SEL COMMUNICATIONS AND INTEGRATION WHITE PAPER

David Dolezilek
Schweitzer Engineering Laboratories, Inc.
Pullman, WA USA

SEL Philosophy

As part of our overall mission to make electric power safer, more reliable, and more economical, SEL develops and provides innovative, simple to use, robust technologies to protect, automate, control, monitor, and analyze power systems. An essential element of this strategy is the development of appropriate communications technologies and protocols. Our product development and customer support continues in the spirit of our following philosophy:

- Invest in research and development to continually improve the state-of-the-art of integration, automation and communications, and protection technology.
- Continue technology exchange with the market through participation in committee meetings, conferences, and seminars.
- Invest resources to develop and support interoperability with devices from other protection, SCADA, and communications vendors.
- Implement standard protocols where possible and develop and implement SEL protocols when necessary to advance technology. Continue to offer free and/or licensed use of SEL protocols.
- Implement standard protocols using the intended standard nonproprietary interoperability at the most appropriate system level through interfaces within SEL relays, separate SEL communications products, and third-party communication devices.
- Protect customers' investments through backward compatibility to all generations of SEL products and a migration path to all future development.
- Implement technologies to support systems of all sizes through features and functionality developed to accommodate a variable device count and wide range of communications infrastructure.
- Support customer implementation of SEL technology without dictating what protocols or communications media will be used. Continue to create and offer the most robust and efficient technology while making SEL products flexible enough to support other vendor or end-user topologies and strategies.

This white paper describes the fundamentals of intelligent electronic device (IED) communication, and the SEL communications technologies and strategies developed to support the needs of end users and system integrators.

PROTOCOL STANDARDIZATION

To date, standard interfaces have not been adequate to create safe, reliable, and economical systems. Therefore, we have developed SEL-specific interfaces. Standard interfaces are developed for ease of interoperability between vendors and not optimized for performance. SEL has implemented these market driven protocols to support loose relay sales and interconnection to many other relay and SCADA vendor system architectures.

Two domestic efforts for standardization have gained support in different camps. An IEEE working group addressing IEDs in substations selected DNP V3.0 Level 2 protocol (DNP V3.0) and IEC 870-5-101. The second group is lead by EPRI, which is promoting and developing the UCA/MMS protocol recommendations.

International groups are promoting IEC 870-5-101 and 103 as the "recommended practice" for substation use. The major international SCADA and EMS manufacturers appear to be embracing this recommendation. IEC 61850 Technical Committee 57 is working to produce international standards in the field of communications between equipment and systems for the electric power process, including telecontrol, teleprotection, and all other telecommunications to control the electric power system. After EPRI creates UCA/MMS recommendations, IED TC 57 may adopt these recommendations as part of the 61850 standard.

SEL SYSTEM INTEGRATION PURPOSE

The purpose of the development of communications technologies, protocols and customer support is to communicate data among IEDs and to operators and engineers. The propagation of these data enables data acquisition, control, monitoring, automation, protection, analysis, test, maintenance and operation of the power system.

The power system is enhanced, and other applications supported, as long as the data can get from the Instrumentation and Control (I&C) devices to the remote operator or process within the appropriate time. The protocols and communications channels do not concern the user but are simply tools used by the communications network designer to perform integration. Therefore, it is important to understand the use of information to best determine the paths it should follow in route to the appropriate destinations.

Power System Data

The types of power system data that I&C IEDs collect and create include:

Instrumentation Digital representation of analog signals and discrete contacts derived from sensors – the source for all other data.

Protection Results of protection analysis that indicate presence, type and severity of disturbances on the power system, enhance power system when communicated quickly to several relays coordinated in a protection scheme.

Metering	Calculated analog values that emulate power system operating conditions. Uses include protection, monitoring, control, and revenue purposes. These values are less affected by passage of time or changes in the environment than data instrumented in other devices.
System Automation	Results of automated algorithms that indicate the relay needs to perform control, acquire and archive data, or generate event reports – can optimize entire power system.
Control	Results of functions initiated by logical processes or operators to perform control actions that influence the state of the I&C system and the power system in accordance with protection and system automation decisions.
Supervisory	Relay data displayed on a local display or communicated to a remote device for the purpose of monitoring the power system allowing operators and processes to make rapid, better informed decisions about system-wide, and device-specific protection.
Device Diagnostic	Operating parameters of Power System and I&C system devices such as frequency of use and self-test status – enhance protection by maximizing availability of the power and I&C system and by preventing deterioration after failure.
Historical	Information about the reaction of the power system and I&C system over time or to an event; include system profiles, event reports, sequential events recorder (SER) reports, power quality reports, and protection quality reports that provide a clear picture of system performance.
Settings	Variables used to configure relays to function optimally in specific end-user applications. Settings groups allow the protection system to change dynamically to compensate for changes in the power system or I&C system and reduce unavailability of system protection by quickly configuring replacement relays.

POWER SYSTEM DATA INTEGRATION

In general, the term "power system" describes the collection of devices that make up the physical systems that generate, transmit, and distribute power. The term "instrumentation and control (I&C) system" refers to the collection of devices that monitors, controls, and protects the power system.

The I&C system is comprised of four levels.

Process Level	The lowest level of I&C devices, considered the process level, are physically connected to power system and are sensing their current status. These include current transformers (CTs), to sense current, voltage transformers (VTs) to sense voltage and resistance thermal detectors (RTDs) to sense temperature as well as various other sensors. Transducers are process level devices that convert the sensor output of the above devices from one level to another.

