

# Fault Indicators for the Safe, Reliable, and Economical Operation of Modern Power Systems





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Cover photo courtesy of City of Carlyle.



### Tips From Ranger

Ranger is the "mascot" for SEL's RadioRANGER® Wireless Fault Indication System. He'll be providing tips and insight throughout this document.

## Introduction

Field experience shows that faulted circuit indicators (FCIs) are the most cost-effective way to improve the reliability and safety of overhead and underground distribution feeders. This pamphlet briefly describes what fault indicators are and presents a broad range of practical applications and tips that you can easily adapt to your company's specific needs.

Fault indicators cost as little as \$30 per phase for manual reset devices used in troubleshooting, to several hundred dollars for devices that communicate status and monitoring data via radio. The applications and their analyses reveal impressive

improvements in distribution performance for very small investments. For example, just one set of fault indicators (\$240, assuming \$80 per phase) and a midpoint disconnect (which may already be present) can reduce fault-finding time by 50 percent or more. That's on the order of one-fifth the cost of the relay or meter that is monitoring that feeder!

How to realize these kinds of improvements, showing how they pay off quickly (typically in under a year), and making your system safer for your crews and the general public—all at the same time in most situations—is the purpose of this pamphlet.

## Section 1 What is the value of using fault indicators?

Fault indicators (also known as faulted circuit indicators or FCIs) improve distribution circuit reliability, improve the safety of line crews and the public, and reduce costs associated with power system downtime, equipment, and regulation. They “complete the job” of fault location started by protection and fault locating equipment.

Re-fusing, manually opening, and reclosing circuit sections are traditional methods for identifying the fault location in distribution systems. These methods are time consuming and potentially dangerous; they repeatedly expose distribution equipment to fault current that leads to instantaneous failure or decreased product life.

Faulted circuit indicators show whether fault current was present at their monitored

locations, providing an indication of the fault path. Combined with digital protective relays and recloser controls, fault indicators have the ability to lead line crews directly to the location of a fault. The result is that consumers of electricity experience shorter outage times, and the providers of electricity experience less lost revenue as a result of the shorter outage. Line crews spend less time searching for the location of the fault and are able to more quickly isolate and repair faulted sections, resulting in increased cost savings.

Today, investor-owned utilities, municipalities, and rural electric cooperatives make up a large percentage of FCI users. The number of applications in industrial and commercial areas is also growing.



