Migrating from SCADA to Automation

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***Abstract*--This paper describes the City of Naperville's migration from a traditional SCADA system to an integrated SCADA and Substation/Distribution Automation System. The paper will examine:**

- **Change Drivers that provided the impetus for the migration**
- **The system design criteria and the architecture selected**
- **Key features of the system and expected benefits**
- **Value-added applications**
- **The migration strategy that the City developed**

Index Terms-- **SCADA, substation automation, integration, distribution automation, intelligent electronic devices, bay controller, multi-function devices, PLC-based control, HMI.**

I. Introduction

The City of Naperville operates a Department of Public Utilities, which includes a municipal electric utility. Naperville's electrical distribution system is nearly 90% underground, except in older areas of town where overhead facilities are still utilized. The nominal voltage of the system is 12.47kV transformed from 34.5kV and 138kV. There are 6 points of service on the 138kV transmission system from bulk power providerComEd. The City does not have generation capability at this time.

TABLE I
Electric Department Statistics

Supply Source	ComEd Wholesale Bulk Power at 6 Substations – Metering Locations
Substations	12 existing (4 Future)
Peak Monthly Demand (7/99)	317,680 Kilowatts
Peak Month Energy Use (7/99)	143.083 Million Kilowatt-hours
Distribution – Feeder Lines	116.59 Miles
Distribution - Sub Feeder Lines	108.72 Miles
Distribution – Primary	677.51 Miles
Transmission Lines	36.75 Miles
Customers - Total (12/00)	50,830
Rates/Residential	\$9.50/mo. customer charge plus 6.62 cents per kilowatt hour energy charge

The service area includes 46 square miles of land within the corporate limits of City of Naperville, which presently has a population of approximately 125,000 with an expected population of 160,000.

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II. Existing Practices

A. SCADA System

The current platform for remote control and indication of the City's substations is an ACS 7000 SCADA System. The SCADA software runs on the Hewlett-Packard variant of the UNIX operating system know as HP-UX. Purchased in 1990, the hardware has been systematically installed and the last of the RTUs are scheduled for installation in the winter of 2001.

The SCADA system is modest by today's standards. The HP servers are no longer in production and the workstations are operational but not Y2K compliant. Communication takes place over a licensed 900Mhz data radio system operating at 9600 bps. That notwithstanding, the system performs well for real-time remote indication and control and has been very reliable. Personnel have developed the necessary skills to keep the system running at the required level of performance.

B. Distribution Automation System

The City of Naperville's Electric Utility is continually striving to improve the reliability of the distribution system. It is the current design philosophy to install distribution automation equipment on all primary feeders, using a combination of overhead and underground switchgear with automatic reconfiguration capabilities.

The typical Distribution circuit design utilizes 600 Ampere main looped feeders from different substations, which are tapped at pad mounted switchgear to serve distribution loads. The City normally uses a configuration of 3 switches - two "Normally Closed" (one on each feeder) and a "Normally Open" one to loop them. When a fault occurs on one feeder segment, or power is lost to the circuit, distribution automation equipment identifies the problem section and reconfigures the circuit to minimize outage area.

The first Distribution Automation system was installed in 1998 as part of a pilot project. Since that time the City has gradually deployed feeder automation on other circuits.

Existing distribution automation equipment utilizes S&C Electric Company switchgear with EnergyLine Inc. IntelliTEAM Controls. The IntelliTEAM controls perform

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automated reconfiguration or sectionalizing of the feeders. The controls process data locally and exchange information with each other using peer-to-peer communications over a spread-spectrum radio network.

In order to evaluate team operation, view real-time data, review historical events, or change settings, operators are required to access the controls locally.

C. *System Integration*

In short – none. Neither the existing SCADA nor Distribution Automation systems are designed to integrate third party equipment. As a consequence, the City has functional silos with no mechanisms to integrate the data contained in either.

