# Color Touchscreens Maximize Usability for Protective Relays

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# Purpose

Life without color touchscreen technology is now hard to imagine. We rely on them for everything from smartphones and tablets to ATMs. Touchscreens are in our homes, cars, planes—virtually everywhere. Their intuitive interfaces, efficiency, and overall superior user experience have made them ubiquitous and make them ideal for protective relays in power systems. This paper explores how touchscreen technology has evolved, compares popular touchscreen technologies, and discusses common misconceptions about touchscreen technology for power system applications.

# Introduction

Protective relays play a critical role in power systems around the world, from electric utilities to heavy industry and critical infrastructure operations—they protect power systems by isolating faults and keeping the remainder of the network in operation. Advanced, microprocessor-based protective relays can also provide valuable information about the origin of a fault to help personnel troubleshoot faster and identify the root cause.

Protective relays must accommodate a wide range of users, from dedicated power protection engineers to infrequent operators and third-party contractors who may perform only monthly or annual maintenance. An ideal relay user interface is flexible, intuitive, efficient, and easy to use, requiring less time to do tasks and improving work quality by reducing user errors.

With color touchscreens, user interaction shifts from an externally-driven process that heavily relies on training and documentation to an experience-driven process that incorporates commonly used conventions and direct input. The inclusion of colors, icons, folders, rich tooltips, and simplified workflows in touchscreen interfaces all provide additional context to the user. When compared with traditional relay user interfaces, color touchscreen technology significantly improves user-relay interactions. Touchscreens can simplify multistep processes with intuitive folders and icons to reduce time-consuming training and documentation. They can also provide a new, yet familiar, way to interact with protective relays by following the familiar design paradigm used in smartphones, tablets, and ATMs.

The popularity of touchscreen technology in consumer applications is both a testament to its advantages and a barrier to its acceptance in power system applications. Consumer touchscreens are on coffee makers, televisions, computers, watches, vehicle dashboards, home appliances, and, of course, smartphones. However, users are often concerned about the fragility, reliability, and usability of capacitive touchscreens. The large market for smartphone protective cases is evidence that users view touchscreen technology as fragile and in need of protection. Nevertheless, the idea that capacitive touchscreen technology is overly fragile is a myth.

Capacitive touchscreens are reliable, durable, and provide many benefits, especially in power systems. Power systems require durable, user-friendly technology, and touchscreens are one of the best options for an input device. Scientific studies show that touchscreens benefit users with:

- More efficient input than physical keys [1].
- Avoidance of strain injuries from mouse use [2].
- An overall greater level of user satisfaction [3].

Touchscreens also remove the many potential failure points of other input technology, such as keyboard keys, mouse buttons, and keyboard and mouse wiring.

# Color Touchscreen Technology

## Capacitive Versus Resistive Technology

Not all touchscreen technology is created equal; application fit is the most important qualification for choosing which touchscreen is best. A capacitive touchscreen uses a thin transparent film of electrodes that interact with the capacitance of the human body [4]. Resistive touchscreens are activated by pressure [5]; any item that can depress the soft transparent overlay of the screen can activate it. However, the softer the flexible screen is, the more vulnerable it is to damage with continued use. This is especially true if users apply higher levels of pressure than are needed or use a sharp-edged object. Still, it can be a plus that the resistive touchscreen works with anything capable of applying pressure, including a gloved finger.

Capacitive touchscreens use “light touch” technology. They are activated by any capacitive object, such as a finger, capacitive glove, or stylus, encountering an electric field generated by the screen [4]. Still, the lack of any moving parts, like the flexible polyester screens in resistive touchscreens (shown in Figure 1), makes capacitive screens much more durable than resistive touchscreens. The durability of capacitive screens makes them ideal for power system relays, especially where they need to withstand long periods of operation and time.

