Case Study

SCHWEITZER ENGINEERING LABORATORIES

Town of Clayton Improves Underground Feeder Protection With the SEL-FT50 and SEL-FR12

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Region

North Carolina, USA

Overview

Clayton Public Power, a municipal utility in North Carolina, was facing a common problem for utilities—how to provide safe and reliable power to their customers while maximizing the useful life of their equipment. Their distribution system includes substations where underground cables carry power to overhead lines that, in turn, serve their customers. If there was a fault on the lines, their system automatically reclosed to rapidly restore power and keep power on for their customers. This method worked when there were momentary faults, but for a permanent fault in the underground cable exiting the substation or in the voltage regulators, their system still reclosed, potentially damaging their substation equipment.

To ensure that the system does not reclose onto permanent faults on underground cables, Clayton Public Power installed the SEL-FT50 and SEL-FR12 Fault Transmitter and Receiver System. This system protects Clayton Public Power's expensive equipment from damage by eliminating unnecessary fault current exposure while maintaining the benefits of automatic reclosing on overhead lines.

A Long-Established Problem

Many electric utilities run power cables underground out of the substation before transitioning the feeder to an overhead power line. This common practice helps utilities minimize the clutter of overhead cables at the substation, reducing the chances of an overhead fault. Though a segment of the feeder is underground, most of the feeder has overhead construction. Therefore, automatic reclosing is typically enabled at the substation to help clear momentary faults on the overhead power line. This practice ensures uninterrupted power is delivered to customers, but it is not without risks. Each reclose attempt into the fault exposes the faulted phase of the power line to fault-level current, as shown in Figure 1. Additionally, the unfaulted phases experience fault-level inrush currents, a condition of re-energization.

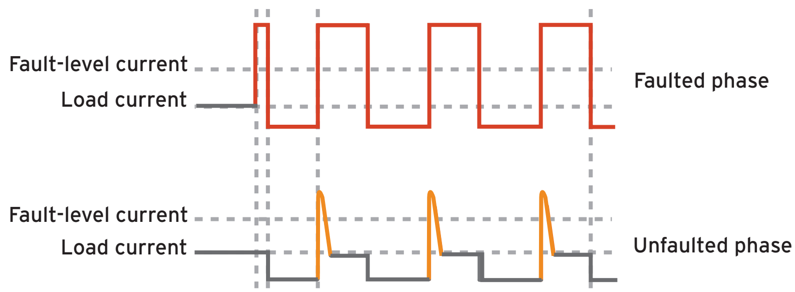

Figure 1—Simplified example of typical automatic reclose sequence.

Automatic reclosing schemes are intended to clear the cause of a fault (e.g., vegetation or wildlife) off overhead power lines. Automatic reclosing can prevent momentary faults from causing a permanent outage. However, faults on underground cables are almost always permanent and therefore cannot be cleared by reclosing. There are no benefits to reclosing into permanent faults. Reclosing into permanent faults exposes the entire feeder and connected utility equipment to large fault currents upon each reclose. While distribution systems can handle these fault currents in the short term, such events negatively impact the overall system life and will contribute to equipment failure. Like many other utilities, Clayton Public Power assumed they could not avoid the damages from reclosing into faults in underground cables that are connected to the overhead power lines.

Case Study

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Northside Substation

Clayton Public Power's Northside substation has four three-phase feeders. Each feeder (and each feeder's inline voltage regulator) is protected by an SEL-651R Advanced Recloser Control, as shown in Figure 2. The feeders individually exit the substation fence as underground cables before coming to a riser pole, where they transition to overhead conductors. Each recloser control was configured to reclose twice into the fault to allow a fault on the overhead lines to clear and to prevent sustained customer outages for momentary faults. However, with the recloser control being at one central monitoring point at the substation, there was no way for the control to determine if the fault was underground or overhead. Therefore, a permanent fault on the underground cable would always result in two recloses, when it should never have been reclosed into at all.

