other uses, mixed-case lettering is more legible.
- Ensure consistency with abbreviations. Use a master list and glossary (later in this document).
- For text size decisions, use mockup graphics and actual control room display hardware with various sizes of text, and ensure the operators can read them. Arial 10 is generally a good choice for the smallest text size for an on-console display. Once legibility is determined, use that text size consistently in all similar elements.
- Text and numbers shall never flash or be animated.
- All major vessels and process lines shall be labeled. Labeling rather than color is the proper differentiator for process line contents.
- Items or lines entering or exiting a graphic shall be labeled.

5.6 Display of Process Values

A general principle of high-performance graphics is that screen elements are depicted simply (Figure 5-2):

- Process values should display only the significant digits needed by the operator.
- Live values from the control system are shown using dark blue, bold, Arial 10 or 12 point text. Font size should be chosen based on testing with the actual operator population and the actual hardware to be used. The color choice differentiates live values from simple text on the graphic.
- When numbers are arranged in vertical tables, a fixed-width font such as Courier or Lucida Console is an appropriate choice, and an alternative process value indicator should be created for that option.
- Engineering unit labeling is in black or dark gray, lowercase, nonbold, and uses standard abbreviations from the list later in this document. Not all indications will need engineering unit labeling when their context is obvious.
- Invalid measurements are usually accompanied by an alarm indication as shown in the next section. The priority is based on the alarm philosophy.
- Tagnames are not shown by default, as they are visual clutter that is rarely needed.
- The simple depiction of numbers on a screen is a generally ineffective way to convey process information. More powerful methods are shown later in this document.
- When several numbers are presented vertically, the decimal points should line up. Leading zeros shall be suppressed, except on fractional values (0.76).

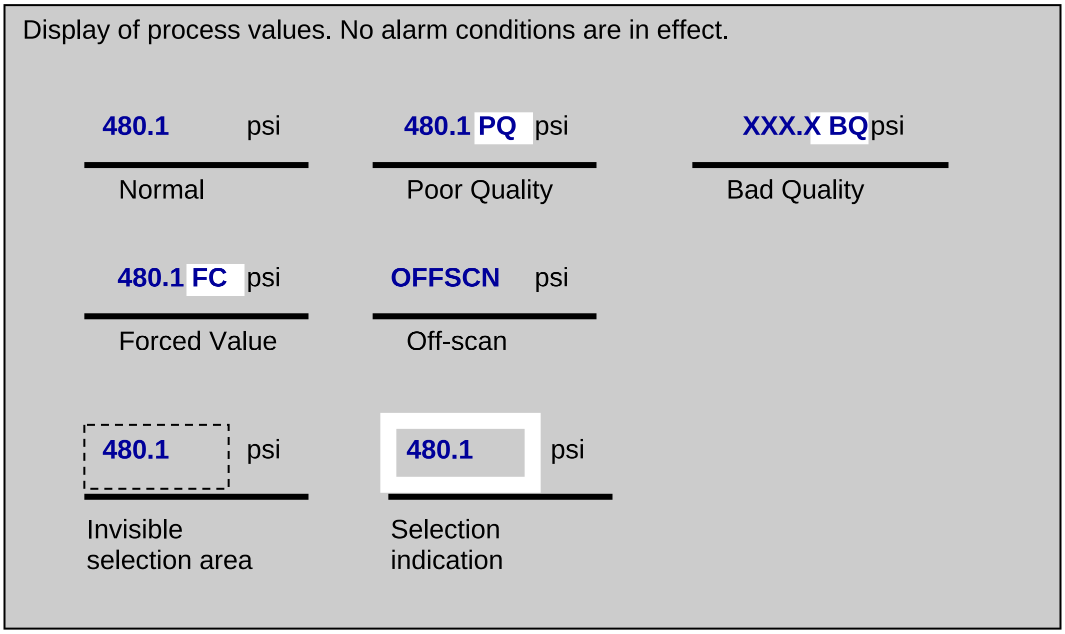

Figure 5-2
Process Value Depiction

Normal: Value is valid and no alarm is in effect.

Poor Quality: Value is suspect as determined by the control system.

Bad Quality: Value is invalid, due to any number of conditions (for example, out of range and lost communications).

Forced Value: The value is not measured; it is the result of operator input.

Off-Scan: The measurement sensor is not being read; the point is offline.

Every process value on the screen has an invisible target area that allows it to be selected. When selected, the faceplate for that value is brought up. The white selection rectangle appears around items that are currently selected.

In the above examples, no alarm is shown. Normally an alarm would accompany the bad quality condition, in accordance with the alarm philosophy. See the following section for alarm depiction.

Note: In some control systems, the "last good value" can be displayed, with an indication that it is not current.

The process value of digital states is similarly depicted using clear, unambiguous, action words. For example, "RUN" and "STOP" are ambiguous in that they can be confused for either a current status or a command for change in status. "Running" and Stopped" are unambiguous for status (Figure 5-3).

(List of all digital state and command words omitted, these are usually DCS-specific.)

Digital Input (DI) and output (DO) depiction may be in a tabular form, shown later in this document. A single DI or DO should appear similar to the following example. If the DI represents equipment status, other example representations are shown later in this document.

Note that in this simple boxed depiction (Figure 5-3), room is left for an alarm indicator. A digital word can be used without a label or bounding box if the depiction is obvious, as in the word "Running" or "Stopped" next to a pump. Digital values have invisible target areas, selection indicators, and alarms like the analog values shown in Figure 5.2.

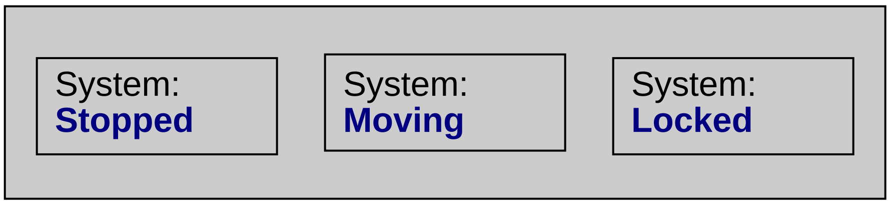

Figure 5-3
Digital State Value Depiction

5.7 Alarm Functionality

Alarm indication on graphics shall be accomplished in the following manner:

- Values or conditions in alarm shall be indicated by the appearance of a normally invisible alarm indicator located next to the value or condition. The location of the indicator is flexible.
- The color fill of the alarm indicator flashes until the alarm is acknowledged, and is then steady. The flashing behavior contrast should be checked to be visible even if an operator is color-deficient. (Check by "turning down" the color of the display as a test, or printing the symbol differences on a gray-scale printer.) The entire alarm indicator disappears when the alarm condition clears. The value or condition itself never flashes and does not change color.
- The indicator that appears is based on the highest priority alarm in effect on the value in alarm. For many values it is possible to have more than one alarm in effect at the same time (for example, high value, high rate-of-change), thus the need for a hierarchy. It is not practical to attempt to code alarm type with the alarm indicator element. Details of the alarm are shown on the alarm summary screen (description, message) or by selecting the alarmed value to bring up a more detailed popup element.
- Each alarm priority has a separate, distinguishable alarm sound.

For a four-priority system using numbered priorities, the alarm indicators are as shown in Figure 5-4.

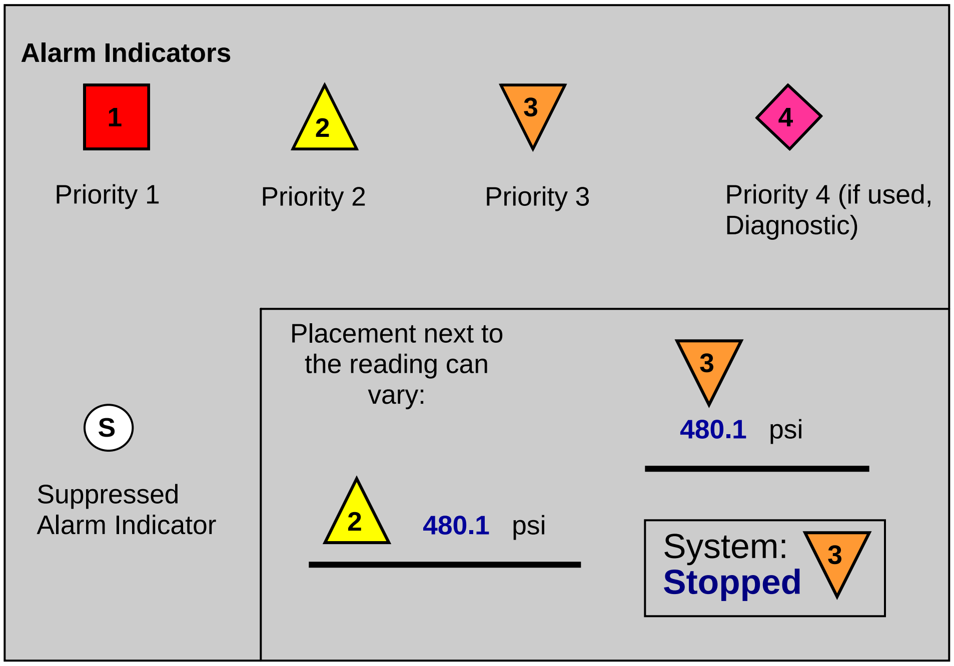

Figure 5-4
Alarm Depiction

(Details omitted.)

It is often beneficial on a Level 1 or 2 graphic to show the total quantity of alarms in effect and unacknowledged. Figure 5-5 is an example of such a depiction, if the numbers can be read from the control system. Note that if alarm numbers are zero for a particular priority, the color of the alarm indicator element and the number background are not shown. The alarm indicator element flashes if there is an unacknowledged alarm of that priority.

