Modernizing Industrial Annunciator Systems: A Digital Approach to Centralized Alarm Management

Shahid Mulla, Tarek Kaddoura, and Muhammad Sheraz
Schweitzer Engineering Laboratories, Inc.

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Modernizing Industrial Annunciator Systems: A Digital Approach to Centralized Alarm Management

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***Abstract*—This paper presents a modern programmable controller-based annunciator system integrating alarm processing, visualization, and communications capabilities within a centralized architecture. Unlike conventional hardwired and lamp-based annunciators, the proposed approach enhances flexibility, scalability, remote accessibility, cybersecurity, and event management through modern digital technologies.**

The proposed system supports centralized alarm management, remote monitoring, event logging, redundancy, and secure user access, while maintaining operational familiarity with conventional annunciation philosophies. It also enables cost-effective retrofit and modernization of existing annunciator infrastructures by preserving portions of the installed base while introducing advanced functionalities, such as buffered event reporting, embedded human-machine interface (HMI) capabilities, and communications-based integration with supervisory control and data acquisition (SCADA) and supervisory systems.

Additionally, the architecture improves operational reliability through redundant alarm visibility and peer-to-peer communication mechanisms, while reducing wiring complexity and hardware requirements. The paper discusses system architecture, design principles, and key functional enhancements, demonstrating the suitability of modern programmable controller-based annunciation systems for applications in power generation, substations, oil and gas, manufacturing, and other critical infrastructure applications.

***Keywords*—Alarm, Annunciator, Cybersecurity, Event, Monitoring, Retrofit, SCADA**

I. Introduction

A. *Alarm Annunciator Function and Conventional System Limitations*

An alarm annunciator is a device used to alert operators to abnormal conditions in electrical, mechanical, or process control systems. It receives input signals from field devices such as sensors, auxiliary contacts, protection relays, and circuit breakers, and then provides visual and audible indications to help operators quickly identify and respond to abnormal events.

Alarm annunciators are widely used in substations, power plants, and industrial control rooms to centralize alarm monitoring. Depending on the system design and operational philosophy, annunciators may support functions such as alarm acknowledgment, silencing, reset, and flashing indications.

Conventional annunciators typically include front-panel alarm windows with configurable labels and lamp- or LED-based indicators for local alarm visibility. They are also interfaced with horns, buzzers, or speakers to provide audible alerts, with different tones sometimes used to indicate alarm priority levels.

Conventional annunciator systems have long provided reliable alarm indication in industrial facilities. However, conventional architectures are generally limited to hardwired, point-to-point signaling and local indication functionality, resulting in limited scalability, remote accessibility, and interoperability with modern digital monitoring systems. Early annunciators were predominantly hardwired and electromechanical or lamp-based. Foundational standards, such as ISA-18.1-1979, established consistent annunciator behavior, alarm sequences, and operator interaction principles that remain influential today [1].

Despite their reliability, conventional annunciator systems are inherently static, difficult to modify, and limited in functionality. They typically lack capabilities such as centralized alarm visibility, alarm analytics, event logging, remote accessibility, cybersecurity integration, and advanced event management functionalities that are required in modern operational environments.

In electrical substations, annunciators continue to play an important operational role even with the widespread adoption of supervisory control and data acquisition (SCADA) systems and intelligent electronic devices (IEDs). Their independence from complex software layers and predictable behavior makes them a dependable last line of alarm indication, particularly during abnormal or degraded operating conditions. However, conventional standalone implementations often result in fragmented alarm visibility across multiple control rooms and physical locations [2].

B. *Modern Alarm Management, Digitalization, and Security*

Alarm management standards, such as ANSI/ISA 18.2 and IEC 62682 address many of the limitations associated with conventional annunciation systems by defining a comprehensive lifecycle for alarm systems, including rationalization, operation, maintenance, and performance monitoring. These standards explicitly recognize annunciators and human-machine interfaces (HMIs) as integral components of alarm systems, providing a structured pathway for transitioning conventional annunciator functionality into modern digital platforms [3] [4].

