DESIGN GOALS FOR COMPUTER-DRIVEN CRT DISPLAY SYSTEMS IN THE CONTROL OF GENERATING STATIONS

J.D. Beattie and L.S. Blum
Ontario Hydro

ABSTRACT

Ontario Hydro's nuclear generating station control centres have made increased use of computer-driven CRT display systems in each successive design, as the available technology has improved. In the latest designs, CRT displays are intended as the primary means by which information is acquired by the generating unit operator, and there are several advantages seen in this approach.

To ensure satisfactory performance of the CRT display systems in this demanding role, several necessary characteristics of the hardware and software have been identified and sought in commercially available systems.

Investigations have been carried out by Ontario Hydro to establish design standards for colour CRT display formats, using a minicomputer-driven display system. Recommendations regarding several aspects of format design have been formulated.

LES BUTS DE LA CONCEPTION DE SYSTÈMES DE VISUALIASATION À ÉCRAN CATHODIQUE COMMANDÉS PAR ORDINATEUR POUR LA COMMANDE DE CENTRALES ÉLECTRIQUES

RÉSUMÉ

Un mesure du progrès de la technologie chaque conception successive des centres de commande des centrales nucléaires d'Ontario Hydro fait de plus en plus usage de systèmes de visualisation à écran cathodique commandés par un ordinateur. D'après les conceptions les plus récentes, ces systèmes de visualisation sont envisagés comme moyen principal d'acquisition d'information pour l'opérateur d'une centrale nucléaire; cette façon d'aborder la question semble comporter plusieurs avantages.

Afin de s'assurer que les systèmes de visualisation à écran cathodique remplissent ce rôle exigeant d'une manière satisfaisante, on a déterminé certaines caractéristiques requises du matériel et du logiciel que l'on a ensuite cherchées dans les systèmes disponibles sur le marché.

Des études ont été effectuées à Ontario Hydro à l'aide d'une console de visualisation commandée par un miniordinateur, afin d'établir des normes pour l'agencement de l'information et des couleurs dans l'image affichée sur l'écran cathodique. Des recommendations ont été formulées sur plusieurs aspects de cet agencement.

1.0 INTRODUCTION

One of the most dramatic and important changes in the design of nuclear generating station control rooms in recent years has been the growing use of computer-driven CRT display systems for displaying information about the generating unit and the computer control system. This trend has been motivated by the potential advantages of clearer, more powerful, more flexible information display compared with more conventional control panel display hardware, and ultimately by the conviction that the results will be measurable as improved generating unit performance.

This paper contains four main parts. Section 2 is an overview of the evolution and characteristics of displays at a number of Ontario Hydro nuclear generating stations. Section 3 describes the role of CRT displays in generating unit control and some of their advantages. Section 4 discusses the requirements of CRT systems suitable for playing this role successfully. Section 5 describes recent progress in defining standards for display format design.

2.0 EARLY DEVELOPMENT OF CRT DISPLAYS

This section sketches briefly how the number and scope of CRT displays for operating data has increased in successive designs of Ontario Hydro nuclear generating station control rooms.

The earliest use of computer-driven CRT displays is at Pickering GS 'A', where, for each generating unit, a single monochrome alphanumeric CRT, updated automatically, gives the most recent 24 annunciation messages in chronological order of occurrence. (To allow looking further back, all messages also appear on a printer as they occur.)

Bruce GS 'A' introduced graphics capability (still monochrome) and increased the number of screens: as shown in Figure 1, there are nine CRT's located on seven bays of each unit's main control panel (plus one CRT at each unit operator's desk). Two of the nine are alphanumeric annunciation CRT's; these allow more messages to appear simultaneously than at Pickering GS 'A'. The graphics CRT's are distributed among the major plant systems, e.g. one for primary heat transport and moderator, two for reactor regulating system, etc., and each screen is normally used to display data from the system corresponding to its location on the panel (although any display is in fact available on any CRT). Any display may be hard-copied on demand, using an electrostatic copier.

