Smart Traction Power Substation Concepts
A White Paper for Enhanced Operations and Maintenance
Prepared for the 2011 APTA Rail Conference, Boston, MA (June 2011)

ABSTRACT

Traction power design practices are evolving through the refinement and adoption of “smart” substation standards and a proliferation of new hardware and software technology which provides enhanced capabilities and greater flexibility for transit agencies to more effectively operate, maintain and secure critical power distribution infrastructure and related substation facilities.

Traditionally substations were designed upon a distinct separation between the substation components and the SCADA system. The substation manufacturer wired out control, indication, and analog points to an Interface Terminal Cabinet (IFTC). These points were then wired over to an RTU. By applying distributed control techniques in the substation the wiring to the IFTC can be eliminated and replaced by a local network.

As these advancements gain greater awareness and acceptance, many in the industry have begun to embrace or at least recognize the potential benefits of deploying smart technology in traction power substations to keep pace with emerging operations and maintenance (O&M) trends and regulatory requirements. However, there seems to be less consensus regarding the extent or how best to apply smart substation technology across the power distribution network to enhance operational performance, increase reliability, ensure interoperability, simplify maintenance, address life-safety concerns and control costs.

This paper focuses on smart substation concepts for enhanced operations and maintenance by first exploring the technical characteristics and advantages of modern traction power substations and then presenting some practical benefits that can be realized through the integration of the latest intelligent electronic device (IED), networking and software technology to support:

- Web-enabled Accessibility to the Substation
- Transfer-Tripping
- Multifunction Relay Protection
- Power Management
- Sequence of Events Recording
- Remote Breaker Racking
- Equipment Condition Monitoring
- Maintaining Systems and Equipment
- Video Surveillance and Security

VALUE PROPOSITION

Until recently the technical and performance requirements specified for many traction power systems failed to keep pace with modern technological advancements and changing O&M practices. Traditional practices drove procurement policies and design decisions for the core electrical equipment and constrained the potential capabilities of modern SCADA, substation automation and protection systems.

Moving forward, there is little doubt whether smart substations will become the norm in the transit industry as the need for distributed intelligence and decentralized operations becomes prevalent to more effectively manage and maintain sophisticated power distribution systems. The primary questions to consider when justifying the investment are:

- To what extent should smart substation concepts be deployed?
- How best to invest and apply technology to reduce recurring O&M costs, support future expansion and simplify system maintainability?
- What is the potential impact on staff resources and continuity of operations?

While smart substations may introduce additional technical challenges and complexities into the design process and require a different skill set to deploy and maintain, there are tangible and practical benefits that can be realized through the implementation of modern concepts including:
**Simplified Installation** - Smart substations employ a modular approach in the manufacturing process that simplifies production and can streamline substation deployment during start-up and testing phases.

**Less Reliance on Proprietary Technology** - The application of standards-based commercial-off-the-shelf (COTS) or open source products is an important safeguard against future excessive cost escalations, reduces the risk of dependence on any single vendor, and provides a more comprehensive and competitive supply chain should obsolescence or spare parts availability become an issue.

**Scalability** - Due to the configurability and distributed nature of the smart substation architecture, there is an inherent flexibility and scalability designed into the system to better accommodate incremental enhancements and future expansion by significantly reducing dedicated wiring, conduit and cable trays routed between devices for monitoring, control and circuit protection. This reduction in circuitry is especially important when prefabricated power control rooms with shipping splits are employed for the installation.

**Reduced Downtime** - The latest available hardware and software products can make a maintenance technician’s job much easier when it comes to diagnostics and troubleshooting. Modern IEDs contain extensive online tools to identify, isolate and monitor the operational state of equipment and integrated system as a whole. With basic instruction, even novice technicians can quickly diagnose problems, identify failed components and make the necessary corrections to restore normal operations.

**Configurability** - Smart substations support the convergence of disparate systems and components to achieve integrated solutions that best fit the application. This convergence is achieved through the “tight-coupling” (integration) of hardware and software platforms which can be programmed to expose expanded real-time data sets and historical records that can be used to enhance process visualization and optimize system performance.