Unit Level The next level is the device, unit, or bay level comprised of IEDs that collect the sensor data, create information from it and react to it. A bay refers to an area where a power system device, such as a feeder breaker, and all of the I&C devices associated with it are located. These power system IEDs include protective relays, meters, fault recorders, load tap changers (LTCs), VAR controllers, remote terminal units (RTUs) and programmable logic controllers (PLCs). As the name implies, an RTU is a device that can be installed in a remote location, collect sensor data and forward it to another device without processing it any further. A PLC does the same as an RTU plus it has the ability to perform user defined processing of the sensor data to create information. The term "smart RTU" refers RTUs that now also have programmable processing capabilities similar to a PLC. The bay controller, or bay module, is an RTU-like device with expanded functionality.

Station Level Substation controller refers to devices that perform data acquisition and control of IEDs and contain local I/O. They can contain data for the entire station. RTUs, PLCs, bay controllers, and human machine interface (HMI) software running on a personal computer (PC) are all possible substation controllers.

Enterprise Level This is a generic term for all of the end users, or clients, of power system data inside and outside of the substation. These applications acquire data from station-level and unit-level devices.

The threefold purpose of SEL system integration can be summarized as follows. Move sensor measurements and information created from this data among IEDs, between IEDs and a substation controller, and to end user clients directly from the IEDs and the substation controller.

Power System Data Users

Users of the data available in relays include people and processes within utilities, independent system operators, customer facilities, consultants, and vendors. The power system is enhanced by getting relay data directly to these users rather than leaving it uncollected or pushing it to a centralized data warehouse or data historian database where the user must use extraction techniques to find and acquire the appropriate data. In addition to supporting this traditional method, SEL's primary focus is to understand the path and destination of data and optimize it's delivery to the user.

The variety of uses for power system data is comprehensive and growing. A partial list is shown below.

- Communications Assisted Protection – MIRRORED BITS™ communications, POTT, DCUB
- Coordinated Protection Logic – Adaptive Relaying Via Settings Groups
- Distribution Automation – Isolation, Sectionalization, and Restoration
- Substation Automation – Breaker Failure, Reclosing, Battery Monitoring
- SCADA – Operator Control and Supervision
- EMS – Load Flow, Voltage Control, Generation Control
- Metering – Revenue Accuracy for Billing or Validation

- Power System Disturbance Analysis – Forensic Evaluation of an Event and the System Response
- Power Quality – Compare Actual Power System Values to Their Ideal
- Protection Quality – Measure the Fitness of System Devices to Perform Protection
- SER Analysis – System-Wide Evaluation of Events in Sequential Order
- Power System Planning – Analysis of Power System Values to Aid Operations and Expansion

FUNDAMENTALS OF IED COMMUNICATION

Types of Connections

Direct connect and multidrop are two types of data link connections available to create networks. In a direct connection, there are only two devices connected via network media which can be metallic, wireless or fiber. Each interface consists of a separate transmit and receive connection at each device. Since there are only two devices, each of them can constantly control the connection on which they are transmitting and both can know implicitly to which other device they are connected. Several individual direct connections to many IEDs would allow each of them to communicate simultaneously. Many direct connections originating from one device is called a star network topology. Figure 1 illustrates the star topology. Many star networks can be connected in a parallel or vertical hierarchy.

Any protocol, including those designed for multidrop applications, can be used for direct connections in a star topology. Virtually all microprocessor-based relays have a simple EIA-232 serial port connection to support direct connections. Any of the other communication methods can be used in a direct connection as well.

Star network designs support a wide range of IED capabilities. Simple, slow communicating devices can coexist with more complex fast communicating relays. Devices from different manufacturers with different protocols can coexist in the same star network because each has a dedicated direct connection.

Open architecture is a term that refers to networks that are interoperable between hardware and software interfaces and therefore among vendors. The star network is the only design that is truly an open architecture and will accommodate multiple protocols, baud rates, and network interfaces.

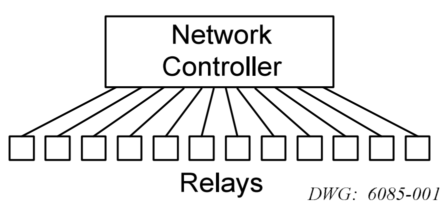

Figure 1: Star Topology

In a multidrop network topology, several devices can be physically connected in a bus or ring network, and control of the transmit and receive connection must be negotiated. Figure 2 illustrates relays connected in a bus topology, and Figure 3 illustrates relays connected in a ring topology. A multidrop connection requires that only one device communicate at a time.

Software and hardware are used to determine which device has permission to transmit so that data does not collide on the conductor. Since several devices are connected, addressing is necessary within the protocol to identify the source and destination of the data being communicated. This addressing adds overhead in the form of processing time and amount of information that needs to be transmitted thus reducing the data transfer rate. Devices compensate for this by increasing the speed at which they communicate and increasing the amount of communications processing that they perform.

Troubleshooting communication problems on a multidrop network is difficult. Messages from many sources must be captured and deciphered. Direct connections are quickly and easily verified using simple LED indication.

Relays have varying memory and computational capacities and, therefore, varying protocol support capabilities. Interactions on a multidrop network must be done at the lowest common denominator and all devices must support the same baud rate and physical network connection.

