Case Study/Overview of Applying an IEC 61850 Parallel Redundant Protocol Communications Network on a University Campus Power Micro Grid Distribution and Generating System

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Abstract

Maintaining a coordinated power distribution network with multiple power sources and numerous network power connections can be very challenging. For some systems, these various combinations for loads and sources that allow power to flow through a customer's distribution grid can also create unsafe conditions for the distribution equipment as well as the operators who work in close proximity to the equipment. The need for a coordinated system in this environment is critical. In the past, methods to maintain coordination or control between devices was done by implementing a hard wired input and output system connecting the digital status of interlocking contacts or to utilize a proprietary communications protocol that only allow devices that operate under that protocol to be connected. Utilizing hard wired connections between protective devices for control and logic can create a number of challenges based on the layout and the geography of the distribution network. A proprietary communication system limits the devices that can participate to the one manufacturer for the devices that need to be interconnected. In many cases these methods are harder to implement and not flexible for any future changes to the logic.

This paper will look at implementing a communications and control scheme utilizing IEC 61850 protocol between intelligent electronic devices (IEDs) for a university campus power distribution micro grid which includes multiple power sources consisting of steam driven generators and utility grid connections. Loads vary throughout the school year which requires shifting the power flow on the campus distribution grid based on time of the year and the environment. Steam reduction via power generation and buying power off the grid are other variables that factor into the scheme for campus power flow. Steam reduction, generated power, campus load and purchased power must be constantly monitored and adjusted for optimal efficiency and cost.

Background

Iowa State University, located in Ames Iowa is a large research and teaching institution with over 42,000 students, faculty and staff on a campus that today resembles a small city. The campus consumes large amounts of energy for heating, cooling and operating their facilities.

Iowa State University (ISU) has a long history of generating electricity dating back to 1884 when an Edison Isolated Electric Plant was installed for the campus that operated only during the evening hours. Some of the early light bulbs used on campus were given to ISU by Thomas Edison for experiments in the physics lab. By 1890, all the major buildings had electric lights which prompted a new campus generating station with a Corliss steam engine to generate power. Over the years the campus load continued to grow as did the infrastructure to support the distribution of power.

Today the campus power plant has five boilers, four steam turbine generators totaling 46 MW, one small wind generator and four centrifugal chillers. A fifth chiller is located remote in the North Chilled Water Plant. The total combination of boilers can created 790,000 pounds of steam per hour through a combination of coal fired fluidized bed burning Midwest bituminous coal and natural gas fired boilers.

Power is purchased for the ISU campus through two 20 MVA transformers that are connected to the City of Ames 69KV power grid. ISU typically generates 50 to 60% of the electric power required by the campus loads. By buying and generating power, it creates another challenge for ISU. The ability to monitor daily/hourly power flow across the ISU campus is required to maintain the balance of power so an unsafe condition is not created for their installed infrastructure. Connecting all sources in parallel would create an available fault current that would exceed their power distribution equipment ratings. Hence the tie connections for both sources from the City of Ames that allows interconnections of the two sources is always open and the steam generators that are being used are balanced onto each side of the open tie connection to keep fault currents to a manageable level for the ratings on the distribution equipment that is involved in distributing power across campus.

Although power is purchased from the City of Ames at 69kV, it is generated and distributed across campus at 13.8 kV and 4.16 kV. There are several distribution substations that reduce the voltage to 4.16 kV for servicing approximately 60% of the campus facilities. The remaining portions of campus are served at 13.8 kV. All large motors and chiller loads are also connected at 4.16 kV. The interconnections at both 5 and 15 kV are set up to allow power to be segregated and/or connected from multiple directions and multiple sources on their campus distribution grid. This distribution scheme allows ISU the maximum amount of flexibility to isolate and/or connect loads and sources in combination to maintain their desired equipment safety fault level while still maintaining the highest efficiency for generation.

A similar but not exact representation of the ISU campus power distribution network is represented in figure 1. As you can see by the various power sources and how the power network is configured, there are numerous ways power can be flowing across campus.