**Regulatory Compliance** - The on-line tools, data archiving capabilities and security features built into many of the latest hardware and software products enable rail operations to better manage and secure their traction power systems, substation facilities and related wayside infrastructure. Advanced features of smart substation include maintaining “firewalls” for authenticated network access, storage of precision event records and integrated video footage. These capabilities can be invaluable should a failure or accident occur in order to comply with more stringent critical infrastructure protection standards, safety guidelines and changing industry regulations.

**Opportunity for Staff Development** - Implementing new standards or making technology improvements often requires an additional investment in training and staff development. In many cases, organizations resist these changes due in part to the added expense and potential disruption to ongoing operations. While these are valid concerns, the migration towards smart substations provides a unique opportunity to not only ensure staff have the necessary skills to keep pace with technology, but also allow them to be more self-sufficient with regard to carrying out application enhancements and other proactive maintenance measures, which are often performed by third parties for additional cost.

**CHANGING REQUIREMENTS**

Supervisory control and data acquisition (SCADA) systems serve an important role for transit operations because they deliver valuable real-time information, facilitate the collection of historical data and provide controls, which are key to delivering power for rail services in a safe, efficient and reliable manner. However, the traditional role of SCADA is changing in an effort to increase the useful life and reliability of equipment through proactive problem detection and intervention, address security concerns, ensure safety for agency personnel and passengers, promote energy conservation and support other strategic initiatives that benefit the efficiency and effectiveness of the rail operation. The need for more flexible and sophisticated SCADA solutions becomes more apparent as:

- The level of integration with other enterprise systems increases
- The requirement for more users to quickly access real-time and historical information grows
- New communication protocols, networking standards and data conventions are adopted based on recognized international standards
- Transit operations seek additional tools and enhanced aids to better manage and maintain systems

Smart substations are highly automated, integrated networks of monitoring, control and protection systems incorporating new levels of functionality that help fulfill these objectives.
Modern system designs do not view traction power as merely a subset of telemetry points under the SCADA hierarchy as is often the case for traditional legacy installations. The traction power system, through the application of smart substation concepts, is evolving into a series of interconnected logical nodes within the rail enterprise and accessible to a wide array of users and systems including: SCADA, facilities management, security, train control, power engineering, corporate IT, reporting and maintenance management.

**BENEFITS OF INTEGRATION**

Are there inherent advantages of smart substations in terms of architecture and functional capability over traditional designs? While technology selection and integration strategy are two important factors, generally speaking smart substations employ standards and methods that provide an integrated framework for platform scalability, operational flexibility, improved asset management, simplified maintenance, and coordinated protection schemes. It is the network architecture, advanced programmability, and distributed nature of smart substations that makes these functional improvements possible. As designs evolve further towards object-oriented models incorporating logical nodes, standard data conventions and common protocols rather than a collection of hardwired discrete components connected to a dedicated RTU or teleprotection devices the disparity between traditional and smart substations will continue to widen.

Individual components within each substation automation system will continue to perform dedicated monitoring, control and protection functions, but as logical nodes accessible to the entire network, these components can be configured and programmed to greatly enhance the operational capabilities of the power distribution system as a whole. Looking at an example of a modern integrated system hierarchy, it is easier to see the logical interconnections between substations and other power distribution systems within the rail enterprise.

**Tier 1 Substation Process and Bay Level Components** - Process and bay-level components like intelligent electronic devices, multi-function relays and programmable controllers maintain a dedicated role and perform specific functions within the substation. These devices are not configured to report solely to any single local master (e.g. SCADA RTU and/or HMI) for monitoring and control purposes nor do they necessarily perform standalone protection or power monitoring functions. While the connections from these devices to SCADA are maintained (either directly over the network or logically through a localized substation controller serving as data concentrator), there is additional flexibility and scalability built into the design through distributed processing and support for peer-to-peer communications.

Moreover, there is an extensive data set and other advanced features resident in these individual “smart” devices outside the scope of traditional SCADA that can be exploited for enhanced maintenance activities and protection schemes. By integrating these devices on a common high-speed network (typically Ethernet) with standard protocols and software interfaces, agencies gain complete accessibility (locally or remotely) to the full compliment data and expanded feature-set needed to perform advanced functions exclusive of SCADA including:

- Oscilliographic waveform capture for power quality and disturbance analysis
- Sequence-of-events (SOE) recording
Smart Traction Power Substation Concepts