Alarms	1	2	3	4	S
Total	0	4	8	1	12
Un-Ack	0	0	2	1	

Figure 5-5
Alarm Summary Element

Alarm documentation should be available in the HMI via a right-click menu action or in a popup element similar to the below (Figure 5-6). This requires graphic element access to the Master Alarm database. If this cannot be accomplished inside the graphic HMI, browser-type access on a separate PC should be provided to the alarm information. When called up, it is beneficial if the element shares the size and shape and positioning of a standard faceplate.

(Further details omitted.)

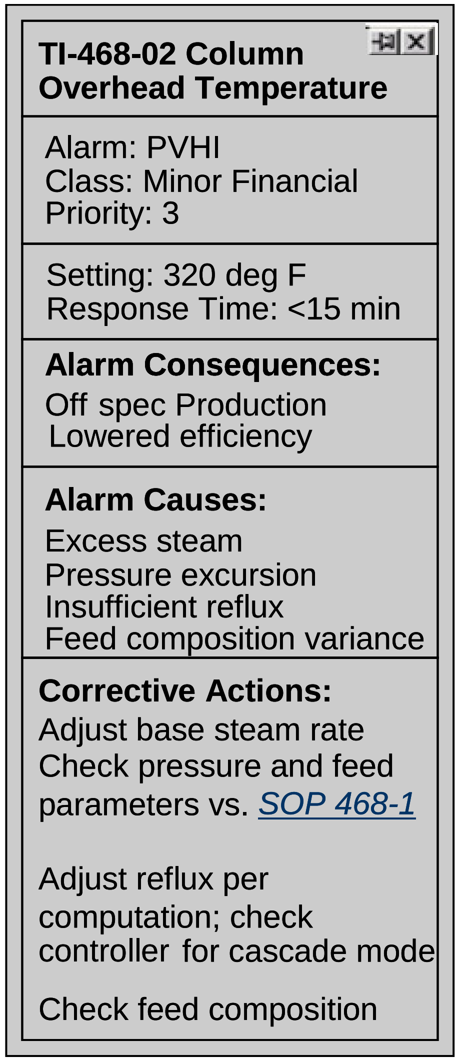

Figure 5-6
Alarm Information Popup Example

5.8 Moving Analog Indicators

The moving analog indicator (MAI) is a fundamental element for high-performance displays. This indicator provides information about a process value as opposed to just raw data. Various conditions of this indicator are shown (Figures 5-7 through 5-9).

The presence or absence of various alarm ranges corresponds with the depictions shown. Different points will have or not have various alarm selections and ranges as determined by the alarm philosophy. The depiction should reflect the actual point’s configuration of alarms.

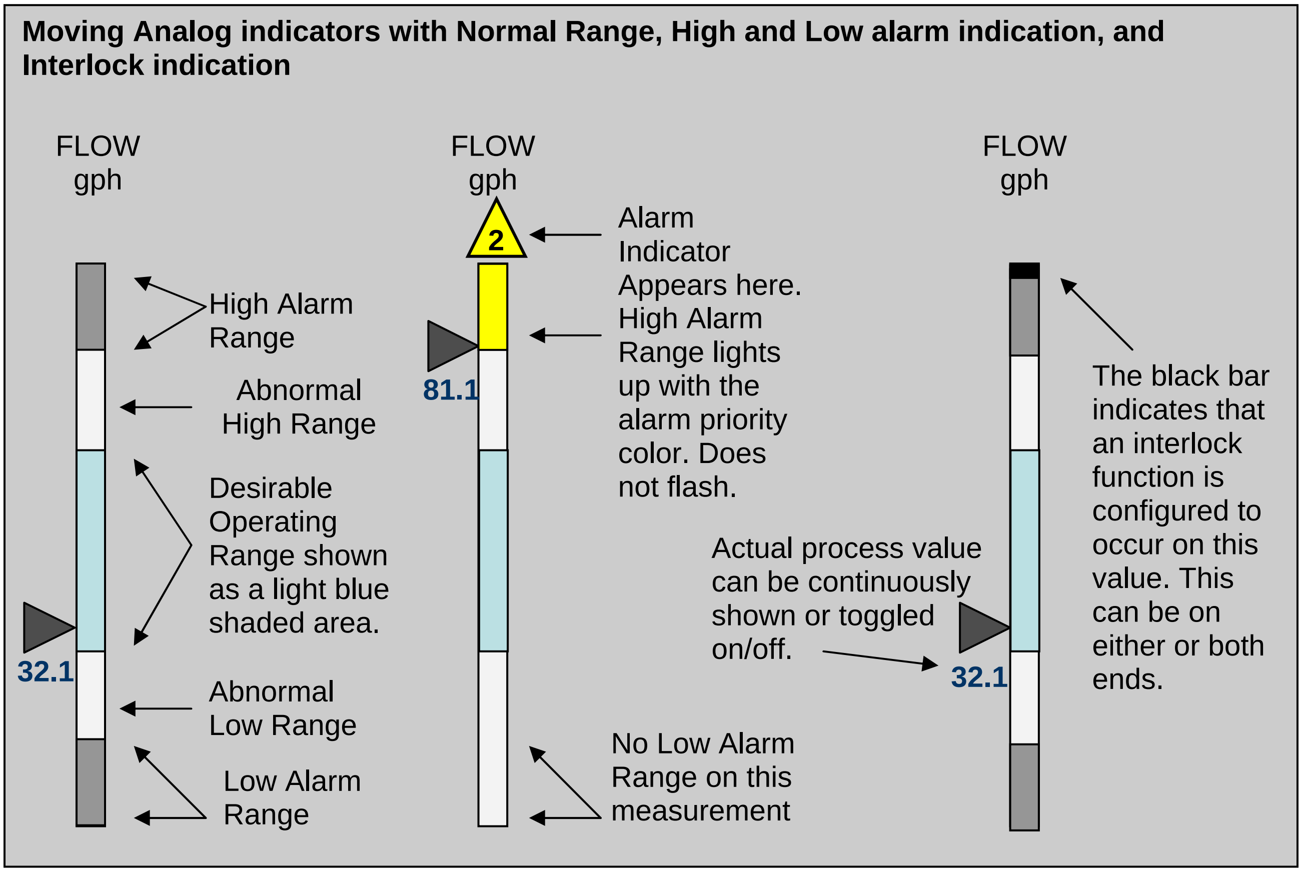

Figure 5-7
Moving Analog Indicators Part 1

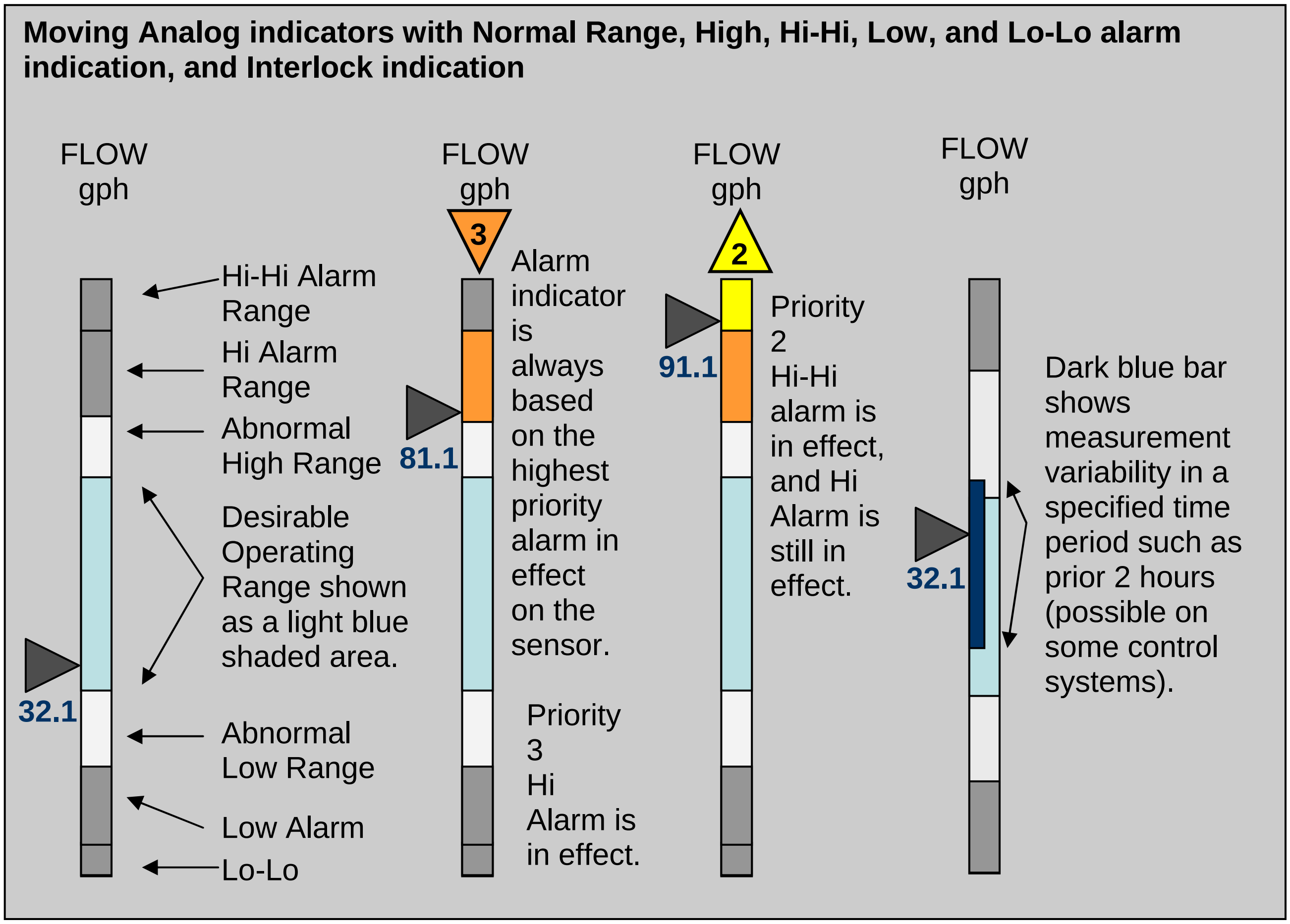

Figure 5-8
Moving Analog Indicators Part 2

In the middle two examples, the Value High alarm is set as Priority 3 and the Value HH is set as Priority 2. This could be different. In the rightmost example, the orange color is in effect on the Value High range because that alarm is still in effect, but the alarm indicator above the indicator is a P2 because the highest priority alarm currently in effect on the tag is a P2.