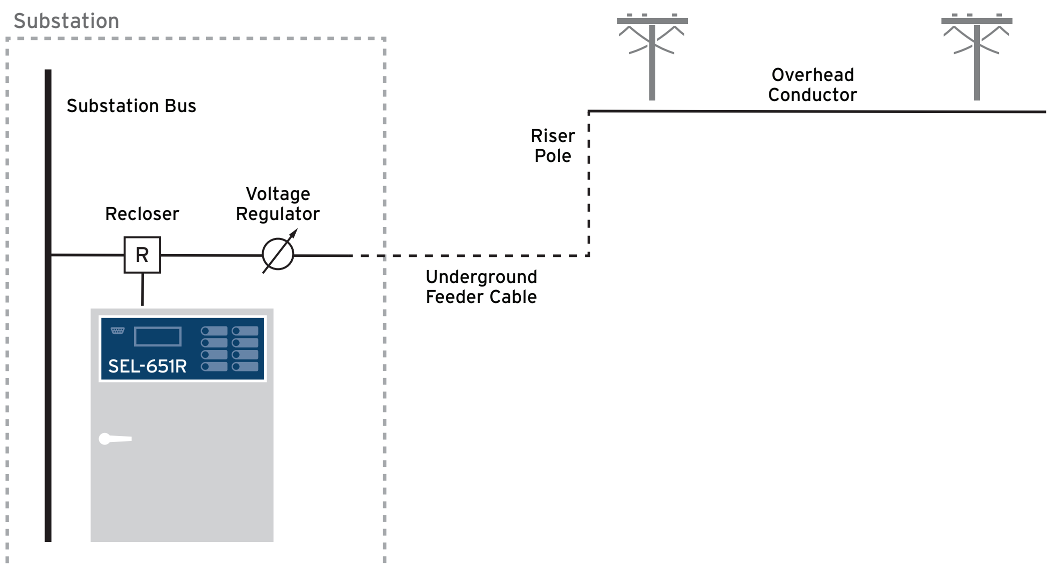

Figure 2—Simplified one-line diagram of the Northside substation at Clayton Public Power.

A Simple and Economical Solution

Schweitzer Engineering Laboratories (SEL) presented a solution to Clayton Public Power that protects utility equipment during permanent faults on underground cables exiting the substation while keeping the power on for Clayton Public Power customers during momentary faults on the rest of the system. The SEL-FT50 and SEL-FR12 Fault Transmitter and Receiver System increases visibility for the substation recloser control by providing precise information about the transition point on the feeder where the cable changes to an overhead line. This information allows the recloser control to selectively block reclosing for underground faults in the feeder. Clayton Public Power installed the system at their Northside substation to implement a high-speed recloser blocking scheme for underground cable faults.

![SEL logo]

Case Study

Town of Clayton Improves Underground Feeder Protection With the SEL-FT50 and SEL-FR12

The SEL-FT50 and SEL-FR12 system provides high-speed indication of faults directly to the substation recloser control. The typical system latency is 6 ms (i.e., less than half a power system cycle). This is fast enough to influence protection decisions before the recloser control acts on the fault. The SEL-FR12 Fault Receiver connects directly to the substation recloser control via a serial cable and uses the Mirrored Bits® protocol to communicate the fault and wireless communications link status from the fault transmitters. When a transmitter detects fault current, it quickly transmits a fault message to the receiver. The recloser control connects to the receiver and is programmed, via SELogic® control equations, to speed up tripping, adjust coordination, or alter reclosing schemes to improve protection.

Recloser Control Programming Logic

Clayton Public Power modified the programming logic of the SEL-651R via SELogic control equations shown in Figure 3. This logic used the specific Mirrored Bits communications inputs from the fault receiver (corresponding to the wireless communications link and fault status of each of the transmitters) to modify the "drive to lockout logic" of the SEL-651R.

When the SEL-651R detects a fault, the logic evaluates if the recloser control has received a fault message from any of the transmitters. Because the transmitters are installed at the riser pole beyond the underground cable, the recloser control receives a fault status Mirrored Bits for all faults on the overhead line. The recloser control then issues a reclose command to the recloser to attempt to clear a momentary fault and restore power in the overhead feeder. If the recloser control detects a fault and does not receive a fault status Mirrored Bit, then the fault occurred before the riser pole on the underground cable or in the inline voltage regulator.