At Bruce GS 'B', colour graphics CRT's are being installed, with quantities similar to those of Bruce GS 'A' (see Popovic et al., 1979, for a more detailed description of this design). Several kinds of display are available to the operator:

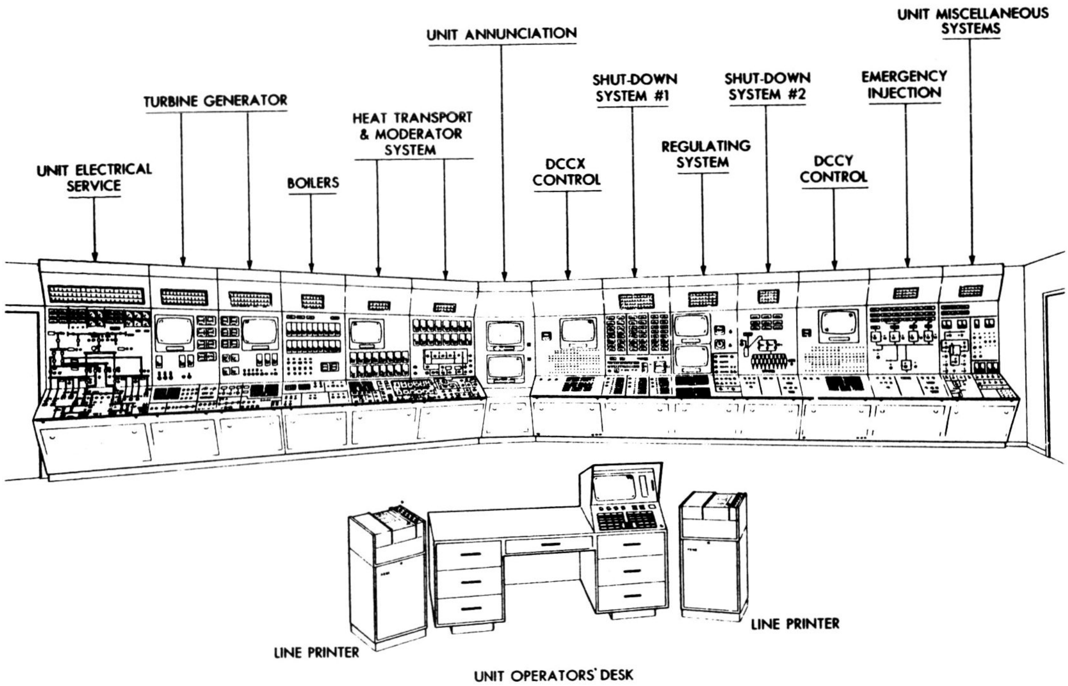

FIGURE 1 TYPICAL BRUCE CONTROL PANEL LAYOUT

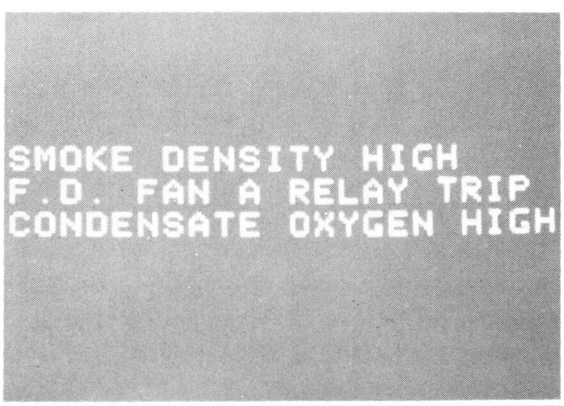

Figure 2

Minimum Acceptable Alphanumeric Character Spacings

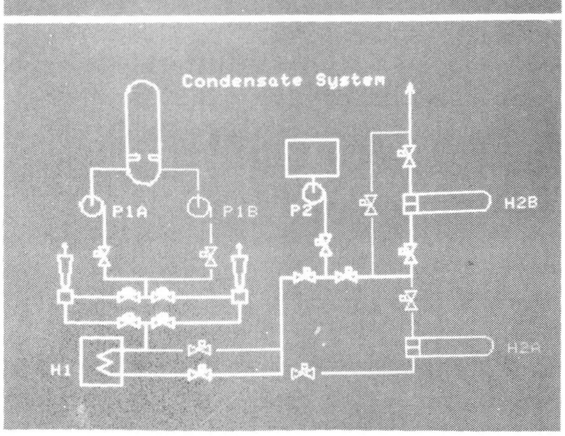

Figure 3

Typical Process Flow Diagram

2.1 Barcharts

Each barchart display presents up to 16 analog variable present values, each with identification label, numeric value in digital form, and individual marked scale. There are roughly 64 such displays available on each unit, and each is updated periodically (every two seconds is the fastest rate) as long as it is on the CRT screen. Colours are used to associate bars into groups and to indicate annunciation limits for each bar.

2.2 Graphical Trends

Each trend display presents up to 4 analog variable time histories (180 points covering as little as 6 minutes or as much as 6 hours, depending on the application). Each analog variable also has identification labels and present values in digital form. There are about 64 graphical trend displays on each unit, and updating rate varies from 2 seconds to 2 minutes. Colours are used to distingush the traces and identify the label corresponding to each.