The rightmost indicator is possible on some control systems if the sensor's highest and lowest process value in a specified time period can be retrieved.

The indicator need not depict the full range of the measured value. If it shows a smaller range, the pointer should "peg" at the top or bottom, but the PV number should continue indicating the proper value. Nor does the scale have to be linear for the overall indicator, but should be linear within each separate portion.

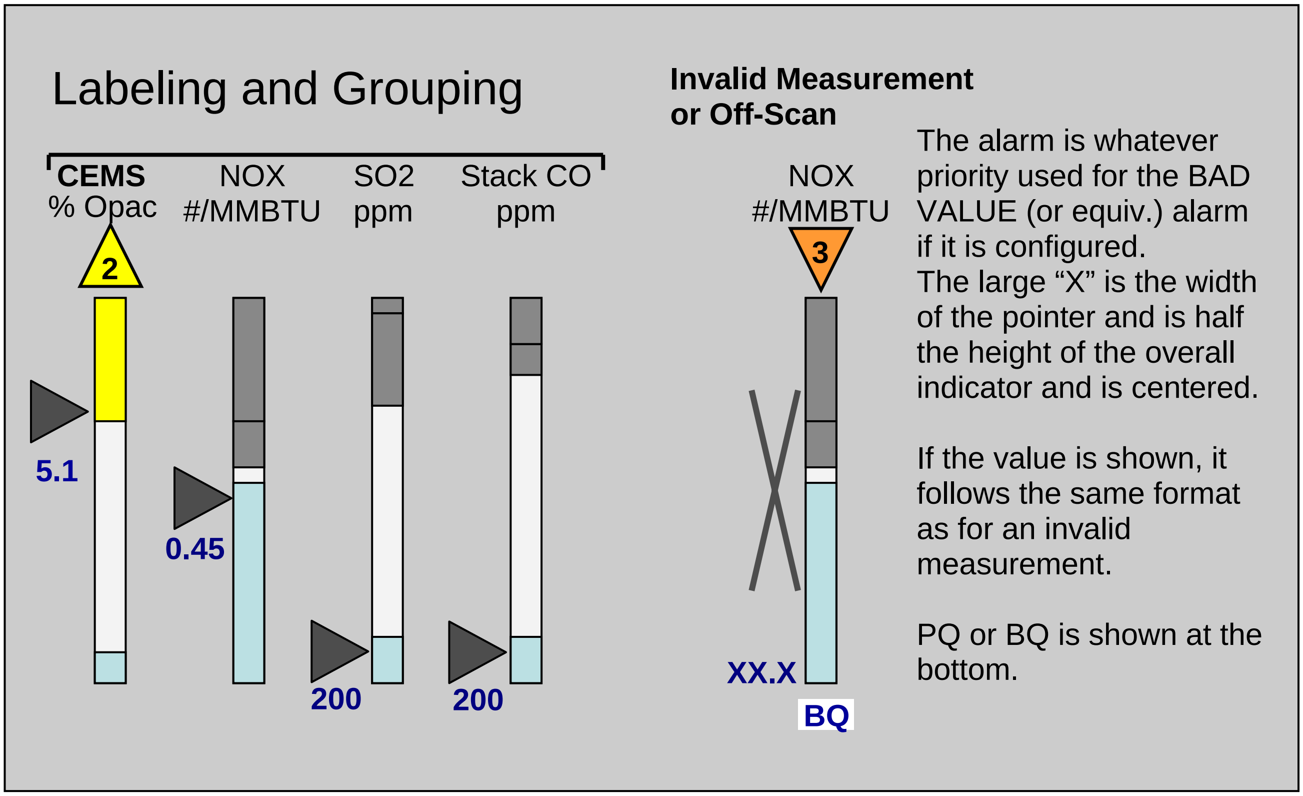

Figure 5-9
Moving Analog Indicators Part 3

Groups of moving analog indicators should be delineated as shown. Invalid measurement or off-scan status is shown on the right.

(Further details omitted.)

5.9 Controllers

Controllers should be depicted as a physical entity, similar to a pump or heat exchanger. By depicting a controller separately, proper information about its operation, status, and connectivity can be clearly shown.

The depiction of controller elements poses a significant problem in "where to stop." The control system's internal construct of a controller may involve several dozen different parameters. All of these cannot be shown at all times on an operating graphic. To depict a controller therefore involves substantial editing and the progressive exposure of more detail as needed. Three effective depictions are shown below in Figures 5-10 through 5-13. They contain the following:

- A text label of the controller (but not the tagname).
- Process Value (PV or P) —the current reading of the process value being controlled, generally in Engineering Units.
- Setpoint (SP or S)—expressed in the engineering units of the PV.

- Output (OP or O%)—expressed as a percentage, generally 0% to 100%.
- Controller Mode—generally automatic (Auto), manual (Man), cascade (Cas), or a few other specialty modes in some DCSs (program or Prog, advanced process control or APC).
- The units of measure are used in the top row showing the process value. This saves space.

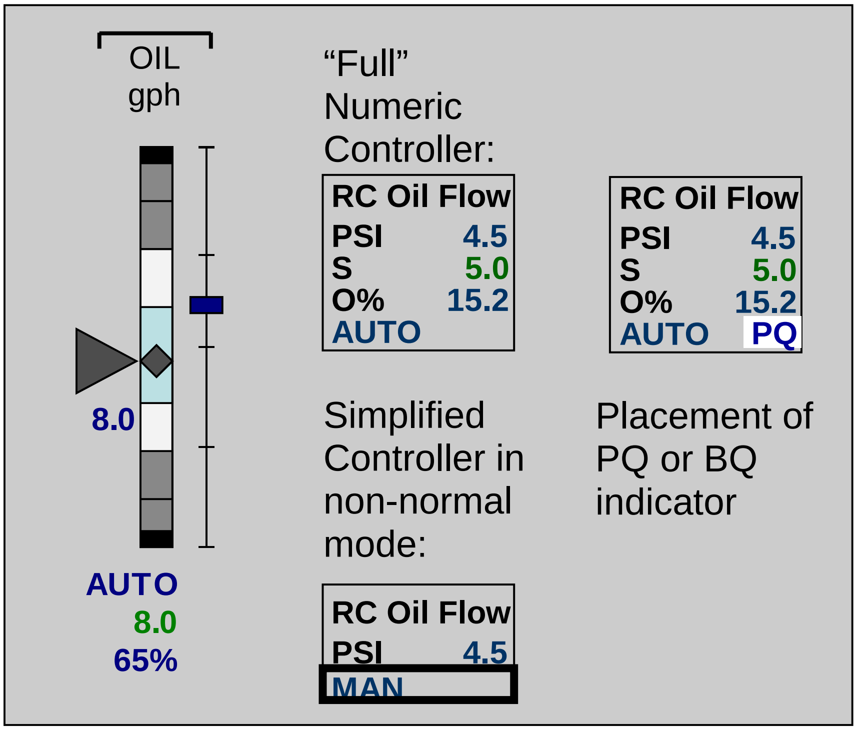

Figure 5-10
Analog and Digital Process Controller Depiction

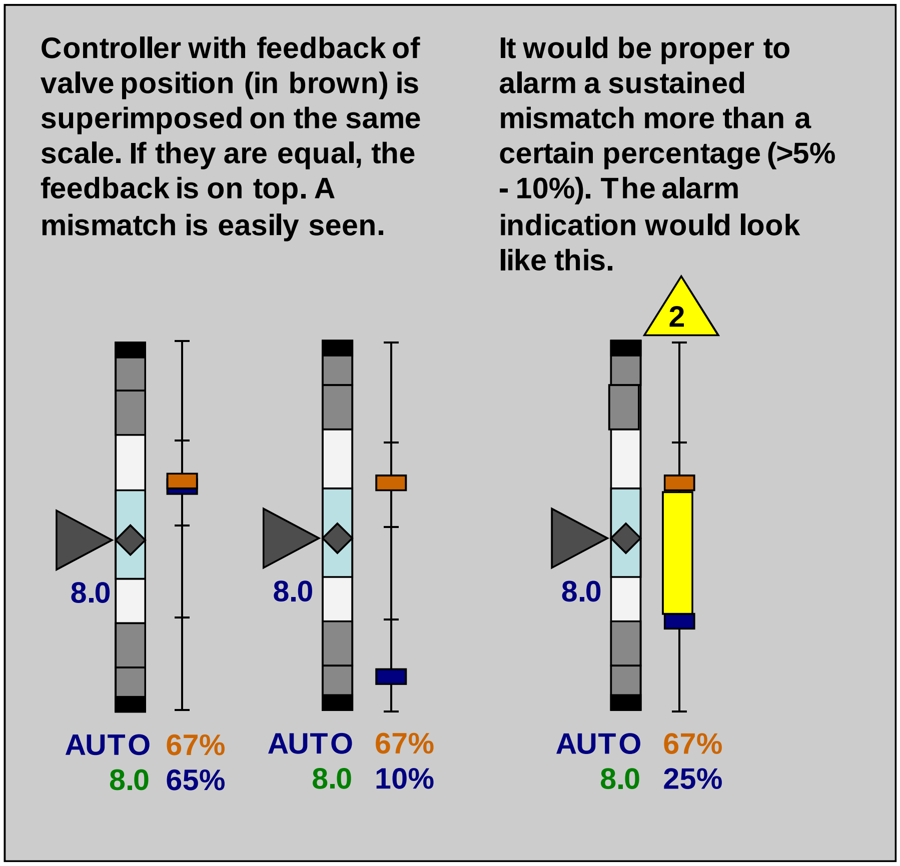

Figure 5-11
Analog and Digital Process Controller Depiction

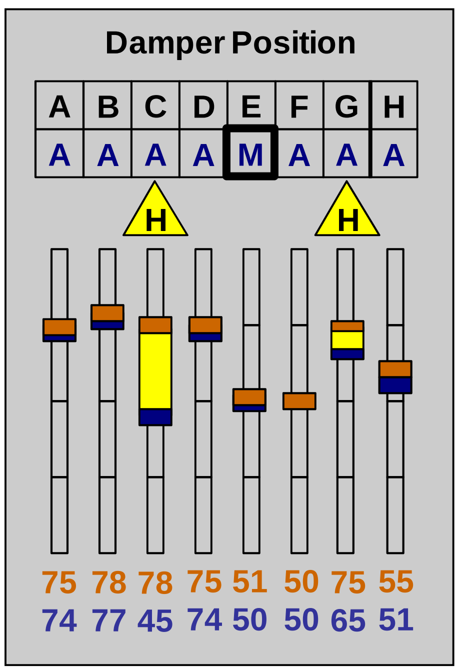

Figure 5-12
Example of a Bank of Damper Position Elements Showing 2 Alarmed Mismatches

In space-limited circumstances, a compressed version eliminating setpoint and output is possible, with the same popup functionality.

