A New Use for Fault Indicators

SEL Revolutionizes Distribution System Protection

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Introduction

Fault indicators have been used for several decades to help locate faults, but the idea of using them to improve protection is new. To enhance protection, wireless sensors must operate faster than ever before and communicate directly with recloser controls and feeder relays. To accomplish this, SEL sped up fault sensing and communication with SEL-FT50 Fault Transmitters and tightly integrated the SEL-FR12 Fault Receiver with protective relays.

Distribution system protection can be improved by using the SEL-FT50/SEL-FR12 Fault Transmitter and Receiver System in medium-voltage applications such as:

- Hybrid fuse-saving and fuse-blowing protection schemes.
- Precise protection selectivity of underground-to-overheard transitions.
- Simplifying or eliminating coordination with downstream protection devices.

Enhanced protection positively impacts reliability metrics, equipment life, system stability, and safety.

SEL-FT50/SEL-FR12 Fault Transmitter and Receiver System

The SEL-FT50/SEL-FR12 System consists of high-speed fault transmitters (SEL-FT50) and a wireless fault receiver (SEL-FR12), as shown in Figure 1. It is designed to be paired with a recloser control or feeder relay.

Figure 1 SEL-FT50 Fault Transmitter and SEL-FR12 Fault Receiver

The SEL-FT50 contains a current transformer and clamps onto an overhead feeder, detects overcurrent conditions, and powers itself without batteries by harvesting energy from the line. When adjustable trip thresholds are exceeded, a radio transmitter in the SEL-FT50 sends high-speed wireless signals to an SEL-FR12 Receiver. The SEL-FT50 Transmitter also sends the radio link status to the SEL-FR12 Receiver every 15 seconds.

The SEL-FR12 is capable of simultaneously receiving fault information from as many as 12 SEL-FT50 Transmitters. The SEL-FR12 communicates to a protective relay using high-speed MIRRORED BITS® communications protocol. The wireless signaling between SEL-FT50 Transmitters and the SEL-FR12 takes place on the 900 MHz unlicensed band and has a wireless link range of up to 4 miles. The SEL-FT50/SEL-FR12 System comes with a configurable network ID that enables the operation of multiple SEL-FT50/SEL-FR12 Systems in close proximity.

The protective relay or recloser control supervises the fault information from the SEL-FT50/ SEL-FR12 System, and it accelerates the trip decision if it also detects a fault based on the programming of its protective elements, making the protection system fast and secure. The protective relay or recloser control is designed to work reliably even if radio communications to the SEL-FT50 are temporarily lost to ensure dependability.

Add an SEL-FT50/SEL-FR12 System to Mix Protection Schemes and Optimize SAIDI and MAIFI

For a given distribution feeder segment, a recloser control can be optimized for reducing outages (System Average Interruption Duration Index [SAIDI]) or reducing momentary faults (Momentary Average Interruption Frequency Index [MAIFI]). Adding an SEL-FT50/SEL-FR12 System to a recloser control allows protection schemes to be mixed to create a hybrid scheme that balances SAIDI and MAIFI.

Mixed Protection Scheme 1: Fuse Blowing Primary, Fuse Saving Secondary

Fuse-blowing schemes are commonly used in urban areas where feeders have numerous taps. In this type of scheme, a fault on a tap causes a fuse at the beginning of the tap to open (i.e., blow). The outage is confined to the tap, and the recloser control avoids reclosing attempts on the main line, which delivers good MAIFI metrics. The downside of this approach is that temporary faults can cause a fuse to blow and create a permanent outage for the tap, resulting in poor SAIDI metrics. To optimize SAIDI and MAIFI metrics, a hybrid fuse-blowing/fuse-saving scheme can be employed using the SEL-FT50/ SEL-FR12 System.