2.3 Annunciation Messages

Two CRT's are dedicated to annunciation messages, which are written in chronological order as they occur. When the screens are full, and when a new message is generated, it overwrites the oldest message and all others remain in their original positions. A horizontal line always appears below the newest message, separating it from the oldest one; this line thus moves down the screen as more messages arrive. This "wraparound" presentation is preferred to the earlier technique of adding new messages at the bottom and scrolling previous messages up the screen.

Colour is used to code the identification of the process system involved in each message; to indicate the annunciation message level (safety system event, major process system event, or minor process system event); and to show when a previously annunciated condition returns to normal.

2.4 Special Displays

In addition to those referred to above, there are several special purpose graphic displays available. For example, one display shows the 14 reactor zones in a schematic arrangement which reflects their geometrical relationships in the reactor itself. Vertical bars for each zone show the neutron flux level and the light water level in the zone control compartment. Colours are used mainly to highlight the more important information-carrying parts of the display.

3.0 THE ROLE OF THE CRT DISPLAY SYSTEM AND ITS ADVANTAGES

To clarify the role of the CRT display system in generating station control, it is worthwhile to look briefly at other pertinent aspects of the control system. Control of major process systems is carried out by a dual computer system (one controlling, the other in "hot" standby to take control if necessary). Both control computers are connected to the display generators, and so a particular CRT may show a display from either computer, based on any data made available to the computer system.

In addition to CRT's, the unit main control panel contains conventional indicators, recorders, indicating lamps, etc. (See Figure 1). These operate, in general, independently of the computer, and provide a continuously available complementary display of particularly important process information. They also ensure that the unit can be safely shut down and monitored in the rare event of dual computer failure, which would, of course, make the CRT displays unavailable. Also, some systems not controlled by the main dual computer system are represented by conventional panel devices (notably the reactor safety systems, which are separate from the control computers). For most operating purposes, however, the CRT display systems are the primary man-machine interface for display of real-time process information and for communication with the computer control system.

In this context, the CRT display system has several advantages over more conventional man-machine interface design. For example, the control panel size, and the number of devices mounted on it, are reduced without resort to overly dense "packing" of devices, resulting in considerable operational (and some economic) benefits. In addition, CRT display systems now represent an economical, technically sound, and commercially proven way of translating computer-stored data (about the process and the control system) into useful visual information. Thus their strength in an era of highly computer-based control is obvious.

Other advantages are harder to quantify (and to realize) but have almost revolutionary impact. No longer must visual information be fixed in space or format. On a CRT, spatial arrangement and other graphic relationships, and the mode of data presentation, can be defined in as many ways as are needed, and the most appropriate format selected by the operator for the situation at any moment. Data which are only rarely needed and for which panel space could not otherwise be considered justified can now be available on demand. Information display requirements not identified in the design stage can often be added in during operation.

All these advantages create the potential for more effective man-machine interaction, measured ultimately in better generating unit performance.

4.0 DISPLAY SYSTEM REQUIREMENTS AND CHARACTERISTICS

Those generating stations which are currently in their early design stages at Ontario Hydro will rely increasingly on computer-driven colour CRT's as the primary interface between the operator and the generating unit. To play its role successfully, as described above, and to realize its advantages, the display system must be capable of providing a clear indication of process operating conditions at all times and must allow the unit operator the ability to diagnose process or equipment problems, and to alter operating conditions easily and rapidly.

4.1 Requirements

To satisfy these requirements, a list of features considered essential was compiled and a survey of commercially available colour display generators was undertaken. Mandatory requirements included the following features:

1. The ability to provide a full colour display (red, green, blue, yellow, cyan, magenta, white, black).
2. The ability to generate a flicker-free display.
3. The ability to control intensity: two levels minimum.
4. The ability to blink symbols and characters from full intensity to a lesser intensity.
5. The ability to generate a display quickly. It is required that the time interval between the first request for a display and the complete image appearing on the screen should not exceed 1.5 seconds. The time interval from the first disturbance of the old image and the completion of the new image should not exceed 0.5 seconds for a new display, and 0.2 seconds for data update. The first requirement is a function mainly of the overall computer loading; the second requirement is a function both of picture complexity and display generator speed. Two sample displays have been used to provide a standard against which display generator performance could be measured.
6. The ability to accommodate "on-screen" interactive devices such as lightpen, joystick, trackerball, and cursor TAB.
7. The ability to provide a variety of alphanumeric character sizes.
8. The ability to provide high resolution, flexible, trend displays and barcharts.
9. The ability to provide a variety of symbol shapes and sizes to facilitate production of schematic and special-purpose graphical displays.
10. The vendor should be established in the North American market, and the display generator must drive a standard North American video monitor. These requirements are necessary to ensure product support and the availability of spares for a reasonable portion of the 30-to-40 year design life of the generating station.

