Implementation of Microprocessor Relays for Transmission Modernization

by

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Background

With deregulation on the horizon, all utilities need to examine the key indicators that drive their business. One factor that determines if they are the provider of choice is the reliability with which they meet their customers' electrical needs. The Tennessee Valley Authority (TVA) recognized that to survive and thrive in a deregulated utility industry, reliability issues of their transmission system needed to be addressed. To examine these reliability needs, TVA conducted benchmarking surveys of utilities of $1 billion in assets and above. The goal of the company is to be a top performer in the highest quartile. The benchmarking survey revealed areas in which TVA could improve its performance and reliability.

As a result, TVA initiated a transmission modernization program to replace protective and control relays on poor performing, obsolete, and high-maintenance equipment. The data for justification were obtained from interruption data and relay trouble reports collected over 15 years. The modernization program consists of four major projects: 1) Static relay technology replacement, 2) Hz relay terminal replacements, 3) 13 kV capacitor bank controls and protection, and 4) Identification and replacement of obsolete relaying technology.

TVA owns and maintains 2700 km of transmission lines. The service area includes 7 states, 80,000 square miles, and 159 municipals and cooperative distributors, and 50 direct-serve customers. There are 12 fossil plants, 49 hydro plants, 4 combustion plants, and 3 nuclear plants for a total of 26,000 MW of generation.

In developing a new power protection and communication design standard, there were several objectives to be achieved.

- Incorporate transducer and metering equipment in the protective devices
- Eliminate auxiliary relays
- Combine backup and control functions
- Procure relays to meet high- and low-voltage applications
- Reduce requirement for spare parts
- Allow for continual and remote interrogation of protective devices
- Allow time synchronization of transmission system
- Install standard test switch to allow for dynamic testing techniques and minimal rewiring for future relay automation and replacements
- Use microprocessor relaying to allow for minimum routine maintenance
- Reduce the panel wiring, design, and hardware costs by using standard designs

Incorporate Transducer and Metering Equipment in the Protective Devices

One of the first things that a company does in trying to reduce costs is to eliminate maintenance. By moving the metering aspects of each line terminal into the protective device, TVA was able to eliminate high-maintenance transducer and metering instrumentation. This met three objectives. First, there is very little drift in the calibration of the microprocessor protective relaying. Second, the amount of wiring in SCADA interface was reduced. Third and most importantly, the new microprocessor relays allow redundancy in the metering information to the dispatchers for that line terminal. At the same time, they allow identification of a potential relay problem on any particular relay on that terminal by monitoring voltage and currents. The information is collected through the relay using DNP to the RTU and, in the future, UCA (Utility Communication Architecture) will be used.

Eliminate Auxiliary Relays

Because 15 percent of TVA's relaying failures occur with auxiliary relays, the elimination of those auxiliary relays has become a top priority. By incorporating the auxiliary relays inside the microprocessor relays, TVA is now able to monitor actions that were previously not recognized until failure occurred. Added benefits are the elimination of panel wiring and the cost of the relays, as well as a reduction in the panel space required. The end result is complete system monitoring rather than individual device monitoring.

Combine Backup and Control Functions

TVA's philosophy in the past was to have protective and control functions performed by separate devices. By combining these functions, TVA was able to eliminate the installation and maintenance of separate devices while being able to monitor the sequence of events of all manual switches, SCADA, and protective operations. The combination of reclosing, SCADA control, backup protection, load shedding, and breaker failure functions allowed TVA to eliminate the need to have more than one relay panel per terminal, thus doubling the board space availability in smaller substations. In voltage applications of 115 kV or less, it allowed TVA to maintain a protective relay in service while maintenance tests were performed on the primary relay. Load shedding was also incorporated into each relay terminal. This allowed selective load shedding of each individual line instead of having multiple load shed devices set at different frequencies.

To better illustrate this logic, each individual part is described in detail.

