Practical Applications of IEC61850 Protocol in Industrial Facilities

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***Abstract* – Various communication protocols are used within a typical industrial facility including Modbus RTU, DeviceNet and Profibus. These protocols used over the years have been in a Master-Slave configuration. Intelligent Electronic Devices (IEDs) are slaves to single or multiple masters with one-way communication with the IED acting as a data/controlled node to the master device. Control is implemented in the IEDs, but only after commands are issued by the master computer. Both serial RS485 and Ethernet have been used for device communications. A new standard, defining protocols has been evolving since 1997, called IEC61850. This standard enables several industrial benefits when using an Ethernet network, such as high speed device-to-device communications (i.e. peer-to-peer communications both digital and analog values) within cycles and between different vendors, high-speed processing of analog signals and a common database naming format and structure. This paper will review the fundamentals of IEC61850 protocol including network requirements. It will also discuss four practical applications of IEC61850 protocol such as zone interlocking protection scheme, main-tie-main bus transfer scheme, load shedding scheme and client-server communications.**

***Index Terms* — IEC61850, IEC61850 GOOSE, Station Bus, Process Bus, LAN, VLAN, Quality of Service, Bus Zone Interlocking Scheme, Main-Tie-Main Transfer Scheme, Load Shedding Scheme, Client Server Communications.**

I. INTRODUCTION

Modern industrial sites have evolved into complex operations that perform many functions and require a wide variety of Intelligent Electronic Devices (IEDs) and controls to work properly and safely. To automate these environments, these IEDs need to work in close concert.

Technological advancements in IED hardware design and the development of high-speed peer-to-peer communication protocols, such as IEC61850 have resulted in a new generation of IEDs. These protective and control IEDs have the capability to accept multiple levels of current and voltage inputs and to analyze these values at significantly increased speeds. The main advantages of using these microprocessor-based IEDs are simplification of the device-to-device wiring, component cost reduction, increased system reliability and extensive data recording capabilities.

An efficient way to apply these microprocessor-based IEDs and obtain a reduction in device-to-device wiring is to use high-speed peer-to-peer IEC61850 Generic Object Oriented Substation Event (GOOSE) messaging between the protective IEDs.

II. OVERVIEW OF IEC61850 PROTOCOL

IEC61850 is a standard for the design of the substation automation and control communication system. IEC61850 is a part of the International Electrotechnical Commission's (IEC) Technical Committee 57 (TC57) communication reference architecture for electric power systems. IEC61850 defines the following communication paths:

- From the measurement process to the IED – known as the "Process Bus"
- IED to IED Communication through what is known as the "Station Bus"
- Client (e.g. – a Distributed Control System/DCS) to Server ("the IED") communications

IEC61850 defines data models and the abstract services to access the data. The abstract services defined in IEC61850 can be mapped to a number of protocols. Some current mappings in the standard are to MMS (Manufacturing Message Specification) and GOOSE (Generic Object Oriented Substation Event). IEC61850 requires an Ethernet physical network and typically uses high-speed switches to provide the network connectivity. With Ethernet as the physical layer, other protocols such as Modbus and DNP can also exist on the same network. This resulting architecture can deliver messages to any device on this network in the 2 to 4 ms time frame. The IEC61850 network that provides device-to-device communications is termed the "Station Bus".

The standard also defines a mechanism for the continuous transfer of digitized "process" data, such as currents and voltages and distributing these digitized signals to multiple IEDs. Field units named Merging Units (MU) are connected to multiple IEDs. The IEC61850 system architecture is shown in Figure 1.

Legacy protocols have typically defined how bytes are transmitted on the wire. However, they did not specify how data should be organized in devices in terms of the application. This "register based" approach requires power system engineers to manually map internal values to numbered registers. There is no standard as to what data item gets mapped into which register so a high degree of configuration between the Client and the Server is required. IEC61850 is unique in how it addressed this issue. In addition to the specification of the protocol elements (how bytes are transmitted on the wire), IEC61850 provides a comprehensive model for how power system devices should organize data in a manner that is consistent across all types and brands of devices. This eliminates much of the tedious non-power system configuration effort, because the devices can configure themselves. For instance, if you put CT/VT inputs into an IEC61850 relay, the relay can detect this module and automatically configure all measurements from this module without user interaction. Some devices use an SCL (Substation Configuration Language – an XML based configuration language) file to configure the device and the engineer need only import the SCL file into the device to configure it.

