Reliant Energy HL&P
Underground Monitoring System
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Background and Overview

The Houston Metropolitan Area is the fourth largest metropolitan area in the United States. Reliant Energy HL&P has five districts within this area that are primarily underground service areas: Downtown Houston, Texas Medical Center, Galveston, Bush Intercontinental Airport and The Galleria.

There are approximately 475 major service locations in the underground distribution system in the Houston area. They consist of spot networks, high-side spot networks, street networks, several different types of automatic transfer services and manual transfer services. Locations vary from high-rise building vaults to pad mount services to subway vaults located in the streets of Houston among others.

Existing electrical devices utilized at the various major service locations include: power monitoring devices, electronic protective relays, temperature sensing devices, float switches, revenue meters, electro-mechanical relays, Cutler-Hammer MPCV network protective relays, Allen-Bradley MicroLogix 1000 and SLC 5/03 PLCs.

UMS Impetus

Deregulation of electric utilities in Texas will take effect in January 2002. In response to deregulation, the need for controlling costs and the requirement for continually improving reliability, the Major Underground Department (MUD) of Reliant Energy HL&P began to upgrade the underground systems. The upgrade includes replacing and upgrading of network protectors, adding new network protective relays and automating transfer schemes using PLCs.

As MUD proceeded to upgrade the network protectors and protective relays, the relay manufacturer began to offer communication-enabled relays. This led to the first MUD experimentation with connecting the network protective relays at one spot network vault to Microsoft Windows 95 - based HMI via dedicated telephone modems to monitor the available data. MUD engineers began to research the available technologies, equipment and software to determine viable alternatives to monitoring systems. MUD management then made the decision to pursue the process of implementing an Underground Monitoring System.

Other expected benefits of a UMS are improved service reliability, reduced operation costs, more efficient utilization for manpower resources, better maintenance and planning information, outage prevention and potential revenue opportunities.

MUD's first step in the process was to select a control system integration firm to provide consulting services to evaluate available equipment, architectures, communications technologies, and to make recommendations. MUD prepared a specification for the consulting services and solicited several firms requesting proposals. Requested proposals were to include not only technical specifics but the background and qualifications of the firms. The selected firm was to evaluate available communication architectures, equipment and software options and to make recommendations. Recommendations were to be made regarding communications architectures, methods and technologies. When MUD had approved the recommended the approach, the consultant was to prepare implementation plans, budgets and schedules.

General System Requirements

The initial phase of the evaluation was to define the system requirements. General system requirements were defined by MUD in their specification. One of the most important criteria was that MUD personnel be able to do much of the work on the installed system themselves. Even though they may elect to use outside assistance, they need to be able to support the system themselves without being forced to use outside firms, even the firm supplying the system initially.

Another requirement was that any system be able to communicate with the network protective relays that were being installed with the new network protectors, the existing microprocessor based protective relays and the existing programmable logic controllers (PLCs) installed on automatic transfer locations. Local support, spare parts availability, maintainability, web interface capability, lockout/tag-out capability, data logging and archiving, telephone paging and alarming, flexibility and lowest overall lifetime cost were important factors.

The optimal solution and recommendations were to be based on life-cycle costs, availability of equipment and support, ease of integration and interfacing with existing and future equipment and systems. The system was to be designed to optimize utilization of the existing Major Underground Department resources such as manpower and existing equipment and devices.

Specific System Requirements

The system is required to have security at each level commensurate with access to actions that can affect system functionality and control. A matrix shows security access by role and action to be performed. Actions which modify program functionality and which allow control actions are to be limited to higher levels of security access.

Control actions are events initiated by an operator that manipulates the status or configuration of the underground system. Control actions are to be accomplished and verified within ten seconds of action initiation from an Operator Interface Terminal (OIT), with faster times desirable if attainable. All control actions will utilize the "select before operate" (SBO) scheme. Two steps are required for a control action to be accomplished: an initiate step and a confirm step.

Data update rate is the duration from the time a data point changes value to the time it is reported to the System Data Server (SDS). The UMS will utilize data reporting on data change to the greatest extent possible. This will improve both throughput and capacity of the system. Changes in state for event and alarm points will be recorded at the SDS within fifteen seconds from the change in the point status. Update rates as fast as once every five seconds are desirable. Data values such as voltages and loads will be recorded at the SDS within two minutes from the time the data changed under normal operating conditions, with once a minute as a goal. Exception conditions apply to periods of time when control actions are being performed, system maintenance is occurring, etc. Stations with no state or value change will report at least once every five minutes as a means to verify communications.