A major focus in recent industrial practice is the retrofitting of existing annunciator systems. Retrofit approaches allow legacy field wiring, alarm inputs, and enclosures to be retained while modernizing processing, visualization, communication, and data handling capabilities. This strategy minimizes downtime, reduces commissioning risk, and significantly lowers capital cost, making it particularly suitable for brownfield installations [5].

In parallel, alarm analytics and centralized event logging have gained increased attention as tools for operational improvement. Centralized alarm logs enable postevent analysis, alarm performance monitoring, and continuous improvement capabilities not available in conventional hardwired annunciators [6].

As modern annunciator systems become digitally connected and centrally accessible, cybersecurity considerations become essential. Industrial cybersecurity guidelines, such as NIST SP 800-82, emphasize access control, authentication, auditability, encryption, and network segmentation for alarm and control systems. These annunciators can integrate security mechanisms while preserving deterministic alarm behavior and operational reliability [7] [8].

C. *Limitations of Existing Annunciator Solutions and Paper Objectives*

Although annunciators remain a critical element of industrial and substation operations, existing solutions often fail to holistically address legacy system retrofit capability, modern alarm management, cybersecurity requirements, centralized visibility, interoperability, and operational continuity within a unified architecture. This paper proposes a secure, scalable, and standards-aligned digital annunciator architecture capable of modernizing existing installations while preserving proven annunciation philosophies and operational familiarity.

II. Conventional Versus Modern Annunciator Architectures

A. *Conventional Annunciator Architecture*

A typical conventional annunciator architecture is shown in Figure 1.

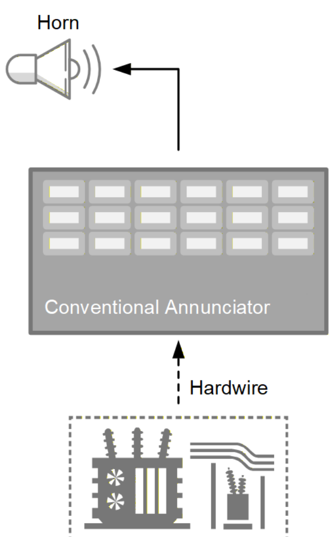

Figure 1. - Typical Conventional Annunciator Architecture

These architectures are primarily based on hardwired alarm inputs connected to lamp- or LED-based annunciator windows through dedicated wiring and auxiliary relays. They operate independently of higher-level supervisory systems and provide reliable local alarm indication through hardware logic and physical panels.

Audible annunciation is implemented using external horns activated through dedicated relay outputs. While this architecture provides reliable operation, scalability is limited due to extensive wiring required for adding or modifying alarm points.

B. *Modern Programmable Controller-Based Annunciator Architecture*

Modern programmable controller-based annunciation systems use embedded HMIs, communications networks, and software-defined alarm processing to provide centralized, distributed, and scalable alarm management architectures.

Unlike conventional standalone annunciators, modern architectures can integrate directly with SCADA systems, engineering workstations, web-based interfaces, and peer annunciators through standardized industrial communications protocols. This allows alarm information to be shared across multiple systems while maintaining consistent operational visibility.

Additionally, programmable controller-based architectures support modernization and retrofit initiatives by allowing portions of the existing field wiring and annunciation infrastructure to remain operational while introducing modern digital functionalities. Figure 2 shows a modern annunciator architecture highlighting different integration capabilities, as discussed in the following sections.

III. Functional Enhancements in Modern Annunciation Systems

A. *Integration With Nonhardwired Signals and Legacy System Retrofit*

Modern programmable controllers can integrate and acquire information through software-based communications with multiple IEDs, including protection relays, GPS clocks, Ethernet switches, meters, and other substation automation equipment. These integrations may be achieved via communications protocols such as IEC 61850 Manufacturing Message Specification (MMS), Modbus, Simple Network Management Protocol, and Distributed Network Protocol (DNP3), depending on the system architecture and application requirements. Figure 2 shows a modern annunciator architecture with the ability to integrate devices via widely used industrial protocols.

