Eaton/Cutler-Hammer, H&L Instruments
Network Communication System

Bob Landman, Pres., Sr. Member, IEEE, H&L Instruments, LLC

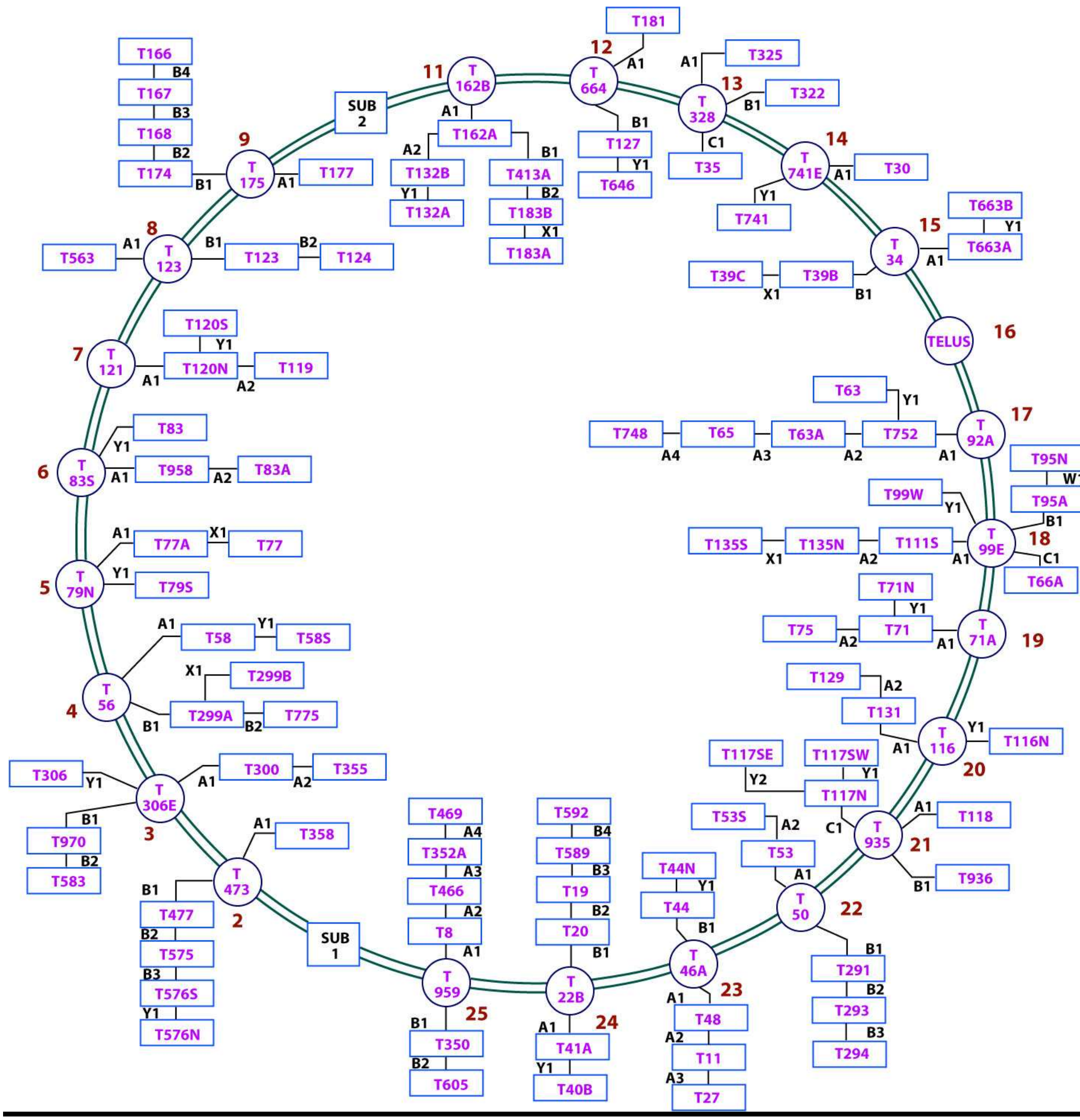
Abstract

A major utility is upgrading an older mechanical relay-based network system to a modern solid-state relay system with two-way communication to avoid the excessive costs of a manual maintenance inspection system. Constant, instantaneous, reliable two-way communication can help avoid general network outages by remote switching, and it can increase safety by avoiding exposure to hazardous working conditions when inspecting the network. The network up-grade makes it possible and practical to turn off part of the network system to avoid dangerous work in manholes and vaults when faults are in progress.

Introduction

This study involves a major electric utility that operates in three Canadian provinces. In addition to being one of the largest electricity retailers, the company offers water treatment and distribution services, and is a natural gas retailer. The company also has generation assets in the state of Washington.

In this case study, an underground network system comprises some 190 network transformers (347/600 V and 120/208 V) distributed among approximately 90 below-grade vaults. Roughly half of the network is fed from a single substation and the other half is picked up by a second substation as pictured in the following network drawing.



Why the system was upgraded and why it included two-way monitoring

The utility found that their network protector (NP) mechanical relays had a useful life of approximately 15 years. Because the existing relays were 20+ years old, they had to be replaced. The cost of some relay parts exceeded the cost of a new MPCV relay, and new solid state relay replacements could provide remote monitoring and control. Manual inspection was planned to occur one to four times a year, but these inspections were usually done only once per year. It was thought that to prevent malfunctions and exposure to unnecessary risks, inspection should be once per month, but this was found to be impractical given the manpower and budget constraints. A typical NP maintenance manual states that: *"after first month and semi-monthly intervals thereafter, read the operation counter, and then every six months to a year thereafter completely test and inspect protectors including relays."* The crew cost was calculated for monthly inspections, which management allowed as part of the cost justification for two-way monitoring and control. Because two-way communication and control was found to cost only about 10% more than no communications and control, it was decided that two-way was a must.