III. CHANGE DRIVERS

The drivers that provided impetus to the adoption of the new automation technology are summarized in a simple mantra – *Do more, with less, faster.*

- As with other users of disparate control and monitoring systems, the City has started looking for ways to integrate the databases of the various systems and eliminate data silos.
- More efficient utilization of resources through "windshield time" reduction by enabling remote diagnostics, maintenance and monitoring.
- Improving service restoration, troubleshooting and disturbance/fault/outage forensics
- Expand the range of IEDs supported within the substation without major modification to the existing SCADA RTUs.
- Add substation to distribution system automated functionality in a decentralized manner
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The challenge has been to design a system that will accommodate all of the above functionality using "off the shelf" technology to ensure expandability and vendor independence.

IV. SCADA VS INTEGRATION VS AUTOMATION

Traditional substation design has segmented secondary equipment into separate functional "compartments". A Remote Terminal Unit performs remote control and monitoring, protective relays provide protection, strip charts record metering data, meter-dials display volts and amps and control handles and annunciator panels provide local control and monitoring.

The industry has experienced significant change in design philosophy over the last ten years. SCADA has been supplemented, and in some cases replaced, by Integration and Automation Systems. It is somewhat difficult to define strict functional boundaries between the three systems and the terms are very often used interchangeably. In the opinion of the authors, the differences can be summarized as follows:

- SCADA is responsible for providing amps, volts, watts, CB status, etc. This is normally accomplished using a RTU.
- Integration systems provide the same data, typically acquired from IEDs using legacy or industry standard communications protocols. In some designs, the integration system supplants the RTU, in others the RTU is treated as another IED. In addition to the "traditional" SCADA data, the Integration System also has access to additional data like fault forensics, diagnostics, maintenance, alarming etc, extracted from the IEDs. The challenge is externalizing these data, and two choices are available – map the data (somehow) into the SCADA protocol the SCADA Control Center supports, or provide a secondary link into the substation to access the data – normally some form of broadband access.
- Automation systems provide the same functionality as the Integration System with one additional and differentiating feature, namely the ability to turn data into something meaningful and valuable.

What additional characteristics does a substation design have to possess to be deemed an Automation system? It must be capable of providing the following advanced, value-added applications:

- **Protection and Process Automation** - the core protection and control processes;
- **Maintenance Automation -** tools and tactics to employ Reliability Centered Maintenance (RCM) and Just-in-Time (JIT) Maintenance for transformers, breakers, switches, CTs and VTs;
- **Information Automation -** the "art" of changing data to information, trending, alarming, archiving and employing expert decisions;
- **Information Distribution** - getting pertinent information to where it can be used.

The City selected a system based on these criteria.

V. THE AUTOMATION SYSTEM

The City selected the Siemens Power Transmission and Distribution SICAM system. The system seamlessly integrates the Protection, Control, Monitoring, Automation and Visualization of the substation. The SICAM system consists of the three level hierarchy depicted below:

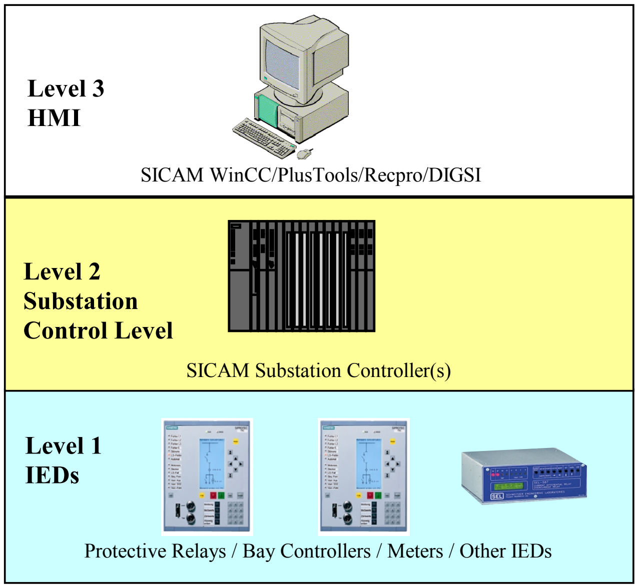

Fig. 1. System Architecture

A. Human Machine Interface

The **Human Machine Interface (HMI) Level** has four components:

- SICAM WinCC – Used by substation personnel to Control and Monitor the system. It is responsible for displaying SCADA data on one-line diagrams, for trending data, for archiving data, and for issuing and recording alarm messages. SICAM WinCC operates on Windows NT and can be configured in a Client-Server architecture so that multiple client PCs can access system data.
- SICAM PlusTools – Used by System Administrators to configure the Substation Controller. It is responsible for identifying which devices are part of the configuration, configuring communications interfaces, specifying which data are available from the devices, where the data has to go, and any processing that has to be performed on the data. SICAM PlusTools operates on Windows 95/98/NT.
- SICAM RecPro – Used by Protection Personnel for post fault forensics to analyze fault records after a system fault has occurred. Fault records are automatically extracted, appropriate alarm indications are generated. Protection Personnel can use the intuitive GUI to navigate through a summary of all system faults and drill-down into detailed analysis of individual faults where desired.
- DIGSI – Used by Protection Personnel for configuration, maintenance and analysis of Siemens Relays and Bay Controllers – either locally or remotely.

WinCC, PlusTools and RecPro interface with the SICAM Substation Controller(s), one level below the HMI level.

- WinCC communicates with the Substation Controller(s) on a continuous basis to get the latest metering, measurement and status data. There can be up to two WinCC Servers independently communicating to the Substation Controller(s). Each WinCC Server can have up to 32 Clients when operating in a Client-Server configuration, or unlimited users when operating in a Web hosting configuration.
- PlusTools communicates with the Substation Controller(s) on an ad hoc basis whenever configuration changes are required. The architecture supports multiple PCs running PlusTools.
- RecPro communicates with the Substation Controller on a periodic basis to check for fault records.
- DIGSI communicates with the Relay(s) and Bay Controller(s) on an ad hoc basis whenever configuration changes or device analysis is required. The architecture supports multiple PCs running DIGSI.

B. Substation Controller

The Substation Controller Level consists of the SICAM Substation Controller. The Substation Controller combines the best qualities of Programmable Logic Controllers (modular design and powerful logic capabilities) and Remote Terminal Units (ruggedized I/O and SCADA communications). It is responsible for communicating with the various Intelligent Electronic Devices (IEDs), processing the data, passing pertinent data changes to the HMI and managing any control requests from the HMI. It can also be equipped with a variety of Input/Output (I/O) modules to directly monitor and control plant data.

The primary tasks of the Substation Controller are:

- Data concentration – it is responsible for communicating with the substation relays and IEDs and performing intelligent pre-processing and filtering of IED data
- Safety and Security - performing interlocking of control commands to ensure that controls are only executed under safe conditions.
- Miscellaneous I/O – controlling and monitoring any I/O that are not available via the IEDs
- Interfacing to the SCADA Control Center via DNP 3.0.
- Interfacing to the existing downstream Distribution Automation equipment via DNP 3.0
- Advanced Automation Applications – Utilizing the PLC logic and math capabilities, applications are developed here to monitor, alarm, and control overall optimization of the electric system and the system components (transformers, breakers, switches, CTs, and VTs).

C. IEDs

The IED Level consists of Intelligent Electronic Devices. The substation is divided into cells, or bays – with one feeder per bay. Each bay is equipped with a Siemens Bay Controller.

These Multi-Function IEDs are a combination protective relay and RTU, which in addition to providing protection, SCADA and metering data, also offer

- A large graphical display that supports local control and

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monitoring
- Embedded IEC 1131 PLC logic that is used to implement automation applications
- Dual-redundant fiber LAN connectivity

D. Communications Architecture

To maximize performance and reliability, the City decided to standardize on a **fiber Local Area Network**. The LAN is configured as a dual-redundant ring to eliminate single point-of-failure concerns. The LAN protocol employed is Profibus FMS – a deterministic, Fieldbus protocol operating at 1.5Mbps.