Unlike conventional annunciation systems that primarily rely on hardwired digital inputs, modern annunciation solutions can monitor both physical and logical signals obtained through communications networks. This expands annunciator monitoring and diagnostic capabilities by enabling the collection of critical operational information directly from connected IEDs. For example, annunciators can supervise relay alarms without requiring dedicated hardwired connections for each indication point. This reduces wiring complexity while improving scalability and centralized system visibility, as shown in Figure 2 (Location 2).

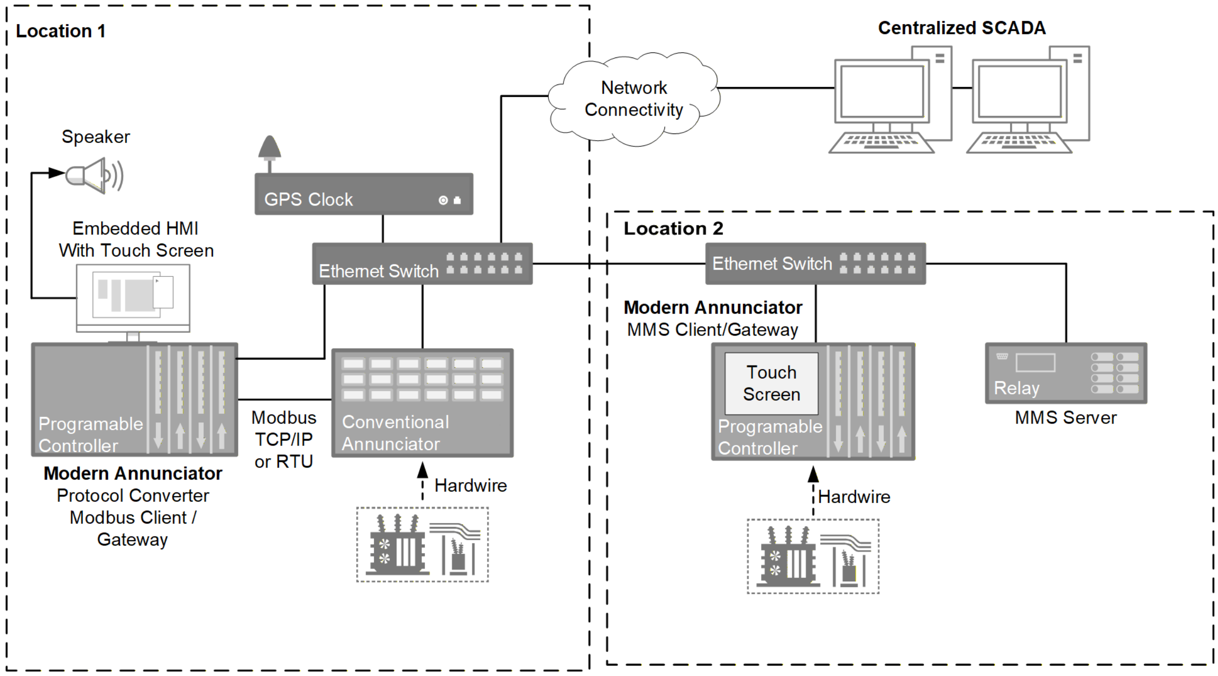

Figure 2. - Typical Modern Annunciator Architecture

Even when retrofitting conventional annunciation systems, communications-based integration may still be achievable through programmable controllers or gateway devices acting as protocol converters. For example, conventional annunciators communicating through protocols such as Modbus can be integrated with programmable controllers that subsequently expose the information using more advanced protocols, such as IEC 61850 MMS to SCADA or HMI systems. This approach enables protocol interoperability, centralized monitoring, alarm aggregation, and buffered reporting capabilities, while supporting relatively seamless modernization of existing annunciator infrastructures without complete system replacement, as shown in Figure 2 (Location 1).

However, overall system behavior still partially depends on the capabilities and limitations of the original source protocol. For instance, if communications between the conventional annunciator and the programmable controller are based on Modbus, functionalities such as event buffering, Sequence of Events (SOE), and time-stamped events are generally not inherently available on that communications segment. Consequently, a communications loss between the annunciator and programmable controller may result in missed or unbuffered alarm events.

