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Fiberoptics: a Reliable Communications Link For Distribution Automation

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Abstract. The development of a reliable fiberoptic transceiver communications system for supervisory control and data acquisition (SCADA) systems is described. Two installations, Pacific Gas & Electric's San Francisco downtown underground distribution network and Cuyahoga Falls, Ohio's substation monitoring and control system, illustrate loop and radial applications.

Introduction

The electric distribution networks for downtown San Francisco and Oakland, California include over 934 transformers – most of which are in underground vaults. Each of these vaults contains two or more transformers utilizing a distribution network with spot transformers to distribute power as it is the most dense load area in the two cities.

A few of these transformers, some of them installed as far back as the 1930's, were failing without warning. Fire and PCB contamination was also a problem. Vaults flooded due to sump pump failure and water main breakage. The San Francisco power system yields approximately 20 million dollars a month in revenue. Measures were needed to insure that power distribution was of the highest quality and uninterrupted.

In 1985, Pacific Gas & Electric Company (PG&E) decided to install supervisory control and data acquisition (SCADA) systems to monitor secondary phase currents, protector status, transformer temperature, vault temperature, flooding and, in installations where relaying is present, relay control. Approximately 650 remote terminal units (RTU) would be installed.

What communications medium should be used?

PG&E considered all means of communications between RTUs and the SCADA Master computer. PG&E decided against power-line carrier (PLC) because it requires detailed engineering, tuned to cable type, size and length of feeders, is affected by reactors installed in the substations and VAr compensation capacitors. Cable failure or open switchgear interrupts communications. Slow, uneven data rate results from random interval transmission collisions. PLC failures are hard to locate and repair may require work on the distribution system.

950 MHz radio was rejected because of concerns about coverage (the need for multiple repeaters) the difficulty in siting antennas (mechanical installation and reliability issues), concern that vault antennas would be occasionally blocked by passing or parked motor vehicles, and the amount of work needed to design, install and test a system.

PG&E decided that it wanted data in a *predictable time* and wanted *positive real-time two way communications.* That meant a solid, dependable physical link between all RTUs. Wire pairs would have required new electrically isolated ducting. Trenching is extremely expensive in downtown areas and also inconvenient because there are only special times that streets can be shut-off. Using conventional copper transmission technologies for the new system would have meant a significant amount of digging since the company's underground ductwork was quite congested. The cost to trench in San Francisco is about $300 a foot. Doing any excavating in the city would make the system cost-prohibitive. Ground potential rise during a fault could create an unsafe condition for communications service personnel as well as damage equipment.

Fiberoptics is chosen

Fiberoptics became the most attractive alternative since it would not require trenching; fiber cables could be placed in existing 12 and 34 kilovolt power-line cable ducts. Optical fiber was the obvious, ideal selection to carry signals because of its immunity to electromagnetic and radio interference and its non-conductive nature.

AOI Engineering, an H&L Instruments company, was contracted by PG&E's Telecommunications Department to evaluate commercially available equipment for a pilot study. Vault locations were superimposed on a city street map; duct routes followed streets. (Figure 1 shows one section of the San Francisco network.) Various topologies were considered to interconnect the vaults and distribution substations.

Fiberoptic multiplexers (drop and insert channel banks) are far too expensive on a per RTU basis. Fiberoptic modems require dedicated fibers from each vault complicating the design and increasing the cost of the fiber cable installation.

AOI determined that the fiberoptic equivalent of a multi-drop copper wire system would be the ideal solution (Figure 2).

A system composed of optical or active star couplers (to combine and reduce ports on the Master) was also rejected as the stars would have to be in the vaults and thus a significant portion of the system would be vulnerable to single point failures caused by sudden flooding of a vault or fire. While fibers can be tapped with optical splitters, unlike wires, there are optical power losses, typically 3 dB (50%) per leg. One soon reaches the point of diminishing return. A complicated system of splitters and modems (used as regenerators) would be required.

Considerable site-specific engineering would be required due to the uncertain layout of the underground ductwork. PG&E desired installation to proceed with a minimum of detailed route planning. Fiberoptic cable would be "shoved in" where possible. If a duct was blocked, a circuitous route would be found to get around the obstacle.

Perhaps a daisy-chained string of fiberoptic modems could be connected "back-to-back", with RTUs wired in between. It was found experimentally that data jitter and pulse width distortion became too great after only six RTUs were inter-connected. The ideal solution was not practical.

A new product is proposed

AOI proposed the equivalent of a telephone cable repeater system with a repeater placed at each RTU location. Each repeater (called a fiberoptic transceiver) would modulate, demodulate and reclock data so distortion would not accumulate. Furthermore, the configuration would be a loop with both ends connected to the Master computer. The loops would be bidirectionally redundant for the obvious benefit that if a transceiver or a section of fiber failed, communications to all other points in the system would still be possible. The 500 RTUs in the San Francisco network system would be in 10 loops of 50 each requiring just 20 communications ports on the Master computer.