When an element of the controller is in alarm, the appropriate alarm indicator appears next to the controller block.

An analog version of a controller (as shown) is useful in many of the same circumstances as for a moving analog indicator.

When the controller is not in the "normal" mode, the mode is highlighted as shown. Note that this is not generally an alarmed condition. The intent is to draw visual attention to the condition without indicating an alarm.

(Further details omitted.)

5.10 Change Zones and Faceplates

When screen objects are selected, additional information about them should be shown. This is typically in the form of a faceplate popup. If the operator can interact with or manipulate the element, the interface for that interaction is contained in the faceplate popup. Faceplate popups should appear in a reserved "change zone" area of the graphic and not obscure other parts of the graphic when called up. Faceplates should be consistently sized for such an area.

A discussion of Controllers provides the best example for this method. Many elements of a controller are changeable by the operator (for example, setpoint, mode, output). A single graphic may need to depict several controllers. Providing for all of their individual input mechanisms uses a lot of screen space. Instead, the principle to be followed is that a controller is selected by the operator, and the element used to manipulate the controller is shown in a designated area. The area is called the change zone.

This reserved area is important. It is undesirable for a popup element to appear randomly on the screen, perhaps obscure important information, and then have to be manually dismissed or moved. Change zones are often a rectangular area on the right side of the screen, or a narrow strip across the bottom or right-hand side.

Only one item on a screen should be selectable at a time. Any new selection on the screen should replace any faceplate popup from a prior selection, without any manual "closing" of the prior faceplate needed.

Faceplates are often supplied as standard elements by the DCS manufacturer.

(Further details omitted.)

5.11 Display Layout

Standard templates for Level 1-2-3-4 graphics should be prepared. These will have aspects that are dependent on the particular control system involved.

(Further details omitted.)

5.12 Navigation Methods and Practices

Several methods of navigation shall be provided to the operator. A good navigation framework facilitates quick access to the primary displays and easy access to secondary or associated information. The use of multiple techniques provides flexibility to meet the distinct requirements of specific situations or varying user experience levels. Screen-based navigation is the primary paradigm, particularly when dedicated programmable keys are not available on the control system interface.

The navigation methods shall support accessing the different levels and types of displays. Navigation links to each related level of display shall be consistently located for easy access (Figure 5-13):

- Display access should require a minimum of operator keystroke-equivalent actions.
- Logical and consistent navigation methods utilize a hierarchy for the progressive exposure of process detail.
- It should never be necessary for an operator to type in a graphic name or a point identification.

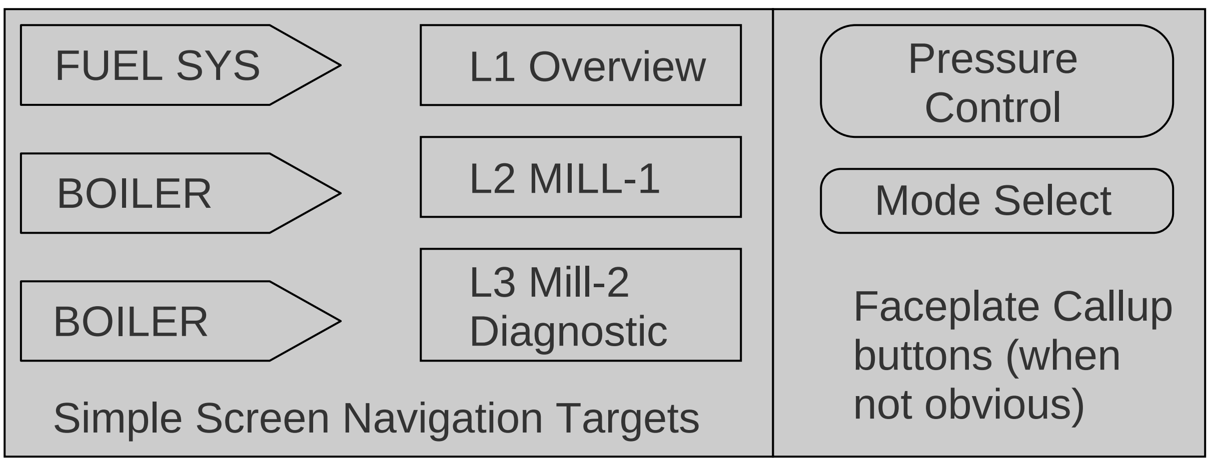

Figure 5-13
Navigation and Faceplate Callup Targets

(Further details omitted.)

5.13 Valves and Other Final Control Elements

Valves should be depicted simply. Shading, and not color, is used to indicate opened and closed status (Figure 5-14 and 5-15).

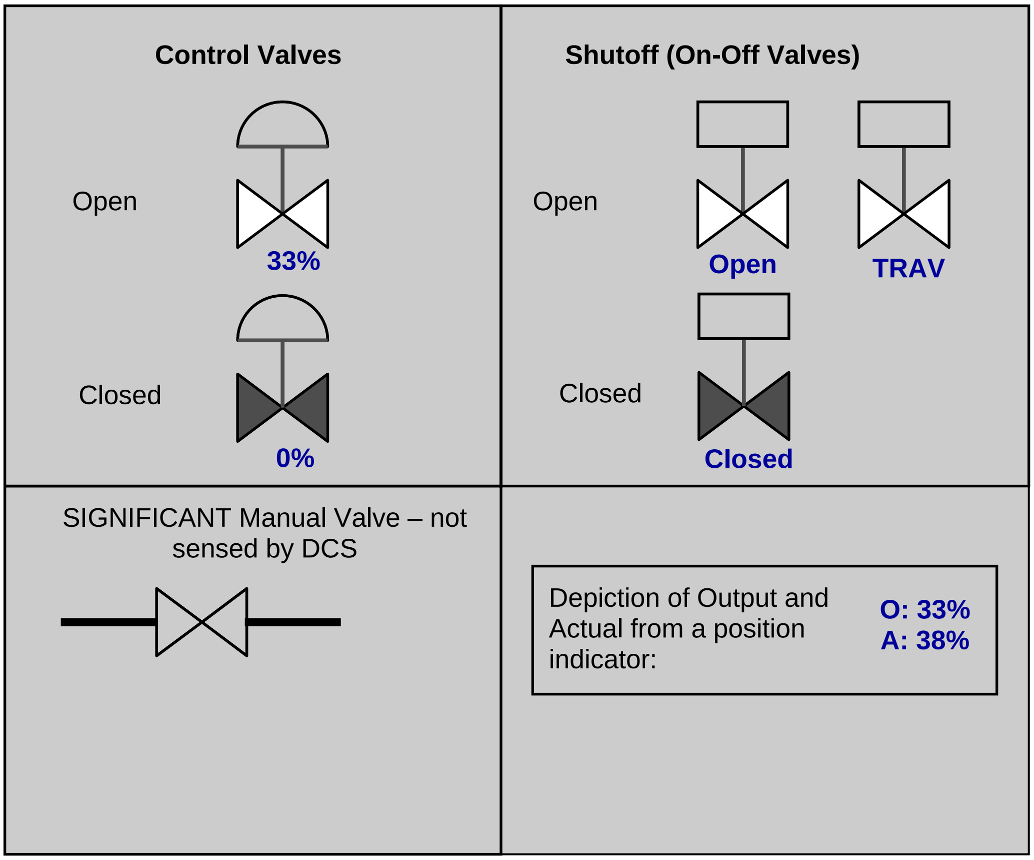

Figure 5-14
Control and Shutoff Valves

(Further details omitted.)