- Equipment condition monitoring for preventative and predictive maintenance
- Improved fault detection and isolation
- Coordinated feeder protection and transfer-trip functions between substations using high speed peer-to-peer messaging between IEDs and relays
- Expanded online diagnostics and troubleshooting

**Tier 2 Substation Master Controller and HMI -**

Like legacy systems, smart substations often incorporate a master controller which serves as the primary interface (or data concentrator) to the host SCADA system while also performing localized substation monitoring, interlocking and control functions independent of SCADA. In many respects, a smart substation master controller functions much like a traditional RTU by processing I/O and carrying out logic functions. However, modern substation controllers are designed around open standards that promote interoperability and the direct integration of third party technologies over the substation network(s) following industry-recognized communication protocols (e.g. IEC 61850, DNP 3.0 and Modbus) and data tag conventions. The use of extensive hardwired circuitry and terminations within dedicated I/O marshalling cabinets, typical for legacy RTU-based designs, is avoided to the extent possible. Following this approach, the DIOs, IEDs, MFPRs and other “smart” devices located throughout the substation and distributed within the electrical equipment lineups essentially become a logical extension of the substation controller. The I/O terminations are maintained at the bay-level edge device to simply installation and troubleshooting, but the master controller has access to the full complement of I/O, supplemental data and localized control functions resident and/or programmed in the edge devices.

The use of human machine interface (HMI) panels in substations is an accepted practice for local monitoring, alarm annunciation and control functions. For installations that incorporate HMIs, an “embedded” form of touch screen-enabled graphics terminal is often used rather than a standard-office grade or industrial PC platform. These commercially available ruggedized HMIs are configured and programmed through software and networkable like a PC, but often rely on special purpose or embedded operating systems with reduced instruction sets to host and run the HMI software applications. These simple operator interface terminals certainly deliver the performance and reliability needed to manage the local substation environment. However, in recent years industrial PC-based HMI technology running variants of Windows® or Linux based operating systems has gained additional interest as the cost of industrial PCs vs. embedded HMIs narrows and the demand for more flexible computing platforms at the substation level grows. This white paper does not advocate one approach over the other as either option fits well within the smart substation architecture depending on application-specific operating and maintenance objectives. However, there are some additional benefits agencies can realize by deploying industrial PC-based HMIs in the substation including:

- Computing platform and operating system(s) consistent with corporate IT standards
- Flexibility to install and run greater compliment of software applications
- Additional options for communications port expansion, protocol support and drivers
- Local HMI software can operate as a thin-client to host SCADA and other enterprise systems
- As a client to the host SCADA system, the “look-and-feel” of the HMI software environment and user interface remains uniform from the field level to central operations
- Ability to install local programming, provisioning and diagnostic software to support the full complement of substation automation, relay protection and network devices
- Ability to store online copies of electronic O&M manuals, drawing sets and other relevant documentation needed to maintain the substation
- Ability to deploy standardized online forms to support site inspection procedures and create deficiency reports that can be uploaded automatically and integrated with enterprise maintenance management systems
- Ability to generate electronic or hardcopy work orders at the site for maintenance staff and field technicians
- Configuration management; current copies of applications programs and substation documentation can be maintained in central repository systems and then downloaded to the local HMI PC to ensure revision control

**Tier 2 Facility Systems -** Access control, intrusion detection and security/surveillance systems may be integrated components within the smart substation architecture, but considered ancillary facility systems in the context of this report. While these systems serve an important role by monitoring and protecting substation facilities against unauthorized entry and other malicious
attacks, they are not a focus of this paper. What it is important to recognize is that further integration of these ancillary systems into the smart substation platform, and ultimately SCADA, can greatly enhance situational awareness for operators and first responders to quickly detect and more effectively respond to potential threats and emergency situations. Given the convergence towards Ethernet networking to the substation, greater industry support for host system APIs and data exchange mechanisms (e.g. web services, schema-based SOAP/XML, JAVA RMI, OPC, etc.) and modern IP-based multicast video, this level of functionality becomes more cost effective and justified to better address security concerns. The last section of this paper highlights a practical example of how access control, intrusion detection and security/surveillance functions can be integrated with SCADA to augment substation monitoring capabilities and incident preparedness.