<u>Reclosing</u>

TVA's reclosing was based on standards set over 75 years ago. It was imperative that the operation and characteristics of the relaying reclosing schemes remained constant. TVA's reclosing package runs independent of the primary protection but uses canceling or knock-down signaling for restrictions of reclosing actions. The requirement to use a multifunction relay was the replication of all reclosing selections currently in use. The reclosing schemes are complex and include: 1) Eight different reclosing selection options from a selector switch on the panel, 2) Ability to interrupt the sequence from external triggers, and 3) Ability to change modes of operation from dispatching commands. TVA's reclosing functions vary between relaying schemes depending on transmission stability requirements. The different options need to be changed depending on system conditions, be contained in one logic group setting, and must include TVA's standard options:

1. Off - Recloser Cancel
2. First - First shot reclose only (high, fast, standard, etc.)
3. First/Synch - First shot (high, fast, standard, etc.), second shot synch check only
4. First/Synch/Dead Line - First shot (high, fast, standard, etc.), second shot synch check or dead line only
5. First/Synch/Dead Bus - First shot (high, fast, standard, etc.), second shot synch check or dead bus only
6. Synch/Dead Bus - Synch check or dead bus
7. Synch/Dead Line - Synch check or dead line
8. Synch - Synch check only

One key to using standard logic was assigning the inputs and outputs to standard functions. For example, if the scheme called for a third reclose cancel, the standard input would be wired without any changes to the logic. If the scheme didn't need the third reclose cancel option, then the input would be left blank. The same technique was applied to carrier blocking and other controlling input requirements. If the line requires a pilot on/off switch, the carrier input would be wired. If not, the input would not be wired. The logic was designed to allow a function to be wired or not without affecting the logic's operation.

SCADA Control

The logic for breaker control and recloser control was also designed so that tripping and close functions of the breaker were performed by the relay. By using the same protective contacts that tripped and closed the breaker, functional tests could be relaxed on the device. The control signals were issued through DNP 3.0 or hardwired inputs. The hardwired version of the control logic was designed for retrofit applications if it was not economical to replace the primary protection. The DNP version eliminated the need for interposing relays, reduced wiring requirements, and eliminated RTU modules.

Backup Protection

The relay's protective elements were utilized to serve as backup to the primary protection of the terminal. It has been TVA's policy to have different protection requirements for various voltage levels. For example, 500 kV systems required two separate pilot schemes and backup protection for each transmission line. It also required two different manufacturers of the "A" and "B" set protection. By using the multifunction relay, TVA was able to eliminate the cost of the backup relays. Greater benefits were achieved on subtransmission line terminal applications. The subtransmission relay terminals only required one level of protection and were backed up by station protection. By using a multifunction relay on the lower voltage terminals, TVA had a primary protection device and a backup relay on each terminal.

Breaker Failure Protection

Many of TVA's older designs used bus breakup schemes. By installing a multifunction relay to replace obsolete line terminal equipment, TVA was able to implement breaker failure schemes while still maintaining a bus breakup scheme on terminals that were not being replaced. This allowed TVA to modernize station protection as older line terminals were retrofitted. The breaker failure logic was designed into the standard logic and is available for use when ready to implement.

Load Shedding

TVA, like all utilities, is under NERC requirements to maintain load shedding capabilities. Before the use of multifunction relays, at least one underfrequency relay was placed at stations and operated lockout devices to drop load. By using the underfrequency logic in the multifunction relay, TVA is able to eliminate load shedding relays and obtain smoother frequency responses to system-wide problems. Each line is set to a frequency dropout based on criticality.

Procure Relays to Meet High- and Low-Voltage Applications

TVA wanted to use relays that were compatible with their specifications on 500 kV lines and utilize them on their lowest voltage applications. This allowed TVA to concentrate its training on three primary devices, eliminating the need for a slower learning curve. By allowing redundancy in technology, the field, design, and planning departments became more rapidly familiar with the functions and capabilities of the devices.

Reduce Requirement for Spare Parts

Three years ago, TVA put forth an effort to reduce the number of spare parts in inventory. One method of accomplishing this was to eliminate the need for those parts. TVA was able to reduce the number of parts required to maintain 500 through low-voltage applications down to three basic devices. These devices were procured so that they were the state-of-the-art models. By using the same device for all voltage applications, two relays in stock could provide spare parts for all relay terminal line applications. In the past, multiple relays and parts were required to maintain adequate spare inventory.