Another consideration for performing a network upgrade was an incipient arcing fault incident in which the utility had to manually separate conductors to contain the damage. During that incident, the vault could not be de-energized without shutting down the power throughout the entire downtown area. It was a very dangerous situation. With remote communication and control, it is possible to isolate a fault and de-energize only the affected area.

Budget Argument

An excerpt from the utilities 1998 budget submission for the communication and relay upgrade project shows the following:

<u>*Reasons for undertaking the project*</u>*:*

1. *To avoid the full cost of an appropriate manual maintenance inspection system*
2. *Two-way communication can help avoid general network outages by remote switching and provide:*
    a) *Increased safety making it possible and practical to turn off part of the network system to avoid working in manholes and vaults with faults in progress*
    b) *Reduced damage in case of a fault*
3. *To make possible the spliting of buses on multiple transformers at a substation [e.g. by first adjusting the network protector relays to local conditions].*
5. *To properly make changes in a secondary network system we need to know status of the network. The correct information is time consuming to collect, difficult to acquire, and difficult to check. Two-way communication can provide much of the required information.*
6. *Changes in the secondary will occur or will have to be made. These changes include but are not limited to the following:*
    a) *The failure of network tie cables*
    b) *Removal of duct and cable or transformers to meet customer requirements for land use*

c) *possible conversion of network circuit breakers for normal 15 kV circuit duty*

<u>*Consequences of NOT undertaking the project*</u>*:*

1. *Frequent exposure to hazardous working conditions when inspecting the network*
2. *Day-to-day operating status of possibly critical areas of the network will remain unknown, with consequent increased equipment damage risk*

System Design

The network upgrade has two components:

- Upgrade relays serving the network protectors to Eaton's MPCV and 2) provide communication to all such relays.

  The choice of the C-H MPCV relays was indicated as most cost effective due to the following key considerations:

  * MPCV had a less expensive and safer way to handle the requirement for 347/600 volt relays
  * Eaton had a well thought out and field proven communication system that was recommended by users
  * The MPCVs were considered the best and most reliable of the designs available

  The MPCV's in tandem with a robust communication system held the promise of better system knowledge, improved response to network disturbances, and improved safety (in part due to less exposure of field personnel to the network environment). While one cannot put a price on a single human life, infinite spending cannot drive the statistical likelihood of a fatality to zero. As Dr. Richard Wilson, Professor Emeritis, Physics at Harvard University wrote in *Regulation Magazine*, "cost-benefit analysis cannot be stripped of emotion until we arrive at an agreed cost per life saved." He noted that the EPA has suggested that "health and safety regulations are reasonable if they cost no more than $4M (USD) per statistical life saved".

  Additionally, the MPCV have provision for four close-contact inputs. These inputs provide the means to collect alarms in the vaults. The first input is used to provide the Network Protector status. The second input is for vault-flooding switches that will raise an alarm through the MPCV relays when water or oil starts filling the vaults. The utility wants this alarm to address environmental concerns —there used to be drains in the vaults but they were plugged to avoid oil spilling into the nearby river. The third input is for oil-level switches in the network transformers and protectors that will be added to detect oil leaks. The fourth input will be used for a fire alarm.

1. The utility wanted a fast, highly reliable and safe communications backbone that provides real-time response—one that could handle waveform file downloads with ease and capable of accommodating future requirements including those unforeseen at the time of upgrade.

The utility decided very early in the planning to pursue an fiberoptic communication solution due to the

- Safety of using all-dielectric cable
- Inherent high bandwidth of fiber
- Confidence in the underlying fiberoptic technology substantiated by an inter-substation SONET fiberoptic transmission system deployed in previous years and the reliability of redundant-loop optical systems.
- A SONET system, which is very expensive, was considered inappropriate for the harsh environment of network vaults.

A 16-Channel Fiberoptic Communications System

A few years before this project began, the utility's engineers learned of the H&L Instruments FiberLoop II™ system. It was a good fit: field-proven, redundant-loop architecture, not too complicated, and not too expensive. It fit the needs perfectly and allowed the implementation of an optical backbone with communication nodes along the backbone collecting data from nearby MPCV relays via inexpensive RS-485 opto-isolated copper cables. The engineers completed a successful proof-of-concept bench test at the company with several C-H MPCV relays, an H&L Model 560 Fiberoptic Network Controller (master unit), and an H&L Model 562 Fiberoptic Transceiver (field device).

To maximize system performance, they needed more than H&L's standard virtual 4 channel system. Initially, consideration was given to breaking the system into two parts as this would reduce the number of devices needed. However, that approach would require an additional H&L 560 master unit and the use of additional precious fiber strands (due to the way the optical network is laid out). H&L proposed an engineering effort to expand the channel capacity of the H&L FiberLoopII system and to develop a master unit with 16 serial ports. The proposal was accepted.

With the newly developed H&L Model 560-16 master units, the utility was able to allocate 6 channels (9600 bps per channel) for half of the network, allocate another 6 channels for the second half of the network, and still have four channels available for future requirements.

Fortunately for Network Engineering, the utility had a wholly-owned, non-regulated Telecom business unit which was interested in deploying fiber in the downtown core. This was at the same time that the electric utility was engineering the fiber needs for the project. The costs of materials and installation were split on a fiber-count basis; as Telecom's fiber count was much higher than Network Engineering required for the electric utility network, and therefore, the Telecom unit picked up most of the costs. The H&L transceivers were required to be singlemode (SM) partially because the Telecom group needed singlemode fiber, and partially because of the utilitiy's pre-existing SM expertise and equipment. As well, when multimode (MM) cable was priced, it was found to be about triple the per-length cost of SM. Thus, employing SM allowed a savings on cabling costs, even though there was an offsetting increase in end-equipment costs.