**Tier 3 Wayside Systems** - Traditional traction power designs that incorporate wayside systems like rail heating and emergency trip/blue light often rely on dedicated hardwired and fiber optic circuits between electrical facilities for monitoring, safety-circuit interlocking and control purposes. While these methods have been in use for decades in the industry, the functional capabilities of such discrete systems is often limited and the resources needed to support, diagnose and troubleshoot problems can be labor intensive and time consuming. A growing number of agencies are interested in exploring more flexible automated wayside options as an integral component of the traction power system and SCADA that can be deployed for both green field projects or as retrofits on existing lines to provide:

- Real-time monitoring of the “health” of wayside circuits and associated equipment
- Access to more extensive diagnostic data points to help isolate system faults and failures
- Precise geographic indication of emergency trip/blue light events in a GIS-enabled SCADA environment
- Automated rail heating scenarios
- Enhanced power management capabilities for energy conservation initiatives

This level of functionality requires “intelligence” to be expanded from the substations throughout the wayside systems using distributed I/O or other intelligent electrical devices (IEDs) located at the field nodes. The wayside DIO/IEDs serve as remote monitoring points, provide safety interlocks or permissives, and support track segment and rail heater energization functions as logical extensions of the integrated smart substation platform. All remote devices interface the power SCADA system through the nearest substation LAN segment(s) and/or directly over the rail DTS network rather than the dedicated point-to-point circuits typically used. While the initial capital expenditure to implement this level of automation may be higher than that for traditional discrete hardwired systems, the improved performance capabilities, increased safety, simplified maintenance and potential energy savings can result in greater operational efficiencies and return on investment.

This concept of distributing intelligence and network connectivity to the field nodes can be expanded further to incorporate video and voice (i.e. call box and intercom) capabilities between central operations and the wayside systems. Using blue light as an example, the usefulness and practicality of the application becomes evident. Operators receive alarm notifications of emergency events and may even have some method of communications to the location in question. However, often times there are no provisions to visually confirm an incident to better understand the circumstances or severity of the problem without dispatching personnel to the site. By supplementing the existing failsafe alarm and interlock circuitry with a modern network interface for video and voice functions, additional data can be collected from the site for incident management purposes coupled with real-time video and voice communications.

**Tier 3 Internetworking Smart Substations** - The ability to directly interconnect substations over high speed networks is an important consideration for modern traction power system designs. This capability enables automated feeder management for transfer-trip functions and other coordinated protection scenarios that can be refined and expanded through software configuration of breaker IEDs and multifunction relays without reliance on additional fixed point-to-point teleprotection circuits. Most of the leading suppliers of controller, IED and protective relay technology in the industry currently support such communication options for their equipment. To the extent practical, substation planning and design should accommodate master controller and/or smart bay-level components that support this functional capability; if for no other reason than to keep pace with emerging standards and minimize the potential for future costly field retrofits.

**PRACTICAL APPLICATIONS**

The final section of this paper demonstrates some practical examples of how smart concepts can be applied to expand the operational capabilities of substation...
monitoring, control and protection functions, simplify diagnostics and troubleshooting, safeguard personnel, support proactive maintenance, secure facilities and manage incidents.

Web-Enabled Accessibility to the Substation

Many legacy substation designs incorporate simple annunciators or mimic boards to display critical status indication and alarm points locally within the substation. This approach provides field technicians a high-level view of the overall state and health of the traction power equipment and related systems under normal operating conditions. However, since these displays often only provide summary information with a fixed compliment I/O points they are not a particularly useful tool to isolate, troubleshoot and further diagnose the source of problems should they occur.

Modern substation designs have evolved to accommodate improved local data acquisition and control through the use of software-programmable operator interface or HMI panels networked directly to the local substation controller(s), IEDs and other microprocessor-based equipment. The HMI dynamic screens provide a basic level of functionality and “look-and-feel” comparable to the host SCADA system software, but these units often run autonomously from the host system as a portal for local user access. HMI panels are not constrained by hardwired I/O connections. They acquire data and issue control commands directly over networked connections to other components within the substation automation system. As such, they are configurable through software to “link to” as many devices and I/O points necessary to provide adequate visualization and control of the traction power equipment and related processes. This capability also includes direct access to the diagnostic and event data resident or stored in the smart devices for improved online troubleshooting and maintenance. While these HMIs offer significant advantages over legacy annunciators and mimic panels, they are not always accessible to maintenance or engineering staff without using special software or client licenses for remote access.