In Figure 2, all of the taps are fused. If a fault occurs on a tap, the recloser control will allow the fuse to blow. In Figure 2, the top-right tap is an exception. This tap may, for example, be in a wooded area with numerous temporary faults that do not require the fuse to blow. Alternately, it could be a tap with an important load (such as medical life-support equipment) or a tap where fuse replacement is difficult because of its remote location.

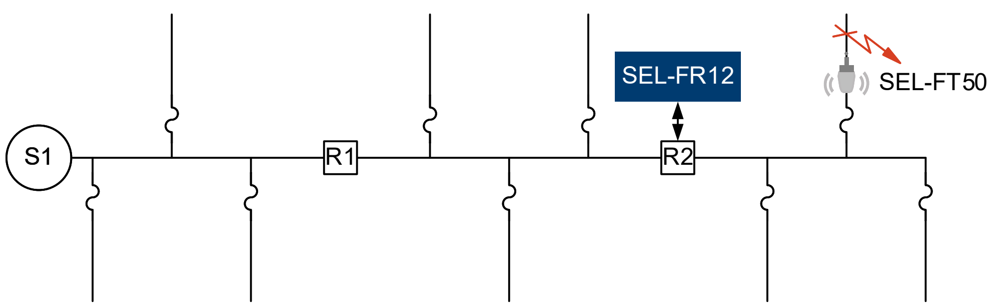

Figure 2 Fuse Blowing as the Primary Protection Scheme With a Fuse-Saving Scheme Employed on the Top-Right Tap

For the top-right tap, an alternate protection scheme is desirable. By using the SEL-FT50/SEL-FR12 System and some SELOGIC® programming, the recloser control will employ a fuse-saving approach when it senses a fault on this tap, allowing reclosing to clear the fault before the fuse melts.

Mixed Protection Scheme 2: Fuse Saving Primary, Fuse Blowing Secondary

When fuse saving is the primary protection scheme, maximum effort is spent to clear all temporary faults on the feeder. This approach is commonly used in rural areas, large coverage territories, rugged terrain, areas with severe weather, and when personnel availability is constrained. The goal is to only take outages for permanent faults. Fuse saving improves SAIDI metrics and operations and maintenance costs. The downside of this scheme is that repeated reclosing results in poor MAIFI metrics.

In Figure 3, the SEL-FT50/SEL-FR12 System allows the substation feeder relay to treat the top-left tap differently. This tap is easy for crews to access, so it makes more sense to use a fuse-blowing scheme to avoid blinking the entire feeder for a temporary fault.

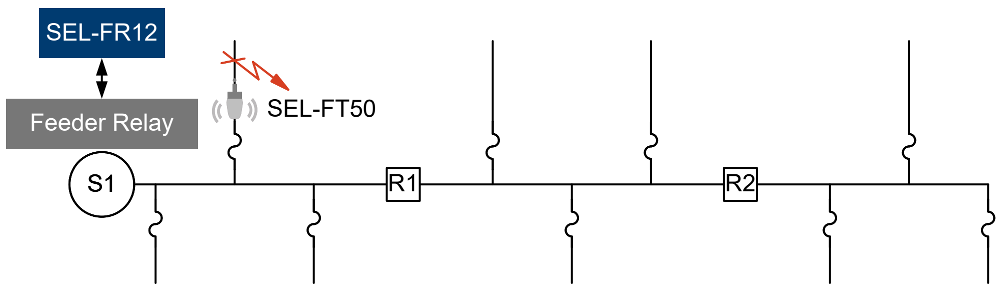

Figure 3 Fuse Saving as the Primary Protection Scheme With a Fuse-Blowing Scheme Employed on the Top-Left Tap

As shown in both examples, the addition of the SEL-FT50/SEL-FR12 System allows a hybrid protection scheme to balance MAIFI and SAIDI based on the characteristics of specific taps.

Improve Protection at Underground-to-Overhead Feeder Transitions

Feeders with underground-to-overhead transitions present utilities with a protection challenge. Underground faults are typically permanent and overhead faults are usually temporary. Mixing underground protection schemes with the SEL-FT50/SEL-FR12 System can fine-tune protection at feeder underground-to-overhead transitions. In Figure 4, to reduce congestion in the substation yard, a feeder leaves a substation underground and transitions to an overhead riser pole after some distance.

