AEP Process Bus Replaces Copper

Innovations in stations translate to more savings in material, time and manpower

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A huge opportunity for material, time and manpower savings exists in the reduction or elimination of substation copper control cables. This has inspired American Electric Power's (Columbus, Ohio, U.S.) interest in the process bus technology.

AEP decided to evaluate a next-generation distributed protection and control system with all process interfaces located in the switchyard, thus taking control cabling, with its associated material and labor costs, out of the design and replacing it with fiber-optic communication.

1. At the Forefront

For decades, AEP has been at the forefront of power system protection and control technologies. In the 1970s, the utility participated in the introduction of digital relaying. In the 1980s, it took part in early research into optical instrument transformers. In the 1990s, it was an early participant of the Utility Communication Architecture (UCA) group, subsequently the UCA International Users Group, and the IEC61850 standard.

As the concept of a microprocessor-based relay matured and turned into practical products, AEP led the way with widespread adoption of the technology. Major improvements have been achieved in the areas of material cost savings, operational efficiency through remote access, control capabilities, multi-functionality, availability of data, simplification through integration of protection and control functions, and elimination of some auxiliary devices with associated panel wiring.

AEP envisions a possible future generation of protection and control systems with interface devices dispersed throughout the switchyard. The dispersed devices would provide the required input/output structure for the existing apparatus: a simple, robust standard communication architecture and interoperable intelligent electronic devices performing traditional functions, working exclusively with communication-based inputs and outputs.

AEP encouraged the vendor community to pursue this vision. In 2008, GE Digital Energy (Markham, Ontario, Canada) developed the HardFiber system, a complete and commercialized solution designed to eliminate copper control cables from the switchyard. In the second half of 2008, AEP completed the installation phase of an evaluation retrofit project with the HardFiber product.

Figure 1.
A demonstration installation at the AEP Corridor substation used the HardFiber process bus system, shown dispersed around the station, for communications interface.

2. Technology as a Brick

The HardFiber process bus system is a remote I/O architecture for protection, control, monitoring and metering that allows designing out copper wiring for protection and control signaling within substations, replacing it with standardized optical fiber-based communications. The system includes relays and fiber cross-connect panels, factory pre-terminated fiber cables and switchyard I/O interface devices known as bricks.

The bricks implement the distributed concept of an IEC61850 merging unit, expanded to optically connect relays with all types of I/O signals in the switchyard, not just instrument transformers. The bricks are interconnected to the relays in a simple point-to-point arrangement that does not involve other active components such as Ethernet switches.

Figure 2.
HardFiber protection panel with three relays and two patch panels (top and bottom). All I/O signals interfaced via fiber optic communications.

The relays are GE Universal Relay series devices. The relay's current transformer/voltage transformer and contact I/O plug-in modules are replaced with an IEC61850 process card to allow optical rather than copper signal interface. The balance of the relay hardware, firmware, functionality, configuration software, documentation and user-setting templates are unchanged.

3. Evolution of the Digital Substation

Early on in this Digital Age, American Electric Power recognized the applicability of digital technology for the protection, control and monitoring of the power system. As early as 1971, AEP began taking steps to foster this technology by funding research into digital architectures and algorithms. AEP teamed with IBM to develop and install a prototype of the world's first communicating digital relay. The device sampled voltages and currents, performed basic protection functions and communicated the resulting data and events to a mainframe at AEP headquarters.

In those early days, AEP envisioned architectures where a single digital data source could be shared by multiple protection units. As technology improved, AEP continued to track and evaluate what was available. In the mid-1980s, AEP evaluated a Delle Alsthom digital current transformer, whereby measurements made in the head of the current transformer were digitized and transmitted to ground through fiber-optic cables. The digitization was attractive, but at the time, there were no digital devices that could accept such a data stream. In addition, the concept of having active electronics at line potential was thought to be too revolutionary. In the late 1980s, companies such as ABB, Square D and 3M developed optical voltage and current measurement devices. The measurement technology was desirable, but the lack of integrated and complete solutions impaired AEP's use of the technology.

In the mid-1990s, work began on the development of a standard low-energy analog interface between measurement sources and protection, control and metering devices. During this time, AEP installed and evaluated an ABB 345-kV optical current transformer for metering. In a subsequent demonstration in 2003, AEP installed a NxtPhase 345-kV combined optical current transformer/voltage transformer and successfully integrated conventional and low-energy analog-output signals into GE and Schweitzer Engineering Laboratories protective relays and a Power Measurement revenue meter. The data from this demonstration also was used in a research project of Power Systems Engineering Research Center to evaluate the performance of a digital protection system.