Costs

Budget Center:	*Network Distribution*	*SCADA & Communications*	
Year ($USD):			
1998	*$250,000*		
1999	*$250,000*	*$250,000*	
2000	*$250,000*	*$250,000*	
2001	*$100,000*	*$ 40,000*	
2002	*$ 50,000*	*$ 40,000*	*(estimated)*
Subtotals:	*$900,000*	*$580,000*	
Grand Total:			*$1,480,000*

What this paid for:

- *30 H&L FiberLoop transceivers, including spares*
- *26* Eaton *Mint II RS-232/Incom transceivers*
- *26 polycarbonate waterproof communication enclosures, for housing the Mint II's, the H&L field transceivers*
- *26 PC-type UPS units*
- *roughly 100* Eaton *Incom Couplers (surge suppression devices)*
- *installation of all of the above in network vaults*
- *purchase and installation of approximately 14,000 m of Incom twin-axial cable (used for connecting each MPCV relay back to a communication node)*
- *purchase, installation, splicing and termination of network's share of 12,000 m of all-dielectric, loose-tube single-mode fiber cable*
- *roughly 200 new* Eaton *MPCV relays, including spares*
- Eaton *PowerNet software*
- Eaton *Engineering Services support to configure Modbus connection to SCADA system*
- *DeviceServer workstation (dual PIII-600 with hot-swappable SCSI RAID HD)*
- *WonderWare software for HMI development*
- *Consultant to develop HMI*

What this didn't pay for:

- *installation of the new* Eaton *MPCV relays: these were installed incrementally, in concert with regular maintenance inspections*

Benefits of Final Design and Network Installation

- H&L Instruments Model 560-16 network controller provided 16 virtual channels, which enabled implementing the network on an existing single-two-fiber loop saving thousands of dollars.
- Six channels were dedicated to each of two subnetworks, and four channels were reserved for future expansion.
- H&L Instruments standard FiberLoop II System software provided:
    - Configuration and monitoring of fiberoptic transceivers and controllers
    - Self-healing fiberoptic network
    - True optical repeaters with no optical degradation
    - 16 virtual channels at 19.2k baud
    - Multidrop loops, radials, and branches
    - Environmentally robust system that operates from –40 to +85C

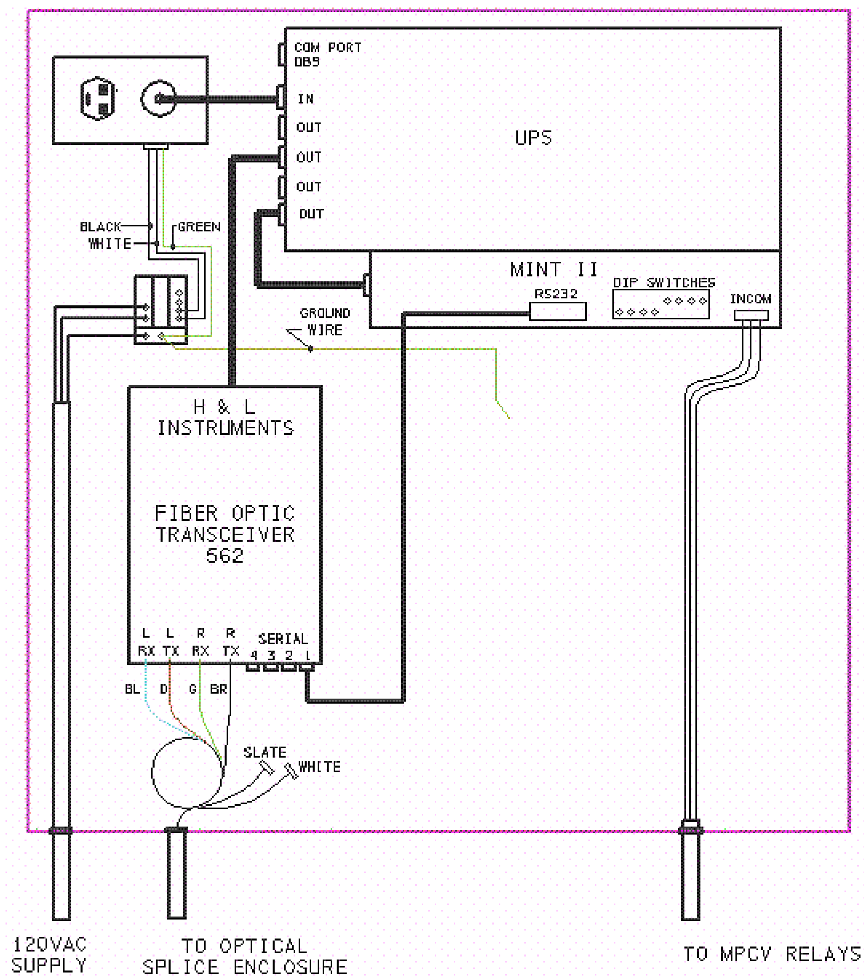
The Model 560-16 Network Controller is shown in the following figure.

Appendix A - Photo

Communication enclosure in vault: a typical installation of an enclosure. Mint II, H&L 562 and UPS are visible through the enclosure's plastic window. Note: This photo was taken before the fiber optic cable (with yellow marker tape) was terminated and dressed. The junction box for the 120VAC is visible to the immediate right of the communication enclosure; the same type of box is used for the INCOM cables. All boxes are installed above the height of the cable ducts; the hope (faint though it may be) is that these boxes will stay above the water level in the vaults the great majority of the time. (Most of the network transformer vaults are dry but water still seems to get into the light fixtures on the vault ceilings) The water-tight enclosures are mounted near the ceilings of the vaults. While vaults do have drains in them, some vaults have been known to fill up with water (occasionally even to the top!) and because of environmental concerns, drains are being sealed.