## Top Reasons to Use Fault Indicators on Your Distribution System

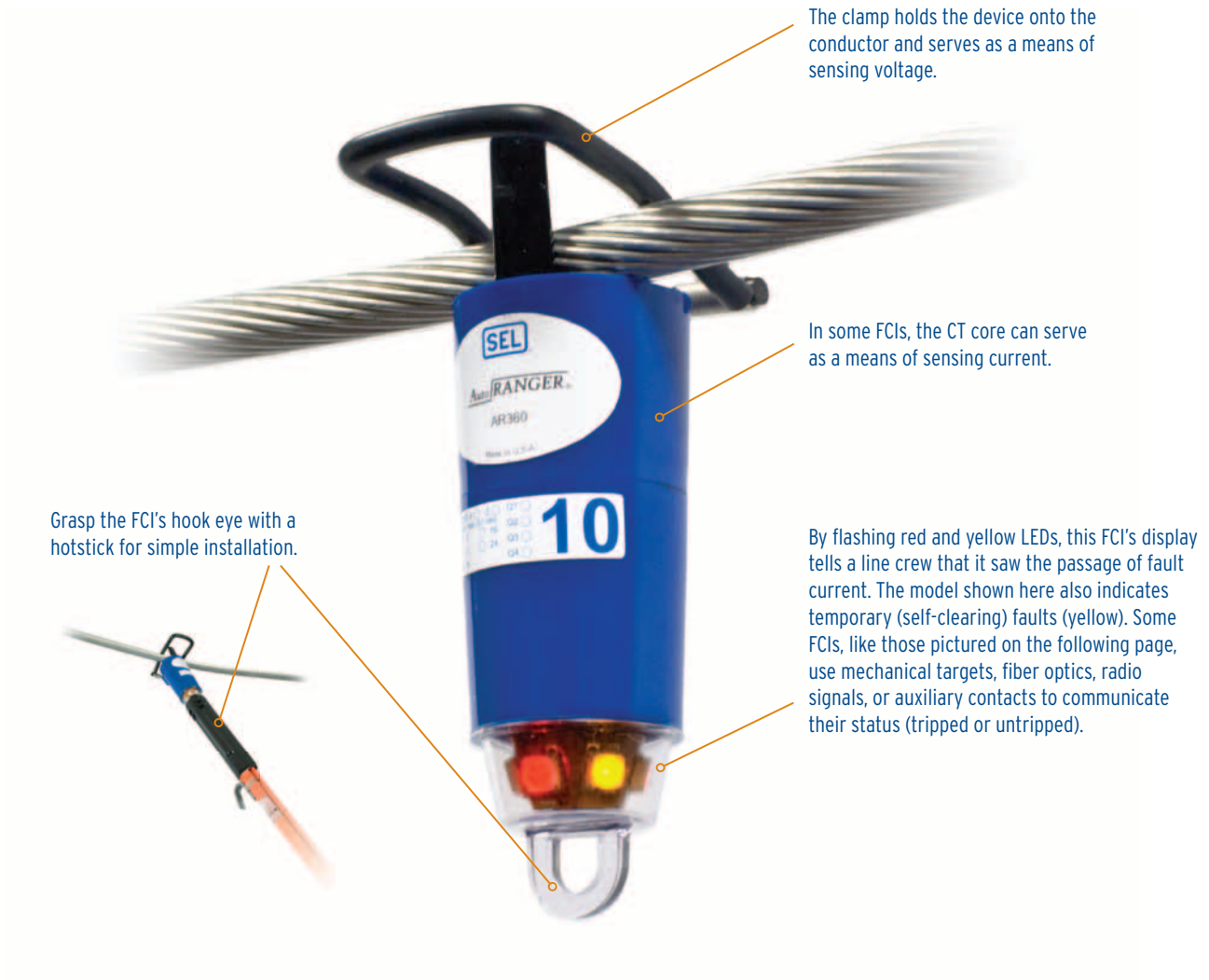
1. Fault indicators, coupled with training for troubleshooting groups, provide an efficient, cost-effective means of improving system reliability. Fault indicators reduce fault-finding time by 50 percent or more, which makes them a particularly powerful way to improve CAIDI.
2. Fault indicators pay for themselves!
3. Fault indicators “complete the job” started by protective and fault locating devices by pointing a line crew to the tap or branch affected by a fault.
4. Fault indicators installed at the midpoint of a distribution line allow line crews to restore power to the unaffected portion of the system—even before identifying the specific location of the fault. This midpoint sectionalizing method improves reliability and reliability metrics.
5. Manual reclosing, re-fusing, and sectionalizing (“closing and blowing”) to find the location of a fault can put line crews and the public at risk. Fault indicators eliminate this risk and reduce system wear and tear at the same time.
6. Remote displays on underground fault indicators eliminate the need to open an enclosure to determine fault indicator status. Radio Frequency (RF) options and SCADA-compatible auxiliary contacts also make opening the enclosure unnecessary.
7. Installing fault indicators at dips and risers allows troubleshooters to quickly determine whether a fault occurred on the overhead or underground section of line.
8. Using fault indicators as preventative tools reduces costs to utilities and their customers, and improves overall reliability. Apply fault indicators and fault counters in areas affected by brownouts, momentary outages, and flickering lights.
9. Today’s temporary fault frequently becomes tomorrow’s permanent fault. Use timed reset fault indicators to get to the root cause of temporary faults and avoid a bigger outage.



These lucky overhead fault indicators reduce fault finding time in Hawaii.

## Section 2 What are fault indicators, and where are they installed?

Fault indicators sense the magnetic field produced by current flowing through a conductor. When fault current passes through an FCI, the FCI “trips,” indicating the passage of fault current. A target, radio signal, flashing light, or contact closure lets you know that fault current has passed the fault indicator.






Some FCIs, like the two shown above, use targets to display their fault status. The indicator on the left (SEL-ARU) is for underground applications; the indicator on the right (SEL-ERL) provides fault indication for overhead systems.

Mechanical target displays require a small amount of energy to operate. FCIs with mechanical target displays can, in many cases, derive all of their operational power from the line on which they are installed.



These fault indicators communicate fault information via a wireless network.