A key requirement for the system is that it gives MUD the ability to select the best IED for any particular application. This means that the system be capable of using and adding different communication protocols and drivers at any level without requiring modifications to the whole system. Among the required protocols are DNP, UCA, TCP/IP, Modbus, DF-1 and INCOM.

The system is to have the capability to store and display historically logged data. Historical data will be updated at the system update rate and maintained for a period of fourteen days or longer. The system is to have the capability to store weekly-interval planning data for a period of one operating year. This data includes minimum/maximum and period averages for load related values. Other values may also be stored in this manner. The system is to have the capability to backup system data to a secondary media and provide a means to archive data off to a secondary media for long-term storage. Data collected through the UMS is to be available to the Reliant Energy HL&P EMSWEB server which is the server for the company Intranet.

The system is to have the capability to display maintenance status and operational lockout information in a familiar "lockout-tag" type view. This information will be available for any device capable of control action or to indicate the status of a circuit breaker.

The system will provide for fault detection and logging. As the system develops, fault conditions will be defined. These faults will relate to thresholds and faults, and they will identify response actions as appropriate. In general, a fault condition will be comprised of a parameter or condition and a threshold value. Fault status may be programmed at each Intelligent Electronic Device (IED). These will be reported to the Area Data Collector (ADC) within five seconds, annunciated on the OIT, and paged if appropriate. Faults may be generated either at the IED or the Local Data Concentrator (LDC) based on a value being out of tolerance of threshold values. A number of condition alarms may be appropriate for vault environmental conditions. Examples are vault temperature and float switches that identify an over-temperature or flood condition, respectively. These points will be only monitored with no automatic controls associated with them. The system will have the capability to annunciate alarms visually on the OIT in both current and historical formats. The system is to have the capability to send messages to alphanumeric pagers, pagers, and voice annunciation systems, filtered by priority, locale or work group. The ability to generate e-mail messages on less severe alarms is considered desirable.

Communication and Architecture Recommendations

Four different communication architectures were considered: a flat architecture with master communication directly with the field devices, an "ADC-centric" three-level architecture, an "LDC-centric" three-level architecture and a four-level architecture. The four-level architecture, as shown in Figure 1, was recommended.

The recommendation for the UMS communications and architecture was made based on the principal purpose of the UMS -- the timely reporting of information to an operator. This data may give the operator information they need to make decisions or to monitor the operation of the system. Several questions had to be answered:

- How much data, and in what format, 'realistically' could be retrieved from the field device, typically an IED?
- How many reads would it take to retrieve the required information?
- What auxiliary I/O points are available on the IED that could potentially be used to provide information?
- What communications protocols and media are supported by different architectures?

In most cases, the IEDs provide more information than is needed on a routine basis. Therefore, effectively organizing the data retrieved is critical to system performance. Due to limits on message sizes or protocol considerations, several of the IEDs require more than one message packet to retrieve the information.

Network considerations are paramount in selecting effective communications methods and architectures. A network can be defined as a group of two or more devices communicating with each other using the same protocol and, for the purpose of this definition, the same communication media. The communications of data between elements needs to be controlled or timed to maintain system capacity.

In most SCADA networks, one station is designated as the master. All the remaining stations on the network take their cue from the master as to when to respond. The protocol used defines the maximum number of nodes that may be allowed on a network. In almost all cases, media length limitations or data update requirements limit the number of nodes to less than the maximum allowed by the protocol.

Almost all physical communications media have some limit to the distance that may be covered in total. This usually is due to some degradation or attenuation of the communications signal as it travels the length of the medium. For copper medium, networks are typically limited to a total wire run of 8,500 – 10,000 feet. Multi-mode fiber optic cable is usually limited to single run distances of one to two miles. Single-mode fiber optic cable is capable of longer runs dependent on the type of transmitter and receivers used. Radio communications is limited by many factors including power, frequency, climatic conditions and geographic factors.

The efficiency of a communications network can be radically affected by how the data is retrieved. In general, the data should be concentrated into large contiguous blocks, organized by the frequency in which it will be required. Further, the timing and control of how it is retrieved is important. In a polled scheme, the network master queries each subordinate station for data, waits for the data and then queries the next station. The polled scheme is typically the least effective of the methods. In a polled/report-by-exception scheme, the network master queries each subordinate station, but only those with data respond with a message. This method allows increased efficiency because only those stations with new information or an exception will respond with data. In the report-by-exception scheme, the master and subordinate stations coordinate in such a way that a subordinate station can send a message to the master without being polled. To gain best efficiency from this method, the subordinate will only send a message for a change in high-priority data.