The protective relays for the medium voltage switchgear used in the campus distribution system were all dated to the installation time of the original switchgear. These protective relays were predominantly single function analog based and when required to be interlocked they were connected together with a hard wired system.

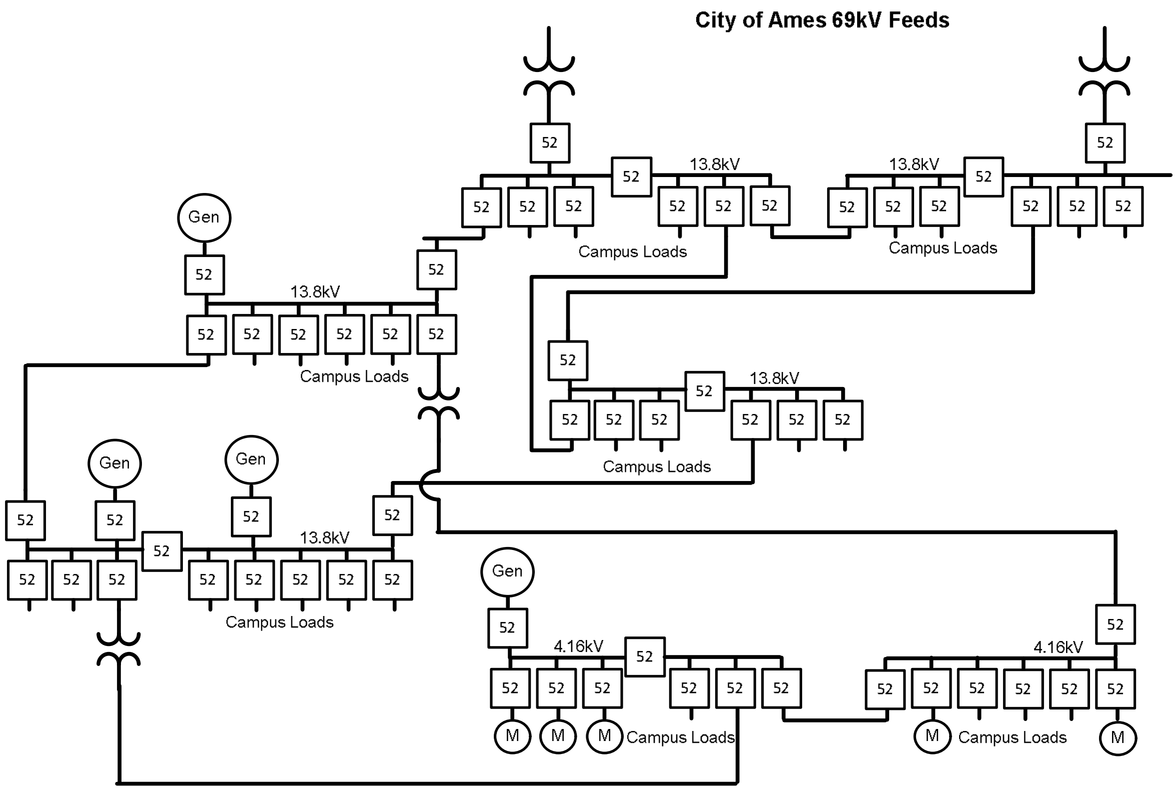

Figure 1

A major expansion project for the 13.8kV distribution system involving the installation of the second 20 MVA transformer and associated switchgear led ISU to evaluate IED based protective relays that would be used for the new project and also consider using the same relay platform for retrofitting the rest of the existing units on campus. The evaluation criteria for selecting the protective relays was based on many factors. Ease of use, interoperability, a high level of reliable communication capabilities and an advanced level of functionality were just a few of the requirements that ISU sought to achieve with the new relays. Incorporating arc detection as part of the expanded functionality to help lower the available incident energy was also part of the evaluation for the relays that would be used for the new switchgear and the retrofitting of the existing switchgear on campus even though retrofitting arc detection into existing switchgear created additional challenges.

A supervisory control and data acquisition system or (SCADA) for the medium voltage system did not exist before the campus grid expansion. The operation, monitoring and control of the power plant boilers, turbines and chillers was done through a digital control system (DCS).