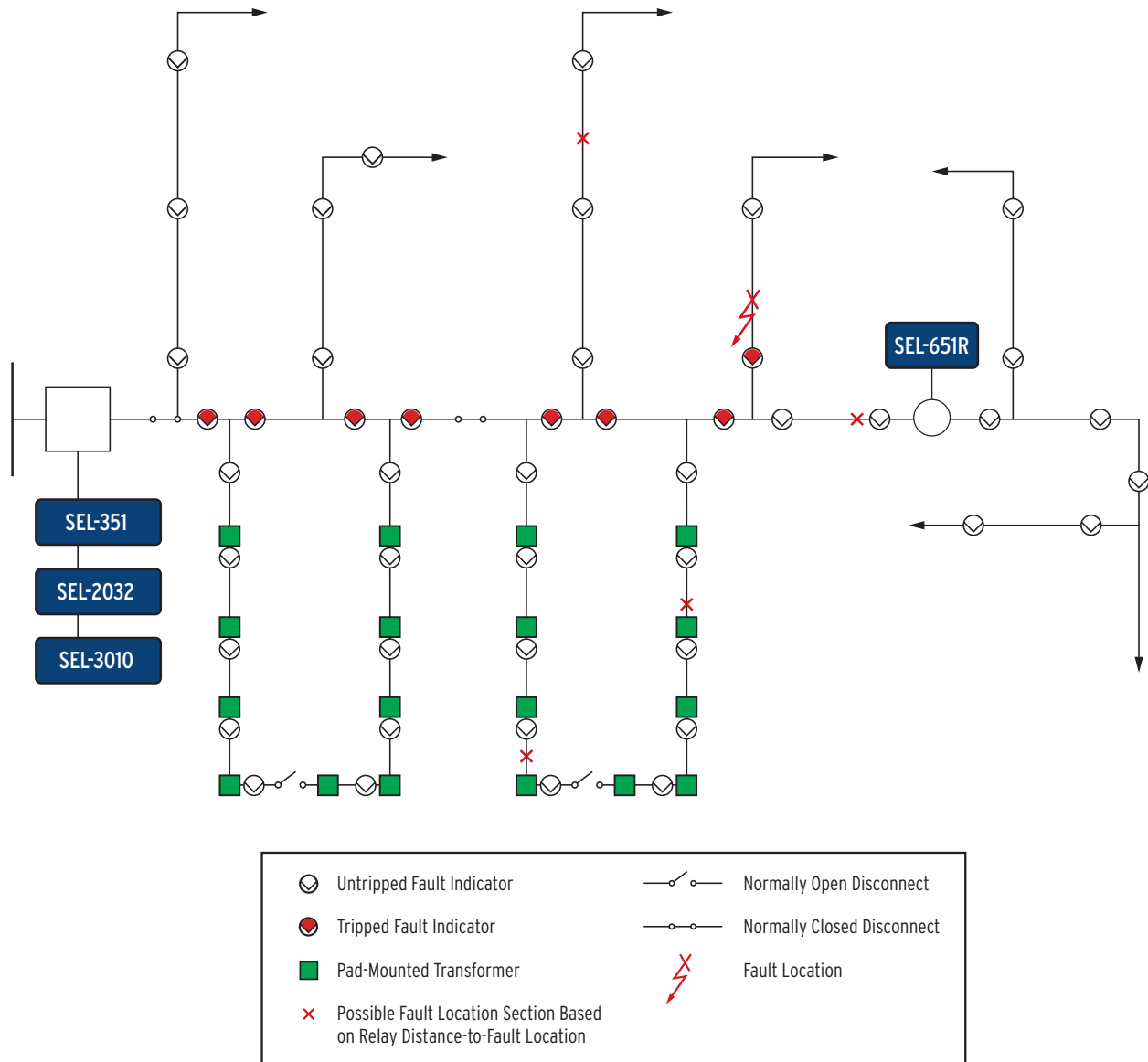
**Tips From Ranger**

Many SEL fault indicators, including the SEL-ERL pictured above, don't have batteries. That means no money spent on the cost and time to replace batteries.

## Locating the Fault

The root cause of every fault, even a temporary one, should be determined. If root cause is left undetermined, then there is the chance that a safety risk remains, or another outage could occur. After a fault occurs and the protection clears the fault, fault indicators lead you directly to the location of the fault. Modern digital protective relays and recloser controls

tell you the distance to the fault, but ambiguity remains because there are usually many taps and branches along a feeder that would yield the same distance to the fault. The relay or recloser control cannot tell if fault current traveled further down the main feeder or branched off somewhere—but fault indicators can!





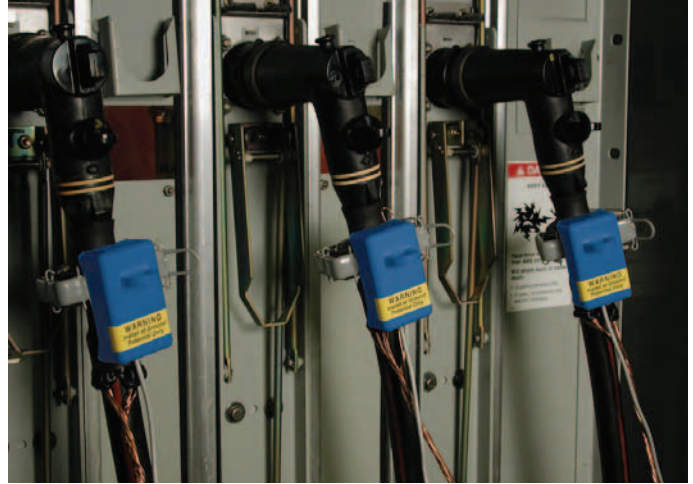
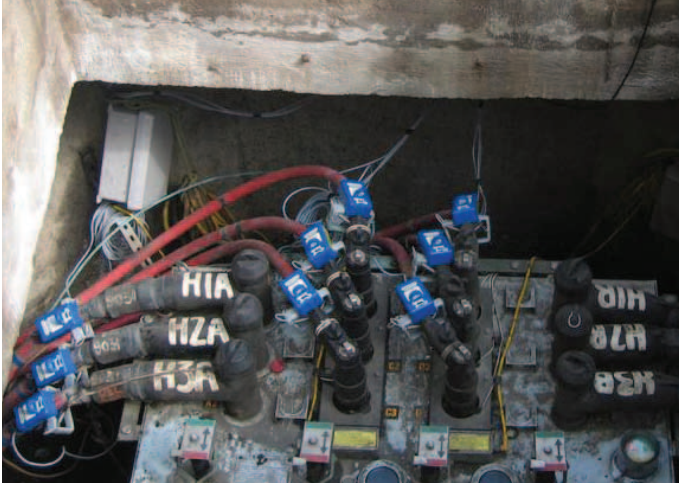
## Underground Fault Indicators and Their Applications