Appendix A — Typical Communication Enclosure Wiring

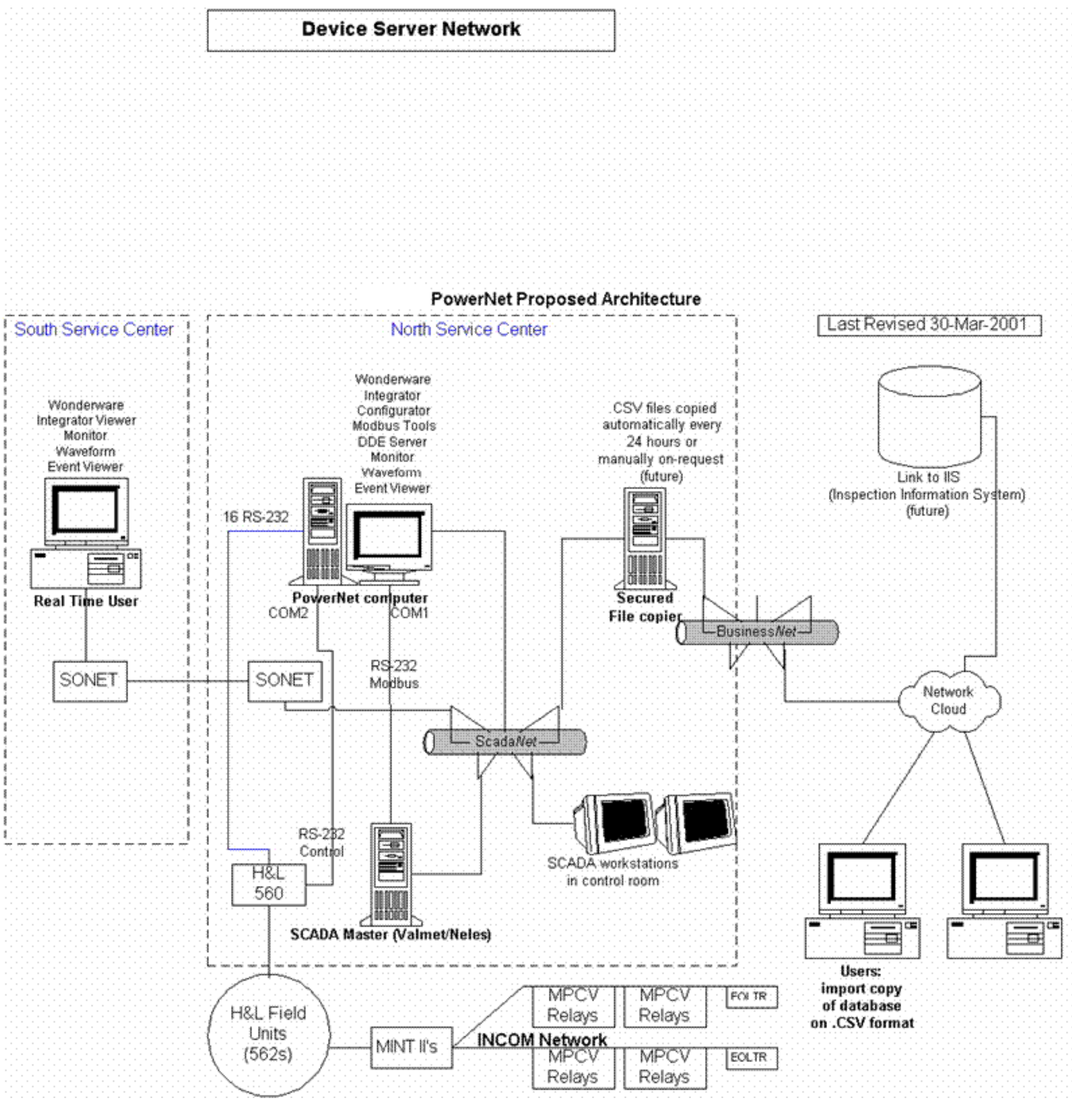
A wiring diagram for a typical installation of a communication enclosure housing a Mint II, an H&L Instruments Model 562 transceiver and a UPS unit is shown in the following illustration.



Appendix B - Control System Overview

Current Software configuration: The main software blocks involved.

- *PowerNet main software communicates with the MPCV relays, and gathers the information, configuration, waveforms, etc. It provides that information to its own view, to Wonderware and to the utility's SCADA system.*
- *PowerNet Viewer is a basic user interface that allows changes to the relay configuration and downloading of waveforms.*
- *Wonderware provides a good geographical user interface and shows the data as it is needed. This software also performs number-crunching and automation functions.*
- *H&L Configuration: administrative software to configure the H&L equipment.*
- *SCADA system: The SCADA system is based on OASyS, developed by Neles Automation (formerly Valmet Automation). It provides the control operator with the same type of screens that are used for the substations. They operator can open or auto the protectors, get status information, and get alarm information.*