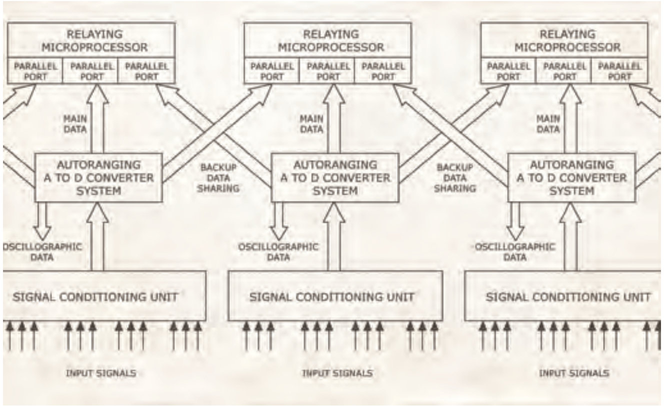

Figure 3.
AEP digital substation architecture concept, circa 1980.

Standardized communications were seen as the necessary link between the optical/electronic measurement devices and the end users of this data. AEP had played a lead role in the development of standard intelligent electronic device communications and interfaces — specifically with its support of the Utility Communications Architecture (UCA) protocol. The work with UCA provided relay-to-relay and relay-to-master communication, but did not address interfaces between measurement devices and relays.

Parallel to the development of UCA, IEC Technical Committee 57 began work on what has become known as a process bus and is now codified in the IEC61850-9-2 document. While some experimentation and implementation of process bus has taken place in conjunction with optical instrument transformers, it has not been widespread, mainly due to the lack of a consensus on the implementation approach and a solid fit-for-purpose architecture that would provide real-world benefits at low risk.

4. Demonstration Installation

The HardFiber demonstration installation is in AEP's Corridor Substation, a 345/138-kV transformer and switching station near Columbus that has been used for other new-technology trials. The HardFiber installation provides distance protection for the Conesville and Hyatt 345-kV line terminals and breaker-failure protection for breaker 302N, which connects these two lines in a breaker-and-a-half-like arrangement.

This portion of the station was considered typical and of sufficient size and diversity to demonstrate the HardFiber system technology. In addition, the lines already had existing Universal Relays installed. So the existence of these devices enabled event and oscillography records to be easily compared to those from the HardFiber system. The trip/close control outputs of the HardFiber system are not connected at this stage of the evaluation.

A site survey was conducted early in the project with the manufacturer. The survey confirmed the viability of the scope described previously, the quantity and location of the equipment, and the lengths of the required pre-terminated fiber optic cables.

Twelve bricks were necessary to provide fully redundant coverage: two bricks on each of the three circuit breakers, two on each of the two-line current-voltage transformers and two on the one free-standing current transformer in the zone. In each case, no space was found for mounting bricks inside the mechanism/marshalling boxes, so brick-mounting locations were selected either on the outside surface of the power equipment or on a supporting steel structure.

The fiber-cable routing for the 12 cables consists of a 200-ft (61-m) section in 6-inch (15-cm) duct, a section of up to 400 ft (122 m) in a pre-cast cable trench shared with conventional copper control cables, a direct-bury section of up to 150 ft (46 m) and an exposed section from grade to brick level. The factory-terminated cables required accurate cable-length measurements; a cable that was too short would have to be replaced and excess length would present slack management problems. Several length-measuring methods were tried, including use of site plans, timedomain reflectometry on existing spare conductors, a pulling tape with numbered foot markings and a measurement wheel. In the end, a surveyor's tape produced the best results. The cables were ordered with a 2% margin over the measured length.

Consistent with AEP's standard design practices, FT-style test switches were installed in the brick current-transformer circuits shared with in-service protection and the brick voltage-transformer circuits were fused.

5. On-Site Installation

Installation of the HardFiber equipment proceeded smoothly and did not reveal any obstacle to future deployments. Since the outdoor fiber cables were installed before the bricks were available, slack was left in the section between grade and the ultimate brick location. If sufficient slack was available, then a loop could be created in free space under the brick. This loop, not likely to be repeated in future installations, will increase the damage exposure in the evaluation installation, making the demonstration a more sensitive indicator of cable ruggedness. The bulk of the fiber cable slack was in the control house, where it was accommodated in an under-floor trench.