Once the information is acquired and exposed through advanced protocols such as IEC 61850 MMS, functionalities including buffered reporting and time-stamped event handling can then be utilized between the programmable controller and upper-level SCADA or HMI systems. This hybrid integration approach improves interoperability and supervisory capabilities while preserving portions of the existing annunciation infrastructure.

B. *Time Synchronization and SOE Accuracy*

Accurate time synchronization is critical for post-fault analysis and correct sequencing of alarms and events across industrial and substation systems. Modern controllers support protocols such as Network Time Protocol and IRIG-B, enabling precise timestamping of events and status changes. This improves visibility and troubleshooting, especially in distributed systems, and allows operators to reconstruct fault sequences and analyze event order during abnormal conditions.

C. *Embedded HMI and Remote Annunciation Capabilities*

Modern programmable controllers commonly support embedded HMI capabilities that allow alarm windows, annunciation statuses, and operational indications to be remotely monitored while maintaining a visualization philosophy like conventional annunciator panels. As illustrated in Figure 2 (Location 1), the embedded HMI in the programmable controller can provide local alarm visualization, operator interaction, and audible annunciation through the same platform.

Unlike conventional annunciators, which are typically limited to fixed local indication windows, modern programmable controller-based systems can provide flexible graphical alarm visualization through integrated displays, web-based interfaces, engineering workstations, or centralized SCADA or HMI platforms. This improves accessibility, situational awareness, and operational flexibility, particularly in geographically distributed or unmanned facilities.

Although some conventional annunciation systems may support basic remote monitoring through protocols such as Modbus, these capabilities are generally limited compared to the advanced visualization and alarm management functionalities available in modern programmable controller platforms.

Additionally, embedded HMIs can provide audible alarm annunciation directly through the HMI platform without requiring dedicated external horns or speaker systems. Alarm sounds, tones, and annunciation patterns can be generated directly through the HMI platform and configured based on alarm priority or criticality. Modern HMI-based annunciation systems may also support advanced functionalities such as alarm filtering, prioritization, event history, remote acknowledgment, user authentication, and integration with SOE recording systems, improving alarm analysis, operational response, and maintenance efficiency.

D. System Health Monitoring and Alarm Validity Supervision

Modern programmable controllers can continuously monitor and report their own system health status, communication status, and the operational condition of connected IEDs. This helps operators differentiate between actual process alarms and issues related to communications failures, device malfunctions, or loss of supervision.

System health indications may be presented locally through LED indicators or graphically through HMIs. One common implementation is the Adjacent Device Status concept, where a watchdog or health-status output from one device is connected to another adjacent device for supervision purposes.

Additionally, programmable controllers can use configurable watchdog outputs and supervision logic to verify conditions such as communications health, valid time synchronization, and availability of critical services, thereby improving annunciation reliability and operator confidence in alarm validity.

E. Consistent Operational Philosophy

To preserve the established operational philosophy of conventional annunciation systems, modern programmable controllers can be configured to replicate familiar alarm behavior and handling sequences. This enables system modernization without introducing significant changes to operator interaction, response procedures, or annunciation philosophy. Figure 3 illustrates an industry-standard annunciator sequence.

Using IEC 61131 programming standards, modern programmable controllers can emulate conventional annunciator functions, including alarm initiation, acknowledgment, reset, audible signaling, and flashing logic. Standard programming elements such as timers, latches, edge-detection blocks, counters, and logical operators allow these sequences to be readily implemented, ensuring consistency with conventional systems while leveraging the advanced capabilities of modern controller platforms.

IV. Reliability and Redundancy Enhancements

The concept of redundancy in annunciation systems can be challenging when dealing with conventional hardwired architectures, as annunciators have conventionally depended on dedicated physical wiring for each alarm point. However, with the evolution of programmable controllers and communications-based architectures, multiple layers of redundancy can now be implemented at both the hardware and software levels to improve system availability, reliability, and fault tolerance.