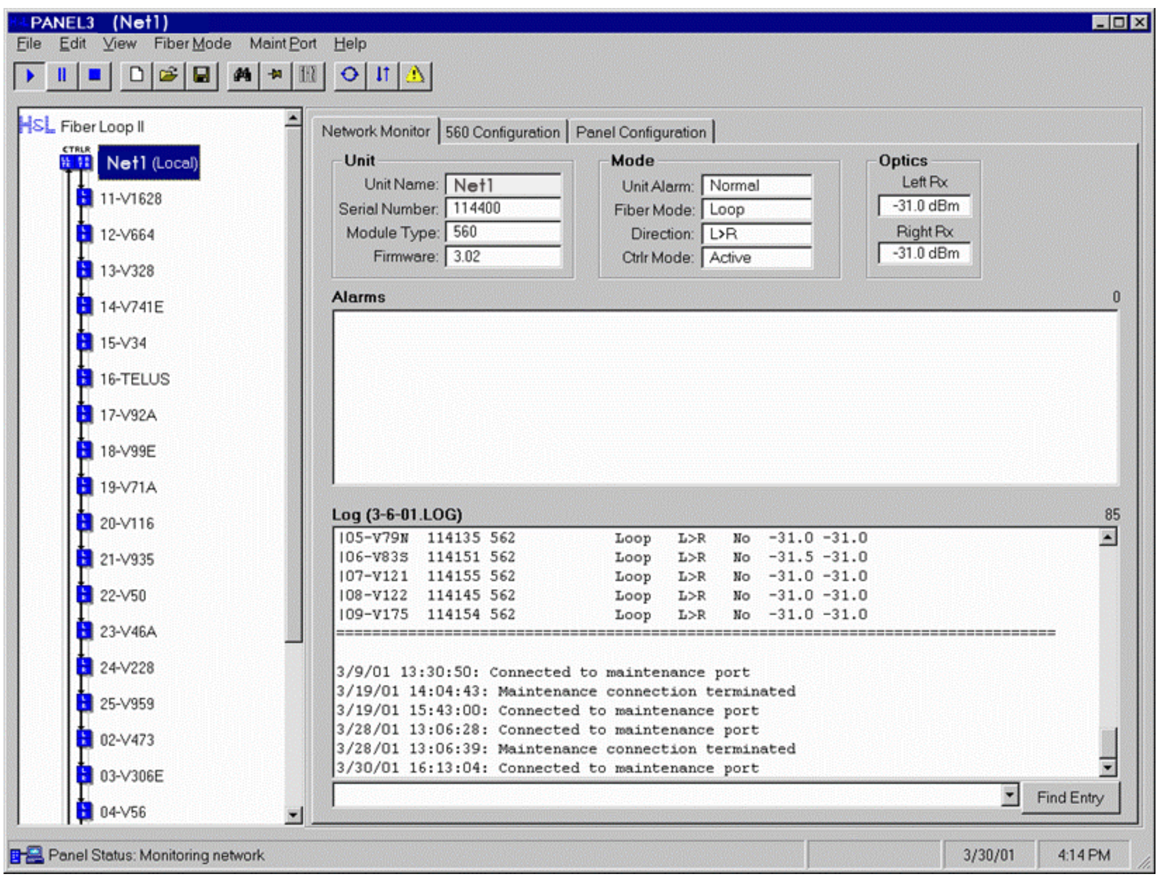
Appendix C - Screenshots

H&L's HLPanel3 network control software automatically detects and depicts field units;shows alarms and allows configuration changes (e.g. change from loop mode to radial). The program provides the user interface for the H&L Fiber Loop II line of fiberoptic controllers and transceivers. It utilizes a serial connection from the PC's comm port to the maintenance port included on each unit. The panel supports remote connections to the fiberoptic network via a standard modem or the on-site maintenance PC can be accessed remotely with programs such as pcAnywhere. A typical panel display is shown below. The panel has two basic functions that are selected by clicking the appropriate tab in the main window:

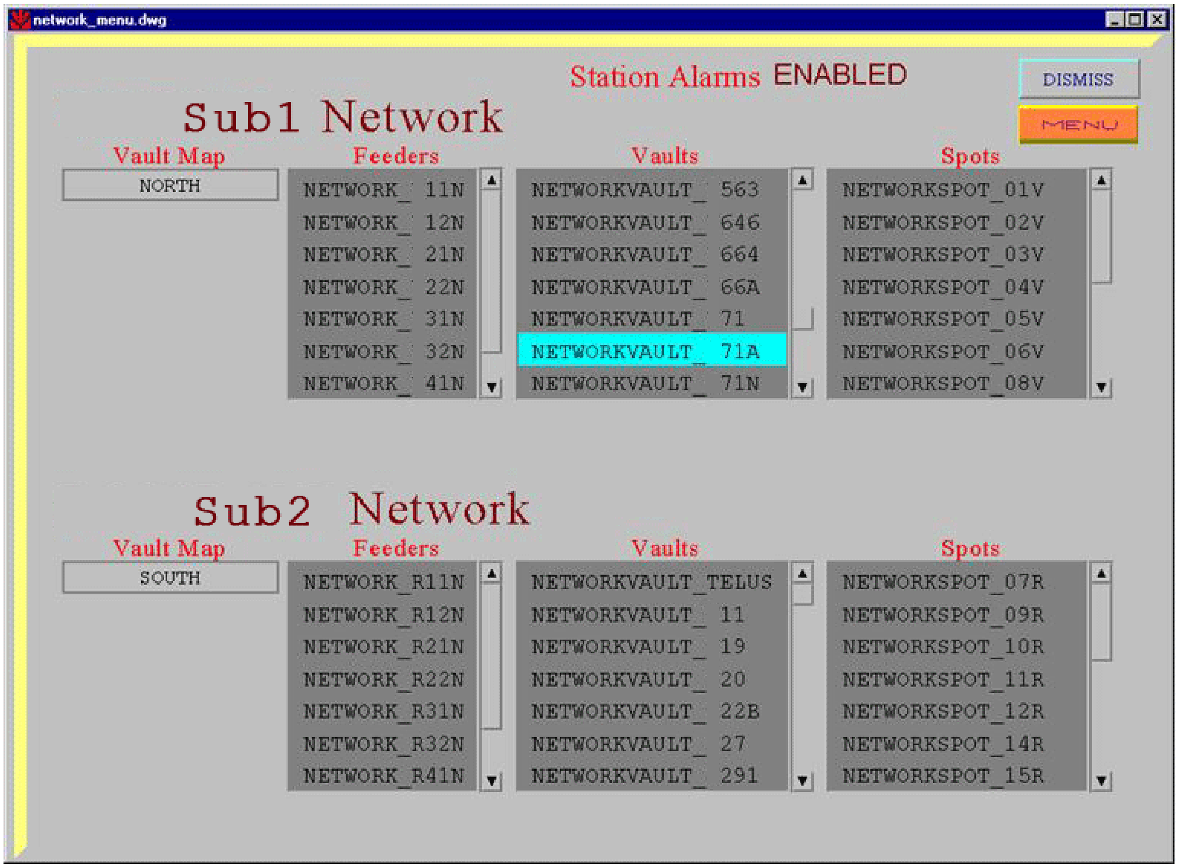
- *When connected to an active **560** controller,the **Network Monitor** continually polls the controller to determine the condition of the network. Network events are alarmed and recorded in a log file as they occur. The **System Map** graphically represents the configuration and status of the fiberoptic network. System failures are easily identified and corrected.*