4.2 Colour CRT Display Generators

Computer-driven colour display generator technology is changing very quickly. It is therefore worthwhile to review the types of raster scan display generators which are currently commercially available. These fall into three distinct categories: character graphics display generators, display list processors, and pixel-oriented display generators.

4.2.1 Character Graphics Display Generators

This type of system divides the display screen into an array (24 lines by 80 characters is common), each element of which is represented by an alphanumeric character. Each character, in turn, is made up of a fixed number of picture elements (pixels) in width and in height (7 by 9 is common). Alphanumeric or graphic characters may be in any one of seven colours (red, green, blue, yellow, cyan, magenta or white). Limitations which exist in the resolution of these systems are partially overcome by the addition of trend hardware which permits the generation of fixed format trends to a greater resolution than the basic character size.

These systems typically have very fast response times and have been widely used in process control applications; however, the limited resolution and rigid format impose limitations on the display formats which can be generated.

4.2.2 List Processors

This type of system provides both fast response and a greater resolution than the character graphics systems. High level display instructions from the host computer are stored as a list in the display generator memory. This list of instructions is then executed by the display processor during each raster-scan line. Changes to the display are accomplished by simply changing the list of instructions in the display processor memory. The complexity of the display which can be generated is limited by the number of display instructions which the display processor can execute in the time of a single scan line. To increase this complexity, a list partitioning scheme is introduced which divides the screen into bands, so that fewer instructions in the list are executed with each scan. This complicates the design of individual displays, as the designer has to be aware of the limitations imposed by the partitioning scheme.

4.2.3 Pixel-Oriented Display Generators

To generate a display using this type of generator, the host computer transmits display instructions to the display processor which interprets these instructions into coded data which are stored in the refresh memory. The refresh memory consists of a memory array with one word in memory for each picture element (pixel) on the screen. The video generation electronics controls the electron guns according to the data in the refresh memory.

Because the display memory has as many locations as there are pixels on the screen, great flexibility in display design can be achieved. The response of the system is limited by the speed with which the display processor can execute the display instructions received from the host computer and update the refresh memory. Until recently, the speed of these systems was inadequate for process control applications where speed of response is vital. However, systems which are now appearing, using powerful microprocessors and bit-slice technology, show marked speed improvements to the point where they are capable of meeting these stringent response requirements.

Software packages are being developed for these systems which will permit a non-programmer to generate sample displays interactively. This should reduce the project software effort and also help to ensure that the displays fill the needs of the generating unit operating staff.

4.3 Interacting With The Display

In previous Ontario Hydro nuclear stations, display call-up and interaction has used dedicated function pushbuttons and a numeric keyboard. This approach works well provided that the number of buttons does not become so large that the operator has difficulty remembering the location and functions of the various buttons.

A variety of interaction devices are available which operate "on-screen", providing the facility to produce programmable button selection. This eliminates the need for the operator to have to choose one button from a number of redundant selections in a particular control situation.

For Darlington GS, currently in the design stage, Ontario Hydro intends using the lightpen, with TAB key control also available, as interaction devices. However, use of the joystick or trackerball would not significantly change the fundamental interaction philosophy.

4.4 The Complete System

Having established the display and interaction devices for the system, it is necessary to integrate these into a configuration which provides the operator with a consistent, easy-to-use information retrieval system. This means that the system, instead of swamping the operator with unnecessary detail, should keep him informed of the state of the unit, alert him of any irregularities, and assist him in obtaining the level of detail necessary to take appropriate actions.

It is proposed that a hierarchical structure for calling-up displays be used. The primary display in the hierarchy will be called-up using one of a small number of dedicated pushbuttons. This primary display will present a schematic overview of the process or subprocess. Relevant process measurements will be displayed and yellow or red will be used to indicate any process abnormalities. Using the lightpen, the operator can select secondary displays or related subprocess schematic displays. In this way, the operator can "zoom" in to identify problems in a particular process, or he can "pan" across to other related subprocesses.

The use of colour, selective blink, and background colour will further help the operator to identify problem areas.

5.0 DEVELOPMENT OF DISPLAY STANDARDS

As with any developing application area, the desire for continuity of knowledge and for efficiency of design effort soon necessitates the formulation of standard design approaches. Ontario Hydro is in the process of defining standards for generating unit operator's CRT displays, and recently have used a minicomputer-based CRT display system in the design office to assist in this work. The intent was to supplement the experience gained from earlier designs with a more systematic and, where possible, objective assessment of CRT display format design alternatives.