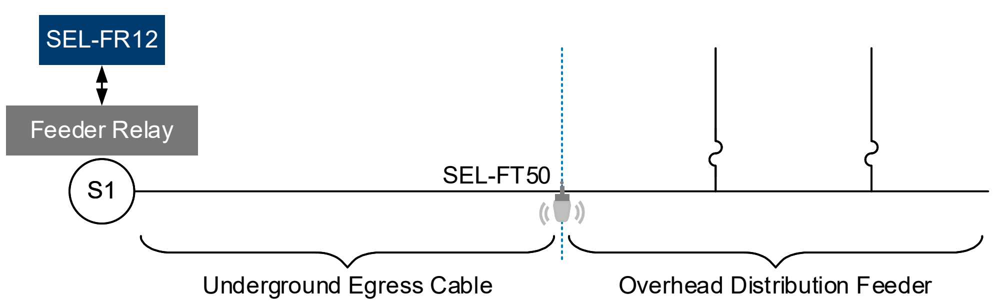

Figure 4 Underground-to-Overhead Feeder Transition Outside Substation

Utilities are often unwilling to reclose on faults near an underground-to-overhead transition because they do not want to reclose on underground faults. Underground faults are typically permanent, and reclosing on permanent faults stresses cables and connectors. Therefore, it is important to precisely know the fault location to choose the best protection scheme.

SEL-FT50 Transmitters can be placed at the beginning of the overhead span. If an SEL-FT50 detects a fault, it sends a message to the SEL-FR12 Receiver connected to the feeder relay. The relay can change its protection scheme from blocking to allow reclosing to clear the temporary overhead fault. This fine-tuned selectivity approach reduces outages and improves SAIDI metrics.

The SEL-FT50/SEL-FR12 System also provides benefits when transitions are overhead-to-underground, as shown in Figure 5.

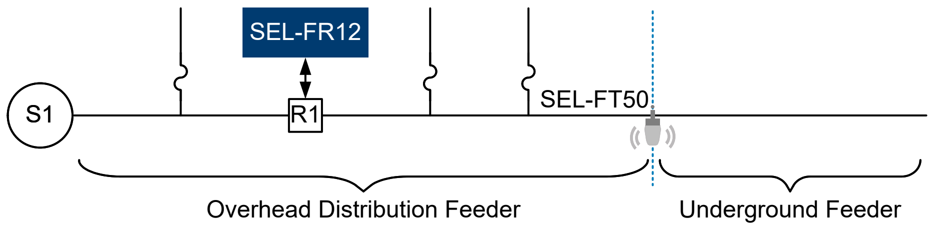

Figure 5 Overhead-to-Underground Transitions in a Distribution System

Distribution feeders can transition to underground to serve loads in areas where developers have installed underground utilities. Utilities with such feeders that choose to reclose on all faults risk reclosing on underground faults. Using sensors at the transition point allows the recloser control to optimize its operation by reclosing for overhead segments to clear most overhead faults and blocking reclosing for underground faults, making the power system more selective.

Bypass Coordination Delays

To clear faults from lines and apparatus along a distribution circuit, distribution protection engineers set up a preset sequence of operations in overcurrent protection devices by specifying certain time-current characteristics and settings. This is known as coordination. When two protective devices installed in series have characteristics that provide a specific operating sequence during fault conditions, they are said to be coordinated. The device that is upstream from the fault is set to operate first. In cases when this device fails to operate, the next upstream device in line operates, providing backup protection to clear faults.

Radial Feeders

Recloser Control R1 and fuses on the taps protect the radial feeder shown in Figure 6. R1 has limited visibility as to where a downstream fault is. In a fuse-blowing scheme, R1 waits for coordination with the Line L1 and L2 fuse curves. If the fault is on Main Line M1 or L3, the 100–200 ms wait for the L1 and L2 curves is unnecessary because M1 and L3 are not fused.