- *When connected to any unit, **Unit Configuration** provides a convenient method of configuring and monitoring parameters within the unit.*

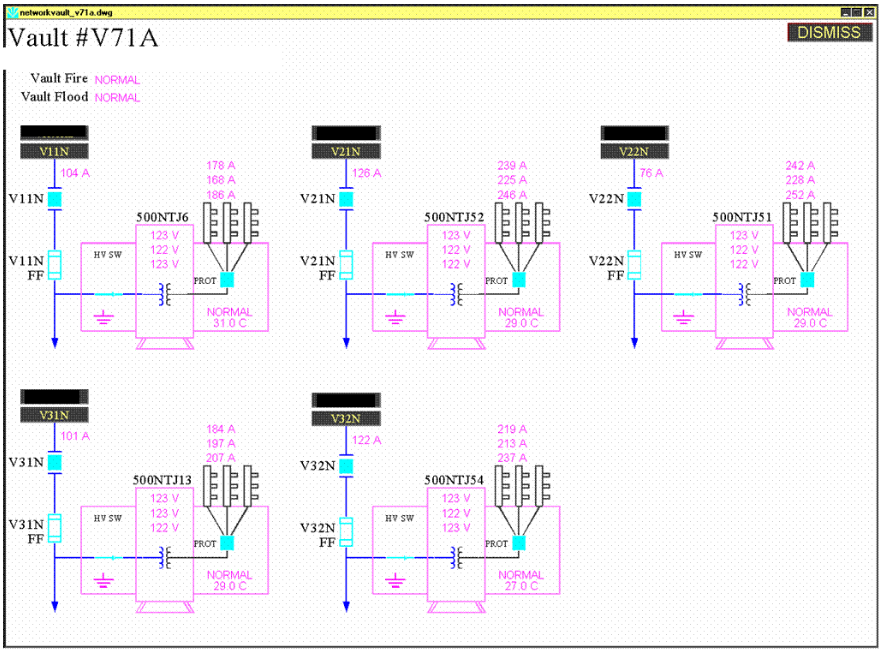
- *A third tab, **Panel Configuration**, is also available which allows the user to customize various panel parameters.*



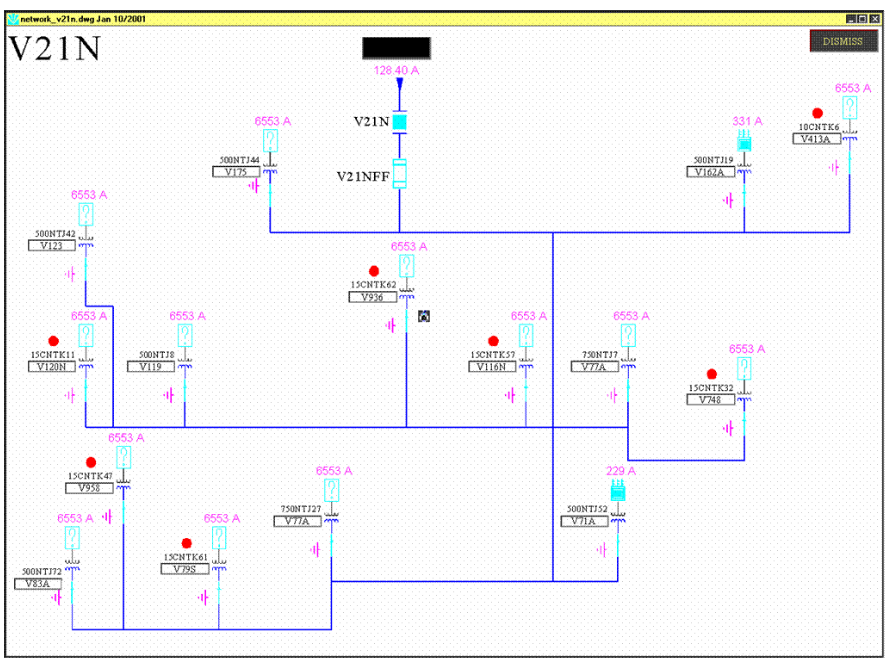
Valmet/Neles OASyS (D&T SCADA) menu screen, allowing an operator to choose a vault by name for closer inspection



OASyS map screens, geographically depicting those network vaults fed from the Sub1 substation. If an MPCV is providing an alarm signal, the blue dot for the corresponding vault changes to a flashing red, and an alarm message comes up in a separate alarm window.