The latest generation smart substations have taken local HMIs a step further by supporting a web-enabled user interface to access the full capabilities of the HMI (locally or remotely over the network) using a standard browser. The term “web-enabled” does not necessarily imply that access can be gained over unprotected public domains like the Internet. While this capability exists for remote staff using authenticated, secure virtual private network (VPN) connectivity, there is no requirement that the connection be exposed outside the secure enterprise network domain. Routers, firewalls, password-protected authentication and other corporate IT security policies are incorporated and/or administered to maintain security and prevent unauthorized access to these HMIs.

This browser-based HMI is advantageous because it allows greater flexibility to deploy user interfaces without having to rely on costly node licenses or special software to perform remote monitoring, control and diagnostics. Because these HMIs support multiple concurrent users over the network, it is a very practical and powerful tool for maintenance technicians and engineering support staff to better manage substations exclusive of SCADA. In many instances, the data and functional capabilities provided through SCADA for normal day-to-day operations, is different than that needed by maintenance and engineering staff to evaluate power quality issues, carrying out routine diagnostics, perform failure analysis and support equipment condition monitoring. What this HMI technology offers transit agencies is a dual-purpose tool that supports both local operating and maintenance functions on a single platform.

Transfer-Tripping

Transfer-trip systems provide coordinated control of substation feeder breakers for common track segments when a fault condition is detected on the third rail or overhead catenary. Under traditional designs, transfer trip functions are often accomplished through hardwired interlocking and dedicated teleprotection circuits routed between substations that actuate the feeder breakers responsible for segment energization/de-energization. While fiber optic based teleprotection provides a reliable and low cost solution for transfer-trip and is well established in the industry, this method does not take full advantage of the programmability and functional capabilities offered by the latest IEDs and multi-function protective relays used in smart substations.

In cases where teleprotection is employed, the transfer-trip network incorporates dedicated fiber optic circuits in the field to transmit trip/close commands and hard-wired connections within the substations that serve as the final interface to control the feeder breakers. These “fixed” circuits can be problematic if a change to the transfer-trip system is required because additional field work is often required to change or expand transfer-trip interlocking, status and control points between substation sites. This is particularly relevant, when transfer-trip functions involve not only adjacent substations, but multiple substations along a given track segment.
Smart Traction Power Substation Concepts

Smart substations can address this problem by offering an alternative for transfer-tripping through direct peer-to-peer communications between substation IEDs and MFPRs using high-availability rail DTS networks as the transport mechanism. To achieve this level of functionality, there must be an Ethernet IP based connection between the substations that supports VLAN provisioning and the end devices controlling the feeders (e.g. IEDs and MFPRs) must be capable of receiving and transmitting messages using peer-to-peer messaging like IEC 61850 GOOSE. The IEDs and MFPRs are configured to maintain communications with each other to monitor the status and health of the transfer-trip system. When a transfer-trip event occurs the devices within the fault zone automatically detect the condition and transmit the appropriate commands over the network to all target devices identified in the transfer-trip plan to control the corresponding feeders. For additional protection, the IEDs and MFPRs can also be configured to monitor the health of the transfer-trip system for network or component failure. When a fault or failure occurs, the appropriate alarm(s) can be stored in the device’s event record and automatically notify operators and/or maintenance technicians of the condition.

The integration of the substation feeder IEDs and MFPRs provides greater flexibility for the transfer-trip schemes because status, interlocking and breaker control is configurable through software, not limited by point-to-point hardwired connections. The resulting systems are adaptable and can evolve as needed to better meet future changes to the power distribution system or enhancements to the transfer-trip strategy.

Multifunction Relay Protection

Many legacy designs rely on electromechanical or solid state relays for interlocking and protection, while a PLC or RTU is often employed to monitor and control the corresponding breakers. Smart substations consolidate the protection, monitoring and control functions through the use of multifunction protective relays (MFPR) that service the individual breakers. Following this approach, protection is maintained by the MFPRs, but hardwired I/O connections to a local PLC or RTU for monitoring and control of the breakers are unnecessary. As a networked IED, the relay is a logical node within the overall SCADA architecture, providing the means to distribute the final I/O interface and critical data processing to the bay-level. Additionally, the MFPR configuration offers greater performance and scalability for protection and control systems through peer-to-peer communications, an enhanced data set and customizable programming.