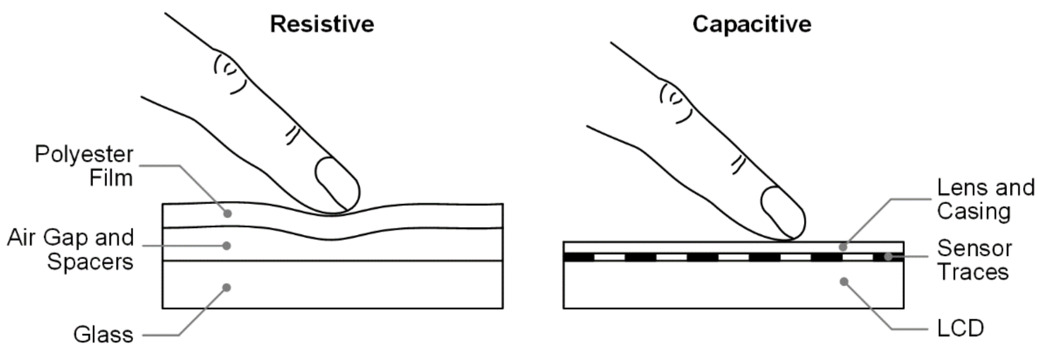


**Figure 1 Touchscreen internal structures.**

The features of capacitive touchscreens make them ideal for protective relays in industrial, utility, and critical infrastructure applications. Table 1 shows a feature comparison between resistive and capacitive touchscreen technologies.

**Table 1 Resistive and Capacitive Touchscreen Technology Features**

| Feature | Resistive | Capacitive |
|---|---|---|
| Touch surface durability | Low | Very high |
| Light emission | 25% less | Excellent |
| Image clarity | Moderate | Very high |
| Recalibration | Periodically | Unnecessary |
| Stylus capability | Any pressure device | Capacitive stylus |

### Touch Surface Durability

Durability is one of the chief concerns for new technology within power systems. This is especially true for touchscreen technology since its rapid adoption in personal devices. Who has not experienced dropping their phone and cracking the screen? However, capacitive touchscreens are durable and only risk being cracked by a high-impact force. For protective relays, a high impact is unlikely because the devices are stationary. Also, even with a cracked screen, capacitive touchscreens still function. Furthermore, glass capacitive touchscreens have become exceedingly durable with the advent of chemically strengthened glass, which is used in several SEL devices, such as the SEL-700 series relays.

Capacitive touchscreens are much more durable than resistive touchscreens. The resistive technology relies on moving parts to detect interactions, whereas capacitive does not. The moving parts on a resistive touchscreen wear over time and become points of failure. More importantly, the primary moving part in a resistive touchscreen is the polyester film—the component a user directly interacts with. The repetitive wear and the delicacy of the material make resistive touchscreens vulnerable to damage and malformation. Any malformation on a resistive touchscreen can seriously alter its ability to function.

### Light Emission and Image Clarity

Light emission is important for the safety-critical displays of protective relays. Light emission from a screen can determine the visibility of onscreen information in various light conditions, the ease of use, and eye comfort during use. In general, capacitive touchscreens offer superior light transmission when compared with resistive technology. Resistive touchscreens offer 75 to 83 percent clarity because they are made of several relatively thick layers of polyester and glass. Capacitive touchscreens consist of layers of thin glass and offer an average of 89 percent clarity [4].

Image quality and light emission are closely related in touchscreen technology. As light transmission and clarity increase, the image quality also increases. Capacitive touchscreens tend to have better light emission, clarity, and image quality. The increased touch resolution of capacitive touchscreens also allows higher display resolutions and the inclusion of more information.

### Recalibration

Resistive touchscreens require occasional recalibration to maintain touch accuracy. It is difficult to perfectly align the coordinate system of the upper layers of a resistive touchscreen with the lower layers. Therefore, if any change occurs in the touchscreen, such as a small shift in the pliable top layer due to repeated use, the coordinate systems may become out of sync.