Underground FCIs are available in single- or three-phase versions with a variety of integral, remote, or wireless indication options. Many FCIs include inrush restraint, auxiliary contacts for integration with a SCADA system, and protection from system backfeed. The SEL AutoRANGER® for underground applications prevents false resetting from backfeed conditions by using historic load values to

set the minimum load current reset value. Other models have fixed trip values specific to their applications. To maximize application flexibility, fault indicators are available with several reset options. Choose from models that reset upon restoration of current or voltage, a set period of time (especially useful for temporary fault indication), or manual reset.



The RadioRANGER® sends fault information from underground vaults to a simple handheld device via radio signal.



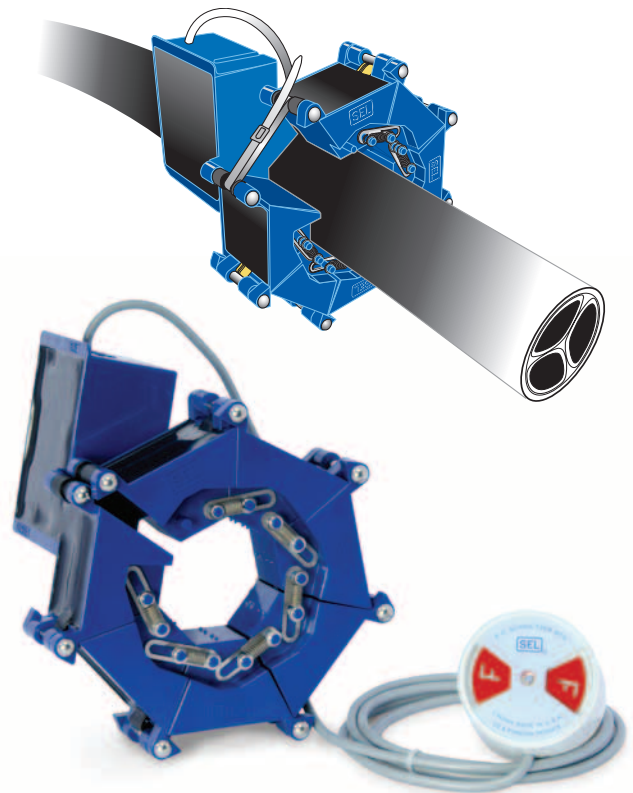
Underground AutoRANGERS as part of the RadioRANGER system (left) and installed in switchgear (right).

Underground applications for fault indicators include transformers, switchgear, sectionalizing cabinets, junction boxes, and splices. Equipment can be located above ground in a pad-mounted enclosure or in subsurface vaults and manholes. Fault indicators with auxiliary contacts provide fault information to a SCADA system, automating fault location.

The RadioRANGER® Wireless Fault Indication System, designed for underground vault applications, uses radio frequency to communicate fault status to a handheld Remote Fault Reader. No pumping, draining, and entering dangerous underground vaults on busy streets!



Fault indication on paper-insulated lead cable.



Even faults on paper-insulated lead cable (PILC), long the source of extended outages and fault-locating processes, are now detectable with fault indicators.

## Overhead Fault Indicators and Their Applications

Overhead FCIs are single-phase sensors with integral displays or remote communications capabilities that convey their status—tripped or untripped—to line crews on the ground. They range from simple manual reset devices to microprocessor-based products with sophisticated tripping and resetting methods. They usually have inrush restraint to prevent false indication caused by inrush currents during recloser operations. The SEL Overhead AutoRANGER® automatically adjusts its pickup value based on system load.

When a fault occurs on an overhead system, easy-to-see displays lead the line crew to the faulted section of line. For remote indication, radio communications fault indicators use mesh networks to send fault information back to a central location.