With the introduction of the IEC61850 standard, it is now possible to implement transfer trip and other automated interlocking schemes internally between protection relays, provided they support the IEC61850 protocol and reside in the same network broadcast domain. The GOOSE messaging capability of IEC61850 allows protective relays to broadcast messages over a dedicated high speed Ethernet backbone, which can then be interpreted by any other relay to carry out specific control commands exclusive of SCADA. This capability allows for maximum flexibility in the protection scheme, eliminates the need for multiple auxiliary devices and reduces the cost to install and maintain the associated hard wired circuits.

Power Management

Smart Substation technology can offer a variety of power management options including:

- Demand Management at the substation level by using Thyristor Controlled rectifiers
- Energy Metering to determine substation utilization and estimating the requirements for system upgrades
- Integration of energy storage techniques using flywheels, batteries and super capacitors or some combination thereof

Energy storage techniques have gained greater interest in the industry as a method to transfer kinetic energy. Current technology allows the use of lightweight carbon fiber flywheels, batteries and super capacitors to store energy for future use. One option is to use these devices to store power, which can then be released on demand back to the power source or within the distribution network. For traction power applications, energy storage can be used to store braking energy generated by the trains traditionally lost through heat dissipation that can be injected back into the system to reduce overall energy consumption. These energy storage techniques can also be used for demand leveling. Power is taken out of the system when trains are not present and injected back in as trains accelerate, lowering overall system demand. Depending on a transit system’s billing structure, this could significantly lower utility costs.

Sequence of Events Recording

Many modern microprocessor-based controllers, IEDs and MFPRs support sequence of events (SOE) recording to capture high precision, time stamped data triggered by alarm/event conditions. The SOE data sets are stored in a device’s nonvolatile memory and not
typically exposed to SCADA for day-to-day operations. The purpose of these historical event files is to retain a time-series record of an incident (i.e. alarm, fault, etc.), which can then be retrieved by engineering or maintenance staff to conduct root cause analysis. By analyzing the SOE files of the device(s) affected by a fault, one can essentially model the conditions before, during and after the fault to diagnose the source of problems and more quickly restore normal operating conditions. Accurate SOE data is also valuable in accident and anomaly investigations.

A typical SOE record includes information including point description, point value/status, time stamp and the device ID capturing the event. Since SOE records are compared using a common time base, typically to 1ms resolution, it is extremely important that all SOE-enabled devices be synchronized using a precision time source based on a common GPS (IRIG) or PTP-derived signal. If the individual device clocks are not fully synchronized, the time stamps applied in the event records will not be consistent between the event records. The SOE files will still contain a log of sequential events with time stamps, but a direct correlation of events at any particular instant in time is not possible.

Remote Breaker Racking

Arcing faults occur many times in electrical distribution switchgear. When examining incidents of faults, it is clear the most likely time for an arc occurrence is when the circuit breaker is changing state between the connected and disconnected positions. This can be particularly dangerous when operators or maintenance technicians are present to place breakers in and out of service. Smart substations support a simple solution known as remote breaker racking or onboard racking to minimize this hazard.

By removing the operator from the equipment during the racking process, the operator does not have to open the cubicle door or interface with the switchgear to rack breakers in or out. Switchgear equipped with onboard racking capabilities includes an integral motor-operated racking feature that allows circuit breakers to switch from the connected to disconnected position (or vice versa) without an operator having to physically intervene. The racking motor is wired through the cubicle’s primary control circuit allowing commands issued from the local HMI or remotely through SCADA to engage the racking sequence. The entire remote racking process is completed automatically with personnel safely located outside the arc flash zone and can eliminate the need to send an operator to the substation to rack out breakers for system maintenance.

Equipment Condition Monitoring

Equipment condition monitoring is becoming a more common practice in smart substations as a means to maintain proper operating conditions and support proactive maintenance in an effort to extend the useful life of traction power equipment. The concept expands the scope of traditional SCADA status indication and alarm monitoring by using the real-time data collected to trigger or initiate condition alarms, work orders or other maintenance notifications before an actual fault or failure occurs. The ultimate objective is to detect, isolate and resolve adverse conditions before they lead to equipment failure or extended periods of improper operation that could result in premature failure, excessive downtime and costly equipment rehabilitation. Two simple examples of how equipment condition monitoring can be applied involve the tracking of breaker operations and measuring real-time temperature trends at selected test points like switchgear bus, rectifier heat sinks and transformers.