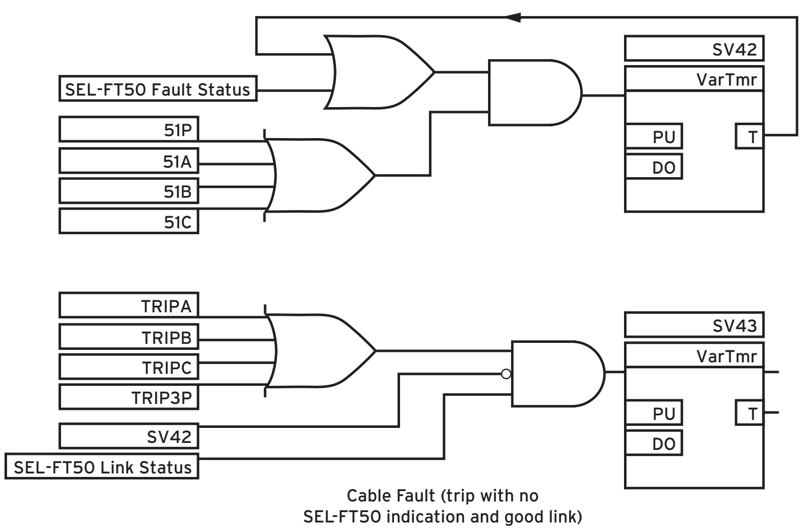

Figure 3—SEL-651R relay logic programming defines how it will use status indication from each transmitter.

If an active wireless link with the transmitters is not detected at the time of the fault, the reclose blocking scheme is disabled. This logic ensures that reclosing is not blocked if the transmitter or receiver fail.

Lab Tests Validate Operation

Clayton Public Power tested the solution to fine-tune settings without affecting the distribution system. Clayton Public Power worked with local SEL application engineers on the settings validation and testing. They first developed programming logic for the recloser control and applied it an SEL-651R in the lab that was identical to the field recloser control. The following equipment was used for the lab tests:

- One SEL-FR12 Fault Receiver
- One SEL-651R-2 Advanced Recloser Control
- Three SEL-FT50 Fault Transmitters
- One SEL-C272A Serial Cable
- Three SEL MCL120 Mini Current Loops
- Three clamp-on CTs

The engineers connected the SEL-FR12 via a serial cable to the SEL-651R to establish MIRRORED BITS serial communications. Then, they clamped each SEL-FT50 to its own MCL120 current loop, as shown in Figure 4, for a simple way to power and trip the transmitters using a 120 Vac outlet. The MCL120 provides a magnetic field (equivalent to that produced by 10 A of load current flowing through a single overhead conductor) to power the transmitter via inductive coupling. It also simulates a fault by producing a larger magnetic field upon the press of a button. After connecting a portable, clamp-on CT to each MCL120, the engineers wired each CT to the current inputs on the SEL-651R, as shown in Figure 5.

Figure 4—MCL120 current loops connected to SEL-FT50 transmitters in the test lab.

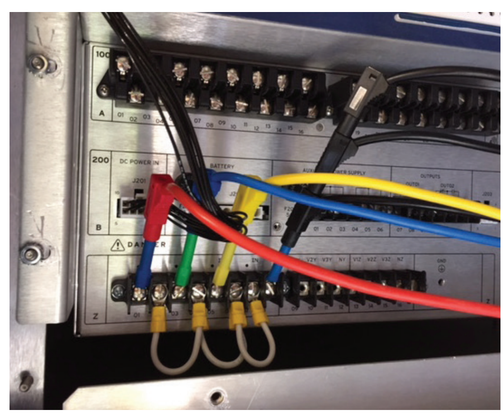

Figure 5—CT wired to SEL-651R current inputs in the test lab.

After confirming each transmitter's wireless link status at the receiver, the engineers conducted multiple simulations to test the operation of the recloser control logic for an overhead fault, an underground fault, and a fault during a wireless link failure of any transmitter.

During the overhead fault test, the SEL-651R reclosed as normal after receiving a fault message from the SEL-FT50. For the underground fault test, the engineers removed one SEL-FT50 from an MCL120 and then simulated a fault before the SEL-FT50 communications link status dropped out. The SEL-651R identified that there was a link status for the SEL-FT50 and transmitters but no fault status, so it drove to lockout to prevent reclosing on an underground fault.