Overhead applications for fault indicators include unfused taps, long feeders with midline reclosers or sectionalizers, overhead-to-underground transitions, and feeders that experience recurring faults.

Faults can be permanent or temporary. Permanent faults are a high priority since they can result in outages. Temporary faults, also known as momentary faults, may not

cause outages initially, but will affect electricity users through blinking lights and brief losses of power. They may be caused by a tree branch touching a power line when the wind blows or a contaminated insulator which conducts briefly during changes in humidity. These types of events can affect computers and industrial processes, resulting in loss of revenue or equipment damage. Over time, temporary faults may turn into permanent faults. Using fault indicators to locate temporary faults can help to prevent future problems.

Fault counters, a special type of FCI, count the number of faults on a section of line experiencing problems. Timed reset FCIs benefit areas affected by momentary outages and flickering lights caused by temporary faults by leading personnel to problem sections of line. Using FCIs to find temporary faults reduces costs to the providers of electric power and their customers, improving reliability (and reliability metrics, too).



### Troubleshoot Problematic Sections of Overhead Systems

Count the number of temporary and permanent faults on sections of overhead line. The clock-style face counts up to ten faults with a reflective red pointer. Single hot-stick installation makes the fault counter easy to apply as a troubleshooting tool—and you can remove it for application elsewhere once the problem is resolved.

## Section 3 How do fault indicators improve safety for people, property, and equipment?

The manual process of opening and reclosing circuit sections is the traditional method for identifying distribution faults. This method is time consuming and potentially dangerous; it repeatedly exposes distribution equipment to fault current. Add to the mix underground vaults on busy city streets, stormy weather conditions, arc flash, unsafe heights, remote locations, and other situations that line crews face every day, and the advantages of using FCIs become very clear.

For the public, downed conductors pose an obvious threat of electrocution. A downed conductor may produce sufficient fault current to trip the protection and the fault indicators, but after that, the current may be insufficient to trip—but the danger remains.

Power outages leave people in the dark and threaten access to everything from heating and cooling to medical equipment. Businesses

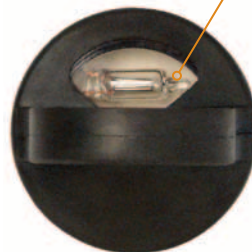
face additional safety challenges as they operate without electric power.

By reducing the outage duration, fault indicators minimize the time during which these safety hazards are present:

- The RadioRANGER Wireless Fault Indication System keeps crews from opening, entering, pumping, and draining multiple vaults while blocking traffic in their quest to find the location of a fault. The system's remote fault reader indicates fault location to street-level personnel, who in many cases don't even need to leave their service trucks. The public benefits from walking and driving in a street clear of obstructions and open vaults—and from seeing a quicker restoration of power.
- The RadioRANGER is also applicable in pad-mounted enclosures that contain transformers, switchgear, and junctions. The system can radio fault indicator status from a secure area in an industrial or utility facility, keeping line crews safe from potentially dangerous environments.
- Voltage indicators warn personnel of the presence of system voltage in pad-mounted transformers, switchgear, and other underground distribution enclosures with basic insulating plugs or capacitive test points. A flashing neon bulb indicates that voltage is present. The faster the flash rate, the higher the voltage.



This gentleman won't need to visit the inside of a vault again for a long time!



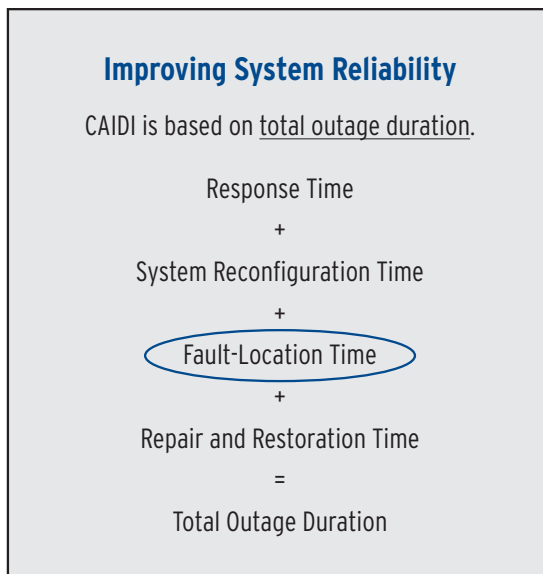
This neon bulb flashes when voltage is present, warning service personnel of the risk of electric shock.

## Section 4 How do fault indicators improve distribution reliability and save money?

Providers of electric power want to deliver reliable power to their customers—and their customers want them to succeed! For hospitals, airports, military installations, factories, chemical plants, research facilities, processing plants, grocery stores, and many other customers of power, outages mean lost revenue and increased cost.