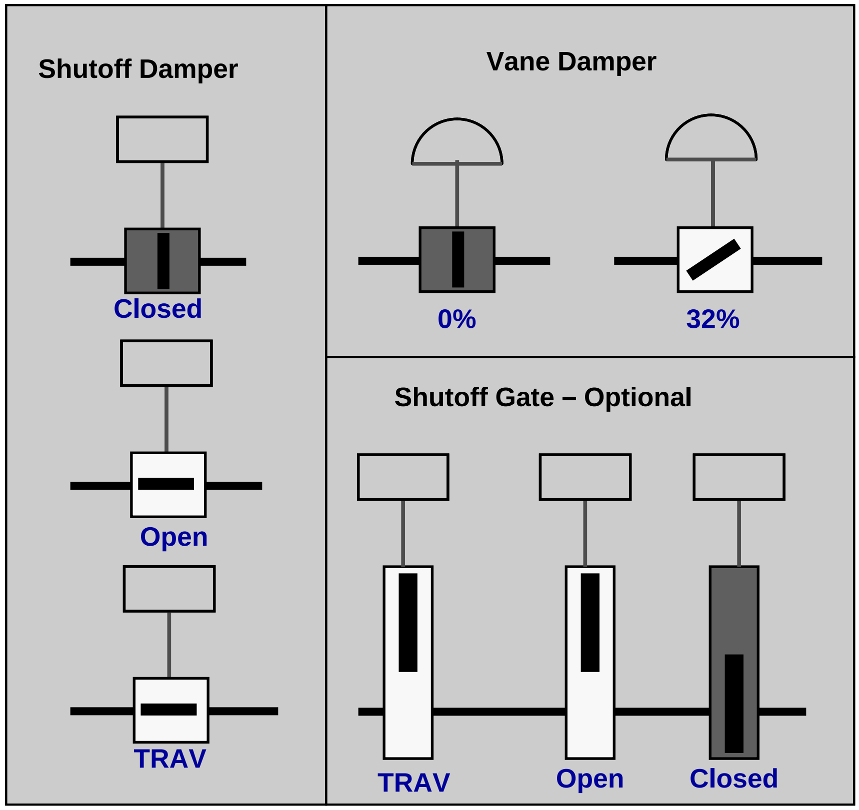

Figure 5-15
Dampers and Gates

Depiction of similar final control elements shall follow the same principles and be included in the object library.

5.14 Process Vessels, Equipment, and Lines

Vessels and Equipment

When a P&ID-type view is desirable, simple 2-D grayscale is used to depict vessels and equipment. Size of depicted equipment should be proportional to its process importance in the process and need not reflect the relative size of the actual item.

Lines

- Primary process flows presented in a display shall be from left to right and from top to bottom. The direction of flow shall be maintained from left to right. When mixed situations are shown, gases flow up and liquids down.
- Line thickness shall indicate significance. A minimal number of different line thicknesses shall be consistently used, for example, primary, secondary, and instrument connection as shown in Figure 5-16 below.
- Color shall not be used to attempt to indicate the content of a process line. Labeling is the appropriate method.
- “Tool tips” functionality or a right-click event can be used to help identify the type of process line or provide additional information.

- Bends in process lines and the crossing of lines are minimized. Where lines are required to cross, the less significant line is broken. If lines are of equal significance, vertical lines are broken.
- Control relationships shall be identified and linked via thin gray dotted lines between the controller elements and associated control objects. t is useful to show a connection between controllers when a cascade loop is in effect. However, graphics shall not be cluttered with excessive control connections; a graphic is not a loop sketch for the purpose of installation or maintenance.
- Process lines shall indicate the direction of flow with arrows placed at terminations to vessels and unions with other process lines. These can be omitted if a similar element, such as a direction-indicated navigation target is nearby. A process line shall indicate direction of flow when the line enters or leaves the display. Judicious placement of arrows is needed to avoid clutter.
- If the process line continues to or originates from another display, a navigation shape shall link to that display.

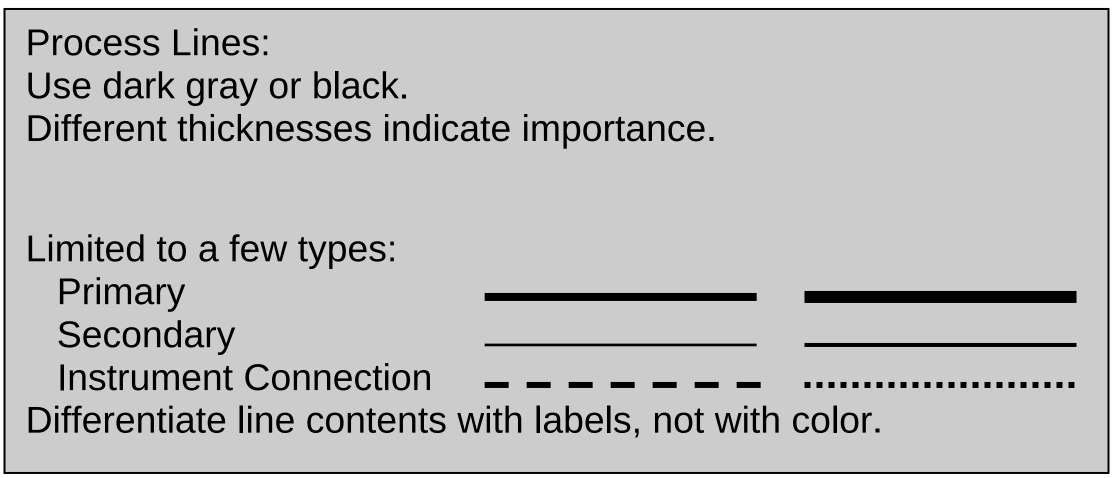

Figure 5-16
Process Lines

Figure 5-17 indicates 3 lines styles—primary, secondary, and instrument connection. Note that the controller shown is split-range and the valves show their individual positions/output numbers, which are not identical to the controller output.

Screen elements that are navigation targets (FEED SYS and SURGE in the above example) appear consistently and differently than those that are not (SCRUBBER).

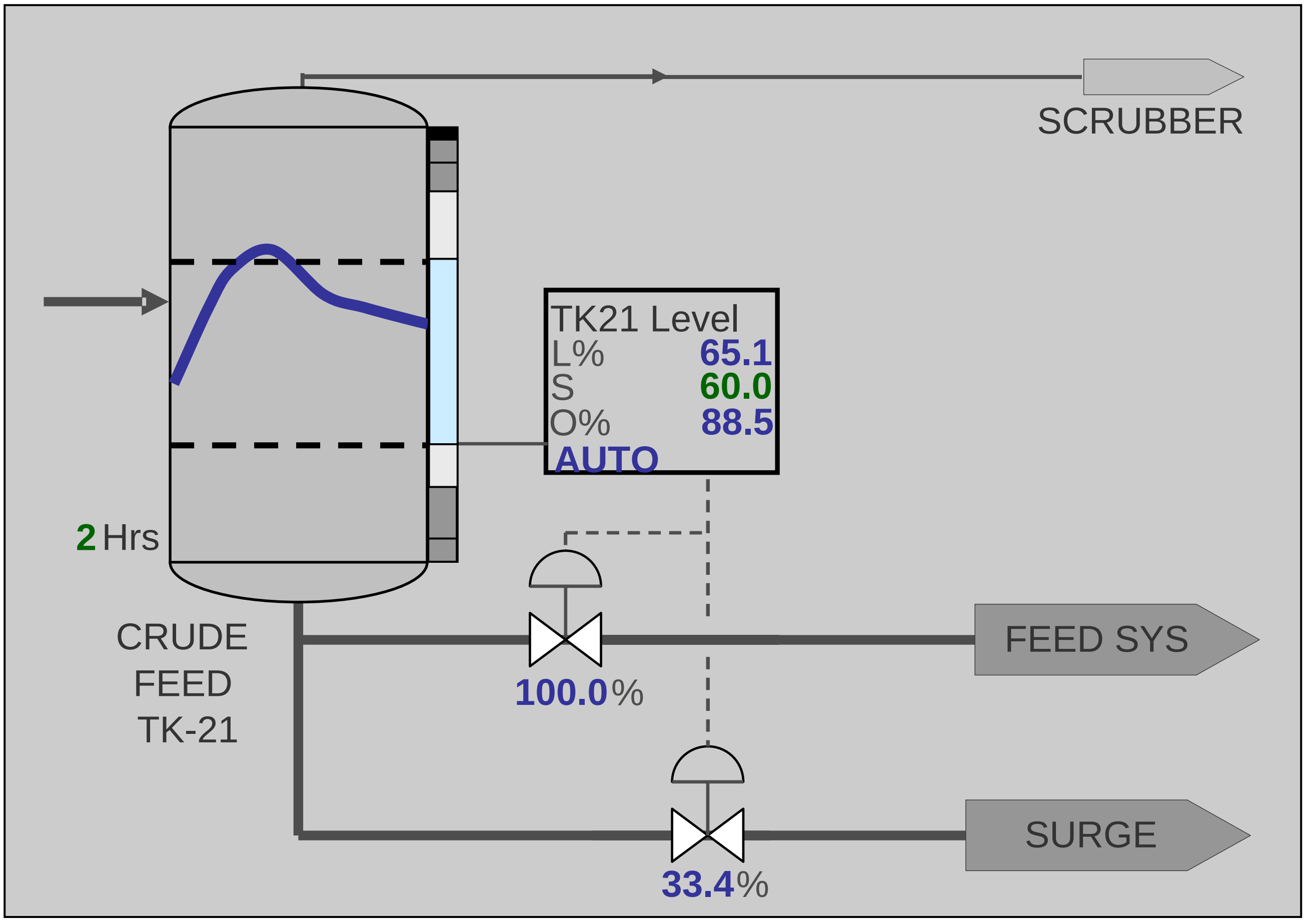

Figure 5-17
Element Combination

(Further details omitted.)

5.15 Depiction of Vessel Liquid Level

Vessel levels shall be depicted without undue emphasis or distraction. Indication of any alarm limits is also recommended. The overall height of the level bar or trend range depicted should correspond with the physical range of the instrument as installed on the vessel.

For some equipment, a trend line is the best method for depicting levels (Figure 5-18).