Figure 4.
HardFiber bricks installed on a bus support structure (left) and a breaker marshaling box (right).

A transcription error made in transferring the measured cable lengths to the ordering system resulted in several of the outdoor fiber being made shorter than intended, but they could still be used by relocating the relay panel within the control house. A manufacturer's engineer visited the site to correct a minor patch panel problem, but otherwise installation and commissioning was completed entirely by AEP field staff.

6. In-Service Experience

The HardFiber relays are connected to the Corridor Station local area network and thus to a station data-retrieval system, making the event records and oscillography of both the HardFiber and conventional relays available for remote access and analysis.

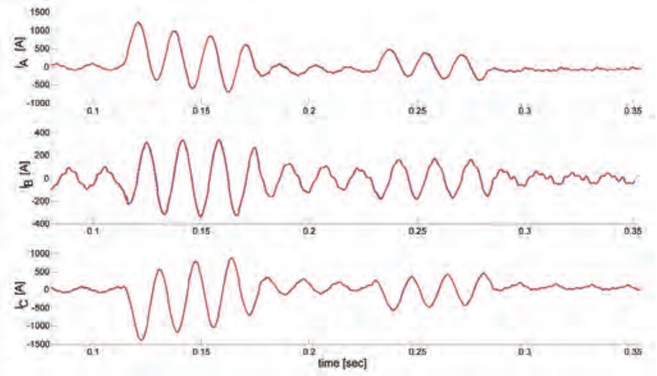

Figure 5.
On Sept. 30, 2008 event – Hyatt line currents: hardwired relay (blue) and measured by HardFiber bricks (red). The resulting pink color is due to exact overlay of traces.

The conventional and HardFiber relays are set up to cross-trigger oscillography through generic object-oriented substation event messaging over the local area network and force an oscillography record weekly in the absence of grid-generated events. Since the HardFiber systems for the Hyatt and Conesville lines were commissioned in June and December 2008, respectively, the corresponding records have been reviewed. Tens of external faults and switching events have been captured by both the traditional and HardFiber protection systems. All the records and responses of the relays are in full agreement.

The system operation meets expectations to date; not a single error or failure has been recorded. It is also worth noting that, through analysis of the HardFiber system oscillography files, a failed coupling capacitor voltage-transformer fuse was found.

7. Observations and Lessons Learned

Installation of AEP's first HardFiber system was successful and uneventful. The following factors contributed to this success:

- The HardFiber system is straightforward and practical. All obvious challenges are addressed "under the hood" and the user is not burdened with solving new problems. For example, once connected, the bricks and corresponding universal relays self-configure to establish communications.
- The system was engineered, installed and commissioned using AEP's existing workforce, procedures and tools.
- Early and continual involvement of the field personnel made the demonstration more efficient and successful.
- The manufacturer's initial site survey, field measurements and subsystem prefabrication shifted much responsibility for project success to the vendor.
- Reliance on a familiar product for the relay part of the HardFiber system made the integration easy.
- The plug-and-play nature of the system, with all components prefabricated, is an important component of next-generation protection systems.
- The factory-acceptance test, performed with the complete Corridor HardFiber system, reduced the time and effort to confidently commission the system on site.

The installation phase of the HardFiber system accomplished the early objectives of this demonstration. In particular, the system proved easy to engineer, install and commission, and is compatible with the existing workforce. Distributed I/O, process bus and replacing copper with fiber cables are seen as a stepwise evolution of traditional solutions.

Based on the evaluation project to date, the system seems to offer opportunities in shortening the construction times and labor required, standard designs for bricks, cables and panel building blocks, easier on-site integration of physical components and reduced complexity in the control building. A more formal comparison of performance and cost is planned in 2009.

The system still needs to prove, through wider field experience, the longevity of its outdoor components and overall performance. Given its simplicity and the rugged design of the bricks, it seems the required maturity is already there and any minor issues can be addressed. As a result, this fourth generation of digital protective relays, with input and output interfaces placed directly at the power apparatus, appears to provide a viable and practical option for utility engineers and designers.

Figure 6.
Before (left) and after (right) — the amount of cabling at relay panels is greatly reduced.

Continual development and commercialization of new technologies are required to address the problems of a shrinking workforce, rising costs, the volume of green field and retrofit projects, and the integration of new generation to the grid. If these technologies incorporate the latest standards, the utility industry can expect to build on the value of systems like HardFiber to arrive more quickly at functionally equivalent and interoperable multi-vendor solutions.

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