A. Hardware-Level Redundancy

In annunciation systems, redundancy for hardwired alarm signals can be achieved by duplicating field contacts or by using auxiliary interposing relays to replicate alarm outputs. In such implementations, a single field alarm signal can be repeated through multiple relay contacts and distributed simultaneously to multiple annunciators, alarm panels, or supervisory devices. This approach ensures that alarm visibility is maintained even if one annunciator device becomes unavailable or isolated.

Modern programmable controller-based annunciators further enhance hardware-level redundancy by supporting dual power supply modules, redundant Ethernet interfaces, and independent communications paths. Although hardware redundancy improves reliability, it can significantly increase wiring complexity, panel space requirements, installation effort, and maintenance activities—particularly in large-scale substations and industrial facilities with extensive alarm points.

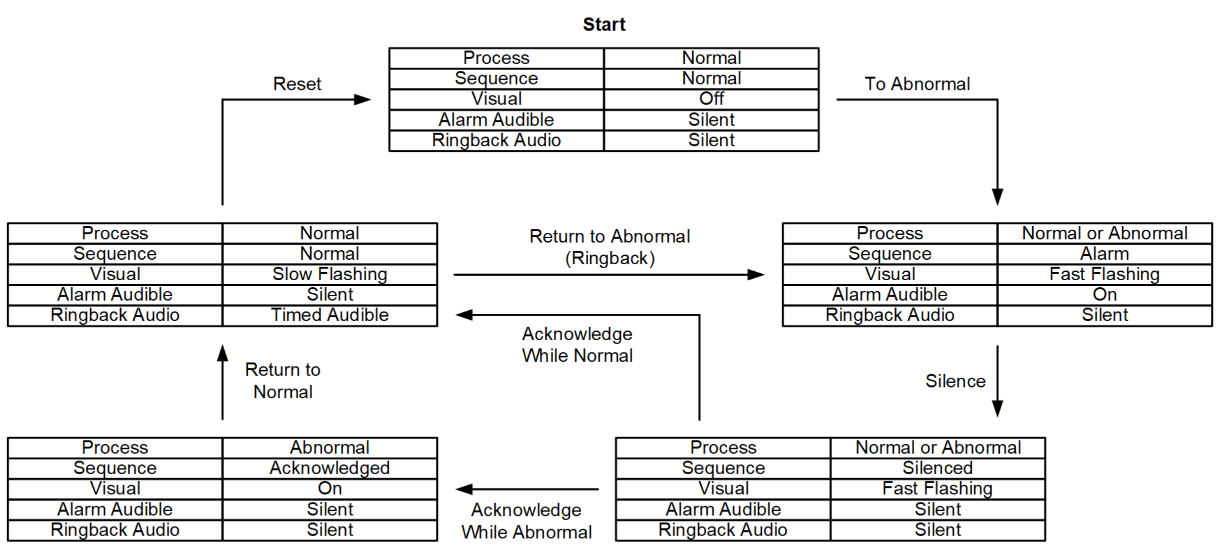

Figure 3. - Annunciator Sequence Example [1]

B. Software-Level Redundancy and Peer-to-Peer Alarm Exchange

Local programmable controller-based annunciators can communicate with peer devices to exchange alarm information, improving system availability and operational resilience. In such architectures, if one annunciator loses communication with the main SCADA or supervisory system, alarm information associated with its hardwired signals can still be distributed to peer annunciators through peer-to-peer communication mechanisms, such as IEC 61850 GOOSE messaging.

This capability allows critical alarms and operational statuses to remain visible across multiple annunciators during partial communication failures, network disturbances or network segmentation events, helping maintain operator awareness and alarm continuity.

GOOSE-based communications are particularly beneficial in modern substation and industrial automation systems due to their event-driven nature, low latency, and deterministic Ethernet performance. By leveraging such communication mechanisms, programmable annunciator systems can improve reliability, fault tolerance, and continuity of alarm annunciation without relying solely on centralized SCADA connectivity.

