Study on the Design of HSI Color System in Nuclear Power Plant

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Abstract. As one of the most sensitive elements of human vision, color is widely used in Human-System Interface system. The quality of color system often plays a vital role in the success or failure of interface design. Its effect directly affects the user's operation experience. Therefore, nuclear power plant Human-System Interface design needs to establish a complete color system. Based on the color system of CPR1000 series power plants and the operation experience feedback of in-service power plant operators, the Human-System Interface color system of HPR1000 reactor type is proposed, and the compliance analysis of the regulations and standards is carried out, in which the relevant requirements of international and domestic laws and standards for color use are analyzed in detail, and the color use schemes of various reactor types in-service power plants are compared.

Keywords: Human-System Interface · Color coding · Display

1 Introduction

In Human-System Interface design, color not only has the effect of decoration and beautification, but also can affect the psychology of users. Color is an important aspect of visual ergonomics study. Through color management of users' concerns to guide users to use Human-System Interface according to design expectations, it is helpful to form an orderly visual process, help users to perform monitoring tasks, and reduce workload.

Nuclear power plant, as a typical complex information system, faces a large amount of information processing for Main Control Room Operator. Reasonable color matching of display information can greatly improve the identification efficiency of operators. Improper color application will make the Human-System Interface crowded and messy, disperse the operator's attention, reduce the efficiency of information cognition, affect or even mislead the operator's monitoring and judgment, and increase the risk of operator's human error. Therefore, it is very important for nuclear power plant Human-System Interface design to formulate a set of color system that meets the requirements of laws and regulations, conforms to operation habits, takes into account beauty and comfort, and forms effective guidance and help for users.

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2 Color Application Requirements in Human-System Interface Design

2.1 Color Consistency

The color consistency requirements are as following. The meaning assigned to each color shall apply consistently within a suite of displays, and should also apply consistently with other related instruments, control and alarm displays [6]. The consistency of colors makes it easy for users to distinguish their meanings.

Most of nuclear power plant's highly-integrated control rooms are based on digital Human-System Interface and supplemented by conventional Human-System Interface. There are two types of display equipment for the same type of information. Therefore, the consistency requirement of color use should be considered in information display design. For example, for equipment switch status feedback, there are both screen display and conventional indicator display, and the colors representing on and off should be consistent.

2.2 Color Coding Requirements in Different Situations

In Human-System Interface display design, bright, saturated and contrast colors should be used to attract users' attention to important and determined key data or safety information, such as high priority alarms. Secondary information can be considered in dim and less degree of saturation, such as the normal operation state of the equipment. The background color is preferably neutral, such as the background color of VDU display.

2.3 Selection of Color Coding

Different colors will produce different psychological effects after entering people's field of vision. The selection of color coding should be based on the traditional understanding of a specific color by users, and must be consistent with the meaning of some colors already defined in users' work [4]. That is, color coding should make use of recognized practices related to the meaning of color, for example, red represents danger and abnormality; Green means safe and normal, as shown in Table 1. In addition, the selection of colors prohibits the design using the default coding method.

2.4 Requirements for Color Contrast and Display Color Difference

Color coding should meet the requirements of contrast and color difference. The color on the display screen should have sufficient contrast with adjacent colors and display background, so as to ensure that it can be clearly and easily distinguished in any lighting environment [8]. For example, if the contrast is less than 20, the contrast is poor; if the contrast is more than 60, the color contrast is good; and if the contrast is more than 20 and less than 60, the color contrast is moderate [1]. In the display design of Main Control Room Human-System Interface, a large amount of information is in the form of text, and the selection of text color should be fully considered to have sufficient contrast with the display background. Alarms are important information to monitor the operation of nuclear power plant. The color scheme of alarm priority needs to fully consider the color difference requirements between colors.

Table 1. Meaning of colors-general principles [3].

Color	Safety of person or environment meaning	Process status meaning	Device status meaning
Red	Danger	Urgent	Failure
Yellow	Warning, attention	Abnormal	Abnormal
Green	Safety	Normal	Normal
Blue	Mandatory meaning	Mandatory meaning	Mandatory meaning
White, grey, black	No specific meaning is given	No specific meaning is given	No specific meaning is given

2.5 Types and Recommended Usage of Color Coding

In order to be clear, the number of colors used in a given application should be kept as minimum as possible. There are generally no more than six colors in the same group representing different meanings [5]. For example, trend group display design should consider as many as possible no more than six variables in the same group. In addition, there are some recommended good practices in international and domestic regulations and standards for color coding, such as NUREG0700-2002, which recommends using a continuous color change like tone to represent the correlation value of a single variable [1], and IEC60073-2002, which uses degree of saturation, brightness or contrast to express more extended information of a certain color [3].

2.6 Redundancy of Color Coding

The single use of color coding will lead to information loss in many cases, such as single-frequency VDUs and printers with color damage [1]. Therefore, redundant coding types such as position, shape, text and other information need to be adopted to ensure that operators still understand relevant safety information in case of color loss and the like. For example, the digital alarm system in main control room can not only use color for alarm priority display, but also add text information to the color background to ensure redundancy.