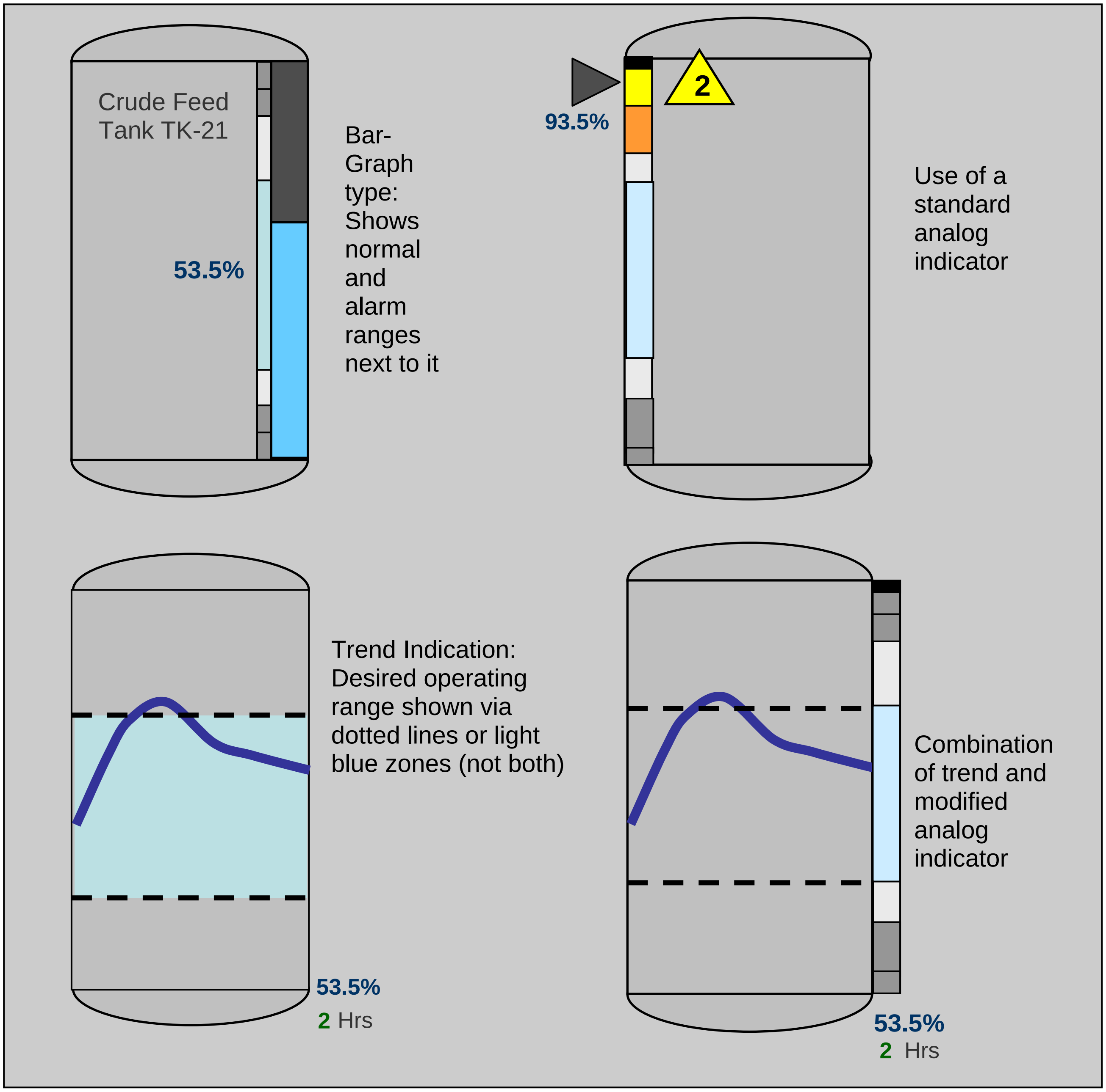

Figure 5-18
Depiction of Vessel Level

(Further details omitted.)

5.16 Depiction of Dynamic Equipment (Pumps, Blowers)

Equipment that has Running or Stopped or other state conditions (for example, Backwash) is depicted simply and with variable shading and dynamic text (and not color) to indicate the status (Figure 5-19).

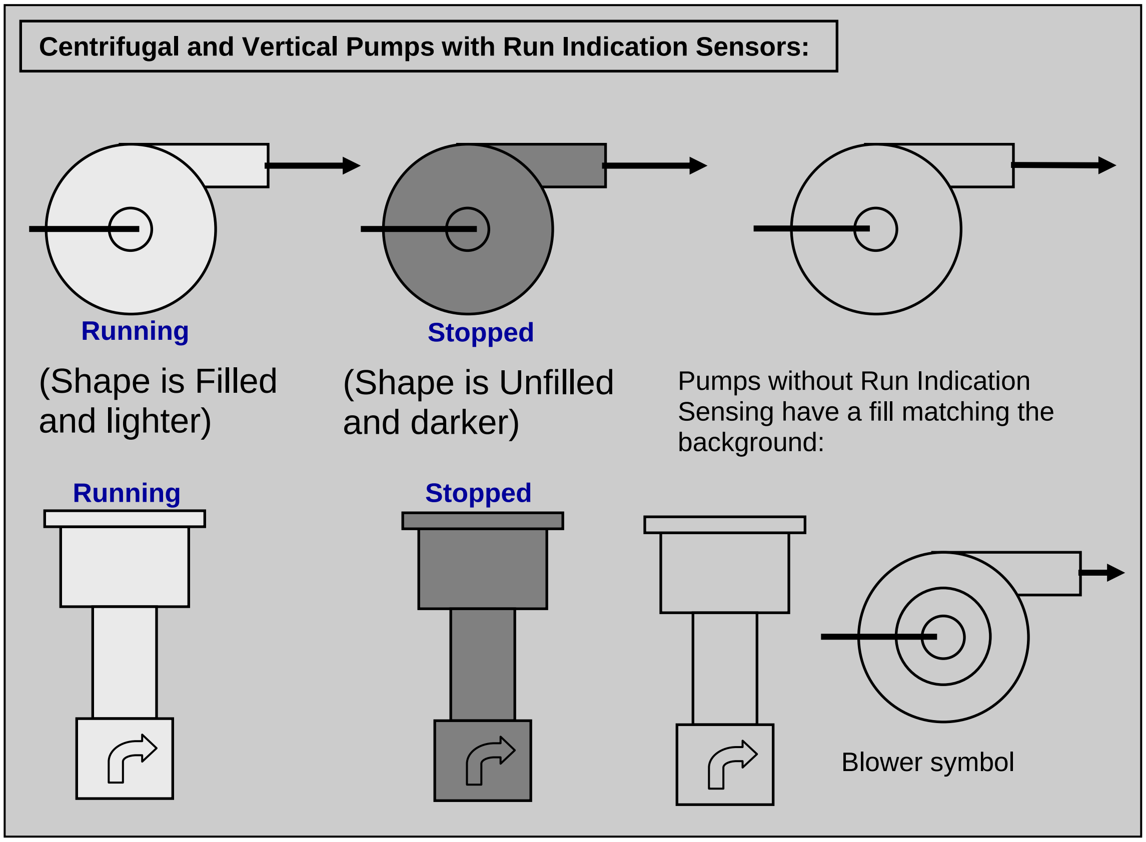

Figure 5-19
Depiction of Dynamic Equipment States

The "ON" condition is lighter than the background, and the "OFF" condition is darker. Text should be used that clearly indicates the equipment status and cannot be misinterpreted as a potential command input. RUNNING and STOPPED are thus preferred over RUN and STOP.

(Further details omitted.)

5.17 Depiction of Choices and Selections

(Details omitted.)

5.18 Depiction of Lists and Tables

Tabular information is sometimes desirable, particularly for Level 3 graphics. Depiction should be straightforward. Room should be allowed for alarm indicators as shown (Figure 5-20). The indication of a potentially abnormal condition that is not an alarm is shown via the enhanced black outline of the reading.

Air Comp	Status	Mode	Diag
C #1	RUNNING	AUTO	OK
C #2	STOPPED	MAN	OK
C #3	RUNNING	AUTO	OK
C #4	STOPPED	AUTO	FAULT 3

Figure 5-20
Table Example

(Further details and examples omitted.)

5.19 Simplified Analog Indication

It is sometimes desirable to show a bank of similar analog readings without the complexity of the standard MAI. Control valve positions are an example. A depiction such as in Figure 5-21 is a good way to do this. Solid bar graphs are a less desirable depiction. Indicators with pointers are usually better for quick perception than are bar graphs (particularly when values are near zero) since it is easier to detect the presence of something than the absence.

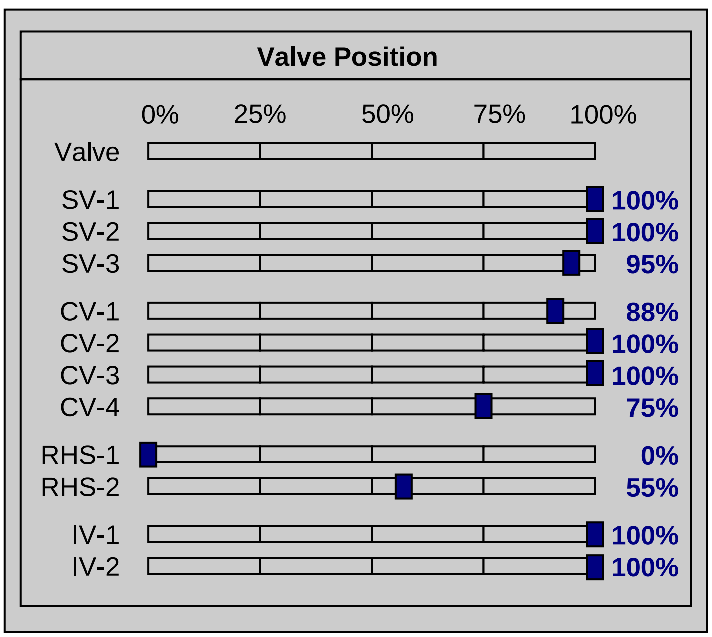

Figure 5-21
Simplified Analog Position Indication

5.20 Temperature, Pressure, and Similar Profiles

(Details omitted.)

5.21 Depiction of Interlock Functionality

(Details omitted.)

5.22 Operator Interaction Methodologies

(Details omitted.)

