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Ethernet in Power Utilities Substations – The Changing Role of Fiber Media

A White Paper for Network Engineers

by

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April 2004

Industry Overview

Utilities are stepping up to the plate with Ethernet implementations throughout the world. With a growing population coupled with increasing demand for power from both proliferation of power-consuming gadgets and other luxuries, and the global delivery of basic necessities, utilities are being called upon to produce more power more dependably. At the same time, environmental, structural, and political factors are causing utilities to reconsider power generation, transmission, delivery, and security measures. Although demand is growing, fiscal responsibility and the simple fact that budgets are growing tighter and more carefully watched, underline the requirement for utilities to create solutions that are cost-effective, reliable, secure and designed to be upgradeable to extend the life of the infrastructure investment.

The facilities within power substations are being rethought to take advantage of new technology and standards to deliver energy in a cost-effective, secure, and continuous manner. Better communications technology is an important component for implementing the utility systems that are going to cost-effectively meet today's needs and also be easily upgradeable as demand and technologies change. As the industry is discovering the hazards of proprietary communications systems, (i.e., high cost, inflexibility, lack of support for older components, etc), Ethernet is becoming the preferred communications vehicle within substations.

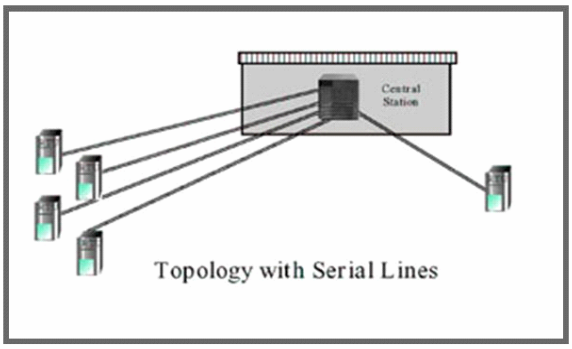
The Role of Fiber Media

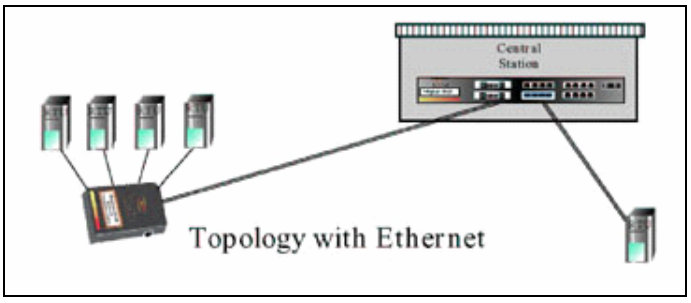
Fiber media is an enabling technology for extending Ethernet into industrial environments generally and power utility substations in particular because of its immunity to electrical interference, its avoidance of ground loops, its virtually limitless bandwidth, and its capability for extended-distance applications. Fiber media have been the choice in power substations for quite some time, much fiber cabling having been installed with legacy serial lines over the past 20 years. It was traditionally used with RTUs, modems and voice-grade circuits, connecting devices that need to communicate, and moving data from distributed relays, RTUs (Remote Terminal Units), PLCs (Programmable Logic Controllers) and IEDs (Intelligent Electronic Devices) to the central control area.

Migration from Serial Communications to Ethernet

Serial communications were traditional in utilities installations; they were well understood and proven, available in robust packaging, and with adequate speed for their time. They required continuous point-to-point connections for operation, thus a fiber cable had to be run from each outlying serial device to the central control cabinets in the substation. However, serial lines have been often associated with proprietary protocols and limited speed. Ethernet connectivity is becoming more popular because it offers standards-based interoperability and performance, along with the hardened characteristics required for many utilities installations.

As older substations with serial communications are upgraded, the same fiber media that is in place can usually be used for Ethernet connections. In contrast to point-to-point cable runs with serial lines, Ethernet, with its shared-media packetized protocol, allows many devices to connect using one shared fiber cable. The fiber cable topology changes when Ethernet is installed, so there is usually excess fiber for new devices and applications as a substation migrates.





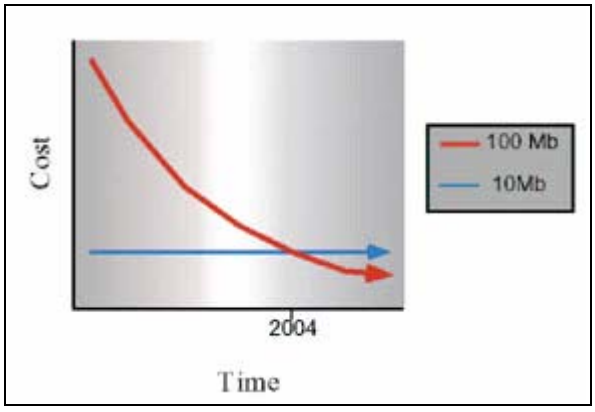
While fiber cable is compatible with both serial and Ethernet, copper cabling is not. Ethernet requires Cat 5 twisted-pair copper cabling with RJ-45 connectors. Although not noise immune like fiber, copper cabling can be used in Ethernet systems for the short runs inside of control room rack cabinets where there is protection from EMI noise. Most substations, as they install Ethernet, use combinations of fiber and copper cabling.