Three broad areas were identified which would benefit from design standards. The first includes characteristics of the basic elements or "building blocks" of displays, such as alphanumeric characters, and graphic symbols to represent process equipment in flow diagrams. The second is concerned with characteristics of the formats referred to in Section 2 (barcharts, graphical trends, etc.), such as information density, use of colour, intensity variation, and other means to represent certain kinds of information. The third is addressed to the dynamic characteristics of the interaction between CRT display system and operator, such as maximum system response time to requests for new displays, data update rates, etc.

Initial work has been completed in the first of these areas, and it illustrates the approaches used.

5.1 Alphanumeric Characters

The study of alphanumeric characters was aimed at specifying minimum acceptable character size, and also minimum acceptable spacings between characters on a line , and between lines of text on a "page". The investigation was limited to 5 by 7 pixel upper-case characters.

Sixteen experimental conditions were defined: all combinations of 4 sizes, 2 horizontal spacings, and 2 vertical spacings. For each condition, a subject was shown a series of CRT displays, each display consisting of three annunciation messages (in white on black). The task was to read aloud the middle message of the three. The total time for the series and the number of errors made were recorded. The data from seven subjects over all sixteen conditions were analyzed, first intuitively, and then quantitatively using analysis of variance.

Results for spacing were clear: line-to-line spacing should be at least 3 pixels; and character-to-character spacing can be as small as 1 pixel if the line-to-line spacing is adequate (i.e. at least 3 pixels). Figure 2 illustrates these spacings.

Results for size were less conclusive. Even at the largest size used in the experiment (about 8 minutes of arc in height), certain errors still occurred too often; our design recommendation would be 12 to 15 minutes of arc minimum height.

Besides the main results, other interesting points emerged. One was that the time taken by the computer-driven CRT display system to "write" even such a simple display as three alphanumeric lines was too long, compared to the time differences to be measured in this and other investigations. This created, in effect, a large uncertainty in the time at which a subject began to look at a display. For the alphanumeric character study, the problem was overcome by writing the text from right to left: this apparently succeeded in discouraging subjects from beginning to read (even mentally) before the display was complete, and the constant writing time could be subtracted from the total measured times. However, the problem was to prove much more stubborn in later studies, and it underlines the importance of fast systems in any work of this kind.

Another point was that when various colour combinations were tried for characters and backgrounds, they varied greatly both in legibility and in identifiability of the character colour. Some of these results differed considerably from expectations: for example, green characters against grey background (half-intensity white) is a very good combination, but half-intensity green against grey is virtually illegible.

5.2 Process Flow Diagram Symbols

Process flow diagrams (see Figure 3) are schematic representations of process systems, where each piece of equipment of interest is represented by a schematic symbol, and lines represent the pipes or other interconnections. On CRT's, process variable and equipment status data can be shown (and updated) by various means: for example, numeric values, colour coding, or variation of symbol shape.

Just as engineering drawings have a standard set of symbols, CRT displays need standards for process flow diagrams. To take advantage of familiarity, they must be based on accepted drawing symbols; but CRT displays provide relatively coarse resolution (typically 240 by 320 or 256 by 512 for the whole screen). This leads to emphasis on equipment function rather than exact identity of equipment (for example, many different valve types may share a CRT symbol). The need to incorporate status indication also dictates a somewhat different approach, compared to drawings.

Possible representations of approximately 50 items of equipment (including different status representations where needed) were devised and stored in the computer. Using the CRT display system, a procedure of viewing, discussing, revising, viewing again, etc., was conducted, with wide participation from design and operations personnel. The result was a standard set of symbols covering all anticipated process equipment.

6.0 CONCLUSION

This paper has shown how the use of computer-driven CRT displays in Ontario Hydro's nuclear generating station control rooms has evolved over several designs, and is continuing to evolve as new systems become available. Continuing parallel efforts are being made to identify design requirements and goals, both in terms of display system performance and improved operator-plant interaction.

7.0 ACKNOWLEDGEMENTS

A great many people have contributed to the development of requirements and standards described in this paper, and although they are too numerous to be named individually, we are mindful of and grateful for their contributions. One exception to anonymity should be made to recognize the work of E.F. Fenton, who has been an influential figure in the developing man-machine interface design philosophy as described here, and has provided a major impetus for the current development activities.

8.0 REFERENCE

J.R. Popovic, R.E. Ashwell, and J.E. Smith, CRT Man-Machine Communication System in Nuclear Power Stations. IEEE Trans. on Nuclear Science, Vol. NS-26, No. 1 (February, 1979).