Data collection rates were an important consideration in recommending an architecture. Rates depend on several factors, including the baud rate, the amount of data to be collected, the priority and urgency of the data, the allowable message packet sizes, and the protocols to be used. Each protocol specifies a maximum packet size. With the advent of TCP/IP, message sizes have increased. However, most utility accepted protocols have evolved from early days of eight-bit processors and are limited to an effective message size of up to 120 data values. DNP 3.0 is actually limited to smaller amounts of effective data as it also includes status bytes with each data value. Each communications transaction has overhead. A single read or write communications transaction actually consists of several messages. These typically could be a master request, slave acknowledgement, slave response, master acknowledgement in its simplest format. Additionally, there is processing to format and decode messages at each end, and usually a processor scan time in between message responses.

Data handling in the UMS is bi-directional. In addition to polling data, data for control actions needs to be transmitted to individual devices, either for control or configuration purposes. Control data needs to be handled in a prioritized manner, including status reply to let the operator know that control actions have been implemented. In order to accomplish the performance requirements of the UMS, data transmitted to a given device must be accomplished on a priority basis. ADC and LDC masters will perform control write and read commands at a higher priority than any other message.

Several communications media were evaluated for use in the UMS. Each medium has its own characteristics, benefits and costs.

- Copper wire is probably the most prevalent communications media for shorter distances. It is readily available and usually one of the lowest cost media. Communications using wire usually have shorter distance limits than other media. Devices connected with wire are also electrically connected. Grounding problems and electrical isolation problems are potential factors when using wire for networks.
- Both single-mode and multi-mode fiber optic cable offer excellent communication media alternatives. Each device on the network is electrically isolated which affords protection from voltage surges, transients, grounding issues and isolation issues. Higher Baud rates and transmission distances are possible with fiber than most other physical media.
- Two types of radios are typically used in SCADA applications: licensed single-frequency and spread-spectrum. The FCC issues licenses for a user to transmit over a fixed frequency. The process of applying for a license may require a survey, and the application process can take from eight to sixteen weeks. In large metropolitan areas, there may be a shortage of available frequencies. (There is a shortage of frequencies in the Houston metropolitan area.) However, higher power transmitters are usually authorized since it is operating on one frequency. This can lead to significantly improved performance over longer distances, reducing both hardware and installation costs. Spread-spectrum radios are popular because they jump around a spectrum of radio frequencies and require no license. They are able to offer some improvements if given frequency sections are subject to interference or static. However, they are limited in transmitter power and can only be used over shorter distances. These factors often make spread-spectrum a more expensive alternative.
- Phone lines are common and have been in use for SCADA applications for a long time. Typically, a user can

purchase a dial-up line that must be dialed up every time data is gathered or a leased line that the user leases for full time use. Recently, cellular phone service also has become popular, which uses radio links to relay the phone connection to a hardwired network. Dial-up is the typical phone line installed for residential service. A user must physically dial-out or answer the line. This type of service can be effective in areas that are not limited by availability of numbers and for which the service will be for local service only. It can be expensive if data traffic is accessed from long-distance service areas. With leased line service, the user pays a monthly or annual lease fee to the phone company for the full time use of a line. While more expensive than local, dial-up service, a leased line can be less costly for a long distance connection or when the service has to be available twenty-four hours a day. Cellular phones or phone radios can be very useful for mobile service types of applications. Most common among these today are services to connect into the Internet or SCADA system from a portable computer such as a service technician's laptop. The effectiveness of cellular service is limited to short use applications since the service and equipment costs are higher.

One of the goals of the UMS is to use standard utility industry protocols allowing for the addition of protocols later with a minimum of system disturbance.

TCP/IP is the protocol of the Internet. It supports large message packets, has good collision detection, and has relatively high throughput of information. Of all the protocols, TCP/IP is best suited for the link between the UMS system data server (SDS) and the ADCs. It is this link which must support the transfer of the greatest amount of data and which is the least protocol sensitive. This communications link will be between a personal computer (PC) and the ADCs. All of the alternatives examined support this protocol utilization.