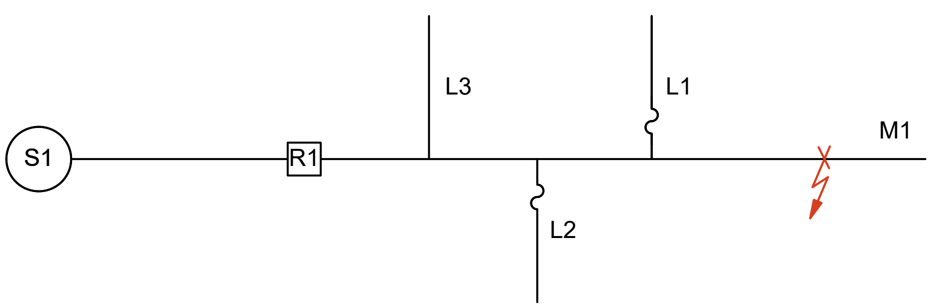

Figure 6 Feeder With Fuses on Some Taps and a Fault

In Figure 7, L3 and M1 after L1 have SEL-FT50 Transmitters communicating with an SEL-FR12 Receiver connected to R1. The SEL-FT50 Transmitter instantly detects the fault on M1 and sends this information to the SEL-FR12 Receiver. Because R1 knows that M1 is not protected by a fuse, R1 can operate without the fuse coordination delay in less than 50 ms.

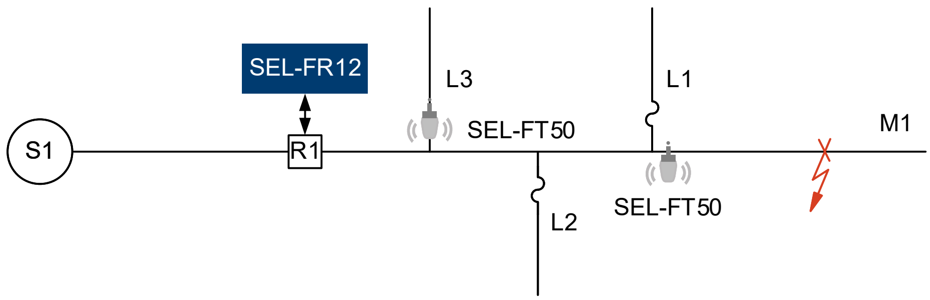

Figure 7 Feeder With SEL-FT50/SEL-FR12 System

Distribution Loops

The SEL-FT50/SEL-FR12 System can also improve coordination in distribution loops. In a typical loop configuration, two distribution circuits are separated by a normally-open (N.O.) point, as shown in Figure 8.

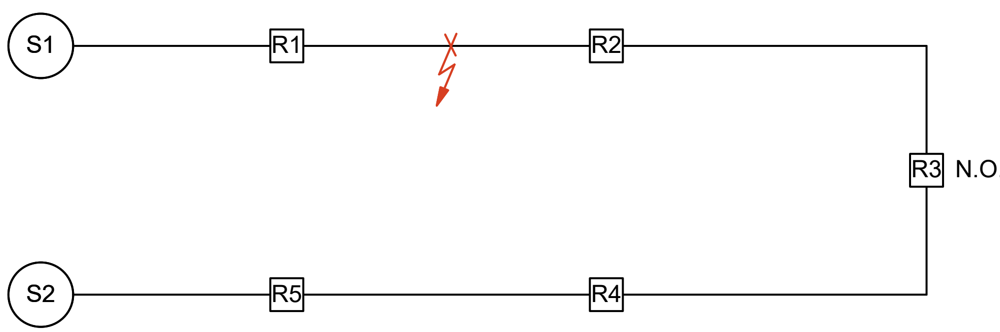

Figure 8 Distribution Loop With a Permanent Fault

Because the permanent fault is between R1 and R2, the goal is to quickly isolate the fault between these reclosers and restore power to segment R2-R3. This can be done without communication; however, isolating the permanent fault and restoring power to the nonfaulted segment takes about 1 minute. With communication to the recloser controls, the process is accelerated to 100–200 ms.

