HIGH RELIABILITY COMMUNICATIONS FOR RELAYING AND SCADA

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Municipal electric utilities generally do not own significant transmission system facilities. Watertown Municipal Utilities (WMU) in Watertown, South Dakota, is an exception. One radial 115 kV line served the city's three substations from the nearby Western Area Power Administration transmission substation. Faults on the 115 kV system could take a substation (or the town) off-line, and with it a significant portion of the industrial and residential customers. The electrical construction issues and system configuration were fairly typical engineering issues; but the communications requirements dealing with relaying, SCADA and other operations applications resulted in an opportunity to try something unusual; sharing a single communications path for SCADA, relaying and other network communications.

WMU 115 kV Closed Loop System

Part of the project was to improve system reliability to meet the long range needs of the growing industrial load in part of the town and the growing residential load on the other side of town. The utility decided to build its own 115 kV closed-loop transmission system and to add a fourth substation, with the design intent of preventing substation outages by isolating faulted line segments. The system one-line is shown in Figure 1.

With the line construction and new substation completed as part of the first phase of the project, the utility chose to replace an out-dated homegrown SCADA system with a full-featured utility SCADA system. At the same time, design discussions were underway to determine the relaying scheme needed for the looped 115 kV lines. It was assumed that the line relaying would have to be piloted for some portion of the system, so the 115 kV loop design included the installation of self-supporting, all-dielectric, fiberoptic cable. The initial design of the SCADA system called for the use of available fiberoptic cables for the SCADA communication channel. The desired configuration was to use the fibers in a loop, rather than in a radial configuration (saving fiber and providing a possible redundant communication path.) The utility intended to use spare cables for other data transmission projects in the future.

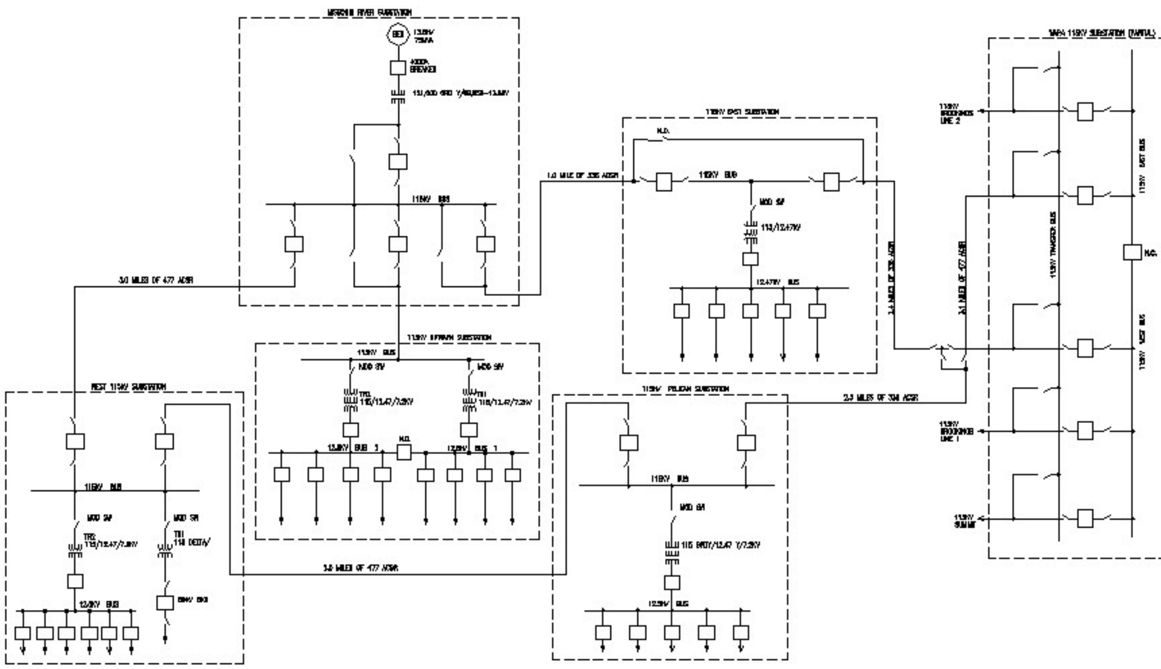

Figure One, WMU 115 kV Loop

Relaying Considerations for Short Lines

With the initial physical configuration settled the design engineers discovered, in discussions with the utilities involved, that the line relaying would still be a troublesome issue. Short transmission lines create problems for typical fault/distance transmission relays. (The longest segment on the WMU loop is 3.0 miles; the shortest only one mile.) The impedance of the short segments is so small, compared to that of a typical transmission segment that the relay can see beyond the next line terminal, overreach it and trip for a fault outside its normal zone of protection. If even one relay overreaches, an entire substation is isolated, when the express purpose of the looped system was to prevent such occurrences.