The Argument for Ethernet

Ethernet's benefits are easy to understand. Because it is a standard, it is the least expensive way to have connectivity. Standards mean more choices in products that can connect together, and greater potential for reasonably priced replacement components and long-term support. As a standard, Ethernet is the protocol of choice for new technologies that are being introduced in industrial facilities such as factories and substations. It is more profitable today for developers of technologies such as programmable controllers, dual-ported IEDs and low-cost security cameras to introduce a product that will work with a large variety of installed communications devices than to go to the expense of developing specific versions to meet proprietary communications requirements. Further, with Ethernet using fiber cabling, bandwidth is essentially free because it is practically unlimited for a one-time installation cost. An added benefit, of course, is that Industrial Ethernet is compatible with IT facilities and eliminates a conversion bottleneck where factory and corporate networks meet.

Changing Cost Models for Fiber Transceivers

While fiber cable is capable of supporting bandwidths greater than the highest commercially available 1 Gb limit for Ethernet, it is terminated by bandwidth-specific fiber transceivers. The fiber transceivers come in speeds of 10Mb, 100Mb, and Gigabit, with the faster components traditionally costing more. As substations and other industrial facilities began to use Ethernet and fiber during the last few years, most installations used 10Mb ports. At the minimum 10Mb speed, the Ethernet connections are still 200x the speed of typical serial connections. The data rates required in substations were well below 10Mb, and the additional cost of higher-speed fiber transceiver parts was not justified.



In 2004, the cost parameters are changing. While industrial Ethernet has continued to favor 10 Mb parts, the high-volume enterprise Ethernet market has long since moved to 100Mb parts. The huge demand for 100Mb fiber parts

in Ethernet LANs has driven down the cost of 100Mb fiber transceivers. Today the cost of 100Mb is crossing over and going below the cost of 10 Mb fiber connections. Going forward in time, economics will drive 100Mb to the dominant position over 10 Mb, even for applications where 100Mb bandwidth is yet not needed. In fact, as Ethernet becomes widely adopted for control, protection, and metering, with their more demanding bandwidth requirements, 100 Mb speed will be the norm.

Fiber vs. Copper – Current and Future Co-existence

While fiber cable is preferred for noise immunity, twisted pair cabling also has a role in substations. Within control room rack cabinets, copper cabling is safely used for short Ethernet interconnections. The same twisted pair cable and RJ-45 port connectors can be used for both 10 Mb and 100Mb speeds, simplifying installations. The assumption has been that copper cabling is less costly, so most RTU, PLC and IED manufacturers use RJ-45 ports on their products for both lower cost and 10/100 Mb compatibility. This, of course, makes some use of copper necessary even if only to connect to a nearby Media Converter.

Fiber	Copper
Use anywhere, immune to EMI noise.	Short runs within control room cabinets.
Product demand is driving costs lower – in many applications, fiber to the end device is now cost-competitive.	Traditionally considered lower cost.
Only medium capable of supporting 10Mb through 10 Gb bandwidth.	Same medium and termination for 10 Mb and 100 Mb Ethernet.
Medium of choice for backbones.	Port connection of choice for many IEDs today, "universal" for 10/100.
Capable of transmitting up to 2Km multi-mode, or 100 Km single-mode.	Maximum distance: 100 m.
Large installed base in substations from legacy serial communications systems.	Copper and fiber co-exist.
Eliminates problem of ground loops.	

The comparative cost of fiber and UTP copper may need to be re-examined. A recent analysis of the installation costs of copper vs fiber (typical for new substations and upgrades) shows surprisingly little difference. In a three-year study by the Fiber Optics LAN Section (FOLS) of the Telecommunications Industry Association (TIA) and Pearson Technologies, copper and fiber installations were modeled for initial cost and found to be about equal. Although the scope of the TIA study does not cover on-going maintenance costs, the argument can be made that fiber is actually less expensive to

maintain than copper. The results were published in BICSI News April 2004, and the cost model in spreadsheet form is available to BICSI members. A mix of copper and fiber cabling is sure to be present in substations, co-existing and complementing each other.

Changing Fiber Port Connector Types

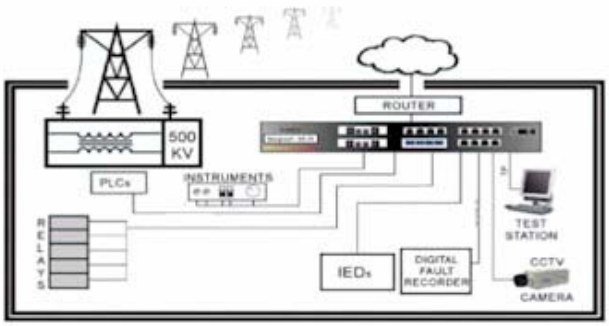
Initially substations use mostly 10 Mb Ethernet fiber and ST connectors (twist lock), which were considered to be highly robust, but also fairly complex to install. As 100Mb Ethernet has expanded its presence, patch panels and media converters have increasingly popularized the use of SC connectors (plug in), which were much faster and less confusing to install.