Breaker Operations - Online tracking of breaker operations (i.e. trip/close cycles) should be a high priority in every preventative maintenance program. By tracking these operations, agencies can receive automatic notification from SCADA or the substation automation system indicating a breaker is near or has reached the maximum total number of cycles recommended by the equipment manufacturer for preventative maintenance. This level of functionality has been problematic in the past because it is straightforward to capture the number of operations if a breaker remains in a designated switchgear cubicle, but can be more complicated if breakers are interchanged between bays. With modern technology, the process of tracking and resetting total breaker cycles becomes much easier to implement because the individual breakers can now be identified by the control system using simple umbilical-style keyed assemblies that provide breaker IDs to ensure the cycles recorded for the switchgear cubicle correspond to the installed breaker. Additionally, a smart substation could track the magnitude of current during each circuit breaker operation. Current magnitude is a more important factor than number of operations in circuit breaker maintenance scheduling and as a predictor of circuit breaker life.

Enhanced Temperature Monitoring - Applying real-time temperature monitoring for switchgear bus and rectifier heat sinks can be a beneficial tool to help maintain the proper working condition of the equipment. A primary advantage of the technology is its ability to
provide engineering and maintenance staff with the data needed to identify hot-spots and analyze temperature fluctuations over extended periods before an alarm condition or equipment failure occurs. Unlike traditional discrete temperature alarms, modern networkable monitoring systems record and transmit precision analog data that can be used to help predict the potential for equipment failure based on the actual temperature profile. Discrete alarms only announce once a failure has occurred or an alarm threshold has been reached. Temperature monitors can be configured to activate alarms through adjustable set-points and also record temperature data at resolutions needed to differentiate momentary fluctuations vs. temperature trends. There are a number of traditional products that rely on resistance temperature detectors (RTDs) for monitoring, but the high electrical potentials in switchgear and rectifiers can present a problem for RTD installation and signal accuracy. The latest fiber optic temperature sensing technology is viable for substation applications, cost effective and provides complete electrical isolation.

Maintaining Systems and Equipment

Maintenance planning and scheduling for traction power equipment is often based on a dedicated maintenance management system (MMS) or in accordance with the manufacturer’s recommended corrective or preventative maintenance guidelines. The application of smart substation concepts like equipment condition monitoring can be used to augment scheduling policies and greatly improve the overall capabilities of maintenance management systems. However, there are other practical solutions that can be deployed at the substation level to ensure personnel have the tools needed more effectively maintain substation systems and equipment, both remotely and locally in the field.

Recent advancements in hardened PC technology have made it more reliable, competitive and technically feasible to deploy PC-based HMIs that can serve both operations and maintenance functions. Standardizing on PC-based HMIs can be advantageous because they are fully-functional computing platforms that can operate independently as local HMIs or under a client-server SCADA environment. Moreover, these PCs can run additional software applications concurrently with the operator interface like relational databases, diagnostic programs, online O&M manuals, electronic drawings and other support programs that can be directly integrated into other enterprise systems. Practical examples of enhanced features available through PC-based systems include:

- **Periodic Inspection Forms** - Online spreadsheets or custom inspection report forms can be made available to personnel to identify deficiencies observed during field inspections. These forms can then be automatically uploaded over the network for input to the MMS to schedule corrective action or parts replacement.

- **Equipment Condition Monitoring Database** – Modern substation controllers have the ability to transfer equipment condition monitoring information directly to corporate-level maintenance management or asset tracking relational databases. This information can be used to generate work orders automatically based on real-time data rather than pre-defined maintenance schedules.

- **Automated Maintenance Requests** - In many operations, equipment alarms are received through SCADA and then a trouble call or work order is issued. Smart substations are capable of notifying maintenance staff directly via email, SMS text messaging or similar means exclusive of SCADA. This capability eliminates an unnecessary step in the notification process to improve response times.

- **Online File and Program Repository** - Current electronic versions of substation O&M documents, drawings and application programs can be maintained in a centralized configuration management system and then made accessible to field technicians through the local substation HMI. This method helps maintain version control for the record documents, CAD files and application programs relevant to the substation.