For the final test, the engineers again removed an SEL-FT50 from one MCL120, but this time they waited until the SEL-FR12 identified the lost link status. When they simulated a fault, the SEL-651R reclosed as expected after identifying the fault and disabling the blocking scheme due to the lost communications link.

The lab simulation tests demonstrated that the blocking scheme worked correctly to prevent reclosing on underground faults. For overhead faults or if communication with the fault transmitters is lost, the tests showed that the SEL-651R will reclose onto the faults as normal.

Commissioning

Engineers mirrored the lab testing in the field for commissioning at the Northside substation. However, they used only two MCL120 current loops and one CT for the field test. Using a spare feeder in the substation, the engineers transferred the load and isolated each feeder to execute the test sequences and confirm the operation of the scheme at each recloser. The small amount of equipment and simplicity of the scheme made it possible to test and commission all four feeders in just half a day. Overall, it took just a few months to go from the concept to a fully commissioned solution.

Line workers installed three fault transmitters, one on each phase of the overhead portion of the feeders at the riser pole. Because they could install the transmitters with a hot stick on the live line, their customers were not impacted by the upgrade. All the transmitters were configured via control (DIP) switches to wirelessly communicate with an SEL-FR12 installed in the SEL-651R control cabinet for the associated feeder, as shown in Figure 6.

Clayton Public Power installed an SEL-FR12 in the SEL-651R recloser control cabinet for each feeder in the substation, as shown in Figure 7. A low-gain omnidirectional antenna was connected to the SEL-FR12 (shown in Figure 8) to receive messages from SEL-FT50 transmitters installed just outside the Northside substation (as shown in Figure 9).

Case Study

Town of Clayton Improves Underground Feeder Protection With the SEL-FT50 and SEL-FR12

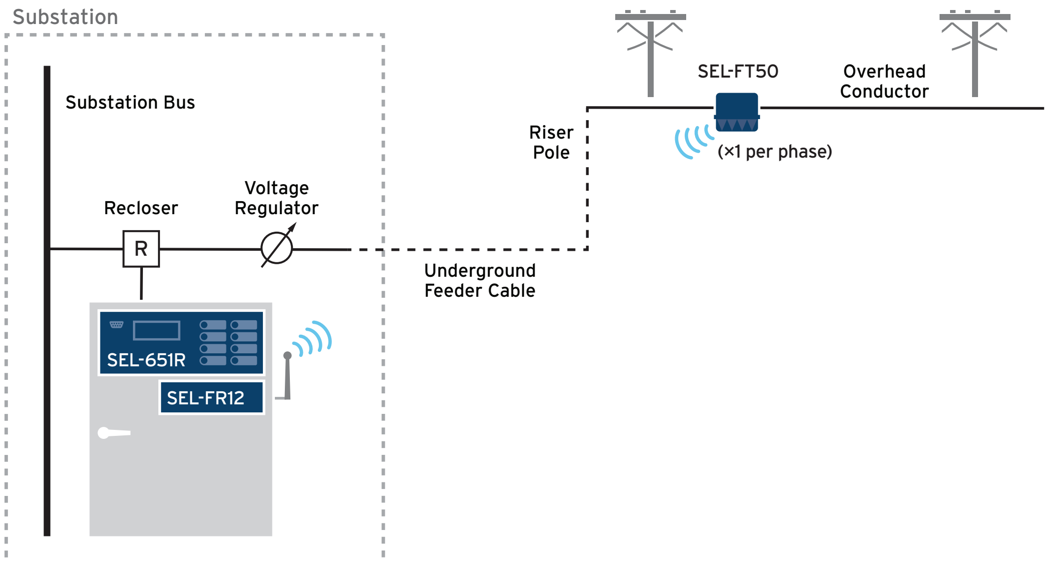

Figure 6—Distribution substation application overview with the SEL-FT50 and SEL-FR12 system.

Figure 7—SEL-FR12 installed in the SEL-651R recloser control cabinet.

Figure 8—Omnidirectional antenna connected to SEL-FR12 to communicate with SEL-FT50 transmitters.