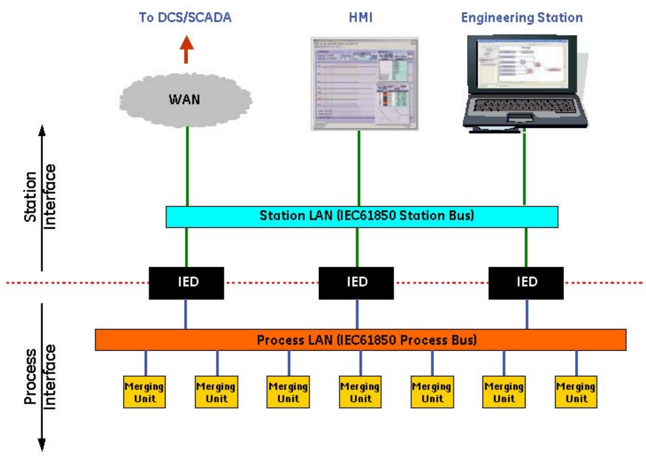

Fig. 1. – IEC61850 System Architecture

On initial startup and connection to a client, the IEC61850 client application can request the object definitions from the device over the Ethernet network (i.e. "self-describing IED). The result is a significant savings in the cost and effort to configure an IEC61850 device.

IEC61850 organizes data in what are called Logical Nodes or LN. A Logical Node contains the Data Items that describe a physical object like a Circuit Breaker or a logical function like Check Synchronization. Multiple LNs are organized in what are called Logical Devices and one or more Logical Devices are contained in a physical device (that is identified by its Internet Protocol address).

III. Industrial Benefits of IEC61850

The various profiles of IEC61850 have benefits to users in industrial applications:

- To start, the Client-Server profile simplifies data acquisition and interface to the plant DCS. Any "modeled" data item in an IED is available to the DCS in a named variable format through OPC (OLE for Process Control). Configuration is a simple matter of connecting to the IED and choosing the desired value for a display or control. As described previously, the IED is self-describing and data is located in standard locations defined by IEC61850.
- An IEC61850 system connects all devices together via what is known as the Station Bus. Given this connectivity, IEC61850 defines a mechanism that enables device-to-multi-device communication known as the GOOSE (described below). One GOOSE message can replace hundreds of wires that would normally be used to enable inter-device functionality.
- Time Synchronization to 1ms accuracy can be achieved through the Simple Network Time Protocol (SNTP) specified by the standard.
- The digitization of Current and Voltage transformers as well as the interface to Optical Voltage and Current sensors in enabled by the Process Bus profile that defines communication of digitized waveforms over Ethernet. The functionality eliminates copper signal and control wires in the switchyard and in the plant.

IV. Overview of IEC61850 GOOSE Messaging

IEC61850 Generic Object Oriented Substation Event (GOOSE) message is a user-defined set of data that is "Published" on detection of a change in any of the contained data items. Any device on the LAN that is interested in the published data can "Subscribe" to the Publisher's GOOSE message and subsequently use any of the data items in the message as desired. As such, GOOSE is known as a Publish-Subscribe message. With binary values, change detect is a False-to-True or True-to-False transition. With analog measurements, IEC61850 defines a "deadband" whereby if the analog value changes greater than the deadband value, a GOOSE message with the changed analog value is sent.

IEC61850 requires an Ethernet LAN as communication between the protective relays at the station bus level. Logical I/O via Ethernet communications is used in place of traditional hard wire to exchange the information between the protective IEDs. The information sent over the network might include connected device I/O, protective element statuses and programmable logic states. Modern IEC61850 implementations are able to send messages between protective relays at speeds between 1 to 2 ms. Also, IEC61850 includes the capability of exchanging analog data between relays in the same message, so actual values of currents, voltages, power, etc. are able to be sent over the high speed Ethernet network to other IEC61850 based IEDs.

When using IEC61850 GOOSE messaging, one can limit the wiring to the protective relay in an industrial facility to the following:

- 3 phase & ground currents
- 3 phase bus voltages
- 1-3 phase line voltages for synchrocheck function
- 52a contact
- TOC contact (is breaker racked in?)
- Trip output
- Close output
- Relay control power

Reduction in wiring is attractive to the switchgear builder and allows them to limit the wiring across shipping splits.

The GOOSE message obtains this high-performance by creating a mapping of the transmitted information directly onto an Ethernet data frame. There is no Internet Protocol (IP) address and no Transmission Control Protocol (TCP). For delivery of the GOOSE message, an Ethernet address known as a Multicast address is used. A Multicast address is normally delivered to all devices on a Local Area Network (LAN). Many times, the message is only meant for a few devices and doesn't need to be delivered to all devices on the LAN. To minimize Ethernet traffic, the concept of a "Virtual" LAN or VLAN (described in section V) is employed.

In the Internet world, TCP is used to "guarantee" the delivery of information, that is, if a packet of data gets lost, the TCP protocol detects that a packet was lost and re-transmits the lost packet. The protocol takes hundreds of milliseconds to operate and was clearly too slow to meet the needs of fast, reliable delivery. To meet the reliability criteria, the GOOSE protocol automatically repeats the message several times without being asked. As such, if the first GOOSE message gets lost (corrupted), there is a very high probability that the next message or the next or the next will be properly received.