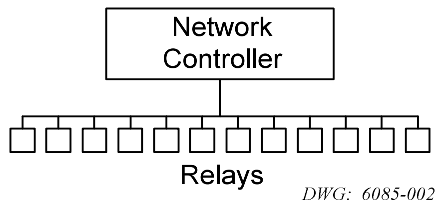

Figure 2: Bus Topology

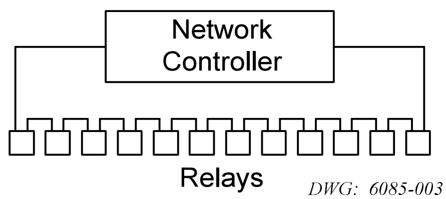

Figure 3: Ring Topology

It is important to keep in mind that if the mediation of control of data transmission should fail, none of the multidropped devices can communicate. This can be caused by relay communications hardware failing to release control, relay communications software failing to process mediation schemes correctly, or corruption of the network.

A common multidrop option is EIA-485 which is a twisted pair network "daisy-chain" connection between multiple devices. EIA-232 connections can be converted to EIA-485 for use on some multidrop networks. Other copper and fiber connections are being developed to support standard interfaces like Ethernet as well as proprietary interfaces.

A broadcast multidrop is a common network that differs in function and purpose. One-sided conversations simply can be sent to multiple receiving devices that do not respond. Inter-range instrumentation group (IRIG) time-synchronization messages are often sent to relays in this fashion. Separate connections on the relay for this purpose are often necessary.

System Automation and System Integration

System automation is the control of operations of apparatus and processes via I&C devices to take the place of the human functions of decision, observation, and action. Substation automation refers to using IED data within the substation and control commands from remote users to control the power system devices within the substation.

System integration is the act of communicating data to, from, or between IEDs in the I&C system and remote users. Substation integration refers to combining data from the IEDs local to a substation so that there is a single point of contact in the substation for all of the I&C data. Remote and local substation control are then mediated by this single point of contact. Since true substation automation relies on substation integration, the terms are often used interchangeably. There is often a need for multiple single points of contact to serve multiple user connections or provide redundancy. The single point of contact is an I&C device acting as a client/server, programmable logic platform, gateway, router, dial-out device, communication switch, time synchronization broadcaster, or a combination of these.

The communications industry uses the term client/server for a device that acts as a master, or client, retrieving data from some devices and then acting as a slave, or server, sending this data to other devices. The client/server collects and forwards data dynamically. A data concentrator creates a substation database by collecting and concentrating dynamic data from several devices. In this fashion, essential subsets of data from each IED are forwarded to a master through one data transfer. The data concentrator database is used to pass data from one IED to another when they are not connected peer-to-peer. Most RTUs and PLCs rely on messages from a master to collect data from one IED and pass it to another through the RTU or PLC. Designs that rely on this master connection cannot share data between IEDs when this connection is lost. The IEDs become stranded and do not work in a coordinated manner. The data concentrator creates an autonomous coordinated protection system within the substation that does not rely on a master connection.

A substation archive client/server collects and archives data from several devices. The archive data is retrieved when it is convenient for the user to do so. A programmable logic platform executes custom automation logic equations. A gateway converts conversations from one protocol to another. Router is another term from the communications industry that refers to a device that routes data in transit between source and destination. A dial-out device initiates conversations or triggers paging from the substation to a remote user. Uses for dial-out include assuring connection security, eliminating the need for a dedicated communication connection, and performing unsolicited indication of a disturbance with fault location. A communication switch is the single point of contact for remote users to make a direct connection to all substation IEDs individually. The user initiates a dynamic conversation with a specific IED and the port switch merely “passes through” the conversation. In order to synchronize the IED clocks, a device in the substation needs to generate, or acquire from an external source, a time value and then broadcast it to the IEDs.

Products from many industries are used to perform substation automation. RTUs, port switches, meters, bay modules, and protocol gateways from the SCADA industry, PLCs from the process control industry, relays and communication processors from the protection industry, and PCs from the office environment.

Substation controller and bay controller are terms commonly used to refer to devices that perform data acquisition and control of IEDs and contain local I/O. The communications processor is the only substation controller that can perform all of the substation automation tasks. The communications processor is also the only device that is designed to meet the same harsh environmental conditions as the relays themselves. SCADA and process control industry products are not designed to meet these environmental standards.

When choosing the best new and in-service devices to create a successful I&C system, it is often necessary to select from multiple vendors and also multiple vintages or generations of products. Many of these devices employ proprietary communications and interfaces. Most substation controllers must have embedded software written specifically to communicate via proprietary interfaces. The communications processor can communicate most relay protocols, or communication languages, without developing vendor-specific protocol software for each type of relay installed. Instead, through database settings, pertinent subsets of these protocols are communicated to the relay from the communications processor for data acquisition and control. The communications processor can also eavesdrop on conversations between two devices in the I&C system, capture, and store the data.

The communications processor simplifies implementation through autoconfiguration. This process automatically determines the proper baud rate to communicate with the connected relay as well as start-up parameters, device type, and capabilities.

Some substation controllers accommodate substations of varying size as well as redundant designs by supporting peer-to-peer and tier-to-tier functionality. Peer-to-peer refers to the direct data transfers between devices functioning in a similar capacity. Tier-to-tier refers to devices that can transfer data while connected such that one is the client and the other the server.