- **Accessibility** - Engineering and maintenance staff have the ability to access the substation remotely or locally for configuration and programming, to analyze event records, perform system diagnostics and modify equipment software settings without additional PC equipment and software licenses.

Video Surveillance and Security

In today’s environment, securing traction power infrastructure is essential. While a subset of basic substation security alarms are often monitored through SCADA, other related security functions like video surveillance remain outside the scope of the traditional SCADA system. In many cases, transit agencies view SCADA and security as separate areas of responsibility, and as such, often rely on separate systems to manage these functions. However, given recent advancements in software and IP-based digital video, many of the technical barriers that hindered the convergence of systems are shrinking. The ability to safeguard substations through
the integration of video surveillance, intrusion detection and incident response systems under a homogeneous SCADA/security environment (i.e. graphical user interface) is more cost effective and should be higher priority given heightened security concerns for critical infrastructure.

**Video Integration** - Fusion of live video with real-time SCADA information provides improved situational awareness for incident detection and response. Video monitoring, recording and camera control functions become an integrated component within the real-time SCADA environment. Operators no longer must rely on discrete alarms alone to detect potential threats and then make decisions whether to dispatch personnel to the site to confirm the threat. Upon receipt of alarms, operators have the ability to access live video on their workstation from facility cameras and automatically record video (pre and post the alarm event) as part of the historical archive.

**Incident Detection** - Fast response times are critical to managing emergencies. When a threat is detected, video images associated with the incident can be automatically switched to the operator’s workstation display with options for additional camera preshots and tours. By integrating intrusion detection and CCTV functions with SCADA, operators can more rapidly validate and classify incidents before to determine the best course of action needed to resolve the threat.

**Incident Response** - The effectiveness of any emergency response plan can be measured by the efficiency in which operators respond appropriately to the incident. A software-based incident response management (IRM) application integrated with SCADA can provide real-time decision support tools and generate computer-assisted response plans to manage security breaches and other emergencies using a set of predefined plans (i.e. standard operating procedures) or defined actions. The typical steps in which a SCADA IRM application can assist in incident response include:

- Incident creation and classification
- Incident confirmation or removal in the case of false alarm
- Displaying the recommended response plan with ability for ad-hoc changes
- Notification of the expected time to complete the plan, ability to continue or terminate the plan
- Terminate (close) the incident
- Maintain a permanent record of the incident and the steps taken to manage the incident

**CONCLUSION**

A common concern reported by transit agencies regarding smart substations is that they can be overly complex, requiring additional technical expertise and resources within the organization to effectively maintain the new hardware, software and systems. While these concerns may be justified given the capabilities of existing staff and limited operating budgets, substation technology and industry standards will continue to evolve and advance nonetheless. Embracing new technology, investing in staff through training and developing innovative methods to improve O&M practices, while maybe painful in the short-term, are key to the long-term success, safety and efficiency of any rail operation.

Traction Power Substation and SCADA systems designers should collaborate earlier in the design process than in the past. Consideration should be given to fully integrating the substation – SCADA design process to achieve full integration of the two. Through realistic assessments and forward thinking, agencies can determine how to best exploit and apply smart substation concepts to enhance operations, streamline maintenance, control operating expenditures and ensure their systems continue to outpace obsolescence.

**AUTHOR INFORMATION**

Mr. Forquer is Vice President, Traction Power, Powell Electrical Systems, Inc., North Canton, Ohio. Mr. Forquer is an electrical engineering graduate of Gannon University, Erie, PA. He has been involved in the design, manufacturing, testing, and commissioning of traction power substations for over 30 years on every major transit system in the US and several overseas. Mr. Forquer is an APTA member.

Mr. Pilcher is the PowlTech services manager for Powell Electrical Systems, Inc., Houston, TX. Mr. Pilcher received his education at the George Brown College in Toronto, Ontario Canada. Mr. Pilcher has over 40 years experience with SCADA, communications and protection systems in the traction power industry and other energy sectors.

Mr. Iannacone is transit segment program manager for Powell-Transdyn, Inc., Duluth, GA. Mr. Iannacone is an engineering graduate of Georgia Southern University, Statesboro, GA and received his MBA from Georgia State University, Atlanta, GA. Mr. Iannacone has over 20 years SCADA, substation automation, and communications system experience in the traction power, transportation and utility industries.