The obvious solution was to have piloted relaying of some sort, with the relays communicating to establish that the fault is within their zone of protection. The construction of the new 115 kV lines also meant that using fiberoptic cable, as a communications path, would be possible, since self-supporting, all dielectric cable could be installed at the same time on the new structures.

Thus, line current differential relays, communicating to their adjacent substation breaker via fiberoptic modems, would provide primary relaying. The relay selected was the SEL-311L, which has built-in fiberoptic modems for this purpose. This method is secure and reliable, but dependent on the constant availability of the fiberoptic cable. Unfortunately, the use of the self-supporting cable, while significantly less expensive than underground or static-wire applications, had a significant risk of failure. Squirrels chewed through the cable twice in the first 18 months of operation.

While varmint protection on the poles and connection hardware reduced the rate of occurrence seen after the initial installation, the conclusion was that the squirrels would probably strike again. Thus, the secondary relaying had to rely on a separate communications path. Because WMU had fiberoptic cable available, building a point-to-point radio system or other communications path was not desirable. Since the problem of short transmission lines meant that the secondary relaying had to be piloted, the preliminary choice of a POTT (permissive overreaching transfer trip) scheme, using SEL 311Cs and SEL Mirrored Bits communications protocol, required additional fiberoptic modems that would communicate “backwards” around the loop. (By routing the secondary relaying the long way around the loop, a single cable failure could not shut down both primary and secondary relaying on a single line segment.)

The primary relaying uses one pair of fiberoptic cables between each breaker terminal, so that its network resembles the system 115 kV one-line diagram. The secondary relaying would use one pair routed the long way around the loop for each pair of breakers, so that a section of cable between two substations contained the primary relaying for that segment, and the backup relaying for the other four segments; in total five pairs for relaying, plus a sixth for SCADA.

SCADA Communication Saves the Day

The SCADA system had been selected with a vendor-provided fiberoptic transceiver (the H&L 561) used in a loop configuration that would self-heal (re-route traffic) if a section of cable failed.

The design team, after considering the fact that the SCADA loop was intended to handle both SCADA polling and access to the SEL relay maintenance ports, asked the following question:
Could the fiberoptic system carry protective relaying data traffic in addition to the SCADA data? Moreover, since longer re-routing times could cause relay communications faults, could the system self-heal, in the event of a fiber failure, in four milliseconds or less?

The design team approached the vendor, H&L Instruments, asking if their Model 561 fiberoptic transceiver system (FiberLoop II aka “FL2”) could carry the secondary relaying traffic on the same pair of fibers as the SCADA data without interfering with the SCADA data. H&L explained that the FL2 system has a 1 second healing time, as it was designed for SCADA, not relaying and that it has 16 channels. More channels are needed for relaying because each pair of relays takes a virtual channel. The channels are constantly busy, unlike SCADA, which is half-duplex poll response. The present FL2 system would not work for relay traffic with the SEL Mirrored Bits, as 4 bytes of data are exchanged between relays every ¼ cycle.

Relaying calls for protected virtual channels that cannot accidentally collide with other traffic on other channels or with anyone accidentally connecting into a paired relay channel that is in use. When the channel is assigned to a relay pair, no additional fiberoptic units can be allowed to use that channel. H&L described a new system (FiberLoop III aka “FL3”) which had been in development for some time and in Beta testing at S&C Electric Co. for use with SEL-351 relays and the S&C Vista switchgear. They suggested that, since there was a long project lead-time, where relay modifications at each substation meant that the final completion date was still a year away, there might be another option for the project. If the communications system could be switched to the new product (the Model 570 which operates at 100MHz), it would easily handle the original SCADA task, provide many more channels (128) protected channels with improved full duplex bandwidth for relaying, and very fast self-healing in the event of a fiber fault. A bonus feature available, for a small additional cost, was to allow the owner to have an Ethernet loop from the main office to each substation.

The design team decided, considering the system requirements and future expected need for Ethernet, to recommend this new product for the application. The new transceiver would allow a network topology, using two fibers in a loop, to join the four municipal substations: a Missouri River Energy Services generating plant located in the town, and the WAPA substation on a single communications loop with a wide area network (WAN) for the utility.

The resulting final topology for the fiber optic loop for SCADA, secondary relaying, the utility WAN and related data sharing applications is shown in Figure 2, below.