As noted above, the GOOSE message is primarily sent on detection of a Change of State of a contained data item. If, for example, the data item is the status of a circuit breaker, it will not change state very often. The question then arises: how does one know if the devices or the links between devices are still functional? To detect a potential failure, a "keep alive" message is periodically sent by the Publisher. In the keep-alive message, there is a data item that indicates "The NEXT GOOSE will be sent in XX Seconds" (where XX is a user-definable time). If the subscriber fails to receive a message in the specified time frame, it can set an alarm to indicate either a failure of the publisher or the communication network. Thus, the IED could then take an alternate action when this alarm occurs.

The header of the GOOSE message contains other relevant information for the subscriber such as:

- The NAME of the GOOSE and its controls (a user setting)
- The number of times the GOOSE message changed
- The number of times the GOOSE message was repeated
- The number of times that the configuration of the GOOSE has changed
- A TEST flag
- The number of Data Items contained in a GOOSE message

A GOOSE message must fit into a single Ethernet data frame, which can be up to 1500 bytes long. A typical GOOSE message, however, is about 300 bytes long or 2400 bits. When modulated onto a 100Mb Ethernet LAN, the time on the wire of a GOOSE message is only:

$$2400 \text{ bits} \div 100{,}000{,}000 \text{ bits/sec} = 24\ \mu\text{sec}$$

As such, the primary limitation of message transmission and delivery is change detection in the IED. A well-designed IED can perform this change detect with an average latency of 1ms. Note that there is typically an application delay of 1ms in the receiving device.

V. Network Requirements

The use of IEC61850 places requirements on the network equipment used. Key requirements of the Ethernet network are support of Virtual Local Area Networks and Quality of Service. Other desirable Ethernet switch features are the ability to operate in a Ring configuration and subsequently automatically recover from a Ring break.

A. Virtual Area Networks (VLANs)

VLAN is short for "Virtual Local Area Network. A VLAN creates separate "virtual" network segments that can span multiple Ethernet switches. A VLAN is a group of ports designated by the Ethernet switch as belonging to the same broadcast domain. One can think of a VLAN as a piece of Ethernet coaxial cable and all the devices connected to that cable. VLANs provide the capability of having multiple LANs co-existing on the same Ethernet network. Two advantages of VLANs are the separation of traffic and security. VLANs can be port based or tag based. Port based VLANs assigns a specific port or group of ports to belong to a VLAN. When using tag based VLANs, a tag called a VLAN identifier is sent as part of the message. Note that the addition of this tag in an Ethernet message also includes the addition of a Priority flag – discussed later. This tag allows the message to move across multiple Ethernet switches whose ports are part of the same tagged VLAN. Tagged VLANs and priority (Quality of Service) are used within IEC61850 GOOSE messaging. Depending on the Ethernet switches used, up to 32 VLANs can be defined per Ethernet network.

B. Priority using Quality of Service (QoS) for IEC61850 GOOSE Messages

In order to ensure high network performance for the delivery of critical data, Ethernet switches offer Quality of Service (QoS) in compliance to IEEE 802.1Q standard. Included in the VLAN message is a priority flag (as part of the 802.1Q extended Ethernet data frame), which prioritizes data flows through an Ethernet switch, so that critical data is forwarded ahead of normal network traffic. Network traffic priority classification can be made by Port, by Tag or by IP Type of Service (ToS).

Quality of Service (QoS) provides the ability to prioritize traffic messages such as GOOSE on an Ethernet network. Prioritizing traffic into different classes is important to ensure critical data is processed first (i.e. protection traffic, data, voice or video). Quality of Service refers to the capability of a network to provide different priorities to different types of traffic. Not all traffic on the network has the same priority. Being able to differentiate different types of traffic and allowing this traffic to accelerate through the network improves the overall performance of message delivery and provides the necessary quality of service demanded by different users and devices.

IEC61850 GOOSE messaging mandates that a GOOSE message implement the 802.1Q extensions, which includes a priority setting with eight levels (0 to 7) of priority and a VLAN address.

C. Network Topologies

The topology of the network is critical when using GOOSE messaging. Since the message may include protective signals, redundancy of the Ethernet LAN may be required. A Star network architectures is shown in Figure 2.

For the star architecture, a single point of failure causes a loss of communication and network recovery times are approximately 5-6ms per Ethernet switch.

A mesh network is a LAN that employs one of two connection arrangements - either full mesh topology or partial mesh topology. In the full mesh topology, each node is connected directly to each of the others. In the partial mesh topology, some nodes are connected to all the others, but some of the nodes are connected only to those other nodes with which they exchange the most data. For a mesh architecture or topology, multiple points of failure are required before a loss of communications and additional cabling is required. A full mesh and ring network architectures are shown in Figures 3 and 4.