This new SCADA system needed to be connected to and fully communicate with the overall DCS since generating power and steam reduction were tied together for maintaining the highest level of efficiency and ease of operation.

A communication connection to the City of Ames for monitoring the power being purchased off the grid and the status of the 69 kV connection to the 20 MVA transformers was also required as part of the new ISU SCADA system. There was an addition need for the SCADA system to be able to remotely control the tap changers for the two 20 MVA 69 KV step down transformers feeding the campus from the City of Ames grid. The power plant operators also needed to be able to control the medium voltage capacitor banks over the communications network as they constantly monitor the power factor and must maintain certain parameters under contract to the City of Ames. Iowa State University's goal was to create a system that supported interoperability and integration for all the challenges previously mentioned. They accomplished this by integrating IEC 61850 with parallel redundant protocol (PRP), which today offers the highest level of secure communications possible in a redundant manner.

What is IEC 61850

IEC 61850 is more than a protocol. It is a global standard that was developed involving the ANSI UCA 2.0 and the IEC 60870-5-103 standards. The development of 61850 was monitored by both Standards Groups for any technical issue resolution and device level conformance testing. The core of this new standard is the representation of functions and equipment, its attributes, and its location all contained within a communications network for a power utility system. It allows interoperability to exchange information between Intelligent Electronic Devices (IEDs) from different manufacturers using 61850. It creates long term stability for a main stream communications technology that supports the evolving system requirements in a centralized or decentralized system.

An extended application scope of the IEC 61850 standard includes the following:

– for the power quality domain;
– for statistical and historical data;
– for distributed generation monitoring and automation purpose;
– for feeder automation purpose;
– for substation to substation communication;
– for monitoring functions according to IEC 62271.

• Smart grid considerations.
• Extensions (and provisions for extensions) of the documentation system relating to report and guidelines) for IEC 61850, especially with part 7-5xx (Application guides) and part 90-xx (Technical report and guidelines).

Multiple sections of the 61850 standard address most of the issues and applications today but certain sections continue to be updated as market needs continue to evolve. The IEC 61850 standard allows interoperability between different protective relay manufacturers to work together seamlessly on a communications network where those protective relays are used to coordinate protection and monitor power flow.

A structured breakdown of the physical device beyond the network address is represented in Figure 2. This structure is universal across all devices and is accessed individually by the standard device naming procedure within the standard.