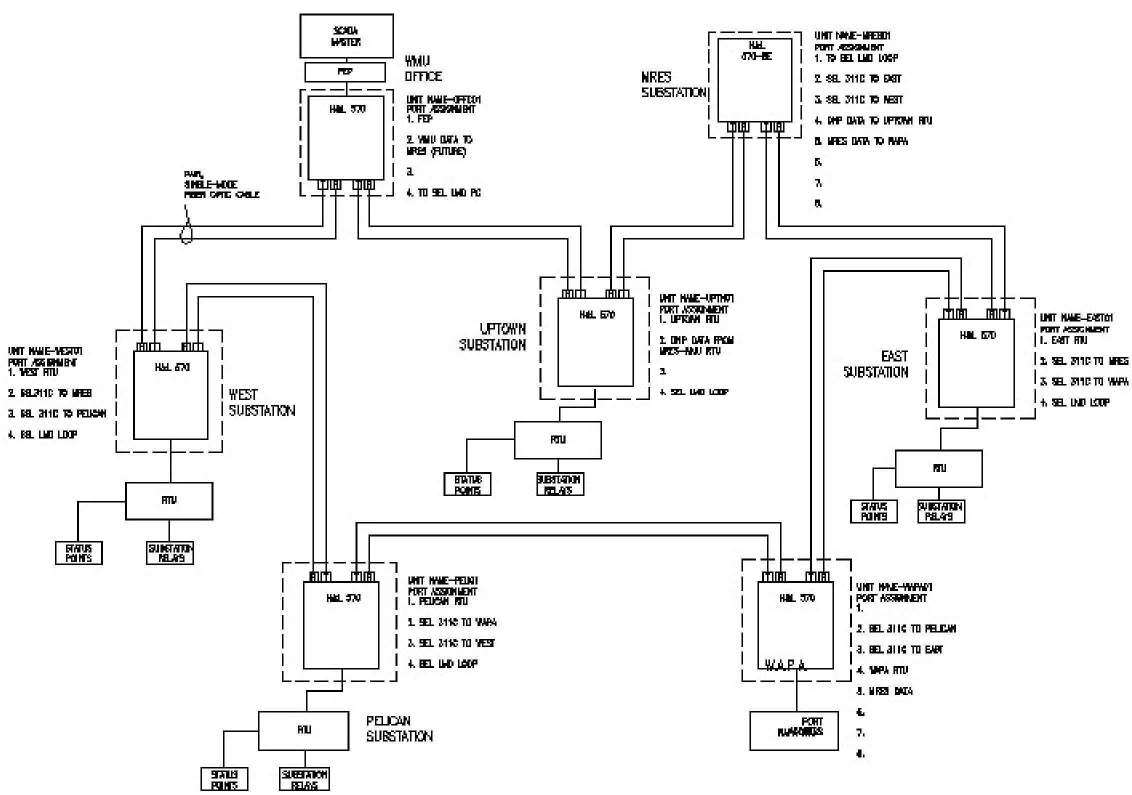

Figure 2, WMU Fiber Loop Topology

The final network configuration compensates for a cable failure by re-routing all the traffic within 4 milliseconds, fast enough to maintain the integrity of the secondary relaying. A single component failure cannot result in the loss of both primary and secondary relaying, since the only shared facility is the fiber termination cabinet inside each substation control house. A squirrel-induced cable failure would take the primary relaying out of service, but the secondary relaying would restore in milliseconds, and the SCADA system would still see the alarm from the primary relay. In addition, because the H&L system has extensive network management diagnostics software (a MS Windows program called FiberPanel), the fiber failures can be quickly located and repaired.

The H&L 570 and Fiber Loop III

In order to provide 128 virtual protected channels and Ethernet, a new operating system was needed. The FiberLoop III system increases the performance of the FiberLoop II system by going to much faster digital logic internally in a new transceiver called the Model 570, increasing the fiber communications speed from 1 MHz to 100 MHz, and introducing some new networking concepts.

H&L Model 570 Fiberoptic Transceiver

<u>Faster Digital Logic</u>

The 561 transceiver uses a 20 MHz microprocessor to transfer serial data to and from the fibers as well as provide a human interface: pushbuttons and an 8- character alphanumeric display and serial port for a PC to connect running a Windows program, called HLPanel3, that does network management and the configuration of each transceiver (setting up serial channels

The 570 uses 561 components that have extensive field tested reliability such as the microprocessor card, alphanumeric display and isolated surge protected power supply. The 561 was enhanced with non-volatile flash memory. A bus interface was added to connect the microprocessor card to a new logic board called the packet switch module (PSM). This PSM contains a very fast fiber packet switch engine (PSE). The PSE relieves the microprocessor of the burden of handling the fiber traffic. It is constructed using a large scale integrated circuit called an FPGA (field programmable logic array). The compact industrial rated (-40 to +85C) CMOS FPGA that H&L selected runs at 100MHz and is configured by software stored in the flash memory in the 570. This flash memory is also where programs for the microprocessor are stored.