The multi-master capabilities of the protocol allow communications between the HMI, Substation Controller and Bay Controllers to occur on the same fiber. In addition, it is possible to perform other functions such as waveform extraction, configuration changes, etc on the same LAN, while the system is operational.

As the diagram illustrates, the Substation Controller and HMI are connected to the City's broadband WAN. The City will utilize their WAN to run 10MBps Ethernet into each substation. This facilitates intelligent alarming, email notifications, remote forensics, remote reconfiguration, and substation database management. In future, the peer-to-peer communications capabilities of the Substation Controllers over TCP/IP will allow the implementation of automation schemes that require inter-substation communications.

Communications to the existing SCADA Control Center, and third party IEDs (either locally or remotely located) is accomplished via DNP 3.0.

VI. KEY SYSTEM FEATURES

A. Integrated System

Integration is very often taken to mean the ability to speak to devices in their native protocol. The SICAM system offers a higher level of integration, namely the **integration of the configuration and operation of all three hierarchical levels**.

The same configuration software is used to configure the Substation Controller and Bay Controllers. After a Bay Controller is added to the configuration, the Substation Controller immediately knows about the device and the data it possesses – this allows seamless **configuration inheritance**. The same software also automatically populates the database of the HMI. Configuration data is entered once, thereafter it is automatically moved up the hierarchical layers, totally eliminating the possibility of database mismatches due to typographical errors – to say nothing of the time it saves.

In addition to making configuration/re-configuration/upgrades easier, the integrated nature of the **system makes it possible to provide an array of value added applications not feasible with conventional integration/automation syste**ms.

B. Value Added Applications

The integrated nature of the SICAM System makes it possible to offer the following categories of advanced, value-added applications: Protection and Process Automation, Maintenance Automation, Information Automation, and Information Distribution.

Some examples of applications are:
- Advanced Breaker Monitoring - monitor various breaker timing sequences such as trip and close initiate to "a" and "b", I/t data and operations count, use of digital oscillography to obtain an operational "fingerprint" (normal operation), and use of oscillography for forensic engineering after an alarm is asserted.
- Advanced Transformer Monitoring and Control – perform multi-variable analysis on measurements like Top Oil temperature, ambient temperature, loading and LTC position, and provide smart alarms and perform controls based on dynamic interpretation of the data
- Unified Sequence of Events for Rapid Fault Forensics – all substation data events are time stamped and presented to the operator in chronological sequence with the associated time stamp (accurate to 1ms)
- Unified Substation Volt/VAR Support - control voltage and VAR support in substations (LTCs, regulators and capacitor banks) using adaptive strategies.
- Storm Mode Fuse-saving/blowing logic - Use input from SCADA (storm, no storm) to change fuse-blowing logic to improve SAIDI/SAIFI indices.
- Load Shedding - Relay-centric or bus centric.
- Automate Indices Reporting - compute and track all performance indices for particular feeders.
- Auto-documentation – automatically generate logic and configuration documentation

C. Automatic Version Control

Any system that integrates IEDs, especially those that support selective mapping of data, (i.e. where users have the ability to select more or fewer data) are faced with the problem of configuration mismatches. If you change the data profile of an IED, all upstream devices are impacted, and must adjust their databases accordingly. The SICAM system not only performs this function automatically, it also checks the version number of the configuration information prior to going operational. If a new HMI is added to the system (for example, to replace a failed unit), it checks to ensure that it and the Substation Controller have the same version. If a mismatch is detected, the system will notify the user that the two systems need to be resynchronized. This **prevents configuration mismatches**, eliminating the risk of mis-operation.

In addition, the tedious (and time consuming) task of re-configuring the system is performed automatically, and safely,

making system enhancements quick and easy.

D. Security

Security is a key feature of the system. In addition to ensuring that database mismatches do not occur as described above, the SICAM system allows the user to define interlocking schemes to prevent mis-operation. If desired, all control commands, whether issued by the remote SCADA control center or the local HMI are passed through interlock checks in the Substation Controller. Only if the control is adjudicated as valid will it be issued to the relevant IED. In addition to these system-wide interlock checks, bay-level interlock checks can also be defined in the Bay Controllers.