Utilities measure reliability by monitoring outage frequency and duration. With the introduction of performance-based rates, utilities increasingly need to minimize outages and reduce outage times.

System Average Interruption Duration Index (SAIDI) and Customer Average Interruption Duration Index (CAIDI) are functions of how quickly an outage can be restored. Because most of an outage time is fixed—time to drive to the circuit, repair time, circuit reconfiguration time, etc.—the greatest improvements in these metrics are realized with reduced fault-locating time.



To make an economic case for buying SEL fault indicators, a utility might want to know how the fault indicators will increase the utility's revenue and decrease its costs.

### Increased Revenue

Fault indicators can increase a utility's revenue. When a fault occurs and causes a power outage, the utility's meters stop running. Stopped meters mean stopped revenue flow. Because fault indicators can reduce fault-finding time by 50 to 60 percent, they can also reduce outage time, achieving the goal of getting the meters running again sooner!

### Decreased Costs

Fault indicators can also decrease a utility's costs:

- **Decreased labor:** fault finding takes less time, so there are fewer customer complaints, and a decreased need for confidence-building PR.
- **Fewer blown fuses:** no need for manually opening and closing into potentially faulted circuit sections to find the fault.
- **Less cable wear-and-tear:** longer cable life and fewer faults because of weak lines.
- **Decreased regulatory fines:** better reliability statistics—CAIDI, SAIDI, and SAIFI—mean fewer fines.
- **Less political pressure:** when customers are happy, politicians are happy.

## Section 5 What is the role of fault indicators in my industry?

### Oil and Gas

Oil fields are typically fed by overhead power lines, making them susceptible to faults when storms move across the area. The resulting loss of power leads to loss of oil production, costing the oil company thousands to millions of dollars.

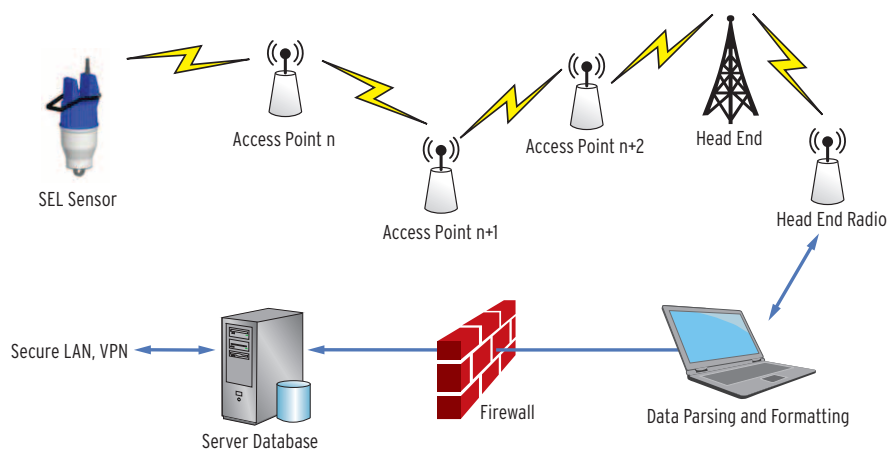
To speed the restoration of power, some oil-producing companies have implemented outage management systems to help restore power to the affected oil pumps more quickly. Because the outage areas tend to be so large, circuit information needs to be provided to line crews, so that they can quickly get to the faulted sections of line. In addition, the outage management system will communicate the status of reclosers on the system back to a

central location. Recloser status information helps crews to identify a wide area where the power outage exists, which could be miles from the actual fault location.

FCIs with communications capabilities narrow the possible locations identified using the information from the recloser controls. For companies without central dispatch centers, underground FCIs paired with the RadioRANGER system are particularly useful in this application since fault indicator status is communicated directly to the crews' vehicles via radio signal, enabling crews to drive directly to the location of the fault, repair the line, and restore power.



Information provided by recloser controls and FCIs with communications capabilities is an important part of outage management systems employed in oil fields.



## Universities and Hospitals

Many large distribution systems on university campuses are primarily made up of underground circuits and provide power to the entire campus. Because of the importance of keeping energy flowing throughout the campus, which may include research facilities and hospitals, many universities apply SEL FCIs to reduce outage duration.

Hospitals may contain more than one electrical feeder to provide an almost immediate source of power if the primary feeder were to experience an outage. Switches near the hospital are

sometimes designed to automatically switch in one of these two feeds. Applying SEL voltage sensors to the capacitive testpoints of elbow terminations within these switching cabinets enables hospitals to detect a loss of voltage. When they sense voltage loss, the voltage sensors are able to trigger the operation of an automatic transfer controller. Voltage sensors are economical and simple to install, making them a good substitute for PTs in this application.