Capacitive touchscreens never require calibration. The surface is glass and does not rely on two surfaces to determine the touch location.

## Innovative Designs Improve Usability

SEL uses heuristic design principles to create touchscreen interfaces that are simple and intuitive. Heuristic design relies on users' past experiences and their ability to successfully apply similar processes to a new experience. For example, SEL relay touchscreen interfaces employ the functionality and look of smartphone touchscreens and computer interfaces that are already familiar to users.

The most popular usability heuristics are those by Jakob Nielson. Nielson's ten heuristics for user interface design are based on research and are an industry standard among user interface and experience design professionals. They include the following [6]:

- Visibility of the system status—always keep users informed.
- A match between the system and the real world—"speak the users' language" with words, phrases, and concepts that are familiar.
- User control and freedom—allow users to easily exit unwanted states.
- Consistency and standards—use the same words, situations, and actions throughout.
- Error prevention—either eliminate error-prone actions or require users to confirm them.
- Recognition rather than recall—make objects, actions, and options visible.
- Flexibility and efficiency of use—tailor interactions for both new and expert users.
- An aesthetic and minimalist design—avoid irrelevant information.
- Help users recognize, diagnose, and recover from errors—express precise error messages in plain language.
- Help and documentation—provide easy-to-search, focused documentation.

Capacitive touchscreen technology can improve the functionality of relays based on these heuristics, and SEL's touchscreen display (see Figure 2) is designed with Nielson's heuristic principles in mind. By applying these widely accepted heuristics to provide information in context and address user errors, capacitive touchscreens become the ideal solution for protective relay interfaces.


**Figure 2 A touchscreen relay (left) and a relay with a classic two-line display (right).**

## Making Information Visible and Intuitive

A touchscreen display makes the system status visible with a rich display that can show information at various levels of abstraction. Not only can a touchscreen display make system status visible, it can also provide context regarding that status, such as what happened and where. Also, users can directly manipulate and control status updates.

The Bay Screen application shown in Figure 3 is just one way SEL touchscreen devices make system statuses visible. It has a one-line diagram system view that incorporates the real-time status of breakers, switches, and important analog quantities. Not only does this provide system status, but it does so in a holistic and context-rich way.

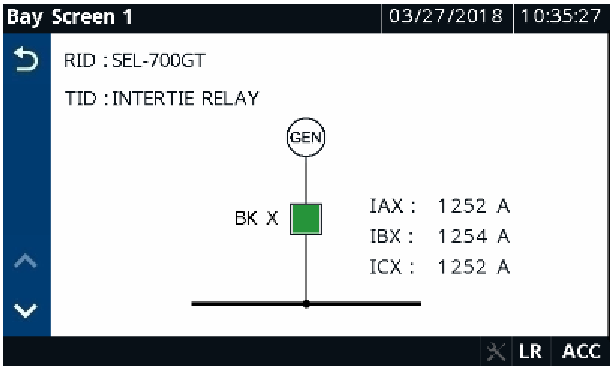


**Figure 3 SEL Bay Screen one-line diagram with real-time status indication.**

Providing information in context, such as in a one-line diagram, makes navigation more intuitive, and helps users by matching the system with what they see in the real world in a natural and logical way. The touchscreen interface display looks like what it is trying to represent, which increases the user's processing speed, decreases their visual strain, and decreases their likelihood of error [7].

Touchscreen interfaces are the next step in interface and user experience for protective relays. A traditional two-line display for protective relays has a very limited ability to show system status information. For example, the SEL-751 Feeder Protection Relay two-line display can show two lines of text with 16 characters in each row. The limited visibility of system status forces the user to rely on LED lights for system status information. The LEDs only show that a status exists, not how to interact with the status or the context surrounding it. Also, many of the options and information on a two-line display are hidden from view. See Figure 4 for an example of hidden information on a two-line display.