The microprocessor still handles the serial ports and displays and maintenance tasks. Both the microprocessor and FPGA programs can be upgraded in the field by the user by jacking into each 570 using a portable laptop PC and H&L's Windows software.

<u>100 fold increase in fiber speed.</u>

The 561 has the capability of fiber optical power measurements as it has a built in analog to digital converter reports dBm levels on the display and remotely to a Windows network management program. Since users found this very useful, it was decided to include it in the 570. The 570 needed 100MHz surface mount fiberoptic receivers and laser transmitters. This meant that H&L could not use "off the shelf" commercial fiberoptic transmitters and receivers as they do not provide a DC signal proportional to optical power. H&L developed 100 MHz receivers The H&L designed 1300 nm single-mode laser transmitter circuit provides >-8 dBm and the new receiver has a –28 dBm noise floor thus optical budget (dynamic range) is 20 dB which works out approximately a 65 kM range. This is more than adequate (between a pair of 570 units).

<u>New networking concepts</u>

The FiberLoop II system is built around the concept of a single intelligent network controller (Model 560) which manages the network (the self-healing and collecting remote optical power data and configurations of slave fiberoptic transceivers (Model 562). Recently the two device types were merged into one unit called the 561. This change simplified customer's spares situation but one unit still needed to be designated by the customer using H&L's Windows software to be a controller (561c) or transceiver (561t). To support a less than 4 msec healing time imposed by relay coordination requirements, a new paradigm was needed – plug and play. The goal was to be able to connect 570s to each other and have them work. Even if the 570s were separated (no matter how many pieces a FL3 loop was broken up into), they needed to function as isolated radial segments and the system would also need to do this very fast.

Fault detection is done in near real time and re-routing of traffic is automatic. The 561 concept of running in a loop either clockwise or counterclockwise is gone. H&L calls this “Loop L>R” which can fail over to the counter-clockwise “Loop R>L” direction. In the 561 this backup path is constantly checked to see if it has a problem before it has to be failed over to, something not done by the sophisticated 100 MHz FDDI. In the 570 traffic always flows in both directions.

Benefits

The number of channels has been increased from 16 to 128 and each channel can be one of four types, master, slave, peer A, or peer B (the peers are for relaying). FL3 is a masterless system. Like the 561, the 570 supports up to 16 physical ports but those ports can now run at up to 56kbps full duplex. Network statistics are maintained for each port.

Configuration at the Substation

Application of the H&L 570 required establishing channel assignments for each function and assigning ports to equipment at each substation. The first dedicated channels were set up for SCADA polling by the master station and for collection of maintenance and fault data from the 60+ SEL relays on the system by using SEL’s LMD protocol on a PC at the main office.

Figure 3 shows the equipment the H&L transceiver supports at a single substation. In addition to the primary purpose-- SCADA, ports are in use for secondary relaying (one SEL 311C for each 115 kV breaker) and maintenance data via an RS-485 loop to all of the other SEL relays.

