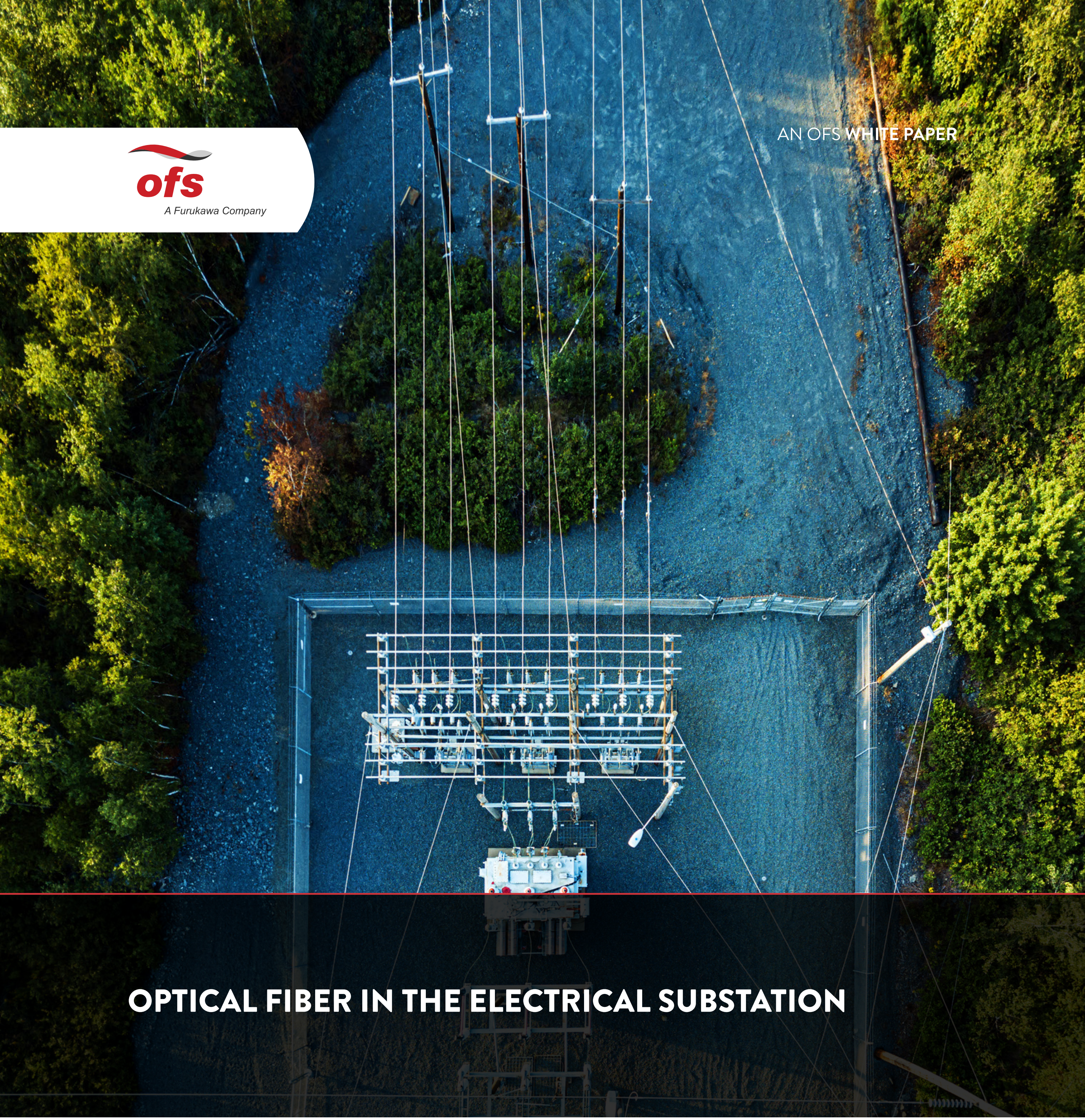

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OPTICAL FIBER IN THE ELECTRICAL SUBSTATION

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Executive Summary

Utilities around the world face increasing pressure to deliver reliable, highly efficient electric power at affordable rates and with minimum environmental impact. At the electrical substation, the demand for "smart grid" technologies using Ethernet-based automation processes is transforming operations, enabling faster and more reliable power conversion, transmission and distribution systems. In response, leading power equipment suppliers are introducing faster equipment, including switches and routers, which in turn require the use of optical fiber, the only transmission medium capable of the extremely high bandwidth – information-carrying capacity – and transmission speed required by the smart grid. An understanding of fiber optic applications and product performance will help operators achieve the high bandwidth, durability and ease of use they need for today's substation automation.

At the Substation

The electrical substation is a familiar sight to many of us, situated behind a chain-link fence along the roadside, but most casual observers don't know what goes on there. The substation receives electrical power from a generating plant like a solar or wind farm. At the transmission substation, the power is processed before it is distributed, as step-up transformers substantially increase the voltage to reduce the loss that would otherwise occur when the electricity is sent over long distances. From there, the electricity is sent to a power substation, where step-down transformers decrease the voltage before it is distributed to the grid.