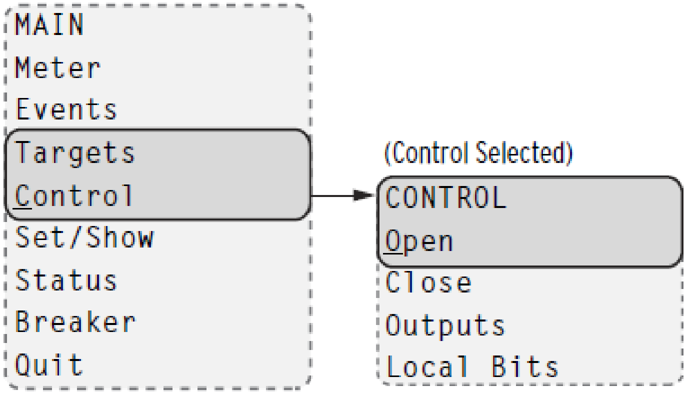


**Figure 4 Hidden information on a two-line display (dotted lines signify offscreen information).**

In SEL touchscreens, options are made visible and the navigational task of finding specific information on the relay is made easier with intuitive icons that are often literal representations of their functions. For example, the icon for the Phasors application is a phasor diagram (see Meter folder in Figure 5). Furthermore, the actual applications themselves, like the Phasors application (see Figure 6), provide users with a view like what they would see in typical PC software.

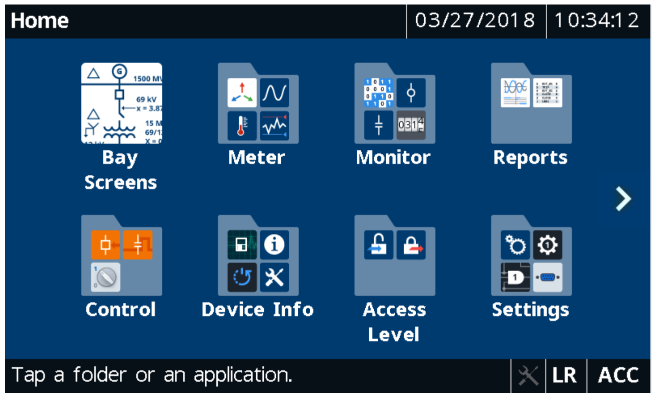


**Figure 5 Intuitive application icons represent their actual functions.**

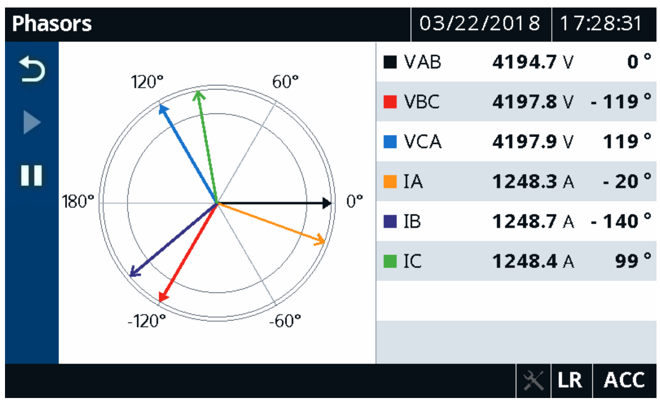


**Figure 6 The Phasor application mimics a typical PC software view.**

Nielsen states that "Users should not have to wonder whether different words, situations, or actions mean the same thing" [6]. Consistency in design and between the interface and the real world creates an interaction environment with a significantly faster learning curve than inconsistent environments [8]. This fast learning curve is mainly because learning in one area of the program transfers to another when similar conventions are followed. This transfer of learning also applies to training. If systems are consistent, training is significantly faster [9].

A touchscreen display uses operating conventions that merge conventional standards from the power industry with the conventional standards of common technology found in consumer electronics, like smartphones. A touchscreen can use familiar textual and graphical elements. For example, SEL touchscreens are organized in a hierarchical structure with two levels: folders and applications. The folders are organized based on the specific application functions, and the applications are purpose-specific. Folders are not only a convention that most users understand without any explanation; they are also a consistent way to organize applications that serve similar purposes.