## Military Installations

The installation of fault indicators on a military installation significantly reduces the fault location time for electric shop personnel. This translates into a safer living and working environment for personnel and families on military installations, as well, since undetected faults are a serious safety hazard.

Launching aircraft, mobilizing personnel, and maintaining runway lights, communications facilities, fuel farms, radar, navigation aids,

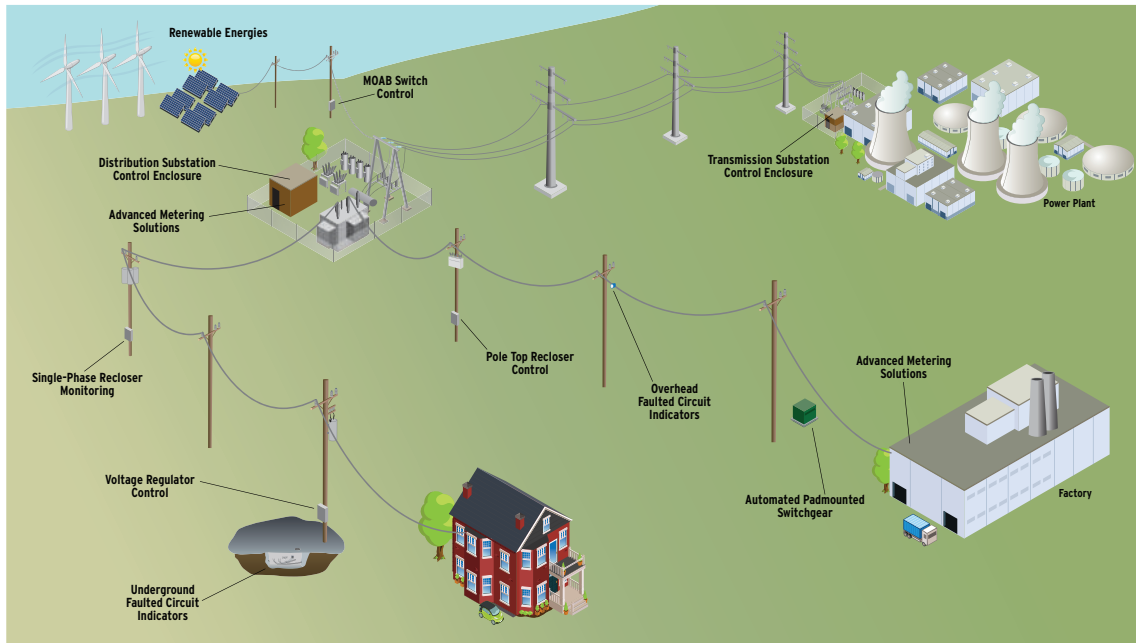
and other critical functions are only possible with reliable electric power. The potential for injury and loss of life as well as damage to expensive military equipment significantly goes up when military facilities lose their primary electric power source. The addition of SEL faulted circuit indicators allows military installations to keep the “lights on” and, in turn, perform their critical missions with minimal interruptions.

## The Smart Grid

Fault indicators are one of the “original” smart devices.

As part of today’s smart grid, fault indicators with communications capabilities reduce fault-finding time by communicating fault status back to a central location. Line crews can then

go directly to the fault location, improving distribution reliability. In underground applications, FCIs with auxiliary contacts communicate via the SCADA system, while the SEL RadioRANGER communicates information from fault indicators in underground vaults to handheld readers.



## Wind and Solar Power Applications

The following discussion focuses on wind farm applications for FCIs, but is generalizable to solar farms.