DNP 3.0 protocol is one of the most widely accepted protocols in the utility market. It offers flexibility in polling schemes. Unlike others, it includes data status bytes with each data value and is supported by most utility devices. Use of this protocol allows a great deal of flexibility for fielding devices of different manufacturers in the future.

Modbus has been an industrial control and utility standard protocol for a number of years. Some devices may require support of this protocol. None have been identified so far, but the capability exists to add support for it at any level. Once popular, it does not have some of the polling and reporting flexibility of DNP 3.0.

Two other protocols are important when considering the UMS system because existing equipment uses them. INCOM is the protocol used by the Cutler-Hammer MPCV network protective relays and IQ Meters. DF-1 is the native protocol of the Allen-Bradley SLC-5/03 and MicroLogix 1000 PLCs that MUD uses for automatic transfer controllers.

System Architecture

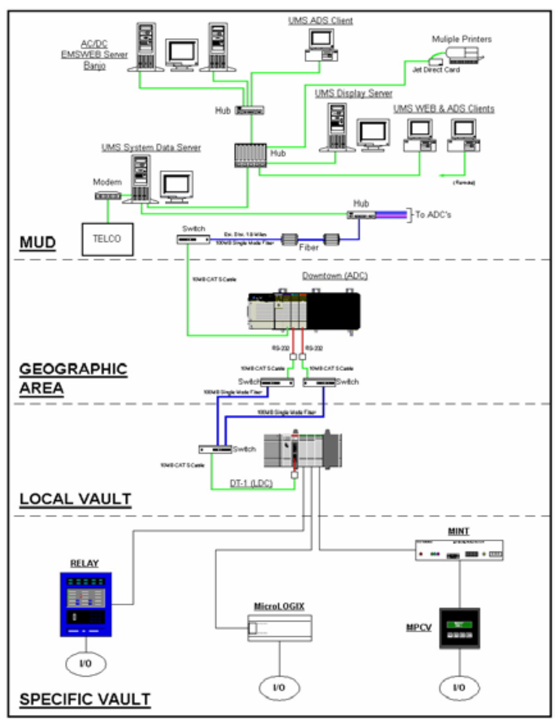

Figure 1
UMS Four-Level Architecture

The Four-Level Architecture as shown in Figure 1 is the architecture chosen by MUD for the UMS. Figure 1 shows four levels in the architecture: Master or MUD, ADC or geographical, LDC or local vault and IED or specific Vault. This architecture involves the greatest amount of hardware components, but allows for standardization of protocols at each layer and gives the greatest flexibility of implementation. This architecture allows for easier development and fielding of modules of program code. It fulfills the goals of an efficient, flexible system that will be able to be expanded and maintained by the existing operations staff. It offers the greatest flexibility and maintainability while optimizing the communications at all levels. Finally, the architecture allows for great flexibility in use of protocols.

All protocols at the LDC will be implemented using functional code modules to improve portability and expandability of the system. The INCOM protocol will be used for the MPCV network protective relays. This is the MPCV protocol, and it is supported by third-party communications modules for the LDC PLCs. DNP 3.0 protocol will be available for support of protective relays and other local devices. DNP 3.0 will allow virtually any well-regarded protective relay or IED with communications capability to be connected given the widespread use of this protocol. DF-1 will be used for communications to the Allen-Bradley PLCs used in the automatic transfer locations.

The protocol used between the ADC and the LDC will be DNP 3.0, TCP/IP or DNP 3.0 on TCP/IP. Regardless of media, the protocol used to serve data from the ADCs to the SDS will be TCP/IP.

There is flexibility in the media that ultimately will be used at each level. The media for the MPCVs will be shielded twin-axial copper wire. This is consistent with the physical connections on the MPCVs and MINT modules used with the MPCVs. It is possible to use fiber optic, if required, for electrical isolation. Depending on the devices, locations and infrastructure, the media for DNP 3.0 at the LDC level will either be shielded, twisted-pair copper wire or multi-mode fiber optic. The media for the DF-1 will be two shielded, twisted pair wire. Fiber optic can be used.

In the Houston Downtown Service Area, the Texas Medical Center and Galveston, the medium for communications between the LDCs and ADCs will be single-mode fiber optic cable. This cable is existing and available. In the Galleria and at Bush Intercontinental Airport, radio or phone line may be more appropriate. Figure 2 shows the architecture for ADC to LCD communication for Downtown Houston, and Figure 3 shows the architecture for ADC to LCD communication for Bush Intercontinental Airport.