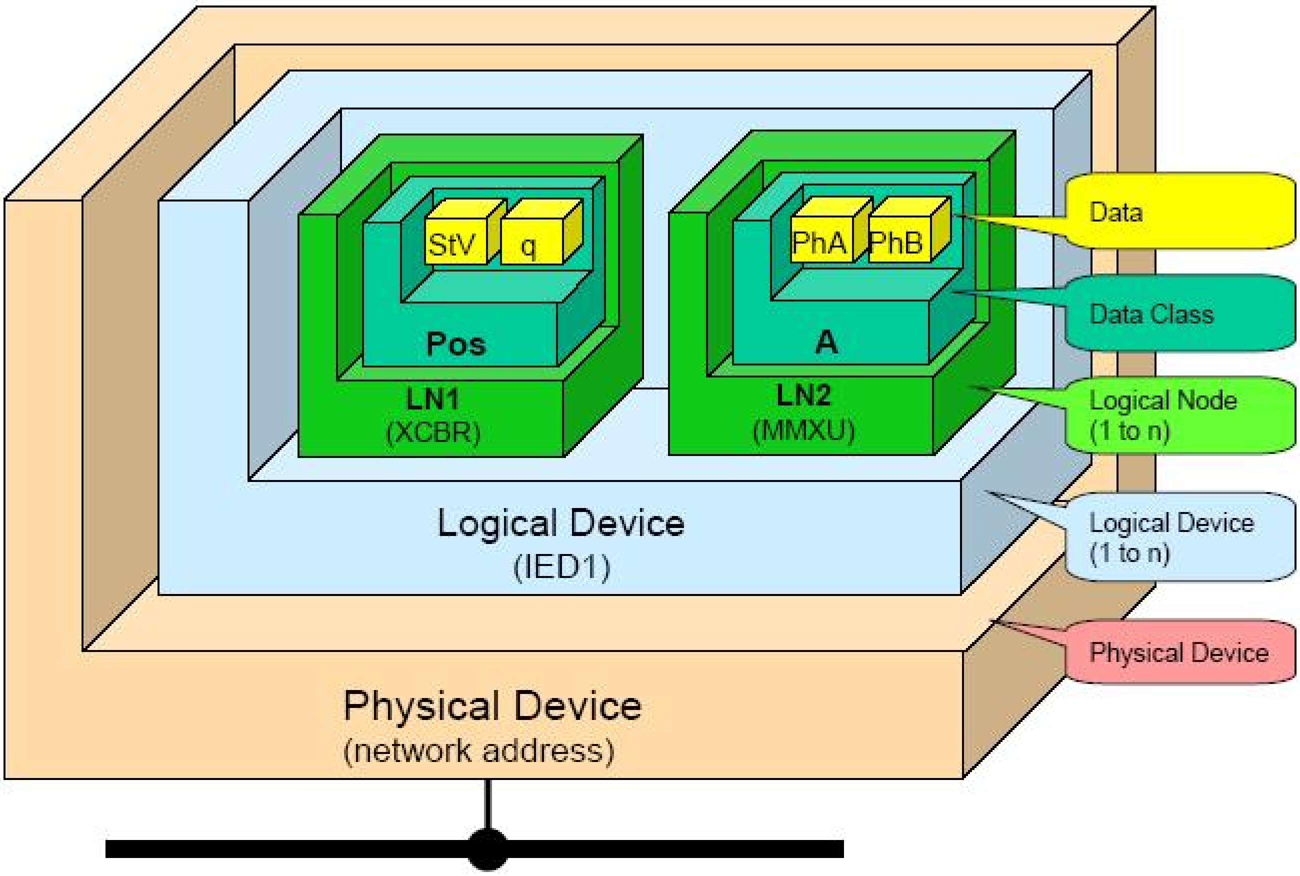

Figure 2

This structure allows a common platform for data to be exchanged or referenced. In addition to this structure, a common naming design allows each device on the network to be referenced. An example of some of the naming references are as follows:

- LLN0, LPHD: IED and function management
- Pxxx: protection (PTOC, PIOC, PDIS, PDIF,….) (28)
- Rxxx: protection related (RREC, RSYN, RDRx, ….) (10)
- Cxxx: control related (CSWI, CILO, CALH, CCGR, CPOW)
- Mxxx: measurements (MMXU, MMXN, MMTR, MHAI, MDIF, MSTA)
- Axxx: automatic functions (ATCC, ANCR, ARCO, AVCO)
- Gxxx: generic functions (GGIO, GAPC, GSAL)
- Sxxx: sensor/monitoring interface (SIMG, SIML, SARC, SPDC)
- Txxx: instrument transformer (TCTR, TVTR)

- Xxxx: switchgear process interface (XCBR, XSWI)
- Yxxx: transformer process if (YPTR, YLTC, YEFN, YPSH)
- Zxxx: further power related equipment (ZBAT, ZGEN, ZMOT,…)
- Ixxx: interfacing and archiving (IHMI, ITCI, IARC, ITMI)

A method to exchange data between devices on the network is also part of the IEC 61850 standard. This exchange is known as a generic object oriented substation event (GOOSE) and allows data to be transmitted and received at a certified rate within the standard. Under IEC 61850, transmission rated devices exchange GOOSE messages at 4 ms or less while distribution rated devices exchange at 8 ms or less. Standard error checking of the data exchange is part of 61850 and the use of Ethernet as a transport medium guarantees the data exchange speed for a GOOSE message.

After the implementation of the redundant networks design, the protective relays for the campus distribution grid are used in applications for transformer differential, main/feeder overcurrent, capacitor bank protection and bus differential protection. Additionally the relays also provide all control and monitoring of the respective breakers through the campus SCADA IEC61850 network connections. Arc fault detection is also monitored from switchgear to switchgear or between protective relays that may reside in different switchgear line ups and in different buildings. The flexibility of controlling remote relays that may feed power or receive power is done using the redundant communications network and is scalable as the campus power flow changes and expands.