Figure 9 shows the setup for a looped fault detection and isolation scheme with two SEL-FR12/SEL-FT50 Systems. Each recloser control is connected to an SEL-FR12. The three SEL-FR12 Receivers in the top network (blue) are set up with the same network ID as the nine SEL-FT50 Transmitters attached to the feeder conductors near S1, R1, and R2. The three SEL-FR12 Receivers in the bottom network (gold) are set up with the same network ID as the nine SEL-FT50 Transmitters attached to the feeder conductors near S2, R5, and R4. At R3, the normally-open point, each SEL-FR12 Receiver receives communication from nine SEL-FT50 Transmitters.

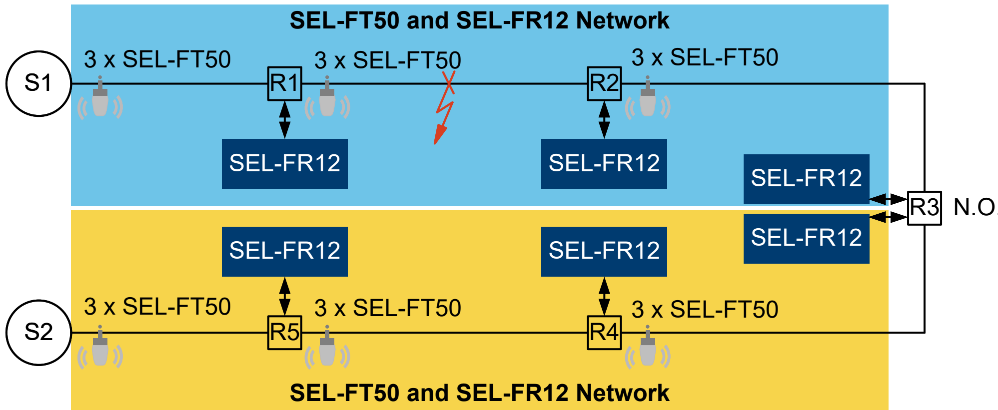

Figure 9 Distribution Loop With Two SEL-FT50/SEL-FR12 Systems

The fault between R1 and R2 is detected by the SEL-FT50 Transmitters located near R1 but not by the SEL-FT50 Transmitters located near R2. The SEL-FT50 Transmitters located near R1 send a high-speed wireless signal to all three SEL-FR12 Receivers in the top network within 6 ms of detecting the fault. R2 opens, isolating the faulted segment, and R3 closes to restore the R2-R3 segment.

Adding the SEL-FT50/SEL-FR12 communication capabilities to the loop significantly reduces the time to isolate a fault and restore the system. With a cost under $7,000 for the two SEL-FT50/SEL-FR12 systems, the SEL-FT50/SEL-FR12 System is a low-cost approach to achieving high-speed fault detection and isolation in a distribution loop.

The Benefits of Faster Protection

Reducing the duration of faults not only improves reliability metrics, but also has the following additional benefits:

- Extended equipment life. Clearing faults before they can fully develop reduces stress on infrastructure.
- Improved system stability. Shorter fault-clearing times reduce voltage fluctuations.
- Increased safety. Faster fault clearing reduces the chance of fires, electrocution, and other safety hazards.

Figure 10 shows the life expectancy curves of a substation transformer with frequent and infrequent fault durations. As shown in Figure 10, faults have a cumulative effect on transformer life. Therefore, reducing exposure to faults extends transformer life.

During fault conditions, voltages can fluctuate. Phases adjacent to the faulted phase can experience voltage sag. Shortening the duration of faults lessens the impact of voltage deviations, which is especially important for devices like consumer electronics that have tight tolerances for power quality.