Media for ADC to SDS communications is where the greatest variation in requirements exists. Given the distances to be covered, these links may well be leased line (T-1, DSL, ISDN, or normal phone) or fiber optic. Fiber optic will be used for the Downtown Houston ADC, and is under consideration for the Texas Medical Center, the Galleria, or Bush Intercontinental Airport ADCs.

Technology Recommendation

The technology options studied for the UMS included monitoring systems based on a traditional Remote Terminal Unit (RTU), a Programmable Logic Controller (PLC), and a Personal Computer (PC). The final technology recommendation uses PLCs at the LDCs, high level PLCs at the ADCs, and one or more PCs running Windows NT software applications dividing the tasks at the Master Station. It is believed that these technologies will provide the best combination of low life-cycle cost, flexibility, long life, and ease-of-use. The key factors in this decision were the need for interconnectivity at the upper and lower ends and the need for flexibility and reliability in the mid-level locations.

Connectivity at the Master Station includes passing data to an OIT, the existing web server, and to other office or database-type applications used for sharing and evaluating the data collected by the UMS. In the other direction, the Master Station needs to be able to receive data from the ADCs using formats that are compatible with moving large quantities of data. The hardware and software available for server class personal computers (PC) can support these communication interfaces. Additionally, the Master Station will be located in the MUD office since it includes the OIT functionality, so the environment will not adversely affect the life expectancy of a PC. The Master Station application software selected is Microsoft

Foundation Class assuring the most flexibility and supportability.

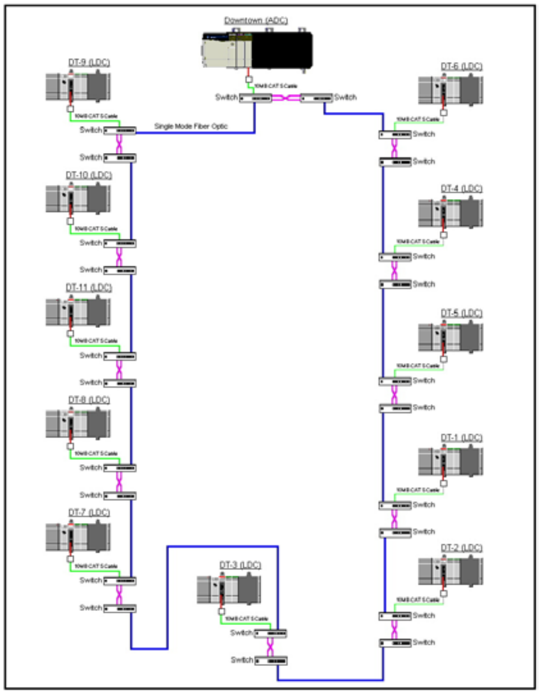

Figure 2
Downtown ADC to LDC Architecture

Geographically, the ADCs are located to provide reasonable connections to the LDCs. These could be located in office type environments, but they may also be located with switchgear in a distribution type location. These stations will receive metering data on a regular poll from a group of LDCs in addition to priority messages reporting trips or other exception events. The ADC packages this data and sends it on to the Master Station utilizing a higher speed protocol. Therefore the ADC must be able to communicate using at least two protocols over several possible media. Some media examples are Ethernet, serial EIA-485 and radio. Protocol examples include TCP/IP and DNP 3.0. The high level PLC selected can support many protocols and media by using appropriate communication modules. It was designed around providing support for multiple communications protocols in a seamless manner.

PC hardware and both traditional- and modular-type Remote Terminal Units (RTUs) were also considered for use at the ADC level. PC hardware can be hardened for use in ADC locations; however, PC type hardware requires considerably more software than the PLC and RTU solutions (operating systems, drivers, application software, etc). In addition, the communications diagnostics for PCs are generally more complex. Local hardware, software and training support for the selected PLC hardware is more readily available than for typical RTU solutions. Additionally, data showed the life expectancy of the PLC solution at the ADC level was longer than either the PC solution or the RTU solution.