IEC 61850 Communication Options

The IEC 61850 standard utilizes the IEEE 802.3 Ethernet standard as the communications backbone for its implementation. All the installation and application requirements for 61850 must follow the IEEE 802.3 installation guidelines. Iowa State University requested a communications backbone that was redundant and limited the amount of failure points for every connection along the communications network. Figure 3 shows a network of Ethernet switches where each connect to a number of intelligent electronic devices. The switches are connected by fiber and the IEDs are connect to each switch by copper UTP. The red X's on the figure represent potential failure points that can occur on this network design. An IED failure, a failure in the cable connecting the IED to the switch, a failure in the fiber cable or a switch failure can all create a communications failure and put system communications integrity at risk.

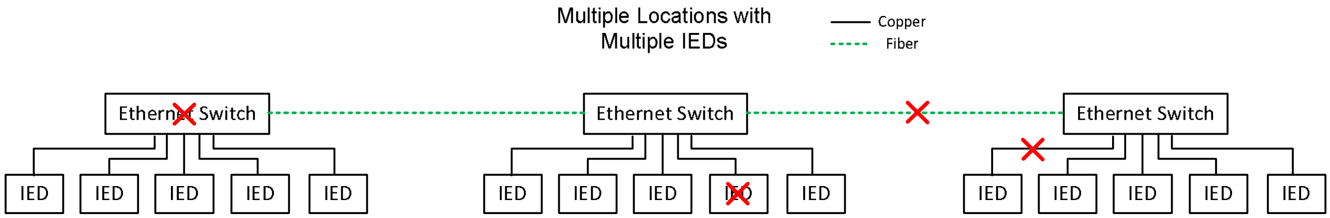

Figure 3

By adding a ring bus design on the fiber that connects the Ethernet switches as shown in Figure 4, you can eliminated a potential failure point that will affect the communications network integrity. The communications will reroute to the find the proper destination as all the switches have two routes to complete its communications send or receive.

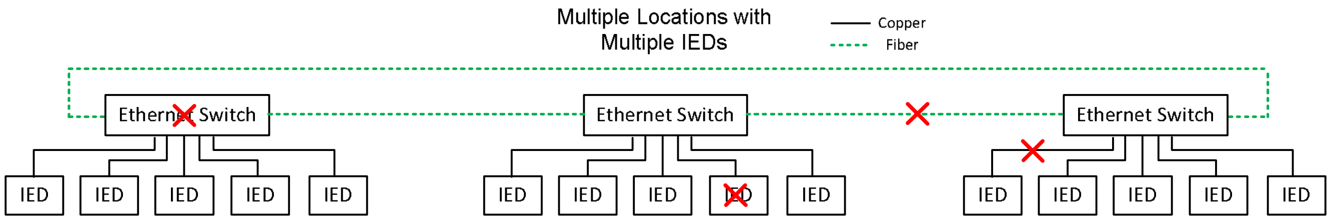

Figure 4

By changing to a ring bus network design at the IED connection level as shown in Figure 5, you can eliminate yet another point of failure that will affect the network communications integrity as the communications from and to the IEDs maintains a connection to the Ethernet switch on the other side of the broken ring.

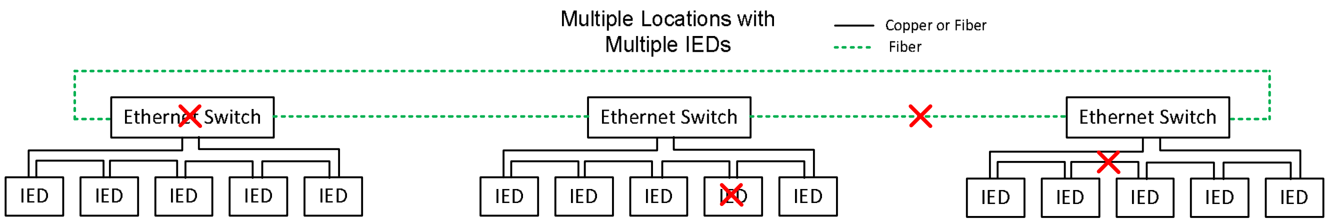

Figure 5

By adding redundant power supplies you can potentially eliminate a switch failure or outage but there is still another configuration that can give the end user the highest network integrity possible. ISU's request at the beginning of the design phase for this project was to create a system with the highest level of communication integrity as possible.