Substation integration enhances the system by migrating some of the communications functions to an intermediate substation device performing some or all of the functions listed above. The resources available within the relay can be focused on optimizing protection solutions. Also, as protocol requirements change in the substation, a single device acting as a client/server can be upgraded instead of each of the relays individually. This obviously enhances protection because the relays are left undisturbed and in service as a protocol change is made in the client/server. It is also more economical to make this change in a single device.

The age of IEDs that are in substations today varies widely. Many of these IEDs are still useful but lack the most recent protocols. Rarely is a substation integration upgrade project undertaken where all existing IEDs are discarded. A communications processor that can communicate with each IED via a unique baud rate and protocol extends the time that each IED is useful. Using a communication processor for substation integration also easily accommodates future IEDs.

Table 1 presents the system integration and automation functions required in a power system. Comparison is made of devices commonly used in substation automation and the functions that each device commonly performs.

Cells in the table that are blank reflect system functions that the communications processor system provides that the other designs do not. The user may be able to add some of these functions to the other systems by adding extra function specific devices.

Table 1: Substation Automation Device Comparison

	Communications Processor	RTU	Bay Module	PLC	PC	Port Switch	Satellite Clock
Client/Server for Dynamic Data	✓	✓	✓	✓	✓		
Client/Server for Archived Data	✓				✓		
Data Concentrator	✓				✓		
Programmable Logic Platform	✓	✓	✓	✓	✓		
System SER	✓	✓	✓	✓	✓		
Protocol Gateway	✓	✓	✓	✓	✓		
Router	✓				✓		
Dial-Out	✓				✓		
Communication Switch	✓				✓	✓	
Time Synchronization Broadcast < 10 ms Resolution	✓						✓
Local I/O	✓	✓	✓	✓			
Emulate Protocol Messaging	✓				✓		
Eavesdrop Communications	✓						
Autoconfiguration	✓						
Tier-to-Tier	✓			✓	✓		
Peer-to-Peer	✓			✓	✓		
Substation Hardened Design	✓					✓	✓

Reliability and Availability

Using methods described in [1] and [2], fault tree reliability analysis can be performed on various system designs.

The unavailabilities of the system components are derived from publicly available MTBF sources including vendor publications and studies performed in the workplace. It is also important to keep in mind that these values are appropriate for the normal operating environment of the product. PCs, PLCs, and RTUs are not designed for the harsh operating environment of the substation, and you can expect their unavailabilities to rise when used in the substation. The fault tree tool is most accurate when MTBF values from a proposed vendor or from your own historical records are used. Analysis described in [6] demonstrates the value of using simple fault tree analysis to evaluate the reliability of different designs.

SEL Communication Capabilities

Protocols

SEL Development of Others' Protocols

As mentioned above, to this date, standard interfaces have not been adequate to create safe, reliable and economical systems. Standard interfaces are developed for ease of interoperability between vendors and not optimized for performance. These protocols include:

MODBUS® – A popular protocol with industrial users that has also become somewhat popular in substations. Designed to emulate PLCs transferring register data to one another.

DNP V3.0 – An ever increasingly popular SCADA protocol governed by a standards committee that was designed to optimize efficiency, through report by exception, remote modem connections and multidrop capabilities—predominantly popular in North America.

IEC-870-5-101 – The European partner to DNP V3.0 but not yet as popular.

UCA – Utility Communications Architecture, designed by North American utilities, vendors and consultants to satisfy every possible requirement in substation feeder equipment and eventually all equipment.

We have a three-pronged third party interconnect development approach:

- Connect SEL relays as an RTU, PLC, or HMI slave, by sharing SEL interleave protocol specifications with SCADA vendors and system integrators, and through the SEL-2020 and SEL-2030 Communications Processors (SEL-2020/2030).
- Connect direct to substation networks as a Modbus slave in the SEL-2020/2030 and SEL-701 or as a Modbus Plus® slave in the SEL-2030. The SEL-351 series relays are often applied outside of the substation fence. We added the slave DNP V3.0 to these products and the SEL-2020/2030 to allow flexibility in the selection of radio or other media for their communications with the substation hub or SCADA master.
- For the long term, we believe that a local high-speed network in the substation will be the method of choice for third party interconnection such as an application protocol running on Ethernet such as UCA/MMS or DNP V3.0.

SEL Proprietary Protocol Research and Development

SEL technology has been developed so that we can build the most robust, economical and efficient systems to serve our customers. In general these are built around the communications processor star topology. Several communications processor stars can be combined in a peer-to-peer fashion or a tier-to-tier fashion. EIA-485 options in many of our products also support multidrop networks and peer-to-peer connections support protection functions. This flexibility in design affords redundancy in communications and protection that cannot be matched by other vendors.

Internally Developed SEL Protocols

LMD - Distributed Port Switch Protocol – A software method to add addressability to standard SEL EIA-232 serial ports which are by design point-to-point allowing SEL relays to exist directly on a multidrop network.

MIRRORED BITS – A point-to-point protection protocol used to reliably transfer small amounts of data at high speeds.

SEL Interleave Binary and ASCII – Interleaved data streams is a simple innovative way to perform multiple conversations. Metering, system automation, control, supervisory, SER, and device diagnostic data are all of similar priority, second only to protection data, and are often grouped into one multipurpose conversation. Multipurpose, historical, and time synchronization conversations can occur simultaneously on a single communication channel. Control of the relay and data acquisition are prioritized. The meter, system automation, control, supervisory, and device diagnostic conversation occurs deterministically, or in a predictable fashion. SER data are forwarded in an unsolicited fashion. An IRIG signal is broadcast in a deterministic fashion and historical and settings conversations are interleaved as time permits.