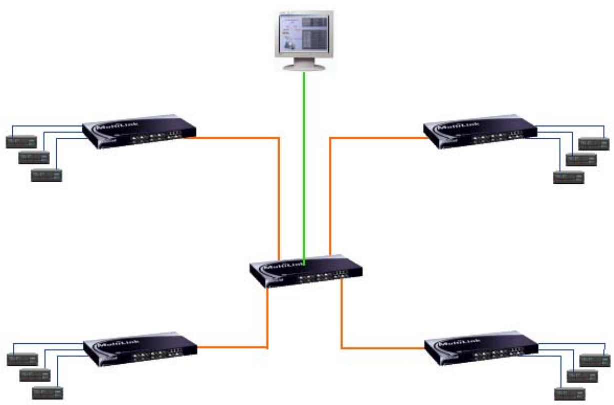

Fig. 2. – Star Network Architecture of Ethernet Switches

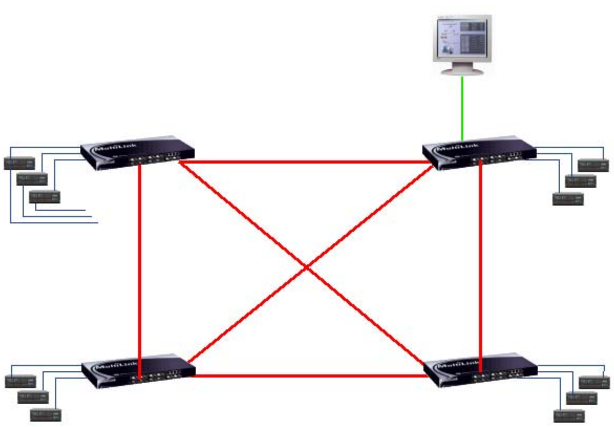

Fig. 3. – Mesh Network Architecture of Ethernet Switches

A ring architecture, by its design, provides network redundancy, and using proprietary techniques, has a failure recovery time of 5 milliseconds per Ethernet switch or hop, and is the most cost effective solution.

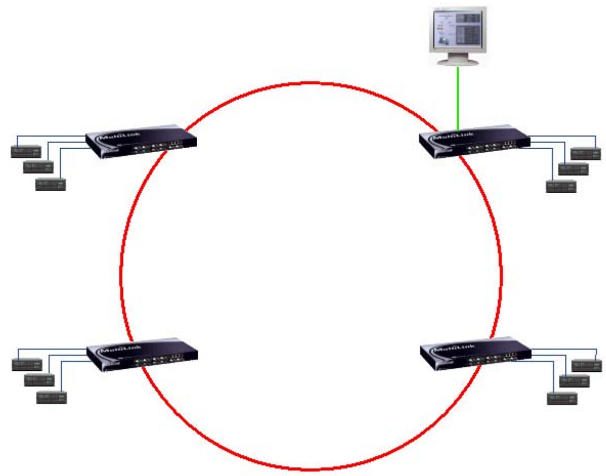

Fig. 4. – Ring Network Architectures of Ethernet Switches

D. Rapid Spanning Tree Protocol

Rapid Spanning Tree Protocol (RSTP) is an algorithm for detecting that there is a broken path in an Ethernet network and automatically re-configuring the network to communicate around the broken part of the network. RSTP is an evolution of Spanning Tree Protocol (STP) – which is now obsolete. RSTP provides for faster communication convergence after a topology change and to ensure loop-free topology for a ring topology LAN. Recovery times for RSTP can be in the order of 5ms per hop or Ethernet Switch. When a number of switches are connected in a redundant configuration, and when one of the components fails, there is a need to detect the failure and to re-configure the communication paths. This protocol implements its functionality by sending out messages to the various nodes in the network to detect the broken paths and to then perform the re-configuration. RSTP works in Star, Ring, and Mesh configuration, but can take “seconds” to operate. A unique requirements for the protection and control industry is to be able to “quickly” recover from network problems. There are several proprietary network recovery implementations that require the switches/devices to be configured in a Ring with no Mesh components. These proprietary implementations can operate in the 3 to 5 ms per Ethernet switch time frame. Figure 4 shows a ring mode only architecture.

E. Applicable Ethernet Switch Standards and Considerations Relevant to the Protection Engineer and Environment

When using Ethernet switches in harsh environments, such as chemical plants, paper mills, oil refineries, water & waste water facilities and power plants, one should consider using hardware that is conformal coated that ensures product function and viability in corrosive or other environments that can damage typical electronic equipment. Reliability is greatly improved when using the conformal-coated hardware.

An important consideration when selecting an Ethernet switch for your protection and control application is to make sure that the Ethernet switch complies with all required certifications and with all major International Standards for networking communications including: UL Listed/CE Agency Approved, IEC61850-3, IEEE 1613, NEBS Level 3, ETSI Certified, NEMA TS2, MIL-STD-167.

Redundant power supplies are offered on Ethernet switches. These power supplies can be of the same type, or of mixed voltage types to ensure even greater reliability through diverse power sources.

