Roles of Annunciators in Modern Electrical Substations

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***Abstract*—The developers of automation systems often view annunciators as devices that can be supplanted by screens on human-machine interface (HMI) monitors. On further analysis, there are compelling reasons for many plant and station engineers to include annunciators in new designs. These reasons include the following:**

- **Providing alarm notification independent of computers or networks.**
- **Using a standalone annunciator that communicates with a substation automation system to:**
  - **Provide rapid alarm notification to all personnel, rather than only those with computer access credentials and training.**
  - **Locate remote annunciators to present alarm conditions determined by the system to provide value to personnel in that area. For example, annunciators can indicate alarm conditions outside of a door or hatch leading to a compartment or vault or in the vicinity where repair personnel are troubleshooting wiring.**
  - **Increase reliability and reduce costs by wiring alarms to annunciators that serve both local alarm display and system remote I/O functions.**

This paper summarizes the actual usage of HMI, supervisory control and data acquisition (SCADA), and automation systems in electrical substations; contrasts the reliability of several approaches with and without annunciators; and explores several annunciation and monitoring applications that can benefit automation, control, and protection systems.

I. Introduction

Annunciators in electrical substations and generating plants provide immediate visual indication of alarm conditions, accompanied by audible sounds to call attention to the visual information displayed. Historically, standalone annunciators were hard- wired to sense contacts from breakers, pressure and temperature switches, and other transducers that convert real-world process variables into contact operations. Typically, the supervisory control and data acquisition (SCADA) systems that linked substations and control centers were entirely separated from the annunciators. Applying microprocessor technology to protective relays, SCADA systems, meters, and other intelligent electronic devices enabled new system architectures. Annunciators are following a similar path. This paper describes the roles of annunciators in modern electrical substations.

II. Annunciator Functions

A. Annunciator Overview

Annunciators in electrical substations, generating plants, and many types of industrial plants provide concise visible and audible notification. An annunciator has a legend area, referred to as an annunciator "window," that contains a concise text description of a condition to be alarmed. An alarm indicator illuminates for the visible indication of the alarm condition. Different annunciator models use light bulbs or light-emitting diodes (LEDs) as separate indicators or to backlight an engraved, translucent window. An audible alarm demands the attention of people near the annunciator. Pushbuttons allow the audible horn to be silenced and to acknowledge that the operator has observed an alarm. Fig. 1 depicts the elements of a representative annunciator. Alarm sequences are the logic schemes that define indication of new, fleeting, and acknowledged alarms through illumination, flashing, or different flash rates and the operation of horns and acknowledge and silence pushbuttons. Uniform annunciator terminology and sequence definitions are defined by the International Society of Automation (ISA) standard ISA-18.1-1979, Annunciator Sequences and Specifications [1].

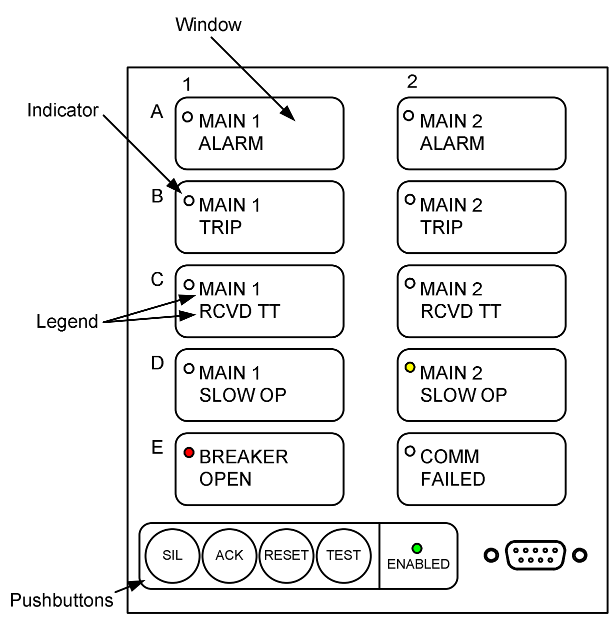

Fig. 1. Elements of an Annunciator

B. Improve Situational Awareness to Prevent Accidents and Reduce Injuries

Zeller and Scheer urged designers of control systems to "consider presenting alarm displays or annunciators with instructions at the points of entry to a hazardous area to increase personnel awareness of conditions" [2]. Accident and injury prevention and containment depend on many human factors. Koval and Floyd summarized these in an accident-injury sequence model [3]. They noted that it is important to recognize hazard and injury potential. People must be alert and assess potentially hazardous situations by applying training, experience, and logic to understand the hazards and injury potential. Safety-related information should be easily distinguished from other data and alarms to prevent safety information from being delayed or overlooked [2].