Additionally, exchanging alarm information digitally between peer annunciators can significantly reduce copper wiring requirements by minimizing the need to duplicate hardwired alarm circuits across multiple annunciator panels. This helps reduce cabling complexity, panel wiring density, installation effort, and overall implementation cost while simplifying future expansion and maintenance activities.

V. Cybersecurity and Secure Access Control

Modern programmable controllers support advanced access control and cybersecurity mechanisms to prevent unauthorized access and unintended operations. Common features include role-based access control (RBAC), where users are assigned different privileges—such as administrator, engineer, operator, or viewer—with configurable permissions for monitoring, configuration, logic modification, and system management functions.

Many controllers can also integrate with identity and access management (IAM) using services such as Lightweight Directory Access Protocol (LDAP) or Remote Authentication Dial-In User Service (RADIUS), enabling centralized user management, password policies, and account auditing across multiple systems and sites.

To enhance cybersecurity, secure communications protocols such as Secure Shell (SSH) and Transport Layer Security (TLS) are commonly utilized to provide encrypted and authenticated remote access, as well as secure communications between controllers, HMIs, SCADA systems, engineering workstations, and other supervisory devices. These capabilities help improve operational security, traceability, and compliance with modern industrial cybersecurity practices and standards, such as NERC CIP.

Unlike modern programmable controller-based annunciators, conventional annunciation systems typically provide limited or no access control functionality. Operations such as acknowledgment, silence, or reset can often be performed directly by any personnel physically present in front of the annunciator panel, without authentication or authorization. In contrast, modern annunciators are often equipped with touchscreen or monochrome displays and may also integrate with HMI or SCADA systems, enabling user authentication and privilege verification before operational or configuration-related actions are performed, thereby improving accountability and overall system security.

VI. Comparative Analysis Between Conventional and Modern Annunciation Systems

Table 1 summarizes the key differences between conventional and modern programmable controller-based annunciation systems in terms of architecture, communication, event handling, cybersecurity, scalability, and interoperability, while highlighting modernization and retrofit capabilities.

Table 1 - Comparison Between Conventional and Modern Annunciation Systems

Feature	Conventional Annunciators	Modern Programmable Annunciators
Alarm Input Type	Primarily hardwired	Hardwired and communications-based inputs
Communications Protocols	Unavailable or basic	IEC 61850 MMS, DNP3, IEC 104, and Modbus, etc.
Time-Stamped Events	Limited or unavailable	Supported with SOE functionality
Remote Monitoring	Unavailable	Possible through network connectivity
Embedded HMI	Typically, unavailable	Supported
Audible Alarm Flexibility	Dedicated external horn required	Software-configurable audible annunciation
Alarm Analytics	Limited historical analysis	Event logging, alarm analytics, and postevent analysis
Cybersecurity	Minimal or unavailable. Physical access typically sufficient for operations	RBAC, authentication, SSH, TLS, LDAP or RADIUS integration. Authentication and privilege-based operational access
Peer-to-Peer Alarm Sharing	Typically, unavailable	Supported through protocols (e.g. GOOSE messaging)
Scalability	Limited	Highly scalable
Maintenance	More difficult	Easier and more flexible
Operational Philosophy Preservation	Native	Can emulate conventional behavior and even be enhanced

VII. Conclusion

Modern programmable controller-based annunciation systems provide significant advancements compared to conventional hardwired annunciators, including improved scalability, interoperability, cybersecurity, event handling, remote accessibility, redundancy, and centralized alarm management capabilities.

By leveraging communications-based architectures, embedded HMIs, buffered event reporting, peer-to-peer communication, and secure access control mechanisms, modern annunciation systems can significantly enhance operational awareness, alarm continuity, and system resilience while maintaining deterministic annunciation philosophies familiar to operators.

Furthermore, the ability to retrofit existing annunciator installations using hybrid architectures and protocol-conversion approaches provides a practical and cost-effective modernization pathway for industrial facilities, substations, and critical infrastructure environments. This enables enhanced alarm management capabilities without requiring complete infrastructure replacement.

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