F. Redundant Networks or Redundant IED Ports Considerations

It is common in most industrial facilities to have a single point connection from the IED to the network. As IEC61850 GOOSE messaging is becoming more widely used in both industrial and utility applications, reliability of these critical messages could be improved by using redundant Ethernet networks, redundant power supplies on the Ethernet switches and redundant fiber optic Ethernet ports on the IEDs. When IEC61850 GOOSE messaging is used for protective functions, reliability and redundancy of the communication network should bear the same considerations as the reliability and redundancy of the protective IEDs.

Per IEEE Power System Relaying Committee Working Group WG119 report, the following recommendations are made when using IEC61850 for critical applications:

"*1. Connect multiple switches in a ring, so that there are at least two paths from any switch port used by a relay to any other such switch port. Ethernet switches include the failover service called rapid spanning tree protocol (RTSP) by which the switches discover and use a normal or default message path without circulating messages forever in a loop – one link in the loop is blocked to achieve this. If the ring suffers a break or if one switch fails, the switches can detect the path loss and immediately set up new routing of messages by unblocking the spare path to maintain communications.*

2. Many GOOSE-capable relays have primary and failover communications ports. Provide two switches or switch groups within the redundant Set A, and also in Set B. Connect the relay's primary port to one switch or switch group, and connect the relay's failover port to the other switch group."

VI. IEC61850 GOOSE Messaging Application 1 - Bus Zone Interlocking Protection Scheme

Arc flash energy may be expressed in $\mathbf{I^2t}$ terms, so one can decrease the **I** or decrease the **t** to lessen the incident energy. Protective relays can lower the **t** by optimizing sensitivity and decreasing clearing time. Low impedance bus protection, high impedance bus protection and bus zone interlocking are protective methods that decrease clearing time and reduce arc flash hazards.

Coordination between the main and feeder relays traditionally has been accomplished using time overcurrent relays (ANSI 51). The coordination time interval recommended has been around 200ms (12 cycles) between the main and feeder relays and instantaneous overcurrent element (ANSI 50) on the main breaker has not been used.

Bus zone interlocking scheme, as shown in Figure 5, is an efficient application of IEC61850 GOOSE messaging. In this scheme, the main relay will use definite time overcurrent element and the feeder relay will use time overcurrent element. The main relay selectively is allowed to trip or block depending on location of faults as identified from feeder relays.

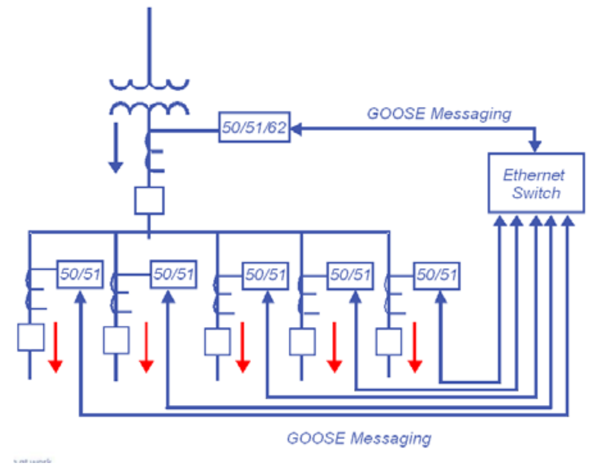

Fig. 5. Zone Interlocking Bus Protection Scheme Using IEC61850 GOOSE Messaging

For a fault on a feeder or an "out of zone" fault, the corresponding feeder will send a ***block*** GOOSE message to the main relay after its 51 time instantaneous overcurrent element picks up. The relay on the faulted feeder will operate only and clear the fault.

For a fault on the bus or an "in zone" fault, the corresponding feeder will not send a block GOOSE message to the main relay and the main relay will be allowed to ***trip*** and clear the bus fault after a fixed time delay. The main relay's 50 instantaneous overcurrent element will operate after a time delay for a bus fault. For an "in zone" fault, the typical time delay recommended is around 3-4 cycles (50-67ms). This time delay consists of the following:

a. Typical operating time of main 50 element = 20ms
b. Typical operating time of feeder 51 element pickup = 20ms
c. Network time delay = 4 ms (worst case)
d. Margin = 8-16ms

This scheme reduces the need for a discrete bus differential relay. A discrete low impedance bus relay or high impedance bus relay has a faster operating time than a bus zone interlocking scheme. A low impedance bus relay can operate within 1 cycle for bus faults and can use existing current transformers. A high impedance bus relay can operate within 1.5 cycle for bus faults and requires dedicated current transformers. This bus interlocking scheme can be easily implemented in retrofit applications where traditional bus differential would be challenging.

The benefits for using IEC61850 GOOSE bus zone interlocking are:

- Reduction of arc flash hazard.
- Transmitting and receiving IEC61850 GOOSE messages between two protective relays high speed via Ethernet port.
- Ease of relay coordination.
- No hard wiring between relays.
- Easy setup and configuration through PC software.
- Scheme alarms when either protective relay is off-line or not communicating.