3 Comparison of Color Schemes for In-Service Power Plants

3.1 Color Schemes in Several Typical Cases

Typical cases where color is used to express information in Human-System Interface design mainly include status feedback of equipment (mainly referring to valves, pumps, fans), pipe media, alarm and display background.

a) Status Feedback Color Scheme for Digital Human-System Interface Equipment: At present, there are mainly three schemes: “Green On and White Off” scheme (“Green” indicates “On” status, “White” indicates “Off” status), “Red On and Green Off” scheme and “Pipe medium filling color On and White Off” scheme.

b) Hardwired equipment Status Feedback Color Scheme:
There are mainly two kinds, “Red On and Green Off” and “Green On and White Off”. At present, the vast majority of nuclear power plants adopt the “Red On and Green Off” scheme.
c) Pipe Media Fill Color Scheme:
There are mainly two types, “media color fill” and “black”. At present, most power plants adopt medium color filling scheme.
d) Alarm color scheme:
Each power plant has different alarm color schemes, but red and yellow are uniformly adopted as priority alarm colors. Orange, purple, blue, white and green are also used as priority alarms.
e) Background color scheme:
There are mainly two kinds, dark and light.

3.2 Comparative Analysis of Color Scheme Application

Among the three color schemes for status feedback of digital Human-System Interface equipment, the “Green On and White Off” scheme is used in digital Main Control Room of High Temperature Gas cooled Reactor and Tianwan nuclear power plant. “Red On and Green Off” is used in conventional thermal power plant. “Medium Color Filling On and White Off” adopts this scheme in CPR1000 nuclear power plant. These three schemes are widely used in the operation of nuclear power plants.

For the color scheme of hardwired equipment status feedback, “Red On and Green Off” is adopted in CPR1000 nuclear power plant, Fuqing nuclear power plant. At present, the vast majority of power plants adopt the “Red On and Green Off” scheme.

For the pipe’s medium filling color scheme, CPR1000, Tianwan nuclear power plant and High Temperature Gas cooled Reactor all adopt the “medium filling” scheme. At present, most power plants have adopted the “medium color filling” scheme.

In the color scheme used to characterize the alarm priority, besides red and yellow. CPR1000 also uses purple, white and green. High Temperature Gas cooled Reactor also uses blue and white. In each reactor type, the alarm priority color scheme varies.

In the color scheme of the two background colors, the conventional thermal power plant uses dark colors (64, 64, 64,) as the background color; CPR1000, Tianwan nuclear power plant, and High Temperature Gas cooled Reactor all use different degrees of gray as background color. Gray background scheme is widely used in nuclear power plant of various reactor types.

4 Color Application Feedback from Nuclear Power Plants

Based on the rich operation experience of CPR1000 nuclear power plant, the operator’s feelings and suggestions during operation were investigated and feedback. According to the survey feedback on operators in Table 2, the following three main opinions can be summarized:

1) For some operators, the change of equipment status color scheme to “green on and white off” is rejected.

2) White is not much different from the background color as the relevant feedback.
3) Background color is somewhat gray and light.

5 HPR1000 Color Scheme Design

Human-System Interface color scheme of HPR1000 Project is derived from the color system of CPR1000 Project, and absorbs the feedback given by the operators and puts forward to meet the monitoring requirements of the user and the requirements of laws and standards.

5.1 Color Scheme Design Principle

Based on the requirements of laws and regulations on color schemes, the general principles of color definition are summarized as follows:

a) The color definitions of Main Control Room digital display interface and conventional pannel design should be consistent as much as possible and should not conflict with each other;
b) In order to be clear, the number of colors used in a given application should be kept as minimum as possible on the premise of satisfying the system functions;
c) The color difference between the same group of colors shall be greater than or equal to 40 (CIE L*u*v*), and the contrast between the color and the background color shall be greater than or equal to 100 (CIE Yu'v ');
d) When safety-related meanings are involved, the color should be bright, saturated and have high contrast. For secondary information, dim and small degree of saturation colors can be used;
e) The color definition shall comprehensively consider the operation habits and Experience Feedback of the operators;
f) In addition to using color coding to express information, other redundant coding methods such as shape and position are also needed.

5.2 HPR1000 Color Scheme

Based on the reference power plant and the operating experience feedback, combined with the advantages of the color scheme of each reactor power plant and in accordance with the requirements of laws and standards, the color scheme of HPR1000 is proposed. The main technical points are introduced as follows.

5.2.1 Status Feedback of Digital Human-System Interface Equipment

Within a set of VDUs, each color shall be given the same meaning [3]. Red has been selected as the alarm color. If red is selected again, it indicates the status of the equipment, which is obviously contrary to this standard. Another requirement is that the color criterion shall base on the user's traditional understanding of a specific color [7]. People who are worked in conventional power plants typically associate Open/flow status with

Table 2. Color scheme user feedback.