System-wide interlock schemes that require inputs from multiple IEDs are defeated in other systems as soon as substation personnel issue controls from the IED face plate. The SICAM system can be configured so that all control commands entered via the Bay Controller face plate are first routed to the Substation Controller for verification before approval is issued. In this fashion, the SICAM system is able to **eliminate mis-operation due to human error**.

E. Power and Performance

No paper penned by Engineers would be complete without the obligatory references to gee-whiz technology, so here goes:

- The Substation Controller is Siemens' latest generation PLC employing Pentium CPU technology.
- All modules are hot-swappable
- All firmware is flashed and can be loaded in the field if required
- SICAM WinCC is object orientated, making screen creation and display re-use quick and easy.
- SICAM WinCC is an ActiveX container, allowing 3rd party controls to be used if desired.
- SICAM WinCC supports smart objects, allowing custom objects and their behavior to be defined.
- The speed and deterministic nature of the Profibus protocol provides system wide update times of one second.
- Both Substation Controller and Bay Controller support an IEC 1131 compliant PLC programming interface called Continuous Function Chart (CFC) which is a powerful, graphically based environment.

F. System Openness

One of the City's prerequisites was that the system be non-proprietary and offer them the ability to add software and equipment from any vendor. The system does this by supporting open interfaces at multiple levels:

- The SICAM WinCC supports ODBC[1], DDE[2] and OPC[3] that allow 3rd party software applications to access Substation data, either locally or remotely via the WAN.
- The SICAM WinCC can act as a Web Server. HTML pages populated with Java applets can be created so that substation data can be published on the intranet or internet.
- The SICAM WinCC supports a variety of protocols like Modbus, Modbus plus, AB DH, etc that allows third party controllers to interface to the HMI
- The SICAM Substation Controller supports TCP/IP connection(s) that can be used for peer-to-peer communications, or to connect to other IT systems wishing to access substation data.
- The SICAM Substation Controller can act as a Web Server – making status data available in HTML format
- The SICAM Substation Controller supports DNP 3.0 or IEC 60870-5-101 communications back to a remote SCADA master should the city ever wish to upgrade the SCADA link or provide a SCADA interface to another entity.
- The SICAM Substation Controller can integrate 3rd party IEDs using DNP 3.0 or IEC 60870-5-103. Legacy IEDs can be integrated into the system via a communications gateway device.

VII. Design Benefits

The City expects the integrated nature of the SICAM system to offer the following benefits:

1) Reduction in the number of devices required with a commensurate reduction in cost, physical size, wiring, installation, engineering and maintenance.
2) Shorter system recovery time after a disturbance
3) Better utilization of installed capacity
4) Simpler to design, faster to implement, easier to replicate
5) Guaranteed repeatability of the automation system from one substation to the next
6) The elimination of integration problems and inter-vendor finger pointing
7) The ability to perform advanced applications that would previously have required multiple devices with a single device
8) Reduction in the number of software tools from a collection of disparate vendor unique tools to an integrated software suite that performs all requisite functionality.
9) "Forward compatability", providing protection against technical obsolescence.
10) The ability to distribute data collection, processing and automated actions to the Bay Controllers resulting in faster response times
11) Less revenue loss caused by wrong settings and IED malfunction
12) Higher system reliability due to automation, integration and adaptive settings

[1] Open Database Connectivity (ODBC) is an industry standard mechanism used to access historical data.

[2] DDE - Dynamic Data Exchange (DDE) is a standard mechanism provided by Windows that allows software applications to exchange real-time data

[3] OPC (OLE for Process Control) is an industry standard that defines how individual software components can interact and share data.

VIII. Migration Strategy

The City has adopted a strategy that leverages the existing SCADA infrastructure, and provides a phased migration to the newer technologies.

A. Integrating SA and SCADA

The City has decided to keep the current SCADA system in operation for as long as possible and install complimentary technology to achieve the required additional functionality.
Real-time data (typical SCADA data) will be sent from the Automation system to the control center via DNP 3.0, where it will be treated as “normal” RTU data.