VII. IEC61850 GOOSE Messaging Application 2 - Main-Tie-Main Bus Transfer Scheme

Main-Tie-Main (M-T-M) bus transfer is a common application in industrial facilities. In a typical Main-Tie-Main bus arrangement (Figure 6), the automatic bus transfer scheme is used to minimize the effect of outages on one of the incoming supplies by opening the normally-closed incoming breaker connected to that supply, and then re-energizing the decaying bus by closing the normally open bus tie breaker after the voltage of the decaying bus voltage drops to a predetermined level. This method is called Residual Voltage M-T-M bus transfer and is a very common transfer scheme within industrial facilities.

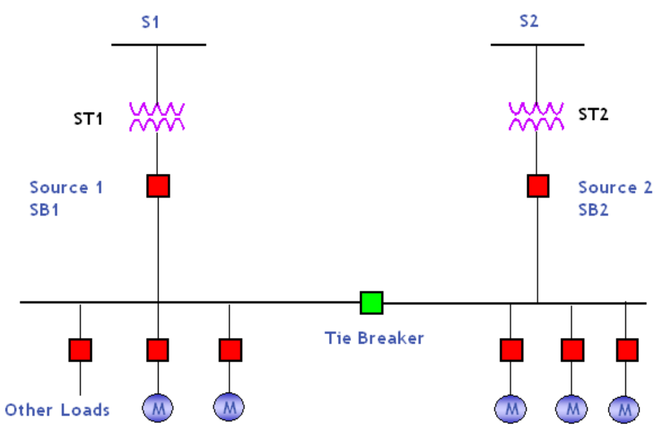

Fig. 6. Typical Main-Tie-Main Bus Transfer Scheme

Main-tie-main automatic bus transfer can be applied using two protective relays and IEC61850 GOOSE messaging. Protective relay 1 will be the master and implement automatic bus transfer logic and provide protection for Main 1 circuit breaker. Protective relay 1 controls Main 1 circuit breaker and Tie circuit breaker. Protective relay 1 also provides phase and ground overcurrent protection for Main 1 circuit breaker. Protective Relay 2 provides phase and ground overcurrent protection and transfer control for Main 2 circuit breaker. Figure 7 shows the typical configuration.

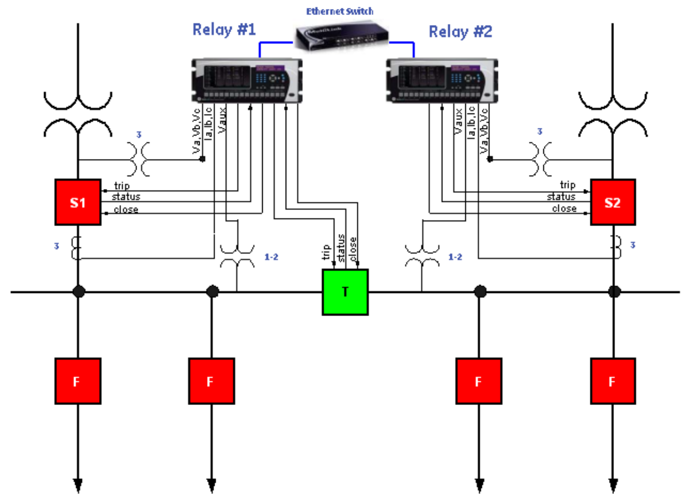

Fig. 7. Transfer Scheme Solution Using Two Protective Relays with IEC61850 Peer-to-Peer Communications

Figure 8 shows the GOOSE messages that are exchanged between the two IEC61850 based protective IEDs, which in past was implemented with hardwire cabling.

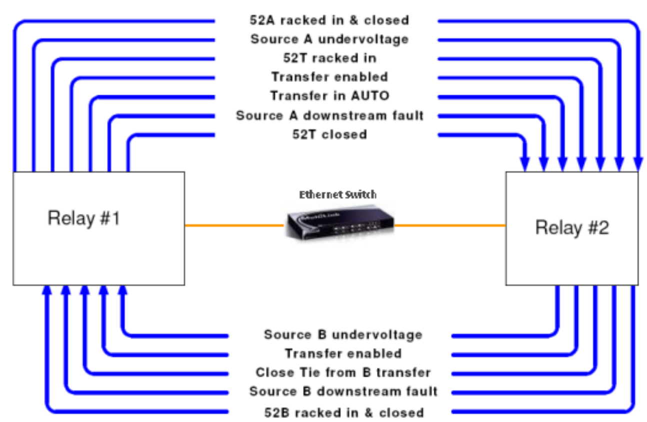

Fig. 8. M-T-M Bus Transfer Scheme Data Exchanged Between Two Protective Relays with IEC61850 Peer-to-Peer Communications

The advantages of using two protective relays and IEC61850 GOOSE communications for M-T-M bus transfer are:

- Significant reduction in hardwiring as compared to that between traditional bus transfer schemes.
- Transmitting and receiving digital status between two protective relays high speed via Ethernet port.
- The use of programmable logic controller functions such as timers and control logic within the protective relay provides for the flexibility to implement a custom bus transfer scheme to best meet the needs of the application.