5.23 Data Input Mechanisms and Safeguards

Operators must generally be able to manually and quickly shut down operating equipment. However, when an important action with significant consequences is based on operator input, the input should have a confirmation mechanism that avoids inadvertent activation. The "cancellation" option should be consistently implemented.

It should never be possible to make a single selection on a screen that results in an inadvertent shutdown. A "Shutdown button" should call up at least one and perhaps two layers of confirmation before it is possible to actually cause such a significant event (Figure 5-22).

The "defaults" of such mechanisms should be on the safe option. Consider the actions that will result from an inadvertent "ENTER" and label screen items with full clarity.

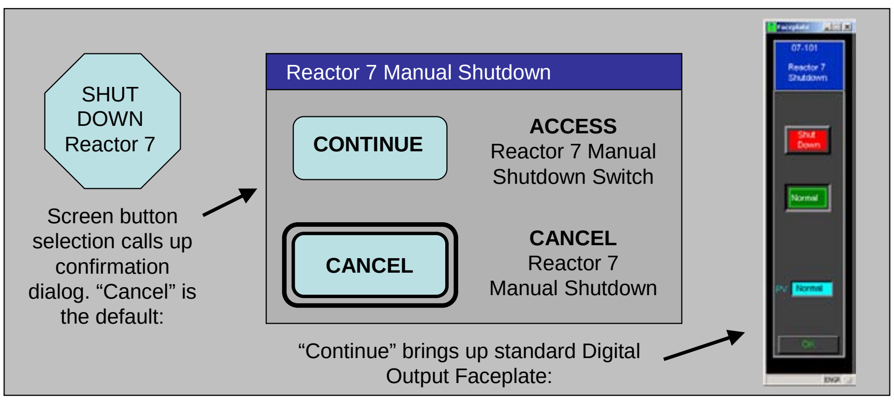

Figure 5-22
Activation Confirmation and Safeguard

Major process upsets have occurred by mistyping an input (for example, opening a slide valve to 47% instead of 4.7%). DCSs using membrane keyboards are particularly susceptible to this type of error. Error-checking methods should be used to require confirmation of numerical entries that seem inappropriate.

5.24 Proper Use and Implementation of Trends

Trends are essential elements of a high-performance HMI. Trends are far underutilized underused in industrial displays. Every Level 1, Level 2, and most Level 3 graphic should have embedded trends of the important values associated with the operation. The information content of trends is far more valuable than the depiction of many typical P&ID elements on graphics.

Do not rely on a control system's claimed ability to "trend any value on demand." The capability and usability of this function is highly overrated. In actual on-demand use, it may require thirty or more selection and scaling actions to create an appropriate trend, which may or may not be easily recalled or used again. Embedded trends address the need properly.

Trends should be implemented with these capabilities and characteristics:

- When the graphic is called up, the trend's *y*-axis span should automatically range itself to a predetermined scale or a predetermined amount relative to the current value of the reading, such as +/– 2% or +/– 5% engineering units. The scale should rarely be the full scale of the value. It should be a tight scale where meaningful change of the value is immediately detectable. The scale span values should be shown and adjustable.
- The trend should come up with a default timebase appropriate for the process condition (for example, to show the last 10 minutes, 2 hours, or the last 24 hours). This choice will vary based on the particular process value being trended. The trend must show this prior history when the graphic is called up, and not simply "start" creating a fresh trace from that instant.
- Normal process bounds, quality limits, or desirable operating range should be indicated based on the state of the process. Dotted lines or light blue shading (examples below in Figure 5-23) are preferred and should be consistent.
- Manual alteration by the operator of the ranges and timebase should be possible and should persist to the next invocation of the display. A "Retrend" button should allow for the trend to return to the automatically calculated values if the manually adjusted ones are no longer appropriate.
- The operator should not have to manipulate any keys to make the trend usable.
- The display of multiple traces should be consistently implemented. Alarm colors shall not be used. Use of more than three or four traces on a trend is generally inadvisable.
- Use of more than two or three scales on a single *y*-axis is generally inadvisable.
- Trends with either the *y*- or *x*-axis size at less than around two inches (perceived at arm's length from the screen) are very likely too small to be effective.

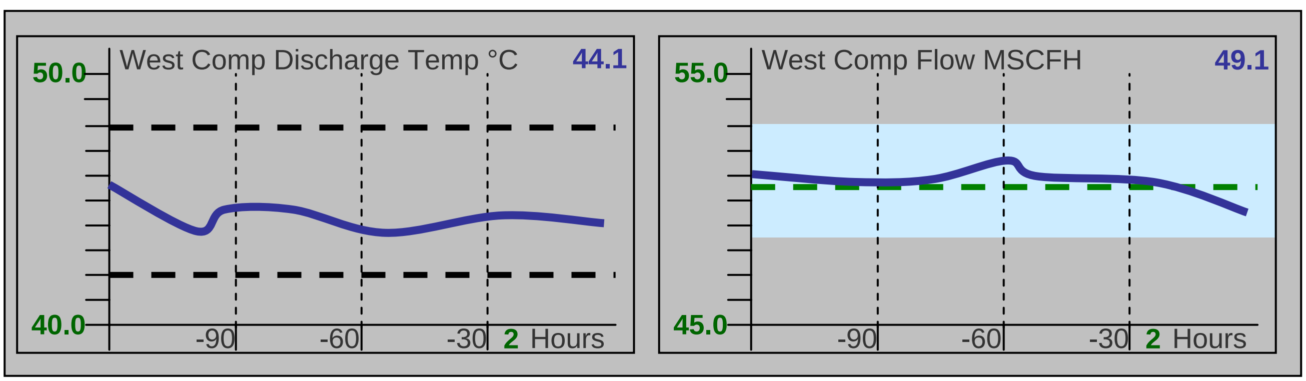

Figure 5-23
Trend Properties

Shaded areas and dotted guide lines may be difficult or impossible to implement on some control system. An alternative method of showing the desired range, good for even multitrace trends, is shown in Figure 5-24.

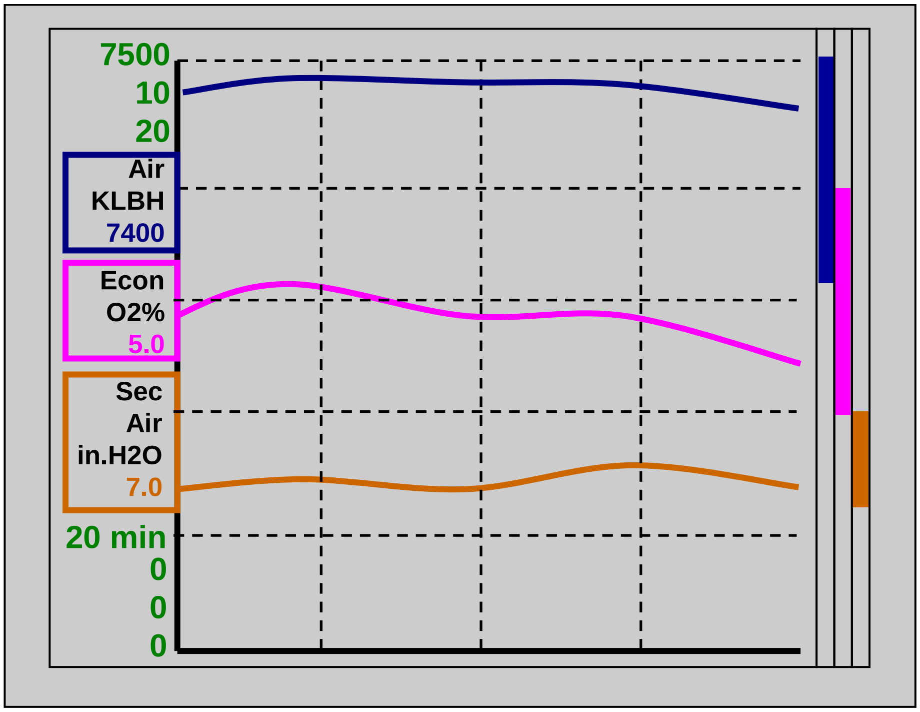

Figure 5-24
Trend Normal Ranges

The guide elements at the right edge of the trend can be dynamic, showing different acceptable ranges based on process state.

Dedicated Level 2 displays consisting of mostly trends and faceplate access buttons to controllers associated with those trends should be considered for each process operation. Experienced operators will often run the process using primarily such displays.

A proper trend of a single controller will show process value, setpoint, and controller output. As a good practice, the controller output trace should be hideable via toggle and default scale to 0% to 100%, regardless of the other scale of the PV and SP. Such trends are highly useful for diagnosing controller problems and particularly valve problems.

(Further details omitted.)

5.25 Mass Balance Indication

(Details omitted.)

5.26 Startup and Checklist Elements

Infrequent or complex process conditions may benefit from special purpose graphics. For example, custom trend objects that display a “map” of a proper sequence of flows, pressures, and temperatures significantly improve startup performance. Such elements should clearly indicate the acceptable boundaries for a proper operation.

(Further details omitted.)

5.27 Pattern Recognition and Radar Plots

A properly featured radar plot element has significant advantages. It can show information from 12 to 18 different values in a compact area. It is effective in showing burgeoning abnormal situations.

The object depiction is similar to the arrangement of several moving analog indicators radially around a central point. The connection of current process values is made into a polygon shape. The polygon shape changes dynamically as the process values change and produces different patterns under different operational conditions.

Depending on control system capabilities, these elements can have the following functionality:

- Capture and save plant process condition patterns for future retrieval.
- Recall precaptured patterns and superimpose them under current data.
- Show either process values or deviation from a predefined "normal operation" set or from a current "snapshot." In deviation mode, any change will become quickly apparent.
- Rate-of-change indication—When values begin changing rapidly, an arrow is displayed indicating the magnitude and direction of the change.
- Variability indication—Range bars indicate the extent each parameter has varied in a predefined time period.