Communication Protocol Overview

The inclusion of the serial port in almost every intelligent electronic device has led to an ever increasing number of ways to communicate on those ports. While the term serial port denotes that data is sent serially, one bit after the next in a line, data can be transmitted as bits or bytes and messages can be exchanged using many protocols. Without compatible protocol interfaces, two devices which have the same physical and electrical interface cannot exchange information.

Many standard protocols exist today and have evolved via the results of standards committees that create specifications and monitor interoperability. De-facto standards evolve as a single vendor creates and promotes a protocol that is accepted by a large percentage of the market. Perhaps the simplest of these today is Modbus. Designed and intended for the PLC industry, Modbus is simple and rugged, but lacks many of the powerful features required by today's applications. For example, Modbus does not include the capability to send unsolicited information from a Slave to a Master. Event Data, notification of only data which has changed rather than the current status of all points, is not available.

Protocols can also be divided into three major categories: serial, Ethernet, and hardware specific. Serial protocols are typically implemented at some level with an RS-232 or RS-485 connection and can readily be used over modems or with local cable connections. Speeds for serial data transmission range from 1200 bits per second to 115.2 kbits per second. Ethernet based protocols use standard Ethernet as a physical layer and use one of the popular protocol stacks like TCP/IP or OSI with an accompanying messaging scheme. Hardware specific protocols like Modbus Plus or Profibus require a proprietary network controller chipset to perform the interpretation function.

Table 2: Industry Protocol Development Summary

Legend: E - Ethernet Interface, H - Hardware Dependent Interface, S - Serial Interface

	Developed to Connect Device/Device	**Type S, E, H**	**Developed By**	**Standards Board**	**Topology**
DNP V3.0	Utility SCADA Master/RTU Master/Sub Controller RTU/IED RTU/IED/HMI	S	Harris /Westronic	DNP V3.0 User's Group	Bus
DNP V3.0 Ethernet	Utility SCADA Master/RTU Master/Sub Controller RTU/IED RTU/IED/HMI	E	Harris /Westronic	DNP V3.0 User's Group	Bus/Star*
Modbus	Industrial Automation Master/PLC PLC/PLC PLC/IED PLC/IED/HMI	S	Modicon	Mfr.	Bus
Modbus Plus	Industrial Automation High-speed Master/PLC PLC/PLC PLC/IED PLC/IED/HMI	H	Modicon	Mfr.	Bus
UCA	Substation Automation Master/IED/IED All devices on same network	E	EPRI	EPRI/IEEE /IEC	Bus/Star*
Modbus TCP/IP /Ethernet	Master/PLC Master/Sub Controller PLC/HMI Sub Controller/HMI	E	Modicon		Bus/Star*
IEC-870-5-101	Master/RTU Master/Sub Controller Sub Controller/HMI?	S	?	IEC	?
IEC-870-5-103	RTU/IED IED/IED	S	?	IEC	?
Sei-Bus	Power device control /monitoring	H	Siemens E&A	Mfr.	Bus
Profibus	Industrial Sensor /Instrument	H	Siemens	Profibus User's Group	Bus
Foundation Fieldbus	Industrial Sensor /Instrument	H	FF Committee	FF Committee	Bus
SEL Interleave *Fast Meter* and Fast Message	SEL IED/SEL IED SEL IED/IED SEL IED/RTU SEL IED/Sub Controller SEL IED/Comm. Proc. SEL IED/Engineering Workstation	S	SEL Inc.	Mfr.	Star Routed Point-to-Point

SEL MIRRORED BITS	Relay-to-Relay	S	SEL Inc.	Mfr.	Point-to-Point
SEL Fast Fiber	SEL IED/SEL IED SEL IED/SEL Hub	S	SEL Inc.	Mfr.	Point-to-Point

*Bus technology that is actually implemented in a star topology for speed and robustness.

Table 3: Industry Protocol Functional Summary

	Register Info	**Bit Info**	**Master/Slave**	**Peer-to-Peer**	**Unsolicited Data**	**Report By Exception**	**Select Before Operate**	**Virtual Terminal**	**File Transfer**	**Time-Stamp**	**Self Description**
DNP V3.0	✓	✓	✓	*	✓	✓	✓	*	*	✓	*
Modbus	✓	✓	✓								
Modbus Plus	✓	✓	✓	✓							
UCA	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Modbus/Ethernet	✓	✓	✓	?							
IEC-870-5-101	✓	✓	✓		*	?				?	
IEC-870-5-103	✓	✓	✓							✓	
Sei-Bus	?	?	?	?	?	?	?	?	?	?	?
Profibus	✓	✓	✓		✓	?					
Foundation Fieldbus	?	?	?	?	?	?	?	?	?	?	?
SEL Interleave *Fast Meter* and Fast Message	✓	✓	✓	Soon Via Routing Capability	✓		✓ Via SEL-2020/2030	✓	✓	✓	✓ Limited Via Autoconfig
SEL MIRRORED BITS		✓		✓	✓						
SEL Fast Fiber	✓	✓	✓	✓	✓			✓	✓	✓	✓ Limited to Describing Quantity of I/O etc.