Allow for Continual and Remote Interrogation of Protective Devices

As previously mentioned, metering and other instrumentation were continually monitored through the relay. Also hidden were sequence of events and fault data information that is automatically provided to the TVA dispatching and control center through their SCADA system. This information allows a rapid identification of location and fault type to TVA line crews for inspection and correction. Also, the data are cross-correlated to lighting detection data. The second aspect of these features is the remote interrogation by TVA system engineers. Full dial-up capabilities allow them to troubleshoot erroneous operations eliminating the need for travel time to and from remote locations.

Allow Time Synchronization of Transmission System

System-wide events that occurred on a regional transmission grid revealed a need for time synchronization between monitoring devices. It became apparent that one of the problems to overcome in analyzing such events is the time disparity of the sequence of events between different ends of the transmission grid. To provide for correct time and date stamping on a system this large would require installation of equipment that was GPS-ready and the installation of the GPS receivers at each location. Typically, this is only done at the larger stations and not carried down to the smaller stations. TVA realized that the cost of implementing GPS in their system would require $2.5 million. They were able to use the protective device and their RTU to time synch the TVA system through DNP 3.0. There are some inherent time delays, but an overall time synch was achieved within 4 milliseconds from end-to-end of the system. This allowed the larger and smaller substations, where SCADA was installed, to be time synchronized to give a more accurate sequence of events.

Install Standard Test Switch to Allow for Dynamic Testing Techniques and Minimal Rewiring for Future Relay Automation and Replacements

One of the goals TVA wanted to achieve with their new relay terminal design was to allow for ease of replacement and a common test point between the different suppliers of electrical devices. This allowed a common familiar access point for test technicians to apply dynamic test techniques. TVA has incorporated a dynamic test method as their routine test for relay terminals. By using the test switch, TVA was able to isolate the many functions that were being incorporated into the new relays and were able to test part of the relay system while the line and breaker were in service without affecting operation. This reduced the need to remove or switch breaks or lines in and out of service, thus reducing the amount of time it takes to perform maintenance on any relay terminal. By using the new test technique through the test switch, TVA was able to reduce relay routine maintenance by 75 percent. The test switch is of a generic design allowing different vendors' products to interface. The switch permits easy installation of newer technologies without wholesale board rewiring and replacement. By not having to rewire the board, only limited print modifications are needed to modify or change out existing relays with other vendors' technology.

Use Microprocessor Relaying to Allow for Minimum Routine Maintenance

One of the factors that determines maintenance routine interval testing on any given technology is its performance/failure rate and self-monitoring features. Taking advantage of the self-monitoring features of the microprocessor relays and using the online monitoring features, TVA was able to increase test intervals for any given relays, which reduced maintenance costs long term and improved reliability. Also, the microprocessor relay is well suited to being tested by dynamic techniques. Over the last three years, TVA has developed a program called DERT (dynamic end-to-end relay testing). The test plans are created by a computer-generated model, which further reduces routine maintenance costs. Microprocessor relays need to be checked as a system, and the DERT program allows that system check.

Reduce the Panel Wiring, Hardware, and Design Cost by Using Standard Design

By installing multifunction devices, TVA was able to reduce its hardware costs on each 500 kV terminal installation by $7,000. The maintenance man-hours were reduced by 75 percent. The Design Department was able to develop three basic designs to satisfy all line relaying installations from 500 kV to 13 kV. This allowed for redundant programming, print, and communication designs. Costs saved on engineering for each job was 20 percent. TVA is able to prewire panels reducing terminal down time and installation time by 60 percent. By being able to wire check and prewire panels, the designs are assembly-line processed versus custom install. The overall savings recognized by standard designs and using microprocessor relays was 40 percent per terminal. Because multiple terminals will be replaced, the total savings were over $1 million in hardware alone. The design cost savings were over $500,000 as well. These savings do not include wiring and installation time.

By implementing standard microprocessor designs and incorporating multiple functions within each device, large replacement programs and new installations allow a win-win situation for power and communication designs, allowing for ease of automation and field maintainability. Future projects concerning transformer protection are underway to allow similar benefits. They will include complete online monitoring of transformer temperatures, fan controls, sudden pressure protection, backup overcurrent, SCADA control, noise and vibration monitoring, and differential protection, while achieving similar benefits in dynamic testing and standardization.