Case Study

Town of Clayton Improves Underground Feeder Protection With the SEL-FT50 and SEL-FR12

Figure 9—A line worker installs an SEL-FT50 outside the Northside substation on the overhead section of the feeder.

Highlights From the Successful Detection of the System's First Event

A few months after commissioning, a fault occurred on the overhead section of one of the feeders from the Northside substation. The event report from the SEL-651R (shown in Figure 10) shows that the control received a fault status Mirrored Bit from the SEL-FR12 and successfully reclosed for an overhead fault. Figure 12 shows the assertion of the SEL-FT50 fault status Mirrored Bit from the SEL-FR12. This Mirrored Bit asserted approximately 4 ms after the fault inception.

Figure 13 shows the first trip event for the fault. Because the fault status Mirrored Bit was received from the SEL-FT50, the reclose blocking logic never asserted and the SEL-651R did not drive to lockout. The Sequential Events Recorder (SER) showed that this feeder reclosed and cleared the momentary fault.

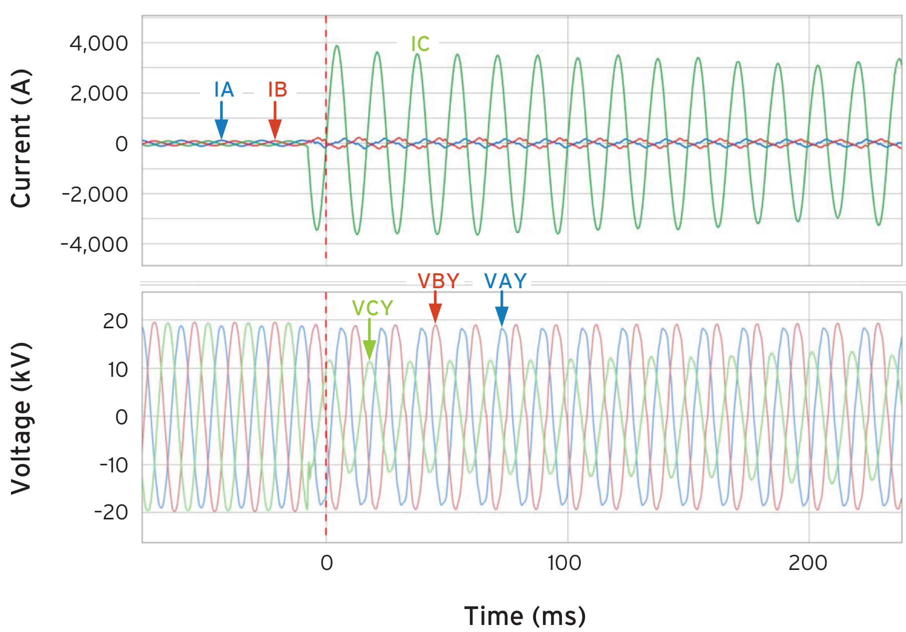

Figure 10—Oscillography from the SEL-651R showing the inception of a fault on Phase C.