*Is available in some instances or is in standard but not generally implemented.

Architectures

Multidrop Network Architecture

The most common communication architecture used today is the multidrop network or bus network. A simple multidrop network is illustrated in Figure 4. All devices are connected to the same physical wiring bus. There are often additional components for terminations and network drop connections which are shown as vertical lines down to the individual IEDs. Because all IEDs share the cable, communications are usually controlled by the network master or a token passing scheme in which IEDs have permission to communicate when they receive the virtual token and then pass the token on when they are done. Peer-to-peer messaging may or may not be available. Data retrieval by the master is usually performed by sequential polling of each IED.

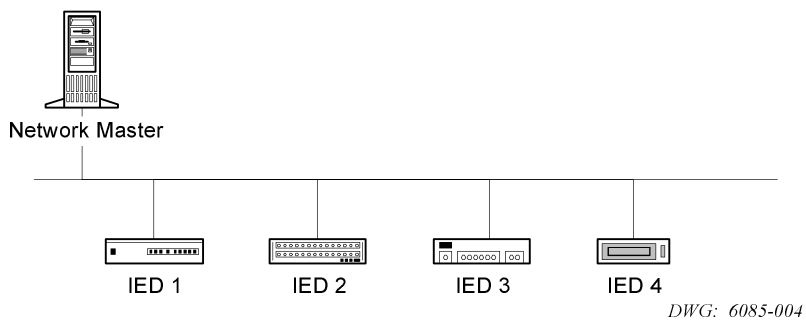

Figure 4: Multidrop Network

Advantages With Multidrop Network

- Conceptually easy to understand.
- Simple, fast peer-to-peer connections possible.
- Can install backbone cable throughout substation so that future nodes can be added without additional cable

Disadvantages With Multidrop Network

- Entire network vulnerable to malfunction of single node.
- Entire or partial network vulnerable to single cable cut .
- Doesn't allow simultaneous data polling of IEDs.
- Time to poll entire set of data is typically longer than in star configuration because must make many more transactions
- Difficult to expand because of cabling rules for drop length, etc., once it is installed. The backbone may need a major re-route to pick up a single new node.
- Cable is very sensitive to length, impedance and may be expensive.
- Expensive impedance matching drop connectors may be required.
- Ground fault potential from one device is transferred to all devices.
- Difficult to implement with fiber-optic cable.

- Some multidrop configurations require a remote master to perform the polling of the IEDs and cannot share data between IEDs when this connection is lost. The IEDs become stranded and do not work in a coordinated manner.

The Future of Multidrop Networks

The long-term trend is away from multidrop networks and toward star networks. For example, consider Ethernet. Originally conceived and designed as a multidrop network using expensive coaxial cable, widespread use has taught us that a star network is far superior in every day life. Today, virtually all Ethernet networks are built using hubs. A hub acts as a very short bus which allows you to wire from the hub using inexpensive cable in a star configuration.

With network traffic and use continuing to rise, we now are beginning to use even smarter devices in place of hubs called switches. A switch can store and forward information making the logical network a star also. Multiple nodes can transmit or receive messages from the switch at the same time. Ethernet has now completed the transformation both electrically and logically into a star network architecture.

Star Network Architecture

SEL started the search for the optimal architecture by identifying the fundamental requirements for substation automation communications with IEDs. We determined that low-cost fiber-optic links provided many advantages that other communications means did not, including immunity from EMI/RFI and ground-rise potential problems. We concluded that using a communications processor as the hub of a star communications topology provided optimal usage of channel bandwidth, device autonomy, speed, device selection freedom, and the ability to use low-cost fiber-optic links. Figure 5 shows a communications processor-centric star topology. The technical paper, “Nonconventional System Design for Flexible Data Retrieval and Use,” [4] has helped many customers, consultants, and integrators recognize the value in decentralizing processing and moving away from RTU/PLC-centric design. The SEL document, “Comparison of SEL-2020 Star Network to Shared Network,” [5] provides additional background for contrasting the star topology with multidrop topologies. Decentralization of data collection and increasing instrumentation and automation in the IED is the heart of our communications processor-centric design solution and the future of substation integration and automation.

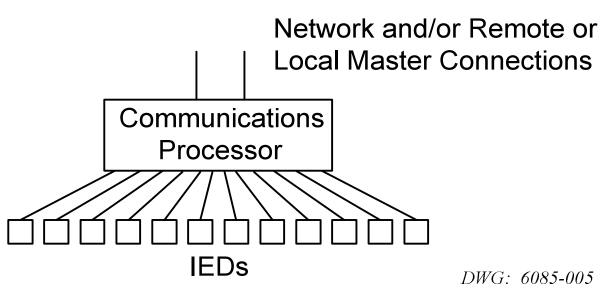

Figure 5: Star Topology

Disadvantages With Star Network

- Concept is not well understood and considered low tech.
- The user must purchase a network controller regardless of quantity of IEDs. SEL star networks require a communications processor for a single relay installation if the relay does not support the required protocol.
- Addition of nodes requires new point-to-point cable be installed.