B. Integrating SA and DA

The IntelliTEAM Control provides a limited access to its data via DNP 3.0 implementation. As a first step in the integration of two vital systems, the city has chosen to bring distribution automation data back to the substations to which automated feeders are connected.

Each Substation Automation System will communicate with relevant EnergyLine switch controls using DNP 3.0 protocol over existing Metricom spread-spectrum radio network. DA switch Control data available through DNP 3.0 will be integrated into the Siemens SICAM Substation Automation System database. Additionally, some data will be transferred to the remote SCADA System. Control commands will be generated from either the Substation HMI or remote SCADA system to the Switch Controllers.

IX. What’s Next?

The City is currently in various phases of design and construction of four new substations. These new substations are specified to be equipped with newer ACS RTUs with provisions for peer-to-peer connectivity with the Substation Automation System. All existing substations will experience systematic RTU upgrades to permit this peer-to-peer connectivity. Relevant information will be shared between the two platforms.

The present fiber based T1 inter-substation communication system will migrate towards an OC-3 network with the ultimate goal to achieve an OC-12 substation WAN. The Substation Automation System systems will use this WAN for communication. A central Substation Automation server will be installed at the Electric Service Center to collect data necessary for engineering and maintenance purposes.

Plans for a new control room are presently in final review. The new control room will have provisions for the new Substation Automation server and communications equipment necessary to support these systems. The ACS SCADA servers and workstations will also be upgraded to faster more modern equipment.

X. Conclusion

The City is in the midst of the first phase of the automation system implementation. Once basic functionality has been verified, the City will turn its attention to the value added applications the system design makes possible.

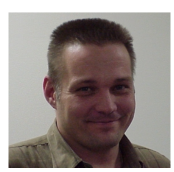
Time will tell to what extent all the expected benefits materialize; but at the very least, the City has positioned itself for the future with a non-proprietary design that will allow existing and future systems to be integrated in a vendor-neutral fashion.

XI. Biographies

Daniel Gacek (M’1986) graduated from the Illinois Institute of Technology in 1988, receiving a B.S.E.E. He received a M.S.C.S. from the Illinois Institute of Technology in 1995. He was employed by Commonwealth Edison as an engineer in the Operational Analysis Department from 1988 to 1993. In 1993 he joined the City of Naperville as a SCADA engineer. After four years in that position he was promoted to Senior Substation Engineer where he manages all substation engineering activities for the electric utility. He is a licensed professional engineer and a member of the NSPE

Olga Geynisman was born in St. Petersburg, Russia. She studied at the Polytechnic Institute of St. Petersburg where she received a MS in Electrical Engineering in 1981. Olga is currently the Senior Automation and Communication Engineer for Naperville Public Utilities. Olga joined Naperville Electric in 1998 to lead an effort in developing and implementation of Distribution Automation, Substation Automation, Automated Meter Reading, and Fiber Optic deployment. Prior to joining Naperville Public Utilities, Olga worked as a facility engineer for Fermi National Accelerator Laboratory, Batavia, IL. Olga is licensed Professional Engineer in the state of Illinois.

Douglas Proudfoot studied at the University of Pretoria in South Africa where he received a BSc in Electronic Engineering and a MBA. Prior to joining Siemens Power Transmission and Distribution, Douglas worked for Integrators of Systems Technology in South Africa. Douglas is currently the Product Manager for Siemens’ new generation of Substation Automation products that include integration, automation and information management platforms as well as multi-function IEDs.



Kevin Minnick was educated at Kennedy Western University, receiving a BSEE in 1992. Kevin spent 8 years with the US Navy, where he served as Missile Technician First Class where he was responsible for the installation, operation, testing and maintenance of fleet ballistic missile systems and support equipment. Kevin was also a certified instructor for seven advanced technical training classes. Kevin also spent 5 years with the City of Princeton where he was responsible for design, implementation of SCADA and protection systems and SA and DA equipment. Kevin is currently a Senior Field Application Engineer in the Power Automation Division of Siemens Power Transmission and Distribution.