One important function performed at the substation is switching, which is the connecting and disconnecting of transmission lines or other components to and from the system. Switching events may be planned or unplanned. A transmission line or other component may need to be de-energized for maintenance or new construction or to add or remove a transmission line or a transformer. To maintain reliability of supply, companies aim at keeping the system up and running while performing maintenance. All work to be performed, from routine testing to adding entirely new substations, should be done while keeping the whole system running.

The by-now familiar Ethernet protocol, so widespread in our work and home environments, is fast becoming the fundamental technology for substation networks. Industrial Ethernet protocols allow intelligent electronic devices (IED) to receive data from sensors and power equipment and to issue control commands with greater speed and reliability.

Automated protocols at the substations are designed to protect and control highly sensitive (and very expensive) equipment and processes. These systems include condition-based monitoring (CBM) systems that can predict equipment failures before they occur, smart motor control systems for low-voltage motor control centers, and supervisory control and data acquisition (SCADA) systems for gathering and analyzing real-time data.

Optical fiber bandwidth and reliability are critical performance attributes for successful substation management. Among fiber's chief roles is monitoring and preventing fault conditions such as short circuits; optical fiber transmission capabilities enable the necessary response time of less than 100 milliseconds to detect a fault and trip the circuit to minimize damage. A closer look at these applications can help the operator choose from several options to select the best optical fiber solutions for the substation.

Optical Fiber Applications

Designed for minimal environmental impact, fiber optic cabling solutions provide for reliable connectivity, bandwidth and optimal performance in critical power generation, transmission and distribution automation processes, including:

CIRCUIT BREAKERS: In the substation, circuit breakers monitor voltage and routing of electricity and re-route power in the case of a break. Typical installations may have between two and tens breakers, connected by optical fiber cable running from the substation breaker cabinet back to the control room. When a break in current is detected, a corrective action signal is transmitted over the fiber, which is usually installed in a covered trough anywhere from tens to hundreds of meters in length.

RELAYS: A relay is used to sense electrical conditions and rapidly trip a breaker to protect people, property, and the power system. The combination of the relay and optical fiber provides internal diagnostics so that the relay can remain in service without interruptions for periodic testing. Although the primary function of the relay is protective in nature, the relay includes automatic control to restore service and demand metering reports, sequential event reports, and event reports with fault type and location and oscillographic data snapshots.

The diagram in Figure 1 shows a protection, monitoring and control system typical of the thousands of substations that use relays, communications processors and optical fiber transceivers. These links are the mechanism to retrieve data from the relays and provide direct control and instructions to the relays. Each link between a relay and a communications processor uses two optical fibers.

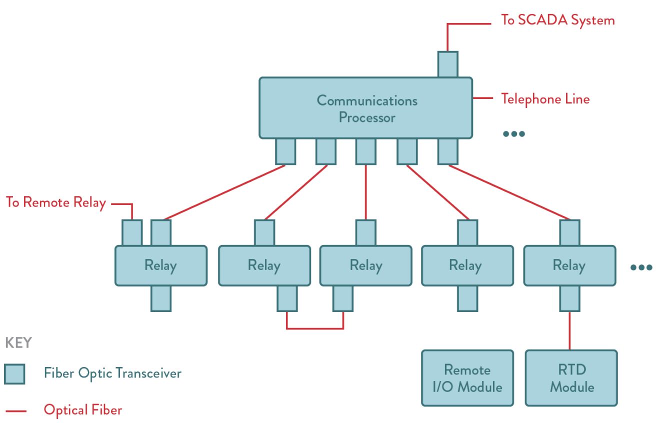

FIGURE 1

PROTECTING MOTORS AND POWER LINES: Electric motor manufacturers embed resistance temperature detectors (RTDs) in their motors to sense the temperature of the electrical windings. An RTD has built-in fiber optic ports to connect to a motor-protection relay using a fiber optic cable. If insulation of the motor winding fails, damaging currents can flow through the RTD wiring. The optical fiber link insulates the relay and the rest of the protection and control system from the RTD wiring. The relay also has valuable monitoring and reporting functions to help prevent process outages because of motor failures. Often, the motor relays are connected to an instrumentation and control system with optical fiber.

Why Optical Fiber in the Substation?

Optical fiber is quickly replacing copper cable in substation automation. Fiber offers several advantages:

- Higher bandwidth that supports higher data rates over longer distances: A typical bandwidth-distance product for multimode fiber is 500 MHz/km, so a 500-meter cable can transmit 1 GHz, while twisted pair optimized for high data rates (Category 6) can transmit 500 MHz over only 100 meters.
- Immunity to EMI/RFI: Optical fiber's intrinsic immunity to electromagnetic Interference (EMI) and radio-frequency interference (RFI) makes it ideal for harsh electrical environments. EMI/RFI is a common property of electromagnetism where electrical current is generated along magnetic fields as it moves across conductors, which modifies the current flow. The interference happens with coaxial cables but not with fiber optic cables as the signal transmission occurs through light rather than electrical current.
- Lighter weight and smaller diameter than traditional copper cables: Fiber weighs less and needs much less space than metallic conductors with equivalent signal-carrying capacity.
- More secure data communications: Because copper cable transmits data using electricity, data may be intercepted more easily by hackers connecting taps to a line to pick up electronic signals. Tapping fiber optic communication technology is incredibly difficult, and because attempts to tap fiber cables will likely result in breaking the glass fibers, potential hacks can be quickly and easily discovered.
- The ability to safely bridge high potential differences for applications where fumes or sparks exist: Events such as a ground fault, very high currents or lightning strikes cause a difference in electrical potential from one location to another. This change in potential can damage equipment and injure people. Optical fiber provides the necessary electrical isolation to drastically reduce the risks to people and equipment.

Selecting the Right Fiber

Substation operators make it their business to understand vital equipment such as switches and routers in order to specify and select the best product for their applications. In the same way, knowledge of the design and performance of optical fiber enable the best selection of fiber, cable and connectivity products for this demanding environment.

The selection process begins by specifying the best fiber cable for the rigors of the substation. The fiber cable must be able to withstand wide ranges in temperature and humidity. Because it is an outdoor application, the cable needs water block and, in some cases, protection against rodents using a dielectric armor as a deterrent.

Next, choose the best combination of fiber specifications for the application. For optimum bandwidth and reliability, OFS recommends a 62.5/200 graded-index multimode fiber with a hard clad silica (HCS) coating. Let's look at each of these specifications individually:

- Multimode fiber is used in most enterprise applications for data communications. As its name implies, it carries multiple modes of light through its larger core (contrast this with single-mode fiber, which carries one mode). Because this larger core makes it much easier to capture light from a transceiver, and because multimode connectors cost less than single-mode connectors, multimode fiber is the most cost-effective choice for applications up to the 500 - 600 meters.
- "Graded-index" indicates that the fiber core has a refractive index that decreases with increasing radial distance from the optical axis of the fiber. It provides significantly lower modal dispersion (spreading of the light signal within the core) than the alternative, which is called step-index fiber.
- 62.5 denotes the diameter, in microns, of the fiber core (the light-carrying section). 62.5 µm multimode optical fiber, also known as OM1, was developed and introduced in the 1980s. 50 µm multimode optical fiber, also known as OM2, is also available, but most systems are designed for 62.5 fiber.
- 200 indicates the outer diameter, in microns, of the glass fiber. The resulting three-to-four-times additional mass compared to conventional fiber allows for easier handling in the field and superior tensile strength.
- Hard clad silica (HCS) is a polymer that is applied to the pristine surface of pure, fused silica during the fiber draw process, providing a protective barrier. It enhances the strength of the glass and remains on the fiber throughout the termination process. This differentiates it from traditional fibers which must be stripped down to the bare glass, subjecting them to humidity and dirt that can substantially weaken the fibers during the termination process.

The resulting product is an optical fiber that is optimized for use at the 650 and 850 nm wavelengths which are common in transceivers deployed in many industrial applications such as substations. Its performance advantages include:

- superior fiber strength
- repeatable and reliable results
- ease of handling
- ease of training (a five-minute process)
- quick and easy field termination (one to three minutes)
- durability in harsh environments
- high yield terminations
- no epoxies or gels that expire.

Fiber Connectivity

Fiber optic connectors are chosen to provide the lowest loss, minimal cost and ease of termination. Traditionally, ST connectors have been the most commonly specified product for all enterprise applications including substations. However, with the migration to Industrial Ethernet, LC connectors have recently been gaining traction in this application space. The LC, which represents the next generation of small form factor (SFF) connectors, reduces the space required on panels, outlets and in closets by approximately 50 percent throughout the network. It also simplifies moves, adds and changes and helps reduce costs for smaller and easier-to-use fiber optic connectivity.

Allowing connectors to be installed directly onto the HCS protective coating enables a connectivity method called "crimp and cleave" termination, attaching to the cable through mechanical means rather than the traditional and more complex epoxy/polish methods. Technicians with minimal fiber experience can rapidly install new or repair damaged fiber optic cables in about five minutes. The crimp and cleave system produces a high-quality endface with a completely mechanical process, minimizing the potential of operator error and yielding more efficient termination than other alternatives.

FIGURE 2: Crimp, Cleave, and Leave

Summary

The growth of Industrial Ethernet in electrical substations has made possible the deployment of advanced automation systems for optimized control, monitoring and protecting the substation's primary equipment and its associated feeders. These systems maximize speed and durability and improve the reliability of equipment and the safety of operators.

More than ever, these systems rely on optical fiber as the transmission medium of choice. Compared to copper, optical fiber cable and connectivity solutions offer greater speed and bandwidth and are lighter in weight and easy to install.

A good understanding of optical fiber design and specifications can help the substation operator design the fastest, most reliable links for their network. A solution featuring a 62.5/200 graded-index multimode fiber with a hard clad silica coating and LC connectors is the recommended choice for maximum performance, reliability and ease of installation.