Conductors coming into contact with trees or other equipment during faults can start catastrophic fires. The longer the fault stays on the line, the longer the shower of sparks continues. Broken or fallen conductors can also be an electrocution hazard. Isolating faults faster can reduce the chances of fires and other safety hazards.

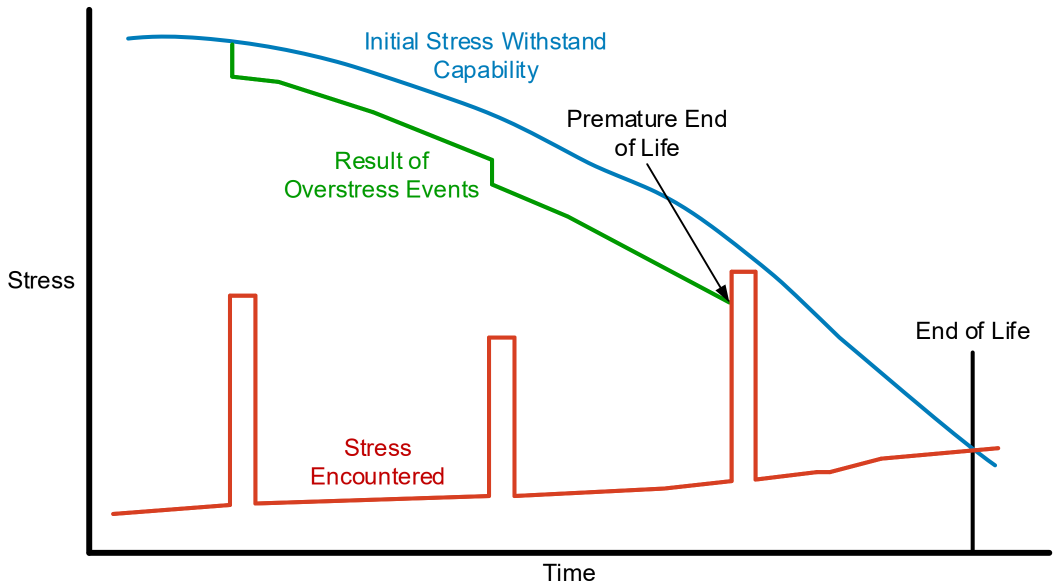

Figure 10 Transformer Lifetime Prediction [1]

Narrow Down Fault Locations

The fault-detection information from the SEL-FT50/SEL-FR12 System can be retrieved from the recloser control, or it can be sent by the recloser control back to a SCADA or outage management system. This provides line crews with more specific location and phase information for a fault, reducing patrol time.

Figure 11 and Figure 12 show the difference in the amount of line to patrol without and with the SEL-FT50/SEL-FR12 System, respectively. Note that the patrol crew first inspects all fuses and only inspects the rest of the line if a fuse is blown.