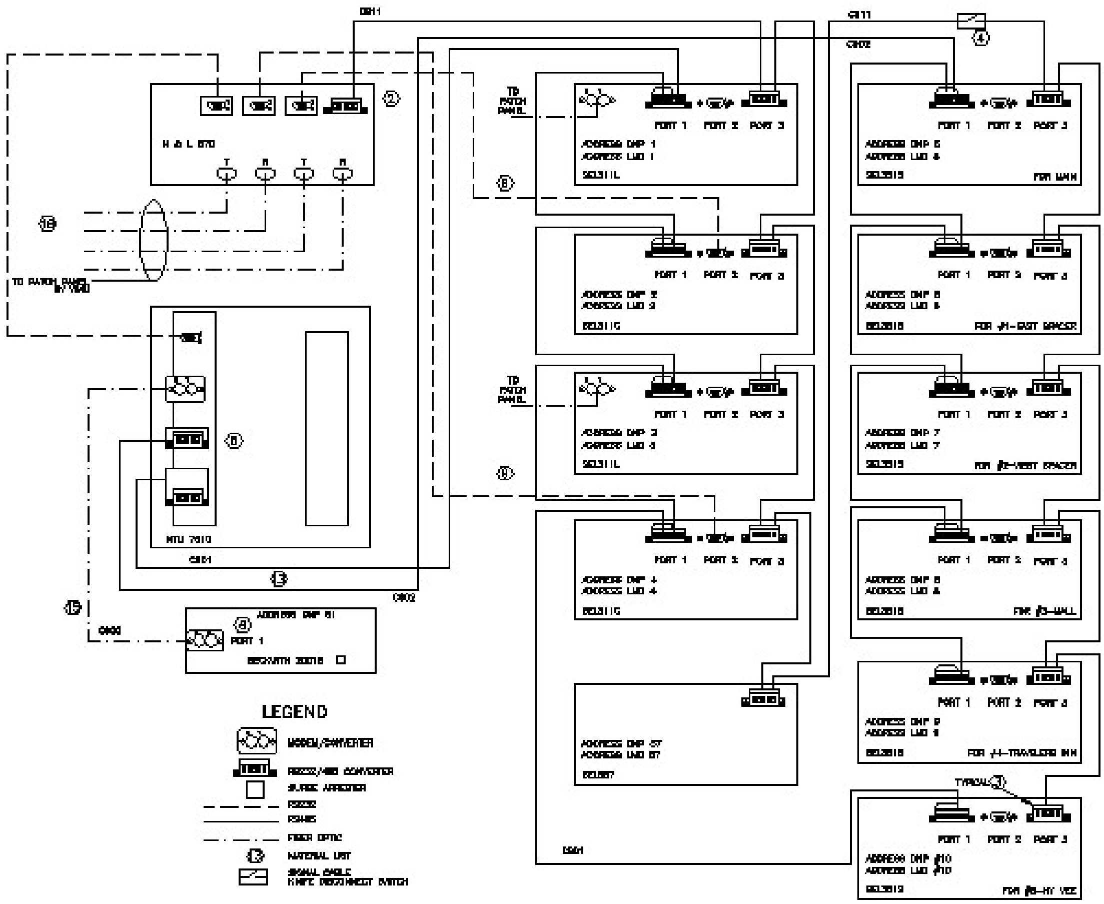

Figure 3, Application of the H&L 570 at a Substation

Channels were assigned for each pair of SEL-311C relays (secondary relaying). As shown on the network configuration diagram - the port designations identify the pair of relays sharing a channel.

Financial Considerations

While the new fiberoptic transceiver cost significantly more that the original H&L 561s, it avoided the cost of fiberoptic modems, installation, and fiber terminations for the secondary relays. The savings allowed WMU to include Ethernet capability into each substation.

The use of such a multiplexed two fiber system also allowed WMU to save fibers for future uses. Since the loop extends all the way around the city and has a limited fiber count, every fiber “wasted” carries a cost.

Future Uses

One future use of the fiberoptic loop is already under construction. By extending the loop into the Missouri River substation, WMU avoided having to install a link between the transmission relays and equipment and the distribution relays and RTU some 300 feet away. While the single-mode equipment was no less expensive than the proposed multi-mode link, it allows MRES to use one of the many spare virtual channels on the H&L loop to transfer metering data to WAPA. It also allows WAPA, MRES and WMU a channel or channels to directly share SCADA data among the three companies - channels available to link Missouri River Energy Services, WMU and WAPA to share SCADA data between utilities and to transfer demand data from MRES to WAPA

Other uses under consideration are drawing access for the technicians from a central drawing database (simplifying drawing management), voice over IP from the main office to the substation (saving some money, but avoiding telephone circuit protection issues because of the fiber optic cable), and substation video monitoring. Since these functions would be Ethernet-based, they would share the available system capacity left over from dedicated relaying and SCADA channels.

Conclusion

The final configuration of the fiberoptic equipment improved upon the original concept in several ways:

- Loss of a single section of cable would compromise only the primary relaying between two terminals rather than the primary relaying between those terminals <u>and</u> the backup relaying for all the other line segments.
- The additional channels provide a simple, reliable path for data sharing between the utilities in town.
- The available Ethernet capability to each substation will be of use to the owner.
- A reasonable number of dark fibers remained for future projects.
- The original schedule and budget were not changed.

The decision to base a large portion of the system communications on signal multiplexing over a single pair of fiberoptic cables wasn't without risk. The transceiver had to be available in time to complete the project, had to be reliable and had to be cost-effective. The new product under consideration was somewhere between “Beta” and “Vaporware,” however it was based on the fall-back product (the original 561s). In the end, the relative luxury of a long time frame on the project and the desire to make the best use of available resources combined to improve system reliability over the original plan, save some money, and provide the owner with additional application options.