The values can be scaled so normal operation produces a circular shape. Humans recognize shapes and colors much faster than complex set of numbers. Color of the polygon is normally dark gray. Other color is determined by the highest priority alarm (if any) in effect on any of the process values (Figure 5-25).

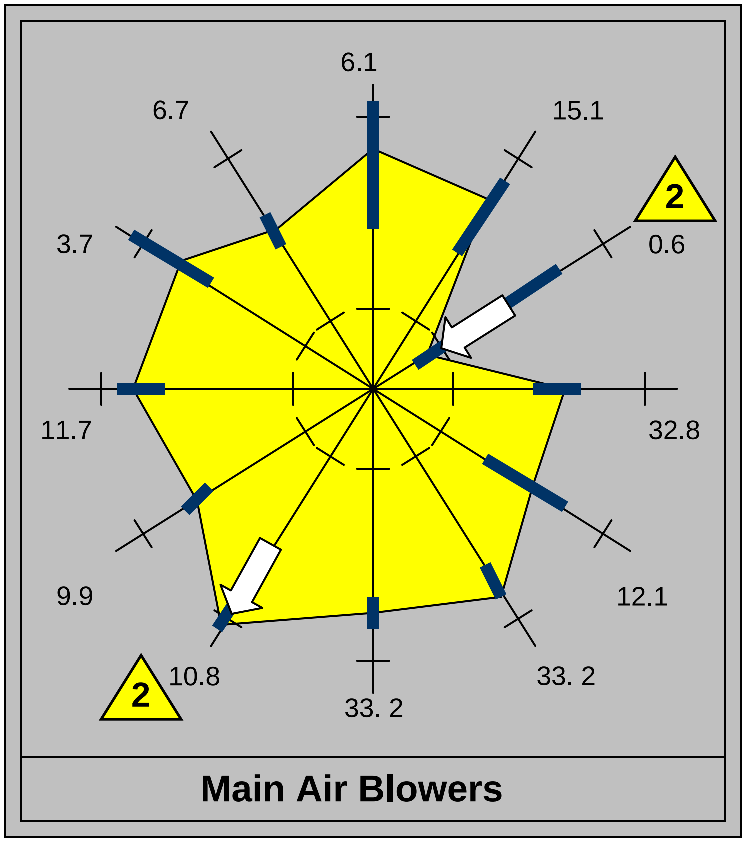

Figure 5-25
Pattern Recognition Object (PRO®)

5.28 Geographic Screens

Some screens should be geographic in nature. Examples include the depiction of:

- Toxic or flammable gas sensors
- Safety showers/eyebaths actuation
- "Help" pushbuttons or pull cords
- "Emergency stop" pushbuttons
- Deluge system or fire box

Ambient flammable gas or toxic gas detectors should be depicted on a geographic layout that includes wind speed and direction. This gives the operator good situation awareness as to the effect of any detected leak. Activation of safety showers/eyebaths and deluge systems should be similarly indicated.

A graphic selection menu that is geographic is often useful.

(Further details omitted.)

5.29 Display Naming Conventions

Graphic naming conventions and path locations should be designated in this section. Naming methodologies should be consistent. Note that it should never be necessary for the operator to type in a graphic filename for a navigation or access purpose. Indicating the level of the graphic as part of the name is recommended.

(Further details omitted.)

5.30 Depiction of Programmatic Functionality

Advanced process control involves automated computational methods that manipulate basic process control elements such as controller setpoints and outputs. The operational status of these systems should be shown with diagnostics that guide the operator in taking the correct action.

In some cases, APC is used to directly manipulate controllers and elements that are manually adjusted by the operator when the APC system is off. Such action should be shown. One method is the appearance of an APC element next to such affected elements, which indicates what kind of APC action is taking place (Figure 5-26).

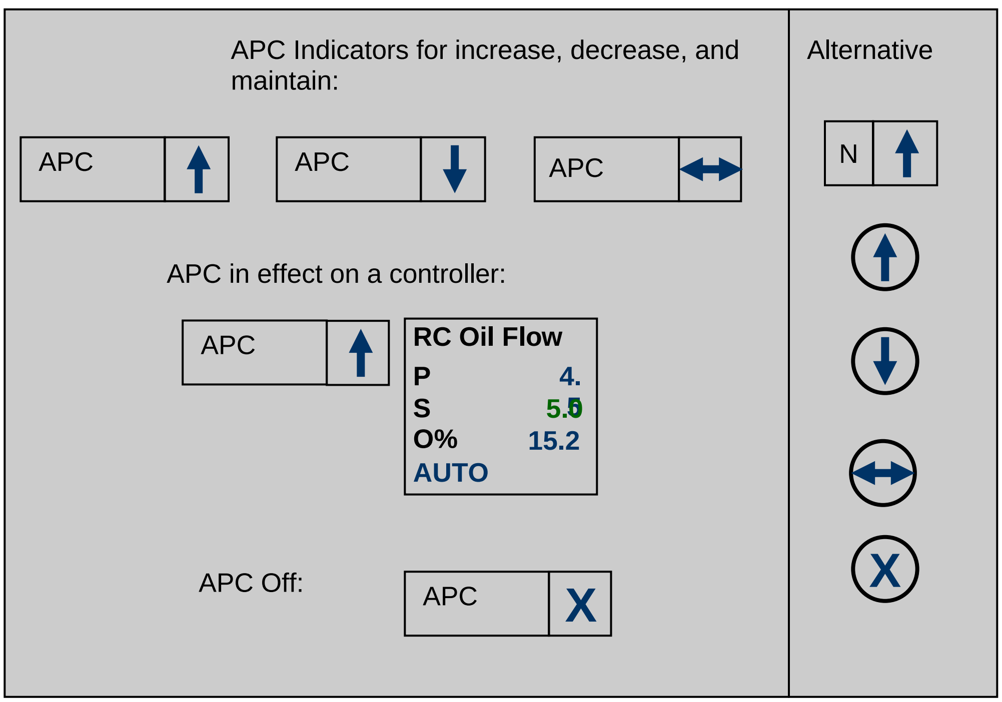

Figure 5-26
APC Indicators

An APC diagnostic screen should indicate not only "what" the APC doing but also "why" it is doing it.

(Further details omitted.)

5.31 Display Callup Speed and Performance Requirements

Graphics used for operational purposes should display quickly when invoked. Graphics taking longer than 3 to 5 seconds to appear become frustrating. However, since almost all high-performance graphics should have certain trend information, this may be a challenging goal, as trends often take a few seconds to populate. Utilize methods by which the simpler content is displayed first followed by the trends, which will somewhat alleviate the “blank screen” frustration.

Screen updating of depicted values should relate to the speed at which the process is capable of change. The need is to avoid excessively high update rates. These can be distracting and also generate unnecessarily high bandwidth utilization on the control system network.

An update rate of up to twice the rate of significant process change is the maximum recommended. For most typical industrial processes, an update rate of every two to four seconds works out fine, with one-second updates chosen for particular things by exception. Subsecond update rates are not very usable by the operator; a screen displaying jittery numbers is a distraction, not a help.

(Further details omitted.)

5.32 System Backup

(Details omitted.)

5.33 Standardized Abbreviations and Engineering Unit Descriptors

Example List

Definition	Abbreviation
Ampere	amp
Barrels	bbl
Barrels Per Day	bpd
Barrels Per Hour	bph
Cubic Feet	cu ft
Cubic Feet Per Hour	cfh
Cubic Feet Per Minute	cfm
Cubic Feet Per Second	cfs
Cubic Inches	cu in
Cubic Meter	m3
Cubic Meter Per Hour	m3/hr
Cubic Meter Per Second	m3/s
Cycles Per Seconds	hz
Degrees Celsius	degc
Degrees Fahrenheit	degf
Feet	ft
Gallons	gal
Gallons per Hour	gph
Gallons per Minute	gpm
Horsepower	hp
Hours	hr
Inches	in
Kilogram per Hour	kg/hr
Kilopascals Absolute	kpa
Kilopascals Gauge	kpg
Kilovolt-Amperes	kva
Kilovolts	kva
Kilowatts	kwh
Kilowatt-Hours	kwh
Magapascals	mpa
Metric Tons (Tonnes)	tons
Megawatts	mw
Megawatt-Hours	mwh
Metric Tons per Day	tpd
Micromhos	mmhos
Milliamperes	ma
Millions Standard Cubic Feet Per Day	mmscfd
Millivolts	mv
Minutes	min
Once	oz
Parts Per Billion	ppb
Parts Per Million	ppm
Percent	pct
Pounds	lb
Pounds Per Hour	lb/hr
Pounds Per Minute	lb/min
Pounds Per Square Inch	psi
Pounds Per Square Inch Absolute	psia
Pounds Per Square Inch Gauge	psig
Revolutions per Minute	rpm
Seconds	sec

Definition	Abbreviation
Specific Gravity	sp gr
Standard Cubic Feet Per Day	scfd
Standard Cubic Feet Per Hour	scfh
Standard Cubic Feet Per Minute	scfm
Thousand BBLs Per Day	mbpd
Thousand Pounds Per Day	mlb/d
Thousand Pounds Per Hour	mlb/hr
Thousand Standard Cubic Feet Per Day	mscfd
Thousand Standard Cubic Feet Per Hour	mscfh
Thousand Standard Cubic Feet Per Minute	mscfm
Volts	v
Volts, Alternating Current	vac
Volts, Direct Current	vdc
Volume	vol

6.0 References

The following references are highly recommended for anyone engaged in HMI design:

Bill Hollifield and Eddie Habibi. *The Alarm Management Handbook.* PAS, Houston, TX, 2006.

Bill Hollifield, Dana Oliver, Ian Nimmo, and Eddie Habibi. *The High Performance HMI Handbook.* PAS, Houston, TX, 2008.

Peter Bullemer, Dal Vernon Reising, Catherine Burns, John Hajdukiewicz, and Jakub Andrzejewski. *ASM Consortium Guidelines for Effective Operator Display Design*. ASM Consortium, 2008.

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