Advantages With Star Network

- A star network allows the migration of some of the communications functions from the IED to the network controller. Moving protocols into the IEDs adds to their cost and accelerates their obsolescence as technology advances. The resources available within the IED are instead better focused on optimizing protection solutions.
- A communications processor used as a network controller can act as a client/server, data concentrator, substation archive, programmable logic platform, gateway, router, dial-out device, communication switch, and time synchronization broadcaster.
- Time to perform control action can be faster from master to IED than in bus topology.
- The communications processor can communicate without developing vendor-specific protocol software and can eavesdrop on conversations between two devices in the I&C system.
- Star networks can acquire and transfer data using much slower direct connections since it is performing many conversations simultaneously. These direct connections are also more reliable, more robust, and less expensive.
- The communications processor simplifies implementation through autoconfiguration, which describes the relay's attributes and capabilities.
- Direct connections in a star network are all independent and allow the network to support a wide range of relay capabilities. Simple, slow communicating devices can coexist with more complex fast communicating relays.
- The star network is the only design that is truly open and accommodates multiple protocols, multiple baud rates, and multiple network interfaces.
- Communications processors acting as a network controller enhance the value of the I&C system data by making it available to multiple master systems and other users.
- The communications processor creates an autonomous coordinated star network I&C system within the substation that does not rely on a master connection.
- Star networks allow mediation of local or remote control of the entire substation.
- As protocol requirements change in the substation, a communications processor network controller can be upgraded instead of each of the relays individually. The relays are left undisturbed and in service as a protocol change is made. It is also more economical to make this change in a single device.
- The age of IEDs that are in substations today varies widely. Many of these IEDs are still useful but lack the most recent protocols. Rarely is a substation integration upgrade project undertaken where all existing IEDs are discarded. A communications processor that can communicate with each IED via a unique baud rate and protocol can extend the usefulness of

IEDs. Using a communications processor for substation integration also easily accommodates future IEDs.

- Star network interleaved data streams is a simple innovative way that multiple conversations can occur simultaneously. Multipurpose, historical, and time synchronization conversations can simultaneously occur on a single communication channel.
- Troubleshooting communications problems is much faster and more efficient through simple LED indication on direct links in a star network than attempting to decipher multidrop networks.

Peer-to-Peer Network Architecture

Protection data, for the purposes of security, reliability, and speed, are highest priority and should be transferred via a single-purpose conversation on a channel dedicated to this purpose alone. These functions perform optimally if this data can be transferred every device processing interval, (1 - 12 ms). SEL determined MIRRORED BITS and other direct connections provide robust, reliable, and secure connections to transfer data that do not need to be on a centralized network. Figure 6 shows a peer-to-peer connection.

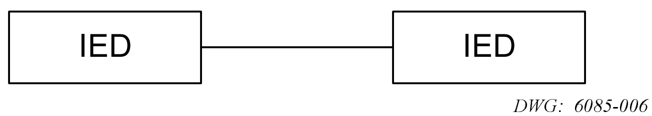

Figure 6: Peer-to-Peer Direct Connection

Hybrid Network Architecture

Using the communications processor as the substation controller, a hybrid system, as shown in Figure 7, can be created to perform control, monitoring, automation, protection, analysis, tests, maintenance, and operation of the power system.

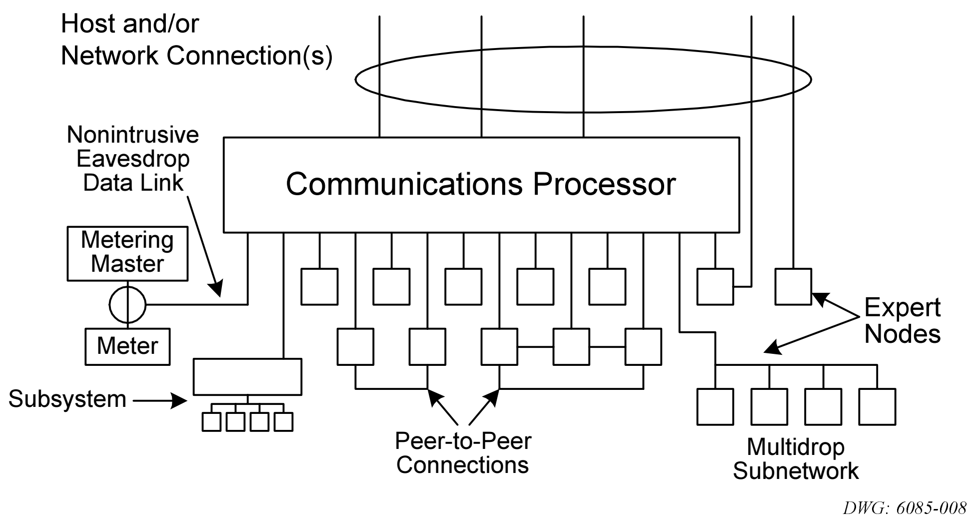

Figure 7: Communications Processor Centric Hybrid Network

Performance Measures

SEL is committed to providing integration systems that satisfy industry performance requirements. SEL is also committed to providing quantitative information on the performance of our products. Key performance measures that we strive to measure and improve include:

- Timing measures
- Security
- Availability
- Reliability
- Cost

Timing measures we consider include:

- Operate time for protection operation
- Operate time for control operation
- Round trip control operation and operator feedback indication
- Response time for data acquisition from a device
- Response time for data acquisition from a collection of devices

These timing measures are considered both on a device basis and on a system basis. Overall system performance is a function not only of individual device performance, but also of the system topology.

Security is the ability of a system to not treat noise and corrupted messages as valid messages. The degree of security required is a function of the type of information being moved. SEL considers the appropriate degree of security for all communications links.