By implementing IEC 61850 parallel redundant protocol (PRP), a network can be designed that eliminates a single point of failure on the communications network except for the device that receives the communications or the device/software that initiates the communications. Figure 6 shows a second set of Ethernet switches at each location with parallel connections to each IED. Network "A" operates independently and separate from network "B". No violations of the IEEE 802.3 Ethernet Standard are made with this design since each IED must still maintain a single IP address. IEC 61850 communications are sent simultaneously from each Ethernet port of the IED to separate independent networks. The receiving device accepts both messages but ignores the second as messages are distinguished within the protocol. If a message does not get through because of a failure on the network, it will trigger a flag or error at the sender but the receiving device will still get the message over the second network.

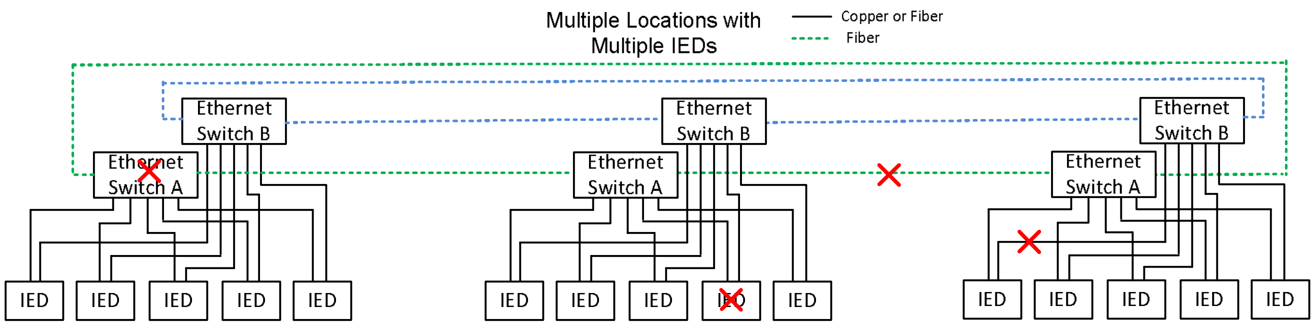

Figure 6

The network design in Figure 6 minimizes the points of failure and creates a network that is extremely reliable and very robust.

Additional Challenges Implementing IEC 61850 PRP

Since IEC 61850 PRP is not supported by some manufacturers, connecting these devices to a redundant network as shown in Figure 6 can be accomplished with special Ethernet switches that are PRP compliant. Connections are made to each network and to the device that still must be IEC 61850 compliant. The special switch monitors the communications and prevents redundant messages being sent to the device from both networks.

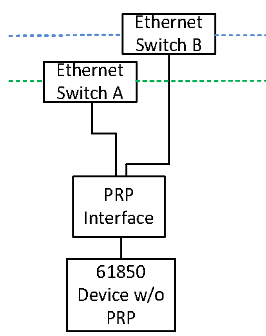

Figure 7

Figure 7 shows such a connection to allow devices that do not support PRP onto the network. The IP address of the device must still be unique to the other devices on the sub network for this design to work.

To complete the network communications for the protection relay project at ISU, the desire for redundancy involved the need for exchanging data to the campus SCADA system in a redundant fashion. This was accomplished with two separate MicroScada devices that support IEC 61850 PRP. Both are connected to the redundant networks that connect to the IED's redundantly and each push or pull data through an Open Platform Communications (OPC). This allows each MicroScada to perform a bidirectional exchange of information to and from the campus DCS software Symphony Plus. In the event that the Symphony Plus DCS fails, each MicroScada also has the ability to fully operate all the components connected to the power distribution network SCADA system. Figure 8 shows the network functionality from the SCADA to the IED. Network redundancy is maintained to minimize any point of communications failure which allows the maximum degree of reliability and scalability possible.