- Selector switch functions (select to trip, auto transfer on/off) can be traditionally wired switches, or implemented via protective relay faceplate programmable pushbuttons, eliminating components and installation costs.
- Scheme alarms when either protective relay is off-line or not communicating.
- Reconfiguration of scheme without time and expense of additional wiring.
- Ability to easily duplicate for additional M-T-M systems by only changing the device names used.

VIII. IEC61850 GOOSE Messaging Application 3 - Load Shed Scheme

Another application of IEC61850 GOOSE messaging is fast load shedding. A fast load shedding (FLS) scheme rapidly sheds load in a large industrial facility in response to loss of one or more incoming sources in order to avoid complete system collapse while maintaining supply to as much of the process as practical. Unlike undervoltage, underfrequency, or rate of frequency decay load shedding schemes, the fast load shedding scheme can initiate load shedding before the system frequency/voltage declines, which in many cases is essential for maintaining system stability. The fast load shed scheme uses IEC61850 GOOSE communications to collect load and incoming source power information from a very large number of end units at very high speed. The end units send power values via IEC61850 GOOSE messaging. This information is processed in one protection pass (i.e. 1ms) of the FLS controller and shed requests issued according to configurable priority or pattern again using IEC61850 GOOSE messaging. A very basic system is shown in Figure 9.

A fast load shed (FLS) scheme consists of a fast load shed controller (FLSC) connected to end devices. A fast load shed controller (FLSC) is the device that makes the final load shedding decisions in real time. Where there are many end devices, there may be a need for a load shed aggregator. A load shed aggregator is a device that combines load information from multiple end devices into a single IEC61850 message, to extend the number of loads an FLSC can control. This advanced scheme is shown in Figure 10. This advanced scheme is able to send load shed commands within 2 cycles of loss of generation.

An end device for the purposes described here is an IEC61850 based IED that monitors, controls, and typically protects the incoming sources and sheddable loads, as well as interfaces with a load shed controller/aggregator to the process equipment.

An FLSC can be configured to shed load groups in the event of a contingency according to a set of priorities or trip masks. A contingency is the loss of any one or more incoming sources. A load group is a number of individual loads that are treated by the fast load shedding scheme as a single unit, allowing the FLSC to handle thousands of individual loads with a manageable number of settings.

Priorities are numbers assigned to each load group, used when the FLSC is in adaptive mode to instruct the FLSC on the relative importance of the load groups. A trip mask is a scenario setting used when the FLSC is in static mode

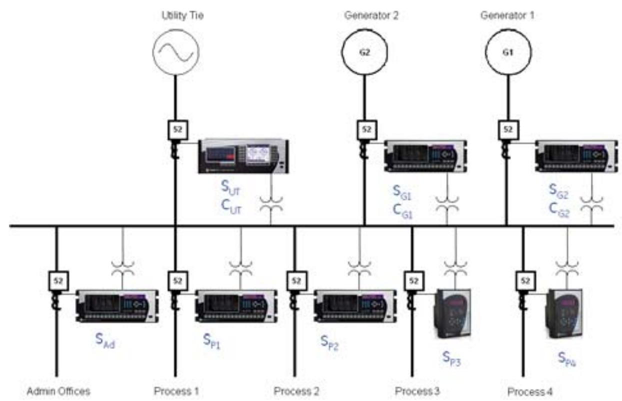

Fig. 9. A Basic Load Shed Scheme Using IEC61850 Based Devices

specifying which load groups to shed for the associated scenario. A scenario is a specific contingency, the presence of which is calculated by programmable logic in the FLSC using the incoming source offline status values and perhaps other information. An example of a scenario is incomer T1 going offline while generator G1 is out of service. The priorities/trip masks may contain permanent setting values, or an external computer can be set up to continuously adjust the priorities/trip mask as required by changing process needs.

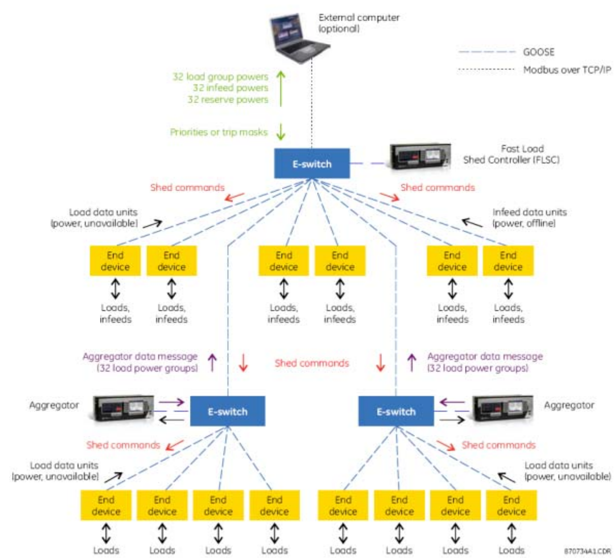

Fig. 9. An Advanced Fast Load Shed Scheme Architecture

The fast load shed controller is informed of present system power flows and of contingencies via IEC61850 data messages (i.e. GOOSE messages) received from end devices, aggregators, or both. The information received by an FLSC or by an aggregator in a data message about a load, an incoming source or an aggregator is referred to as a data unit. Based on settings, on the information in data units, and on the present priorities or trip masks values, the controller generates shed requests indicating which load groups are required to be shed by the end devices. The shed requests are transmitted to the end devices in a shed command message (an IEC61850 GOOSE message). The end devices do the actual shedding. Data messages and shed commands are per the IEC61850-8-1 GOOSE specification and may be used with many types of IEDs that support the protocol.