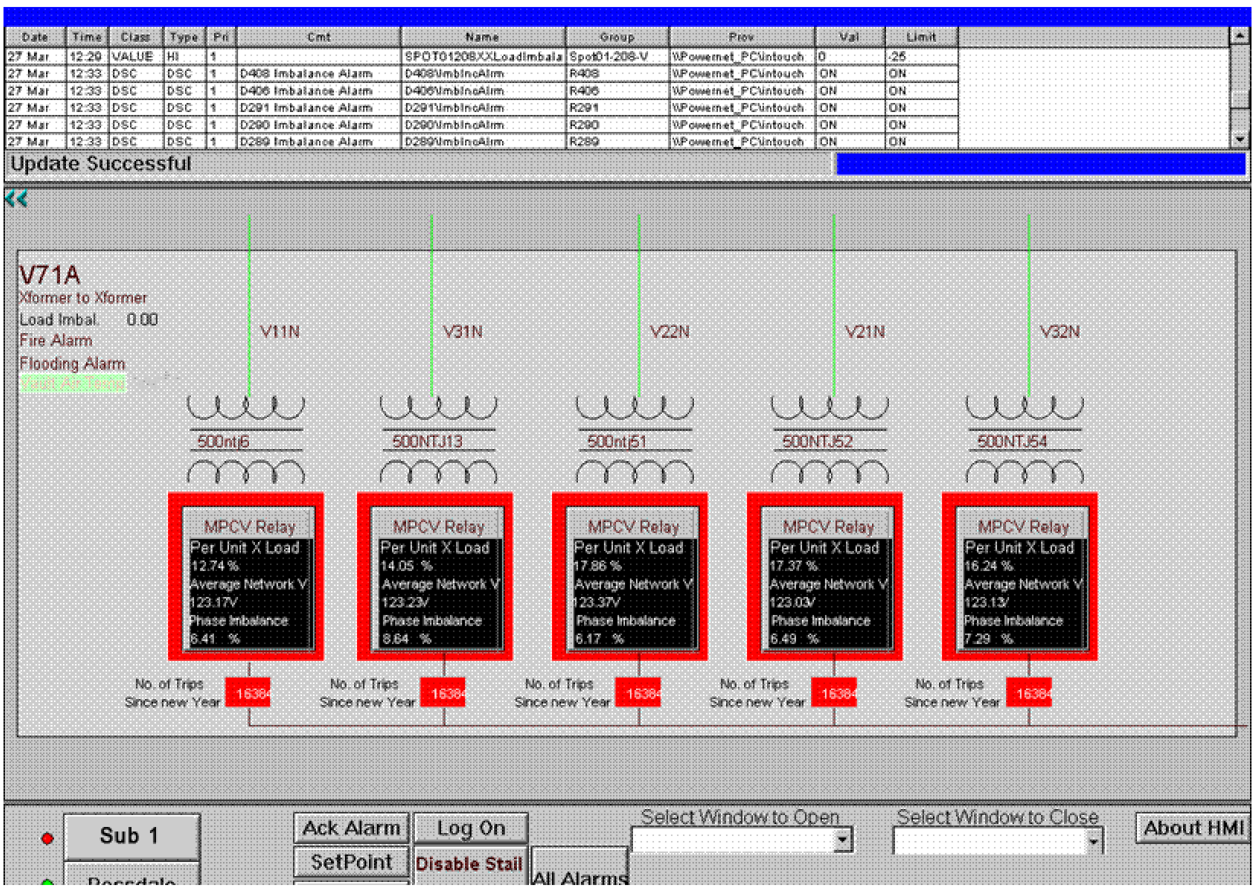
OASyS graphic of Vault 71A, showing the network protectors in the vault and related status and analog information



OASyS graphic showing all vaults fed by feeder V21N, which is a 15 kV feeder.

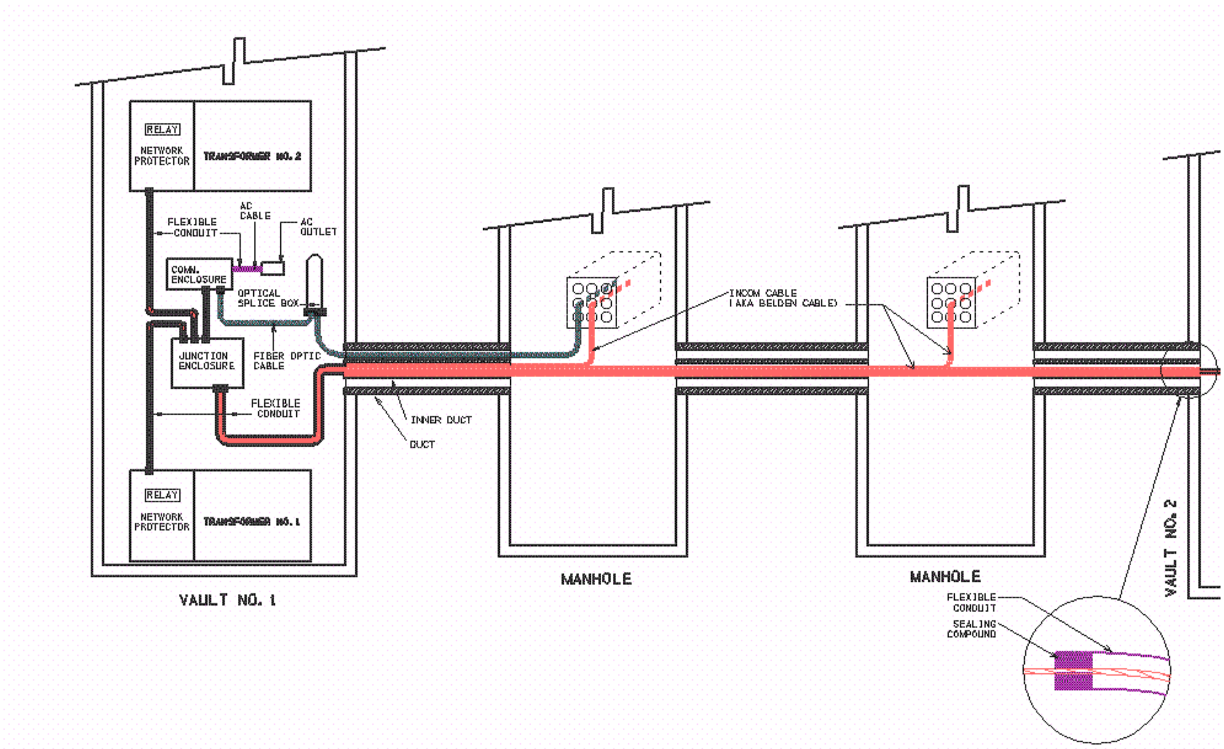
WonderWare graphic of Vault 71A.