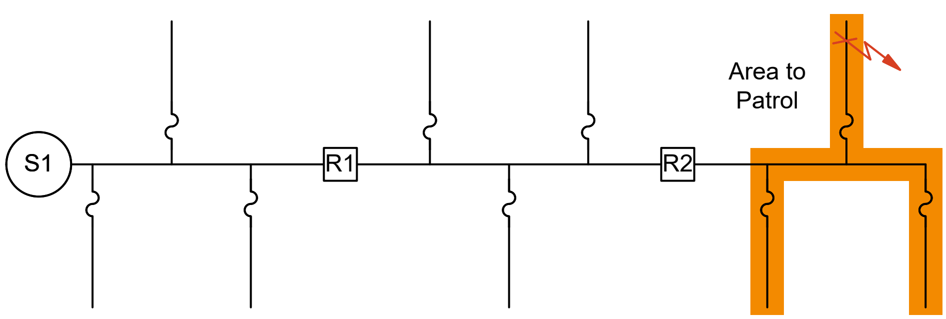

Figure 11 Area to Patrol Without the SEL-FT50/SEL-FR12 System

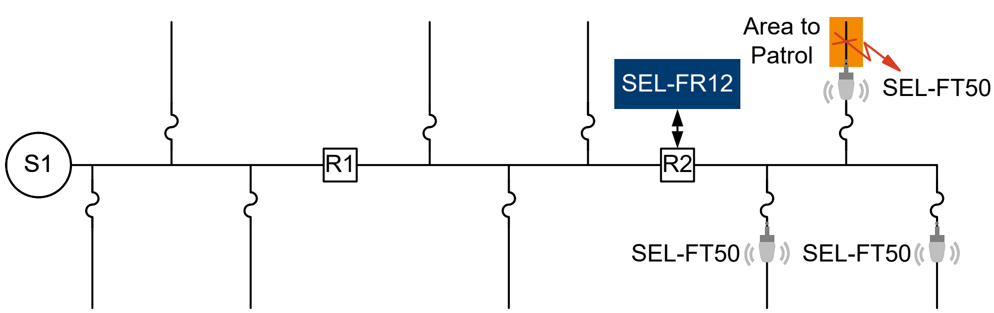

Figure 12 Area to Patrol With the SEL-FT50/SEL-FR12 System

Improved fault location information allows personnel to reduce patrol times and drive right to the faulted tap or segment, improving Customer Average Interruption Duration Index (CAIDI) metrics. The ability to identify the faulted segment ahead of time is especially helpful when feeder lines are numerous, difficult to get to or not close to major roads, or when crews face poor weather conditions.

Conclusion

The key benefits for distribution systems of combining SEL-FT50/SEL-FR12 Systems with advanced recloser controls and feeder relays include the following:

- Improved SAIDI, CAIDI, and MAIFI metrics from mixing fuse-saving and fuse-blowing schemes.
- Selective protection for underground-to-overhead transitions, which reduces permanent outages and the risk of reclosing on underground faults.
- Faster protection on radial feeders by eliminating unnecessary wait times for coordination.
- Faster fault isolation and restoration of distribution loops.
- Increased equipment life.
- Improved system stability and power quality.
- Improved safety.
- Reduced patrol time for fault location.

Advanced recloser controls and feeder relays have driven improvements in reliability metrics by using more precise fault-detection methods, clearing a greater number of temporary faults, and enabling effective fault isolation and restoration schemes. By adding SEL-FT50 Fault Transmitters and SEL-FR12 Fault Receivers to existing protection systems, utilities can improve reliability further and realize additional distribution system benefits.

Reference

[1] C. Osorio and N. Sawant, "EE292K: Intelligent Energy Projects," Stanford University. Available at: http://web.stanford.edu/class/ee292k/proposals/ChristianNandan.pdf.

Biographies

Steve T. Watt received his B.S. in mechanical engineering from Virginia Polytechnic Institute and State University. He worked in the information technology industry for over 20 years at Hewlett Packard before joining Schweitzer Engineering Laboratories, Inc. (SEL) in 2012. Steve is currently the market manager for precise timing and wireless networking products at SEL.

Shankar V. Achanta received his M.S. in electrical engineering from Arizona State University in 2002. He joined Schweitzer Engineering Laboratories, Inc. (SEL) in 2002 as a hardware engineer, developing electronics for communications devices, data acquisition circuits, and switch-mode power supplies. Shankar currently holds nine SEL patents, and he is an inventor on several patents that are pending in the field of precise timing and wireless communications. He currently holds the position of engineering director for the precise time, fault indicators, and sensors division at SEL.

Peter Selejan received his B.S. in electrical engineering from University of Florida in 1992. He worked at ABB for 22 years as an R&D engineer, project manager, and recloser product specialist. During this time, he was awarded two patents in the area of phase selection and coauthored "Technologies of the Self Healing Grid," which was published at CIRED 2013. In 2016, he joined Schweitzer Engineering Laboratories Inc. where he works as an application engineer in protection.

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