ST and SC fiber ports are twice as large as RJ-45 copper port connectors. When Ethernet fiber switches are used in the equipment racks in the premium-cost space of a control center, port density is critical. Small Form Factor (SFF) fiber ports are the same size as RJ-45 ports. Although currently considered a specialty item and more expensive than the ST and SC ports, SFF ports are highly prized in space-limited situations. For multi-mode SFF ports, the MTRJ plug-in port connector has taken the lead. For single-mode SFF ports, the LC plug-in port connector, which is widely used in Telco applications, is the most popular choice.

Within substations, Ethernet fiber cable distances are rarely over 2Km, the distance supported by multi-mode fiber cable. Single-mode fiber cable is selected for greater distances, up to as much as 100Km. Since multi-mode cable is lower in cost than single-mode, it is almost always the choice within substations for speeds of 100Mb or less. However, when substation projects go beyond the boundary of a single substation, single-mode fiber is better for connecting multiple substations over dis
gigabit backbone connections are required

The Need for Speed is Changing

Initially, fiber with Ethernet was operate
enough bandwidth to move data in the su
now is to use fiber at 100Mb speed becau
for 100Mb. Even though 10 Mb speed



The combination of new security features and the demands of new standards such as the *IEC61850* time synchronization requirements are driving the demand for increased bandwidth. Ethernet at 100 Mb bandwidth is rapidly becoming the speed of choice for power substations.

equipment and applications, why not have the additional bandwidth if it costs nothing?

However, 100Mb will soon be a necessity, rather than just nice to have. Three major changes in substation operations are driving the need for 100Mb full-duplex Ethernet speed: 1) security, 2) time synchronization per IEC61850, and 3) redundancy.

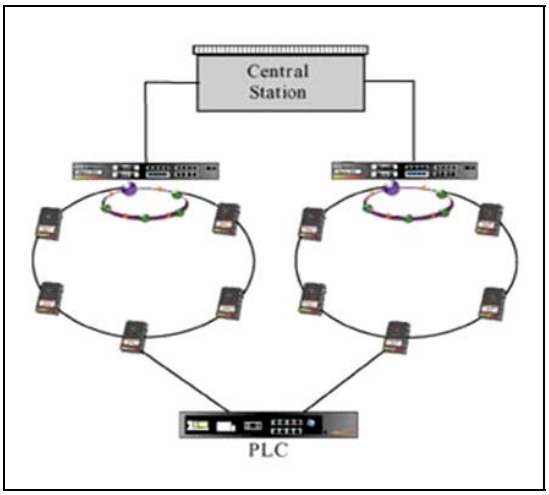
Security Substations are a vital part of essential public services. Pressures to secure facilities continue to grow. An example of an increasingly popular security tool is video surveillance. Video requires roughly 5Mb of bandwidth to support one uncompressed picture-quality full-motion video image data stream. A 100Mb Ethernet environment can easily accommodate several security cameras without compromising other LAN traffic.

Time Synchronization per IEC61850 One of the areas the emerging IEC61850 standard addresses is the data movement associated with sampling and digitization of voltage and current measurements within a substation. Protection IEDs base their decisions on current and voltage samples, measured by other IEDs. The sample data must be moved and synchronized within a few milliseconds to assure proper decisions, and thus assure proper relay and power switching operations. Within a substation, typically 25 to 75 IEDs will be transmitting time-critical sample data. This high data rate can be handled reliably in a single common network by 100Mb full-duplex multi-cast Ethernet over fiber media, possibly with multiple VLAN segments in larger substations.

IEC61850-5 Type-6 Time Synchronization Messages: Maximum Permissible Delay Times

T1	±1ms	Event time tagging on bay level.
T2	±0.1ms	Control and protection: Time tagging of zero crossings and of data for the distributed synchronization check. Time tags to support point on wave switching.
T3	±25µs	Synchronized sampling and advanced functions.

Redundancy The mission-critical communications services for substations need a high level of availability. Within the Ethernet network serving a substation, redundancy is fairly easy to achieve. Networked devices may be sequentially connected by fiber cabling in a ring structure, with any two segments of a ring able to recover from any fault in the ring. With dual-ported IEDs and dual redundant rings, even multiple faults will typically not cause problems from loss of data connectivity. The ring topology - connecting multiple substation devices in series - drives up the bandwidth required in the ring and 100 Mb full-duplex Ethernet can handle the load. Fault management is available in a wide variety of products using both proprietary and new standards-based Ethernet redundancy solutions. Adding redundancy, even if it was not originally designed into the substation automation system, is highly practical when 100 Mb Ethernet bandwidth is available.



Summary

Ethernet with fiber cabling has many benefits for power utility substations. Fiber is highly noise-resistant and easier to work with in high-voltage environments. It also is better adaptable to the industry's requirement for transmission over relatively long distances, and offers the most cost-effective upgrade path to higher bandwidths as they become necessary. Given the changing cost structures of fiber connectivity, as well as increasing demands for bandwidth as utilities adopt more sophisticated and bandwidth-hungry applications, fiber and Ethernet will dominate in the substation communications mix.