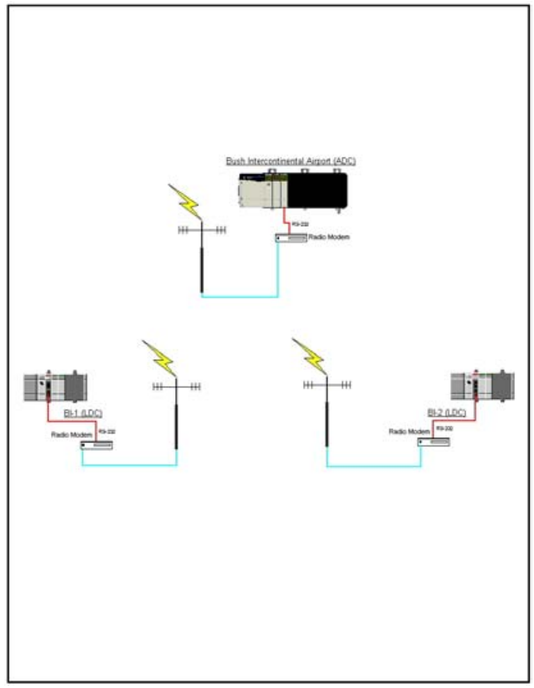

Figure 3
Bush Intercontinental Airport ADC to LDC Architecture

Most of the LDCs will be located in underground vaults, so the hardware needs to be able to survive in a harsh environment. They directly interface with the IEDs on their native or supported open protocols. The LDCs collect the IED data and condense it into more compact data blocks. The LDC passes this information up to the ADC on a regular schedule and generates unscheduled exception reports when it receives a trip or alarm notification from an IED. The selected small PLC supports numerous protocols using appropriate modules. This provides flexibility by letting some LDCs be configured for one mix of IEDs while another LDC is configured to collect data from a different mix. The small PLC is less expensive than the other solutions; yet it provides the flexibility, expandability, and connectivity capabilities needed at the LDC locations.

Considering the environment and locations of the LDC, the PC solution is the least desirable. The purchase price of an industrial rated PC is higher than the hardware requirements of the other solutions at this layer. In addition, the life expectancy is considerably less. This gives the PC solution the highest maintenance cost, causing the life cycle costs to be the highest of the three solutions.

For the LDCs, the small PLCs showed the lowest estimated life-cycle cost. At locations where fewer IED networks are required, fewer modules are required further reducing the life cycle costs. The small PLCs also provided the best solution for expandability.

Glossary

ADC - Area Data Collector refers to the UMS system component that collects the data and serves a given geographic area. In general, the area data collector will gather the data from its local data concentrators relative to a substation's feeders; however, this is not a requirement for system operation. These data collectors will be associated with a geographic area, thus allowing the most effective physical connectivity to the local data concentrators in that area.
DNP – Distributed Network Protocol
EIA – Electronic Industries Association
EMSWEB - Reliant Energy HL&P Energy Management System WEB
FCC – Federal Communication Commission
IED – Intelligent Electronic Device
I/O – Input/Output
LDC - Local Data Concentrator (LDC) refers to the UMS system component that collects the data and serves a relatively small geographic area. An example could be a several block area served by one LDC in downtown Houston. This geographic area, in general, will be a subset of the associated ADC. The local data concentrators provide local connectivity for distance-limited communication channels, while also limiting the number of nodes that must be interfaced to the ADC stations.
MUD – Reliant Energy HL&P Major Underground Department
OIT - Operator Interface Terminal refers to the UMS system components that provide graphical data displays and system control functions. More than one OIT may exist on the system.
PC – Personal Computer
PLC – Programmable Logic Controller
RTU – Remote Terminal Unit
SBO – Select Before Operate
SCADA – Supervisory Control and Data Acquisition
SDS - System Data Server refers to the UMS system component that collects and distributes the UMS system data.
TCP/IP – Transmission Control Protocol/Internet Protocol
UCA - Utility Communication Architecture
UMS -Underground Monitoring System refers to the complete system that provides for data collection, display, logging, archiving, substation control system interface, EMSWEB data interface, and call-out (paging) services for Reliant Energy HL&P Major Underground Department's system.

Biography

Tom Wilson, Senior Member IEEE, is a native of Spokane, Washington. After serving in the US Navy as an Electricians Mate, he earned his BSEE from Washington State University in 1971. While working as a Substation Operations Engineer at Pacific Gas and Electric Company, he attended the University of Santa Clara studying MSEE courses. In 1982 he earned his MBA from Gonzaga University. Wilson worked as an Electrical Engineer for Kaiser Aluminum and Chemical Corporation and as an Industrial Control Application Engineer for Reliance Electric. Wilson is the founder and president of Programmable Control Services, Inc., a Spokane, Washington based control system integration firm specializing in substation and utility automation using PLCs.

Wilson has been active in the IEEE is a member of the Western Power Delivery Automation Conference Program Committee.

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