An intuitive and consistent touchscreen interface is also ideal for applications where personnel only occasionally interact with protective relays, such as for annual maintenance. Users can quickly navigate through menus without extensive training, trial-and-error, or documentation review. Conversely, it is particularly hard for users to remember how to operate two-line display devices when they only interact with them occasionally.

## Preventing and Recovering From Errors

The visibility and ease of navigation with touchscreens help users prevent and quickly recover from errors. Readily accessible shortcuts, such as a back arrow, can allow users to quickly exit any screen if they need to abort a task. Touchscreens can also require confirmation for critical actions. For example, a user can easily avoid accidentally tripping a breaker with an SEL touchscreen because there is always a confirmation dialog, as shown in Figure 7.

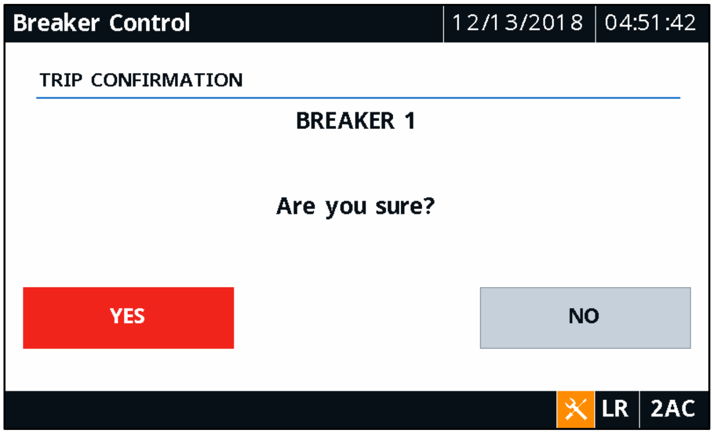


**Figure 7    A confirmation screen in the SEL touchscreen interface.**

Both the two-line and the touchscreen displays can force users to confirm when they want to make a change to the system. The two-line display does this through a yes/no dialog, whereas the touchscreen can have a pop-up window. For error prevention, the major advantage of the touchscreen is the inclusion of contextual information. The touchscreen can display much more relevant information regarding a decision and can use visual cues to convey a sense of importance or danger.

Touchscreen displays have great potential for error notifications and recovery. The touchscreen display has rich interfaces and notifications that provide detailed information about system error status and provide context that helps users recognize, diagnose, and recover from errors. For example, SEL touchscreens provide up-to-the-moment notifications that not only alert users to errors but also help them navigate to where they can resolve the error, as shown in Figure 8.

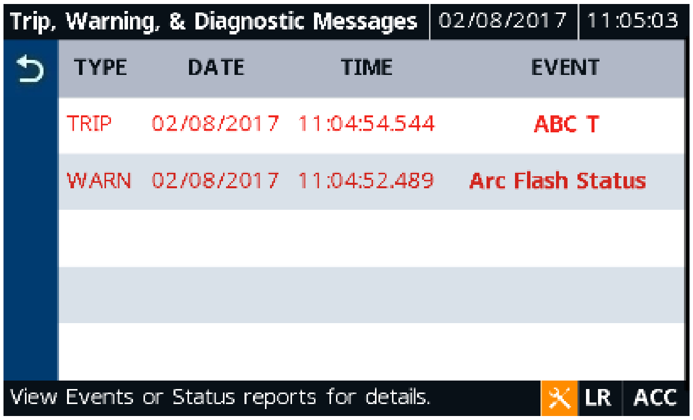


**Figure 8    An error message screen shows details that speed resolution.**

The touchscreen display can also provide help and documentation in context (see Figure 9) to diagnose a potential issue and find the proper help.