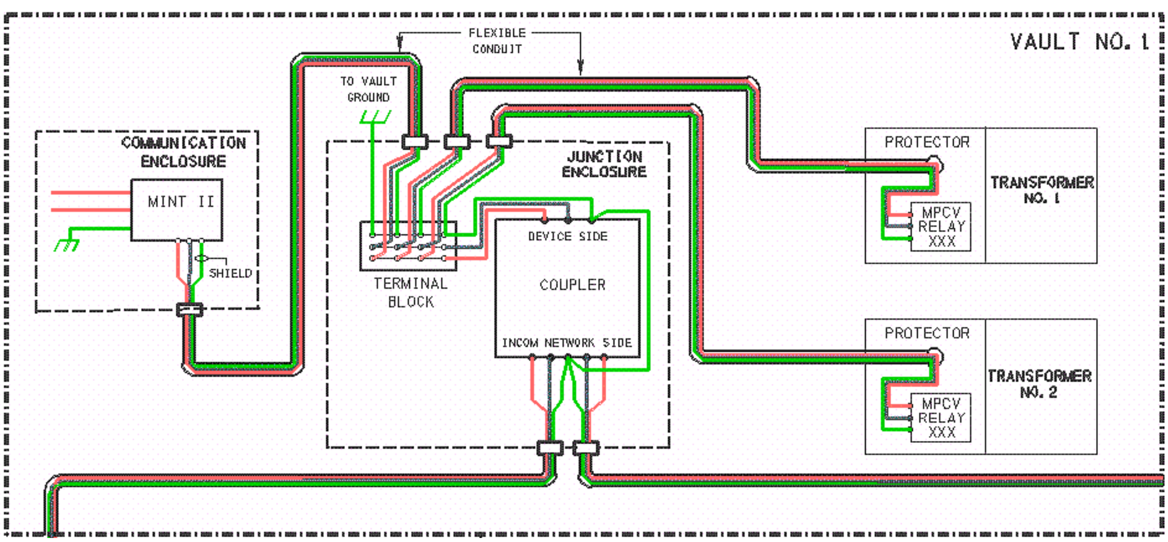
This application is primarily an interface for relay technicians, with occasional use by network engineers. The information displayed is slightly different than that provided to the Control Operators using the OASyS interface. For instance, WonderWare is used to perform calculations, to convert raw voltage and current data into relative loading numbers. The time lag between selecting a vault (either via text menu or by clicking on a map) and the graphic appearing on screen is virtually nil. The subsequent time lag to display the relevant status and analog information is, at present, on the order of 1 to 2 seconds. In the coming months, we will be both hooking more relays up to the communication system, and utilizing more of the H&L's available com channels. No significantly increased delays in bringing up current information is expected.

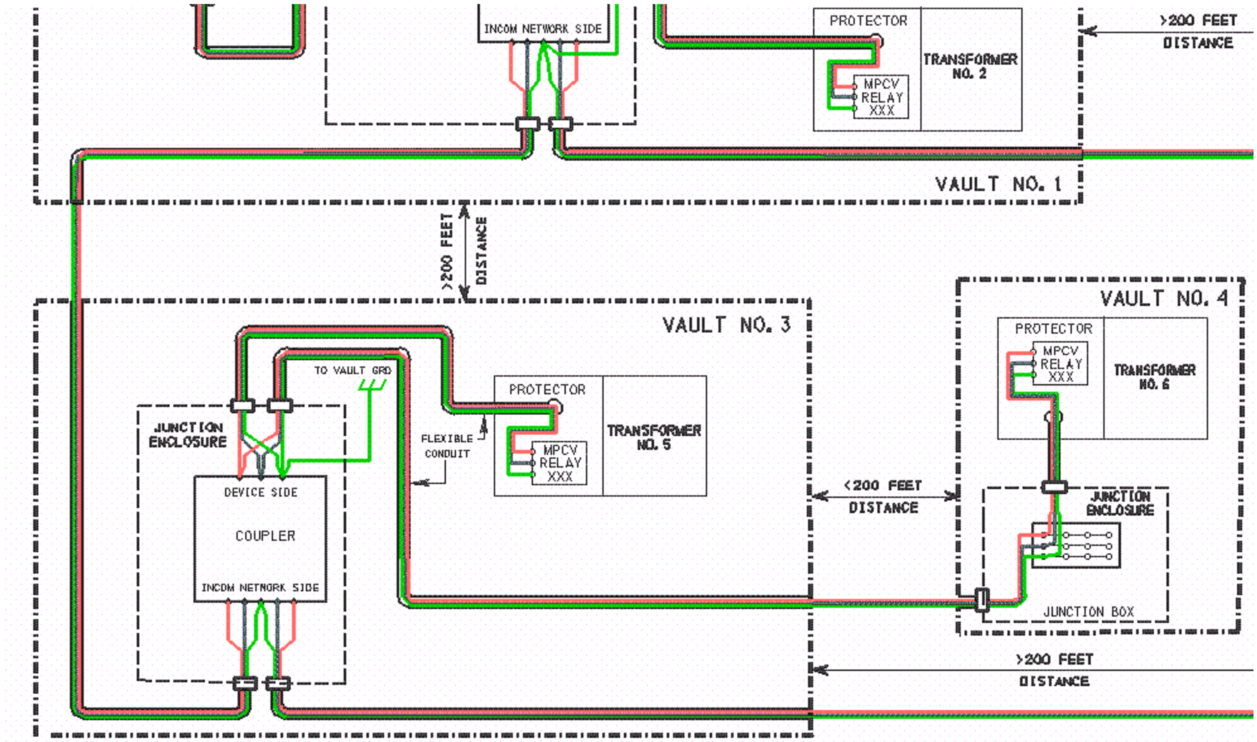


Typical Inter-Vault Wiring Diagrams

Following are several diagrams of inter-vault wiring showing network protector relay hookup, Incom interconnect, and fiberoptic hookup.






INCOM NETWORK SIDE
PROTECTOR
TRANSFORMER NO. 2
MPCV RELAY XXX
>200 FEET DISTANCE
VAULT NO. 1
>200 FEET DISTANCE
VAULT NO. 3
VAULT NO. 4
TO VAULT GRD
JUNCTION ENCLOSURE
PROTECTOR
TRANSFORMER NO. 5
MPCV RELAY XXX
FLEXIBLE CONDUIT
DEVICE SIDE
COUPLER
INCOM NETWORK SIDE
PROTECTOR
MPCV RELAY XXX
TRANSFORMER NO. 6
<200 FEET DISTANCE
JUNCTION ENCLOSURE
JUNCTION BOX
>200 FEET DISTANCE