As no such product existed, Fred Holmes, PG&E Golden Gate Division Manager, contacted H&L Instruments to design and manufacture four prototypes to test the concept. The prototype transceivers were installed in January 1986, in a loop between PG&E's Electrical Engineering Dept. in San Francisco, in a network vault feeding the building and a second vault feeding the Bechtel building across the street (Figure 3).

After a year of successful operation, 40 transceivers were installed in a loop to monitor a 34 kV network. PG&E developed the Master software and installation procedures in this pilot study. In November, 1987, H&L was contracted to supply 654 transceivers to complete the systems in San Francisco and Oakland.

The fiberoptic transceiver

The Model 542A Fiberoptic Transceiver (Figure 4) receives and transmits a modulated optical carrier signal on multimode or singlemode optical fiber. This is done for several reasons. The presence or absence of the carrier is an indicator as to the integrity of the fiber cables, whether or not data is being passed. An optical carrier system has a much better signal-to-noise ratio than a simple light on/off data link.

All transceivers are connected in a daisy-chain fashion as seen below (Figure 5).

The transceiver has two sets of optical ports, left and right. Each port has a light emitting diode (LED) transmitter and a photodiode (PD) receiver (Figure 6). To understand how the transceiver functions, we begin with a Master to Slave communication. The Master is connected to one of the three EIA-232 serial ports. The transceivers have three EIA-232 ports to accommodate more than one RTU at a single location. Data coming into a serial port is encoded and modulates both left and right port LEDs. Note that only one side of the loop is connected to a Master transceiver. There are two Master transceivers, one for each direction on the loop.

The modulated carrier signal is sent to the adjacent transceiver where it is demodulated and the resulting NRZ serial signal is buffered in memory and sent out to the attached RTU. At the same time, the NRZ signal is remodulated and sent out the opposite port to the next transceiver on the loop or bus. The process is automatically repeated at every transceiver on the loop. There is *no limit* to the number of transceivers that can be cascaded.

When an RTU recognizes its address, it responds as requested and the transceiver modulates the NRZ serial signal from the RTU and transmit through *both* left and right ports. The transceivers repeat the signal all the way around the loop. The transceivers at the loop ends demodulate the RTU signal and send it out the serial ports to the Master.

For redundancy, two transceivers are connected to the loop ends and two Master serial communications ports are connected. The Master station polls alternately from each port and has diagnostic capability to identify if there is a break in the loop, based on which RTU's are responding.

Each transceiver is capable of driving a 6 km fiber cable with 850 nm LEDs and optionally, with 1300 nm LEDs, a 14 km cable. Another option is a singlemode 1300 nm LED which, with low loss singlemode cable, can drive 45 km. PG&E used about 26 miles of Siecor 6-fiber loose-tube cable. Each tube has one 62.5 micron fiber – two are required for the SCADA system; this leaves four fibers for company telecommunications requirements. Pre-connectorized tight-buffered pigtails were field fusion spliced to the loose tube fibers. Splice cases were NEMA-type metal enclosures, designed by PG&E's Project Manager, Steve Calvert, to be bolted to the RTU enclosures. A typical vault installation is shown in Figure 7.

Operational advantages

An operational benefit of the new SCADA system is identifying network distribution problems. The network is a fully automated system so it will continue to give full service even when components are not fully operational. For example, when a fuseable link has opened on one of the protectors, a customer still gets three-phase power because all customers are on two or three spot transformers. One of the transformers is now only feeding two phases because of the failure; this is immediately apparent with the new SCADA system. This is inefficient and reduces the emergency loading capability of the vault. Corrective action can be scheduled to replace the link. Without the fiberoptic

SCADA system, PG&E would not know that the link was open until a crew was in the vault for periodic preventative maintenance.

According to Dan Partridge, PG&E's project manager of strategic technology operations, "A significant benefit of the new system is that we can now clear a feeder in a fraction of the time previously required". Before the fiberoptic SCADA system was installed, if any of the network protectors hung-up, it took hours to send a crew to vaults on the feeder to find the defective protectors. With the monitoring system, the Switching Center Operator knows immediately which vaults to send the crew to open the protectors.

Engineering advantages

Besides the numerous operational advantages, there are engineering advantages. PG&E can now load equipment much more efficiently because the customer's true load is known and the load of individual pieces of equipment. Other future benefits may include load management and meter reading. Since these are large customers, the dollar advantage in a faster turnaround of billing would be very significant. Now that PG&E has this SCADA system they have learned that the uses are far beyond the original plan. Because it exists, it causes people to think of more and more applications.

Economic justification

PG&E expects the fiberoptic system to be a real cost saver. For example, the time it takes to read the data on a transformer has been significantly reduced. It is estimated that more than $700,000 per year will be saved because of the system. With that kind of immediate payback, it will not take the system very long to pay for itself. The company is more aware of the condition of the network when a planned outage is started. This allows use of two-unit spots as opposed to three-unit spots. If the outage would cause an overload on one of the two-unit spots, the outage is re-scheduled. Shifting of load can deter the need to upgrade feeders.