III. Instrumentation and Control Systems

Annunciators, SCADA remote terminal units (RTUs), and substation automation systems are within the general discipline of station instrumentation and control (I&C) engineering. Annunciators provide local visual and audible indication of alarm conditions. RTUs were the primary substation component of traditional SCADA systems, feeding data from the substation to the SCADA master systems at the control center and receiving and acting upon control commands from the SCADA master. Traditionally, these subsystems were entirely separate from one another.

By the late 1980s, significant numbers of microprocessor-based relays were deployed in electrical substations. These relays measure ac analog signals and operate electrical circuit breakers to perform protective functions and can communicate digitally with other microprocessor-based devices and computers. SCADA RTUs gathered analog data through transducers and dc analog inputs (AI), sensed breaker status through contact-monitoring digital inputs (DI), and operated breakers with digital outputs (DO).

Engineers recognized that SCADA devices could communicate with protective relays for these inputs and outputs, eliminating duplicate wiring, documentation, and I/O boards in an RTU. Mission-critical protective relays are also designed, built, and tested to more stringent standards than RTUs are. Building distributed systems that replaced monolithic RTU cabinets increased the reliability of SCADA systems because of the higher reliability of the relays and the reduction of components involved in providing SCADA I/O functions [4].

Similarly, annunciators have shifted from low-reliability electromechanical devices with incandescent bulbs to high-reliability microprocessor-based devices with LED indicators and the ability to communicate digitally with other devices.

IV. Stations With Traditional SCADA or Without Device Communications

A. Substation SCADA Communications Links

Usually, substation automation engineers concentrate their efforts on the most important stations of an electrical system and may tend to believe that these stations are representative of all substations. However, there are a significant number of substations without any communications links that could benefit from annunciators and smaller-scale automation projects.

Data compiled by Newton-Evans show that approximately 87 percent of transmission electrical substations worldwide have an RTU or other device that communicates with a SCADA system, but only 55 percent of distribution substations (30 kV and above) have SCADA connections [5]. The remaining 100,382 substations have no SCADA communications links, nor do most of the substations below 30 kV.

B. Mission-Critical Apparatus Readiness

Continuous, self-diagnostic testing by microprocessor-based protective relays is one reason that microprocessor-based systems are far more reliable than systems that depend on electromechanical protective relays.

> If the relay status is not reported to a staffed location, a relay failure will not be detected until someone visits the site. If the relay status is not easily available locally, a failed relay will probably not be detected until a periodically scheduled relay maintenance cycle. [1]

Until failures are detected and fixed, apparatus are not protected as planned, and the risks to personnel and equipment are higher. Apparatus readiness is also determined by devices other than protective relays (for example, pressure limit switches, battery monitors, and transformer monitors). Reference [6] discusses methods to compare the unavailability of protective relaying alternatives for transmission lines.

C. Annunciator Call-Out Via Telephone Infrastructure

Some communicating annunciators are coupled to telephone dialing and notification devices to automatically dial a phone number, convert alarm text messages to speech, and directly inform personnel of problems at the station. This approach provides external notification for stations that do not have SCADA links. Autodialing notification is also deployed to dispatch distribution maintenance personnel for stations where there are SCADA links so that distribution repair crews are not idle while system dispatchers concentrate on higher-priority transmission issues during widespread outages.

D. *Annunciators Serve Personnel at the Substation*

In the stations that have no SCADA or other external I&C communications links, on-site visits by utility personnel are generally required to detect and correct problems. Depending on the importance of the station, these may be periodic visits or might be prompted by an outage detected and reported by equipment at the other end of transmission or distribution lines, by the automatic call-out notification described in the previous section, or by outage or observational reports from customers. In stations with SCADA, a consolidated equipment trouble alarm may lead a system operator to dispatch repair personnel.

Regardless of what initiates the visit, an annunciator concisely provides information to technicians that arrive at the substation. Annunciators that can communicate with each other can facilitate alarm indication at different locations in a station. For example, in a generating plant switchyard, there may be alarm information that is useful in both the plant and the switchyard that is appropriate for annunciation in both locations.