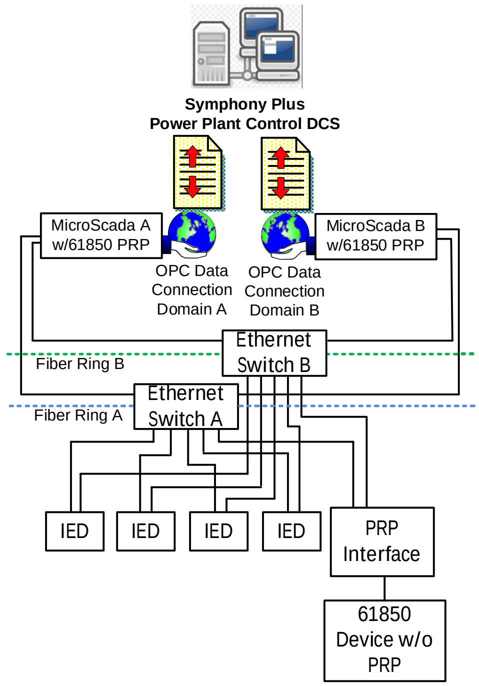

Figure 8

Conclusions

As microprocessor technology continues to allow intelligence or information to migrate closer to the end user, it will become more important to support the access of the information that is created from that increase in functionality. The amount of information also available has expanded at nearly exponential rates as microprocessor based technology provides the user more functionality. From cell phones to protective relays, functionality has increased at rates that are difficult for some to keep up with. In the past, analog based protective relays were designed to provide one or two protective functions. Analog phones were just phones. Today, microprocessor based protective relays take the same analog signals from instrument transformers and then provide multiple protective functions incorporating the ability to provide in one relay what in past took multiple relays that were interconnected. Cell phones still utilize analog based radio wave signals through the airways but can now layer increased functionality over the same signals with digital technology.

This evolution continues with no end in sight as devices become smarter, faster and smaller. The ability to provide more functionality is supported in parallel by the need to access the information which is created from the increase in functionality. Networking intelligent devices together also expands and supports the increase in this functionality as intelligent devices communicate directly with other intelligent devices removing the need for interaction from a human operator or master software platform. The rapid expansion of the Internet is proof enough how networking devices together increases the available amount of information.

Network cyber security with IEC 61850 is supported through the integrity of the device naming and data naming structure within the device. Utilizing IEC 61860 on a private network that is hard wired with restricted access to open switch ports will also provide the physical restrictions that elevate the security. Restricting access to any wireless connections for the PRP network will also elevate the cyber security level even though there are wireless network products today like ABB's Tropos wireless communications that meet or exceed the smart grid security standards that are currently in place. Utilizing wireless technology with a PRP network will need to be evaluated case by case for overall network through put issues as timing for the data exchange could be effected. Utility network architects will need to need to evaluate all the elements of a network to obtain military grade security for their network that will ensure independently verified security compliance ranging from the encryption to the physical hardware.

IEC 61850 parallel redundant protocol has challenges from an implementation perspective, but these are outweighed by the advantages. IEC 61850 PRP supports the creation of a communications network that has the highest possible degree of reliability and scalability for applications where device to device communications in a vertical or horizontal mode are critical in nature or where process control relies on the information that is transmitted over that network. Single point of communications failures are left to the device itself. Alarm or notifications can be sent when network failures do occur. For critical applications where coordinated control is required and the need for speed is paramount, IEC 61850 PRP allows network designs that cannot be challenged by other communications networks today.

Using the communications scheme discussed in this paper gave Iowa State University a flexible design that will serve them well into the future as they continue to replace their existing electromechanical relays with new electronic versions. Connecting them on the redundant network also gives ISU a robust Ethernet communications system utilizing primary redundant protocol (PRP) and supports their master/redundant SCADA system. This installation is scalable and could be applied to any electrical distribution system.

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