Availability is the percent of time a system is available for use. It is important that this be maximized. Availability is typically compromised by noise and device reliability. We strive to create devices that have a high degree of reliability which will help minimize loss of availability. We also select communications techniques that quickly recover from errors and localize the scope of failures.

SEL is also committed to developing components for integrated systems that minimize system installed cost. This sometimes means that we recommend adding costs to one system device and not others so that we can create the minimum cost system.

FUTURE DEVELOPMENT

As part of SEL's development plans, we continue to identify the need to implement non-SEL standard protocols within SEL products to support loose relay sales and multidrop system designs.

Serial

We continue to implement non-SEL serial protocol interfaces within SEL products. The three most popular non-SEL protocols, are DNP V3.0, Modbus, and IEC 870-5.

Ethernet

SEL offers a modular Ethernet interface in the form of the SEL-2701 Ethernet Processor Card. This card interfaces to the SEL-2030 Communications Processor, and therefore to relays connected to the SEL-2030, as well as SEL-400 series relays. The SEL-2701 supports Telnet, a virtual terminal application, FTP, file transfer protocol and UCA/MMS protocol via 10 and 100 Mbit Ethernet connections. Customers use these Telnet and FTP protocols to transfer settings data and historical data such as event reports and profile data. Some customers are even using FTP to transfer supervisory and control data.

The SEL strategy to implement UCA has been to build onto our success with fast, cost effective, and reliable substation integration rather than obsolete all existing IEDs. We added UCA connectivity to completely integrated in-service and new substations at the network controller level and into SEL-400 series relays. Our customers can utilize their installed base of IEDs and their existing communications architecture as they phase in UCA. This strategy allows customers to migrate to UCA with minimal disruption and expense. It also gives instantaneous UCA interconnection to most IEDs available or installed today since the SEL-2030 is compatible with all SEL relays and controllers and many other vendor products.

Recognizing the market will wish to have UCA connectivity direct to the relays and controllers, future relays will support a direct UCA connection. The SEL-2020/2030s assure backward compatibility to every SEL IED ever sold, as well many other vendor IEDs. Previously installed and new IEDs with simple EIA-232 interfaces are easily connected to the SEL-2020/2030. The SEL-2030 bridges these IEDs to other network technology including Modbus Plus, UCA/MMS over Ethernet, and FTP and Telnet over Ethernet.

Using the SEL-2030 with embedded UCA technology as the substation controller and future relays with embedded UCA technology, a hybrid system can be created that designs itself as individual devices are chosen based on their merit rather than their interface. Customers choose from the best in-service or new IEDs to perform control, monitoring, automation, protection, analysis, tests, maintenance, and operation of the power system.

We are also committed to develop DNP V3.0 over Ethernet. This protocol has many advantages, and is popular with SCADA vendors. Several of our customers who are actively designing SCADA systems are using this interface. The SEL-2030 supports the traditional serial connections and with the SEL-2701 supports simultaneous connections to UCA/MMS, FTP, and Telnet, and in the future DNP V3.0 over Ethernet.

SEL-2701 and Utility Communications Architecture

We committed to Ethernet because it is fast, it has a broad installed base, and there are many internet and intranet tools available to enhance development and applications.

UCA requires that an application layer protocol, such as MMS, run on top of Ethernet and use data modeling as described by the UCA compatibility specifications.

We have defined the SEL-2701 and the host shared memory interface so that we will be successful in creating sufficient UCA models both in future products and for devices connected to the SEL-2030.

Many of our customers are involved in the UCA project. Below is a partial list of utilities that are funding the UCA initiative. Those with an asterisk are involved in demonstration projects.

* American Electric Power (AEP)
  Boston Edison (BE)
  Baltimore Gas and Electric (BG&E)
  Cinergy
* Commonwealth Edison (ComEd)
  Duke Power
  Florida Power Corp (FPC)
  General Public Utilities (GPU)
  Indianapolis Power and Light (IP&L)
  Northern States Power (NSP)
  NUON-TB (Netherlands)
* Ontario Hydro (OH)
  Southern California Edison (SCE)
  Tampa Electric (TE)
  Tennessee Valley Authority (TVA)

References

[1] Edmund O. Schweitzer, Bill Fleming, and Tony J. Lee, "Reliability Analysis of Transmission Protection Using Fault Tree Methods," Proceedings of the 24th Annual Western Protective Relay Conference, Spokane, WA, October 21 - 23, 1997.

[2] Gary W. Scheer, "Answering Substation Automation Questions Through Fault Tree Analysis," Proceedings of the 4th Annual Substation Automation Conference, College Station, TX, April 8 - 9, 1998.

[3] David J. Dolezilek and Dean A. Klas, "Using Information From Relays to Improve Protection," Proceedings of the 25th Annual Western Protective Relay Conference, Spokane, WA, October 13 - 15, 1998.

[4] David J. Dolezilek and Gary W. Scheer, "Nonconventional System Design for Flexible Data Retrieval and Use," Texas A&M Substation Automation Conference proceedings, Texas A&M University, 1997.

[5] Edmund O. Schweitzer, Gary W. Scheer, and David J. Dolezilek, "Comparison of SEL-2020 Star Network to Shared Networks," SEL, 1997.

[6] David J. Dolezilek, "Case Study of a Large Transmission and Distribution Substation Automation Project," Proceedings of the 1st Annual Western Power Delivery Automation Conference, Spokane, WA, April 6 - 8, 1999.

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