V. Distributed RTU Systems

A. *Distributed SCADA System Overview*

Distributed substation SCADA systems generally include an information processor that communicates with multiple intelligent electronic devices for much of the I/O functionality that was traditionally provided by an RTU. The information processor communicates to a SCADA master; viewing the data stream from the control center end of the link, it may be transparent whether the substation has a traditional RTU or distributed RTU system, although the designers may elect to exploit additional capabilities provided by the distributed devices. The information processor selected for a distributed RTU design is generally one of the following:

- Dedicated communications processor with firmware.
- Tough computer with embedded/locked software.
- Programmable logic controller (PLC).
- RTU with local communications links and some I/O.
- Tough computer with a general purpose operating system plus information processor software.

Devices communicate with the information processor through serial data links or networks to exchange data. Devices in a distributed RTU system can include protective relays, meters, transformer monitors, PLCs, remote I/O modules or subsystems, voltage regulator controllers, battery monitors, load tap changer controls, and more. Designers choose distributed RTU architectures to improve SCADA reliability and reduce the initial and life-cycle costs of substation I&C [4].

B. *Roles of Annunciators in Distributed RTU Systems*

Annunciators with communications capabilities can play multiple roles in distributed RTU systems. First, annunciators continue to concisely provide information to repair and operating personnel in the station or alert all personnel of hazardous conditions.

If the local digital inputs of the annunciator are used to drive the annunciation functions, the annunciator can additionally serve as the remote input module for these points. This improves the system reliability and saves the cost of a separate input module and the installation, commissioning, and documentation costs of duplicate I/O wiring [7].

Or an annunciator with a communications link and no I/O can serve as a peripheral to a distributed RTU system, where all of the alarm information is provided to the annunciator by the information processor. Once again, a given digital input is connected to only one device, saving the cost of unnecessary duplication. In this configuration, the annunciator can be treated as a remote output module by the information processor.

In many cases, an annunciator serves in all three of these roles, providing visual and audible indication to local personnel, gathering inputs for local display and transfer to the information processor, and operating on data received from the distributed system to drive some of the alarm functions.

VI. Substation Automation Systems

A. *Substation Automation System Overview*

A distributed RTU system and a substation automation system are very similar, and for many purposes, the distinction does not make a significant difference. From a terminology standpoint, a SCADA system performs only human-operator-initiated functions, hence the "supervisory" (S) of SCADA. "Automation" denotes automatic (machine-initiated) action, and the superset of a SCADA system at a control center level that performs automatic control is called an energy management system (EMS). In practice, the usage of the terms has become less rigid than these definitions.

Substation automation systems generally encompass the SCADA functions of traditional or distributed RTU systems and provide some level of automatic control or automatic data collection beyond the collection of SCADA operational data. They generally have a more powerful information processor and more memory than is required for strictly RTU replacement functions. Perhaps 10 percent of the systems have one or more local computer display screens that each serve as a local human-machine interface (HMI).

B. *Roles of Annunciators in Substations With HMI Displays*

Given the similarities of substation automation and distributed RTU systems, it comes as little surprise that annunciators can have the same roles in substation automation systems as those described in Section V for distributed RTU systems. The additional factors to consider in a substation automation system stem from the HMI displays.

1) *Alarm Management*

If annunciators coexist in the same station with alarm displays on HMI displays, it is important that the terminology, severity classifications, and acknowledgment status be consistent across the systems. Substation automation designers can benefit from process industry I&C practices to define comprehensive alarm management plans for substations, in part to provide consistent treatment of alarm conditions. ANSI/ISA-18.2-2009 specifically defines alarm management programs [8].

2) HMI Screens and Annunciation Considerations

Some developers of automation systems view annunciators as devices that can be supplanted by screens on HMI monitors that mimic annunciator windows and sequences. Success in supplanting annunciators with computer screens is dependent on the audience of the alarm annunciation functions and accommodation of their needs by the alarm management plan that drives the HMI display and interaction. To determine whether a distributed station automation system should include communicating annunciators and HMI screens or should provide annunciation only via HMI screens, consider the following factors:

- Audience. Who are the intended users of the alarm information? If all of the potential users and beneficiaries of the locally annunciated alarm conditions have the training and security credentials needed to access the HMI system for other purposes, it is easier to use only HMI screens. If there are personnel who have no other need to access automation systems via an HMI and they are the same people who use annunciators at stations without communications, then using annunciators for this segment of users is probably a sensible choice.
- Location. Is it valuable to provide alarm annunciation at multiple locations, or is a centralized HMI display sufficient? If there is value in presenting alarm information near the equipment monitored or in multiple sites, generally a remote annunciator makes more sense as a peripheral to the automation system than for these remote functions. For example, a small annunciator in each line protection panel can locally provide alarm information and transmit information to be displayed on a centralized HMI.
- Backup and reliability. Is the substation automation system fully redundant and insulated from common-cause failures? If so, an analysis of the availability generally shows sufficient reliability for most purposes. If the system is not fully redundant and there is, for example, a computer failure, having an independent annunciator provides a backup notification method until the system is repaired. In performing a fault tree analysis of nonredundant alternatives, the lower mean time between failures (MTBF) of computers and display screens compared with modern annunciators is also a factor. Modern annunciators experience an MTBF approaching 900 years, compared with the 3- to 30-year MTBF range of most computers and 4- to 12-year MTBF range of liquid crystal display (LCD) screens.
- Safety and hazards. Do the alarm conditions impact personnel safety? If so, it is easier to analyze and determine that a simple, self-contained notification system does not compromise safety than to analyze a more complex system. Certification or company safety policies may also require independent annunciation.
- Cybersecurity. Are there cybersecurity requirements within the local security perimeter? If the physical security of the substation perimeter is not sufficient, then local requirements for cybersecurity may prevent deployment of substation HMI screens throughout a facility. Or a requirement to log individuals who acknowledge alarms may work against the need to quickly silence a shrieking audible alarm.

Consideration of these tradeoff factors can guide the designers of HMI screens and annunciators to mitigate some of the disadvantages of each approach. An HMI screen with a default annunciator display and acknowledge and silence functions that do not require added login steps may be appropriate. Within a security perimeter, use of a physical key without any typing may be a sufficient login to satisfy an alarm acknowledgment logging requirement for a system or an annunciator.

VII. Advanced Annunciator Functions

A. Annunciator Logic

Communicating annunciators include control logic settings to use alarm points received from communications links for local annunciation and to operate on both local and received points to create composite points.

Annunciators with the control logic capabilities of programmable logic controllers or programmable automation controllers can perform additional control or alarming functions so that, in some cases, a single device provides annunciation, I/O, and PLC functions in a distributed automation system.

B. Sequential Event Recording

Connecting a precise time-synchronization source to an appropriately equipped annunciator enables it to serve as a standalone Sequential Events Recorder (SER) or to provide time-tagged SER records to an alarm collection system. To satisfy North American Electric Reliability Corporation (NERC) guidelines, time-tagging to at least one-millisecond accuracy is desirable.

C. Dual Main and Primary/Backup Protection Monitoring

An annunciator with logic and timing comparison capability can monitor the operation of redundant protective relay systems that use two functionally equal protective relays to provide protection (dual main) or of systems that use a primary protective relay plus a lower-performance backup relay (primary/backup). By monitoring the trip signal from each relay and comparing the time between the trip signals to a preset threshold, the annunciator can determine and notify of failure of one of the relays to trip or of one relay tripping too slowly compared with the other. Without comparative trip monitoring, a settings (or other) problem with one component of a dual main or primary/backup protection scheme might be masked by the proper operation of other devices. SER timing detail aids further analysis of conditions reported by the scheme comparison annunciation. Similar logic is feasible to monitor two-out-of-three voting schemes and other redundant control or protection installations.

VIII. Conclusions

Annunciators with built-in communications, I/O, and logic functions provide value in stations with no communications links or minimal automation through the range of those with extensive automation systems and communications:

- In stations without SCADA, annunciators provide alarm and equipment readiness monitoring so mission-critical systems operate when needed.
- In stations with SCADA or automation systems, annunciators can provide local alarm notification functions and interact with information processors to send and receive data to calculate composite alarm conditions and share alarm condition information. These annunciators can supplant duplicate remote I/O modules and wiring and/or serve as networked peripheral alarm display units for automation systems.
- In substation automation systems with HMI screens, there are multiple considerations and tradeoffs that can lead to systems with only HMI screen alarm notification or to hybrid systems that use both HMI screens and separate communicating annunciators.
- The advanced logic and time-tagging capabilities of modern annunciators enable them to monitor and alarm dual main, primary/backup, and voting protection or control schemes and to provide SER functions to a system.

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X. Biography

Gary W. Scheer received his B.S. in Electrical Engineering from Montana State University in 1977. He worked for the Montana Power Company (MPC) and the MPC subsidiary, The Tetragenics Company, before joining Schweitzer Engineering Laboratories, Inc. (SEL) in 1990 as a development engineer. He has served as vice president of the research and development division and of the automation and engineering services division of SEL. Mr. Scheer is now a senior engineer for precise time, networking, and communications products. His biography appears in Who's Who in America. He holds two patents related to teleprotection. He is a registered professional engineer and member of the IEEE and the ISA.

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