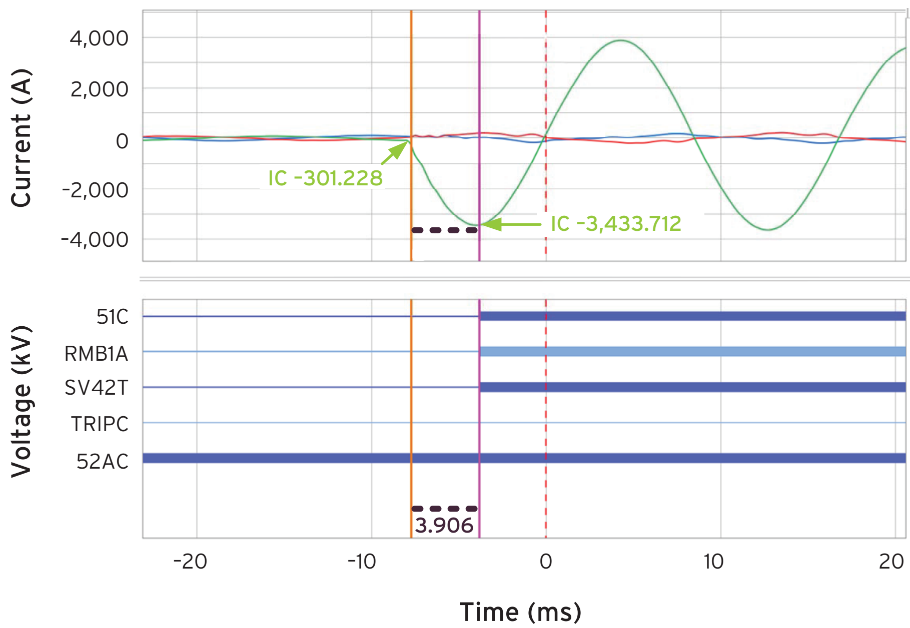

Figure 11—The assertion of the SEL-FT50 fault status Mirrored Bit from the SEL-FR12 approximately 4 ms after the fault inception.

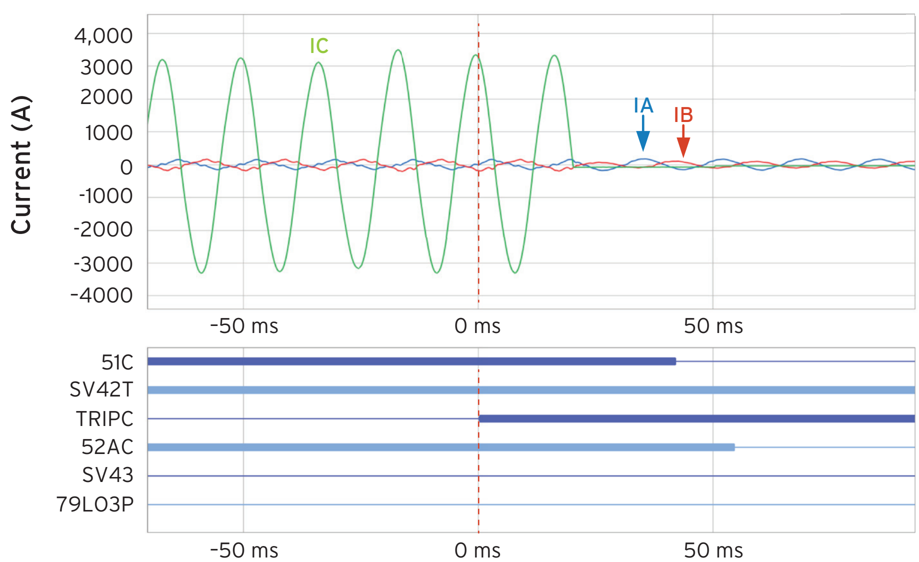

Figure 12—The first trip event for the fault.

Conclusion

On mixed feeders with underground and overhead lines, utilities don't have to assume the risks associated with reclosing onto permanent faults in the underground cable sections. The SEL-FT50 and SEL-FR12 system provides the visibility to distinguish between faults on overhead and underground sections. This allows utilities to implement an automatic reclosing scheme for overhead lines, thereby preventing momentary faults from becoming permanent outages, while blocking reclosing on the underground sections to protect equipment by eliminating unnecessary fault currents.

Clayton Public Power used this technology to improve distribution protection for substation equipment and improve system reliability. The simplicity of the SEL-FT50 and SEL-FR12 solution allowed them to go from a concept to a fully developed, tested, installed, and commissioned solution in only a few months.

About Clayton Public Power

Clayton Public Power provides electric service to residents and businesses in the town of Clayton, North Carolina. Clayton is a satellite town to the state's capital, Raleigh, and is located within a 30-minute drive from the Research Triangle, a region of the state that encompasses three major universities (Duke University, North Carolina State University, and University of North Carolina at Chapel Hill) and is a point of attraction for businesses. Clayton's proximity to these areas has contributed to a significant population growth of over 300 percent in the last 20 years. As their system continues to grow with demand, Clayton Public Power strives to find new ways to improve the safety, reliability, and economy of their electric distribution system.

About SEL

Schweitzer Engineering Laboratories, Inc. (SEL) has been making electric power safer, more reliable, and more economical since 1984. SEL serves the electric power industry worldwide through the design, manufacture, supply, and support of products and services for power system protection, control, and monitoring.

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