An IEC61850 based architecture exists today that can shed over 2500 loads. For example, the FLSC could receive load and incoming source information from up to a combined total of 64 end devices and aggregators, plus 6 local loads and incoming sources. Each aggregator could receive information from up to a total of 64 loads and aggregators, plus 6 local loads and incoming sources. Thus it is possible to have an installation with 12 incoming sources, 18 loads, and 40 aggregators, each aggregator with 64 loads, all this supporting a total of 12 incoming sources and $40 \times 64 + 18 = 2578$ sheddable loads.

End devices send to an FLSC or an aggregator 6 data units in a single IEC61850 data message. Not all of the data units in a data message need be used. Incoming source data units contain the measured real power flowing out of the incoming source and the offline status of the incoming source. Change of offline status from “Off” to “On” is indication of the loss or eminent loss of that incoming source and that is a contingency. Load data units contain the measured real power flowing into the load and the unavailability status of the load for fast load shedding. Loads with unavailability status of “On” are not included when calculating the amount of sheddable load there is at present in a load group. It is possible for a data message to contain both incoming source and load data units. Data messages with incoming source data units should be sent directly to the FLSC.

Aggregators send to the FLSC (or conceivably to another higher level aggregator) a single IEC61850 data message. Aggregator data messages contain 32 load group powers. Each load group power is the sum of the powers of the load data units that are available for shedding and are aggregated by that aggregator to that load group. The FLSC sends back down to the end devices an individual shed request operand for each of the load groups used by the application, typically all in a single shed command IEC61850 GOOSE message. The shed commands are sent directly to all end devices via the switched Ethernet network.

The benefits of using an IEC61850 based fast load shedding scheme are:

- Efficient use of protective IEDs for protection and control without the use of external devices or programmable logic controllers.
- Transmitting and receiving of IEC61850 GOOSE message, both digital and analog, between devices via high speed via Ethernet port
- Scheme alarms when either protective relay is off-line or not communicating
- Reconfiguration of scheme without time and expense of additional wiring

IX. Conclusions

The Ethernet network within an industrial facility has been used primarily for data communications and DCS control, but with the use of IEC61850 communications, efficient protective control of devices can be accomplished. IEC61850 enables industrials several benefits using an Ethernet network, such as high speed device-to-device communications (i.e. peer-to-peer communications both digital and analog values) within cycles, and a common database naming format and structure. There are several practical applications of IEC61850 protocol, such as bus zone interlocking protection scheme, main-tie-main bus transfer scheme, load shedding scheme and client-server communications. IEC61850 protocol in the industrial facility provides the benefits of reduction of device-to-device wiring, component cost reduction, simple configuration and re-configuration and scheme alarms when IED(s) go off-line or are not communicating.

X. Biographies

Craig Wester is the southeast US regional sales manager for GE Digital Energy Multilin in Norcross, Georgia. He was born in Belgium, Wisconsin, and received a B.S. in Electrical Engineering with a strong emphasis on power systems from the University of Wisconsin-Madison in 1989. Craig joined General Electric in 1989 as a utility transmission & distribution application engineer. He is a member of the IEEE.

Mark Adamiak is the Director of Advanced Technologies for GE Digital Energy Multilin and is responsible for identifying and developing new technology for GE's protection and control business. Mark received his Bachelor of Science and Master of Engineering degrees from Cornell University in Electrical Engineering and an MS-EE degree from the Polytechnic Institute of New York. Mark started his career with American Electric Power (AEP) in the System Protection and Control section where his assignments included R&D in Digital Protection and Control, relay and fault analysis, and system responsibility for Power Line Carrier and Fault Recorders. In 1990, Mark joined General Electric where his activities have ranged from advanced development, product planning, application engineering, and system integration. Mr. Adamiak has been involved in the development of both the UCA and IEC61850 communication protocols, the latter of which has been selected as a NIST Smart Grid protocol. Mark is a Fellow of the IEEE, a member of HKN, past Chairman of the IEEE Relay Communication Sub Committee, a member of the US team on IEC TC57 - Working Group 10 on Utility Communication, the US Regular Member for the CIGRE Protection & Control study committee, a registered Professional Engineer in the State of Ohio and a GE Edison award winner for 2008.

XI. References

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