Operator	Can the operator adapt to the color system in the current NC-VDU digital Human-System Interface?	If the filling color of the equipment icon On/Off status is changed from media color to green (i.e. Green on and white off), is it Acceptable?	What suggestions do you have for the color system setting and specific application of NC-VDU?
Operator 1	The contrast between the background color and white (Valves closed state) is not large and is easy to confuse	Acceptable	Don't use too many colors, which will easily lead to confusion. Each color used must be clearly defined and explained
Operator 2	Can adapt	Not acceptable	Consistent with the site
Operator 3	Can adapt	Acceptable	None
Operator 4	Basically adapted, but there was no factor that caused the operator to work more actively and excitedly	Also Acceptable, but it is not recommended that all dynamic pictures be displayed in green and white	Combining the personnel's response to color and Human Factors Engineer, optimize the color system setting to promote the improvement of the operator's working passion
Operator 5	Be adaptable	Acceptable	Can be more lively, watching the picture for a long time is more depressing
Operator 6	The color of the picture is somewhat light	Acceptable	The background color of the picture is gray and light. It is suggested to refer to Ling'ao Phase II
Operator 7	Has basically adapted	Yes, this is more eye-catching	The overall color is gray and not eye-catching enough
Operator 8	Can adapt	It is recommended to keep the media color fill	There is no suggestion for the time being
Operator 9	Be able to adapt	Most operators are accustomed to the current rules, and it is not recommended to change the color unless there is a big need	None

red and Closed/stop status with green. Therefore, using green fill to indicate operation feedback may not be in conformity with the traditional understanding of users.

The medium color filling is adopted for equipment status operation feedback, and the white filling scheme is adopted for stopping feedback, which ensures that red is the only definition of alarm color, and is consistent with the traditional understanding of users. Moreover, the pipe filling color scheme has Reference Power Plant's rich operation experience. Therefore, the scheme of medium color filling is adopted for equipment status operation feedback and white filling is adopted for stop feedback.

5.2.2 Hardwired Equipment Status Feedback

The color criterion shall base on the user's traditional understanding of a specific color [7]. People who are worked in conventional power plants typically associate Open/flow status with red and Closed/stop status with green. Therefore, using green to indicate operation feedback may not be in conformity with the traditional understanding of users. Also, the color should be bright, saturated and have high contrast for the meaning related to safety [3]. The hardwired panel is a security-level device, and using white violates its purpose.

The state operation feedback of hardwired equipment adopts red filling, and the stop feedback adopts green filling, which is consistent with the situation of on-site indicator lights, and meets the definition of safe color in IEC60073-2002. Before that, there have been a large number of application experiences of different types of in-service power plants. Therefore, the scheme of red filling is adopted for the state operation feedback of hardwired equipment, and green filling is adopted for the stop feedback.

5.2.3 Pipe Media Filling Color

Bright, saturated and contrast colors should be used to attract users' attention to key data or security information [3]. Black has a large contrast with any other color and is easy to attract users' attention, but Pipe color is not important information. Therefore, the use of black violates its requirements.

Pipe media filling color scheme using different colors to distinguish different media corresponds to the status feedback color scheme of digital Human-System Interface equipment, and the principle of color coding meet the requirement that color application should be based on the understanding of user tasks [2]. Therefore, different colors are adopted to distinguish pipe media filling color schemes corresponding to different media.

5.2.4 Alarm Color

The color criterion shall base on the user's traditional understanding of a specific color [7]. However, both green and blue are inconsistent with the traditional understanding of users and the recognized practice of color meaning.

Orange is used as the alarm color to meet the users' traditional understanding of color and the recognized practice of color meaning, and has application experience in power plants. Therefore, orange is adopted as the alarm color.

5.2.5 Background Color

The color difference and contrast between black and other colors are too large. Although the intensity and depth of the color are very useful to attract the attention of the user,

excessive use in the display may make the display page too dazzling to be viewed for a long time, and it is easy to cause visual fatigue of the operator, which is not recommended.

Gray is used as the background color to meet the requirements of IEC60073-2002 for secondary information, and its color can be dimmer and degree of saturation smaller. And the color difference and contrast with other colors are moderate, meeting the requirements of NUREG0700-2002 for color difference and contrast. Therefore, gray is adopted as the background color scheme.

6 Summary and Prospect

The color scheme of HPR1000 nuclear power plant is improved on the foundation of CPR1000 according to engineering practice. Meet the requirements of IEC60073-2002 and IEC61772-2009 while referring to some requirements of NUREG0700-2002. Its color system meets the requirements of laws and regulations.

Each nuclear power project has formulated its own Human-System Interface color system on the foundation that meets the regulations and standards. The laws and standards only give the guiding principles and practices of adaptability, and do not give too many index requirements. Moreover, there are conflicts between different laws and standards, so it is very necessary to establish a more detailed and complete system of laws and standards that conforms to its own situation.

The color scheme of HPR1000 has been further improved and optimized in terms of aesthetics, comfort of long-term monitoring, matching of task objects and display equipment, etc. Subsequently, more consideration can be given to the psychological and physiological effects of color on operators from the perspective of human factors. For example, the use of color to divide information areas, emphasis on important information and other means to help operators form an orderly visual process and monitoring environment, and the establishment of a humanized nuclear power plant system Human-System Interface color system that takes into account human psychological, physiological and other factors.

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