Multi-drop bus application

The City of Cuyahoga Falls, Ohio owns their own electric system. They generate, as well as, purchase power from various outside utilities. A 23 kV sub-transmission loop feeds eleven (11) substations throughout the city.

Approximately three years ago, the city's Electric Department retained GPD Associates to investigate the installation of a SCADA system. The purpose was two-fold: 1) to control the line regulators and transformer load tap changers to reduce energy usage, and 2) to automate some of the manual inspection and monitoring functions. It was quickly realized that there would be financial savings if a SCADA system was installed.

Communications methods considered

The method of communications to be utilized between the Master Station and the various remote terminal units (RTUs) was deemed to be the most important feature of the system. Seven options for the communication link were investigated: leased hard-wire lines from the phone company; installing a private, dedicated hard-wire system; using a multiplexed radio station the city was contemplating installing; microwave; power-line carrier; multiplexed fiberoptic system or a dedicated fiberoptic repeater system.

A key factor in the selection process was conversations with SCADA system owners – not just specifics about the computer hardware, but also what communications links were being utilized and the performance of each technology.

Others, utilizing either dedicated or leased hard-wire lines, complained of losing communication when it rained. In some cases, the system was unusable when the weather turned inclement.

It was important that the system could not be disabled by an outside party's negligence or rely upon an outside party to make repairs. In short, *the City wanted to be in full control of the system.*

A multiplexed radio system was rejected because installation, maintenance and repair would not be under the control of the Electric Department. Also a concern was the question of interference. Atmospheric conditions such as lightning, temperature inversions or solar sunspot activity could impair the communications link. Static, random or intentional radio interference from unknown sources could also affect the system.

Microwave communication was not selected because of cost and possible interference from inclement weather. Cuyahoga Falls is a hilly community. Microwave, utilizing line of sight, would have required several very tall and unsightly towers.

Power-line carrier was never seriously considered because of the cost factor and the need to rely on the conductors themselves for the communications link. The city had no power-line carrier equipment currently in place. The installation of this equipment (where physically possible) would be a significant expense. Indoor switchyards would require installation of line tuner/wave traps which would have greatly increased the cost. Outdoor substations would require additional steel work and, in some cases, additional property would have to be acquired.

Fiberoptics is chosen

It soon became apparent that the only utilities reporting "zero" problems with their communications links were those using fiberoptics. A fiberoptic link was the only system which could be fully controlled and maintained by the Electric Department. There were two choices, a multiplexed drop and insert system or H&L's transceiver system. A multiplexed fiberoptic communications link was rejected due to the high cost of the electronics equipment. The transceiver system was selected as the installed cost, per RTU, made it very attractive. The system block diagram is illustrated in Figure 8.

The SCADA Master computer would be located in the City's Electric Department office which is geographically centrally located. A radial multi-drop bus system was determined to be the optimal topology. To implement loops would have required twice as much fiber cable, in this case, which would have increased the costs beyond the City's budget.

It was decided that a six fiber cable would be installed. The four (4) unused fibers would be available for other uses, such as relaying, telecom, or other data links. The cable was a Siecor 62.5 micron, 6-fiber loose tube cable. The City contracted out the cable installation. Cable was installed underground through existing ducts (where available), as well as overhead, lashed to a messenger cable (Figure 9).

About half of the cable was overhead. At three sites, underground conduit was installed from the substation to a nearby riser pole (Figure 10). In total, about 17,000 meters of cable was installed with the longest run between transceivers being approximately 9,000 feet.

A typical installation is shown in Figure 11. The transceivers are located inside the NEMA RTU enclosures; the fiber cable comes directly into the enclosure.

The communications rate was set at 1200 baud because, before the fiberoptic system was cut in, the SCADA system was brought up on leased telephone lines. There has been no reason to change the speed even though the fiberoptic system can run at 19,200 baud. This is sufficient for the City's needs. Changes in data from the RTUs are reported at the Master Station within one second of their occurrence.

System features

The SCADA system is designed to be unmanned. When the data indicates an occurrence at a substation, it is reported back to the Master Station and an alarm sounds to alert someone to check the system. Obviously, it is imperative to minimize the number of false alarms. If the SCADA alarm sounds because of communication failures, the operators will quickly lose faith in the system and not respond, assuming it to be another false alarm. This is definitely an undesired possibility.

With the primary concern being minimizing false alarms in the system and still keeping costs under control, the fiberoptic system was, *and still is,* the best choice. The SCADA system was commissioned in July, 1990. There have been no failures or errors in data due to the communications link.

Conclusions

Fiberoptics should be *the first* communications medium considered, not as a last alternative. Whether underground or above ground, fiberoptics has been demonstrated to be ideal for electric utility communications. The development of a multi-drop fiberoptic transceiver has made fiberoptic communications for SCADA systems economical, fault tolerant and simple to design and install.

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