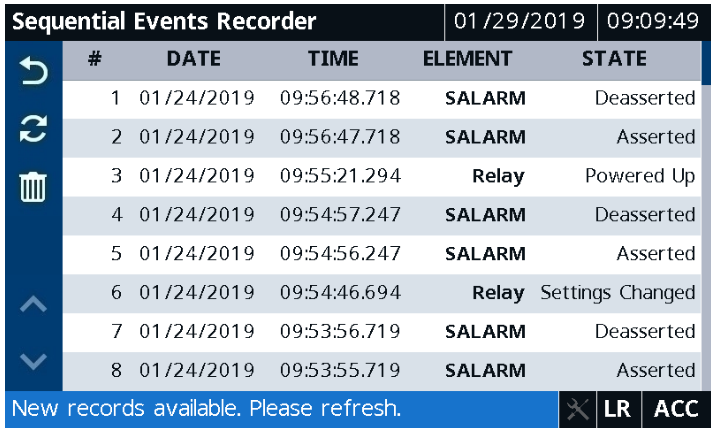


**Figure 9 A Sequential Events Recorder (SER) report providing rich context for improved problem diagnosis.**

## Conclusion

Touchscreen interfaces for protective relays are the next step forward in simplifying user interactions with relays in unpredictable, yet critical, substation environments. Not only must relay touchscreens survive harsh electrical environments, they must also be easy-to-use and intuitive for all users. With careful interface design and capacitive touchscreen technology, both of these goals can be accomplished.

Thoughtfully designed touchscreen interfaces can accommodate a wide variety of users, even those with minimal training or who infrequently interact with relays. Touchscreen interfaces are flexible, intuitive, efficient, and easy to use, requiring less time to do tasks and improving work quality by reducing user errors. They improve nearly every user interaction with protective relays and offer the following benefits:

- Improved user productivity—the intuitive, user-centered touchscreen interfaces let personnel accomplish tasks more efficiently.
- Easy use—the familiar folder/icon design paradigm (also used in smartphones and ATMs) is familiar and user-friendly.
- Greater device reliability—many potential failure points of input technology (keyboard keys, mouse buttons, and keyboard/mouse wiring) are removed.
- Avoidance of repetitive strain injuries from mouse use—the use of a computer mouse is associated with higher rates of carpal tunnel syndrome [10].
- Greater user satisfaction—touchscreens are faster and more comfortable input devices than trackpads or mice [3].

Protective relays can face harsh conditions in power systems, and capacitive touchscreens are ideally suited for such environments. They offer several advantages over other touchscreen technologies, including improved touch surface durability, better light emission, and image clarity and do not require recalibration. When combined with chemically strengthened glass screens, well-designed capacitive touchscreens are a durable and reliable solution that is ideal for industrial and utility power systems.

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## Biographies

**Brian Pugliese** received his M.A., summa cum laude, from Kean University and is pursuing his Ph.D. in human factors psychology at the University of Idaho. Before joining Schweitzer Engineering Laboratories, Inc., in 2017, Brian worked primarily in an academic setting, both teaching and doing empirical research. Brian's research primarily revolves around human safety and complex systems interaction. Brian works with the user experience (UX) team, providing scientific support for user interface design and research. He is a member of the Human Factors and Ergonomic Society (HFES).

**Robert Brum** received his B.A. from the University of California, San Diego, and his M.B.A. from the University of Notre Dame. Before joining Schweitzer Engineering Laboratories, Inc., in 2015, Robert worked in numerous marketing and business development roles with several high-technology organizations, including Hewlett-Packard and Ricoh. He is now the senior marketing program manager for SEL industrial solutions.

**Bryan Foutch** received his B.A. in virtual technology and design from the University of Idaho in 2010. Shortly after, Bryan joined Schweitzer Engineering Laboratories, Inc., as a software engineer. He founded the SEL user experience team in 2012 and now acts as an engineering manager in research and development, managing SEL's team of user experience professionals across a wide array of software and hardware products.

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