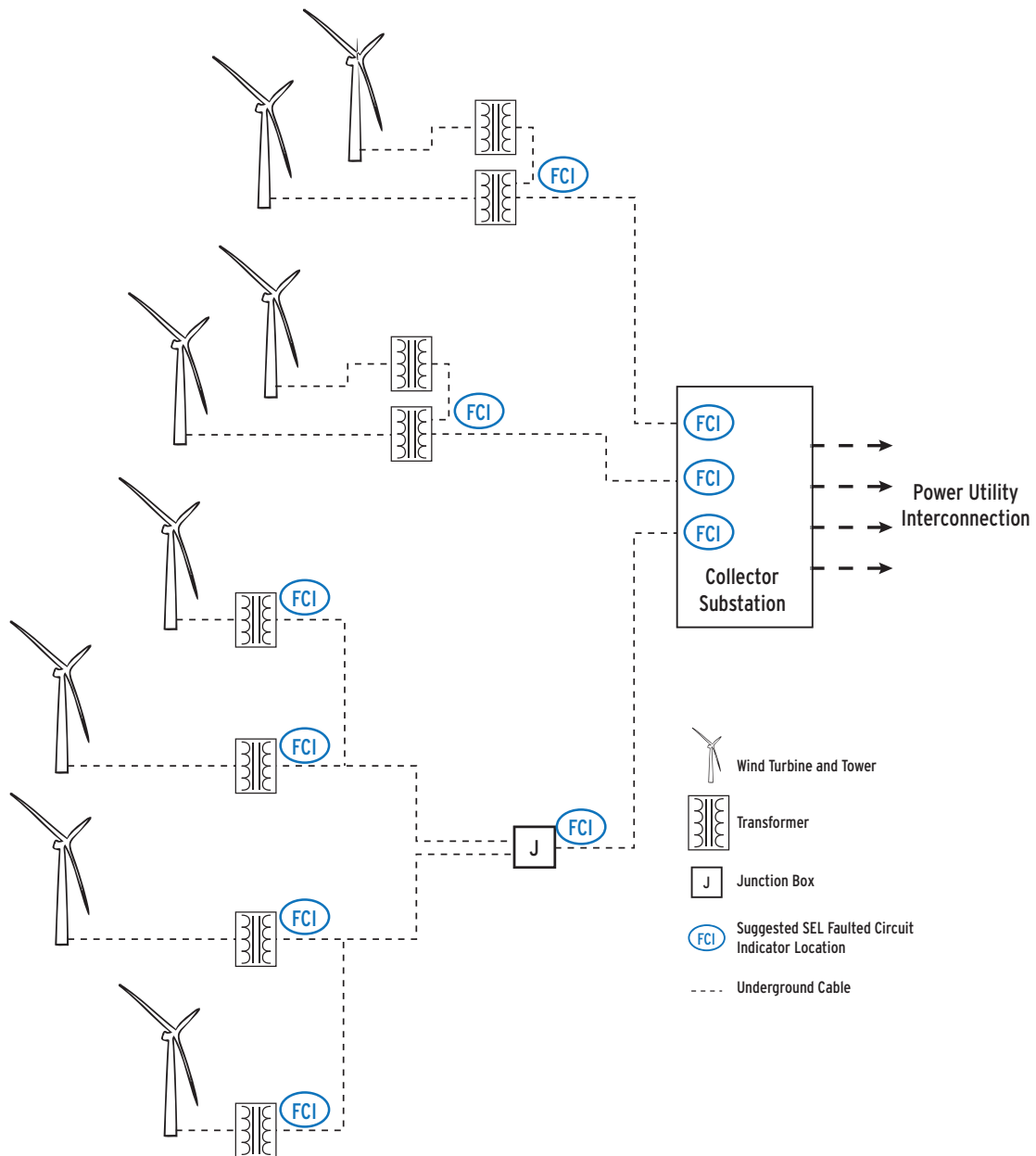
The loss of revenue due to a single cable fault can be substantial for a wind farm operator. As a result, it becomes necessary to determine the location of the fault as quickly as possible, isolate the faulted section, and restore the balance of the wind farm to producing

electricity. SEL Faulted Circuit Indicators (FCIs) can help operations personnel quickly determine the fault location. As depicted in the application of fault indicators in a typical wind farm illustration (on following page), the terminations used for underground cables in the transformers and junction boxes are excellent locations to install faulted circuit indicators.



A traditional FCI application requires coordination of the trip value with the utility substation breakers, reclosers, and fuses. A FCI trip value should be lower than, and its trip response time should be faster than, all of the upstream protective devices to ensure that it activates before the fault is cleared.

Wind turbines introduce another source of energy that requires coordination. During a wind farm cable fault, the power utility grid system can supply higher fault currents for a longer duration as compared to that supplied by a set of turbines on a collector string.



Application of fault indicators in a typical wind farm.

Directional type fault indicators are not required for fault location if the coordination of the substation protection and wind turbines' fault contribution are understood. The SEL solution to wind farm fault locating is to select FCIs with a trip value and response time that exceeds the wind turbine current contribution magnitude and duration. This method prevents the FCI from responding to fault level energy supplied by the turbines. Fault indicators with a delayed trip feature provide the additional time necessary for fault current contributed by the wind turbines to collapse (wind turbine fault current is higher than the FCI's 1200 A trip level).

The only source available to trip the device is the energy being back-fed from the utility power system through the collector substation to the fault. This source provides the higher currents needed to trip the 1200 A FCIs and at a longer duration than the wind turbine contribution.

This fault-locating method is similar to how fault locating is performed on typical utility distribution circuits; only the fault indicators between the breaker and the fault are tripped. This nondirectional fault indication method reduces confusion during the field patrol,



and speeds the fault location process, because the number of FCIs tripped during the fault is limited only to the ones between the breaker and the fault. The SEL coordination method described above provides a simple, practical fault-locating solution for wind farm applications. Test Point Reset FCIs (like the 3TPRV\_J) are ideal for applications that include terminations equipped with capacitive test points.



#### Tips From Ranger

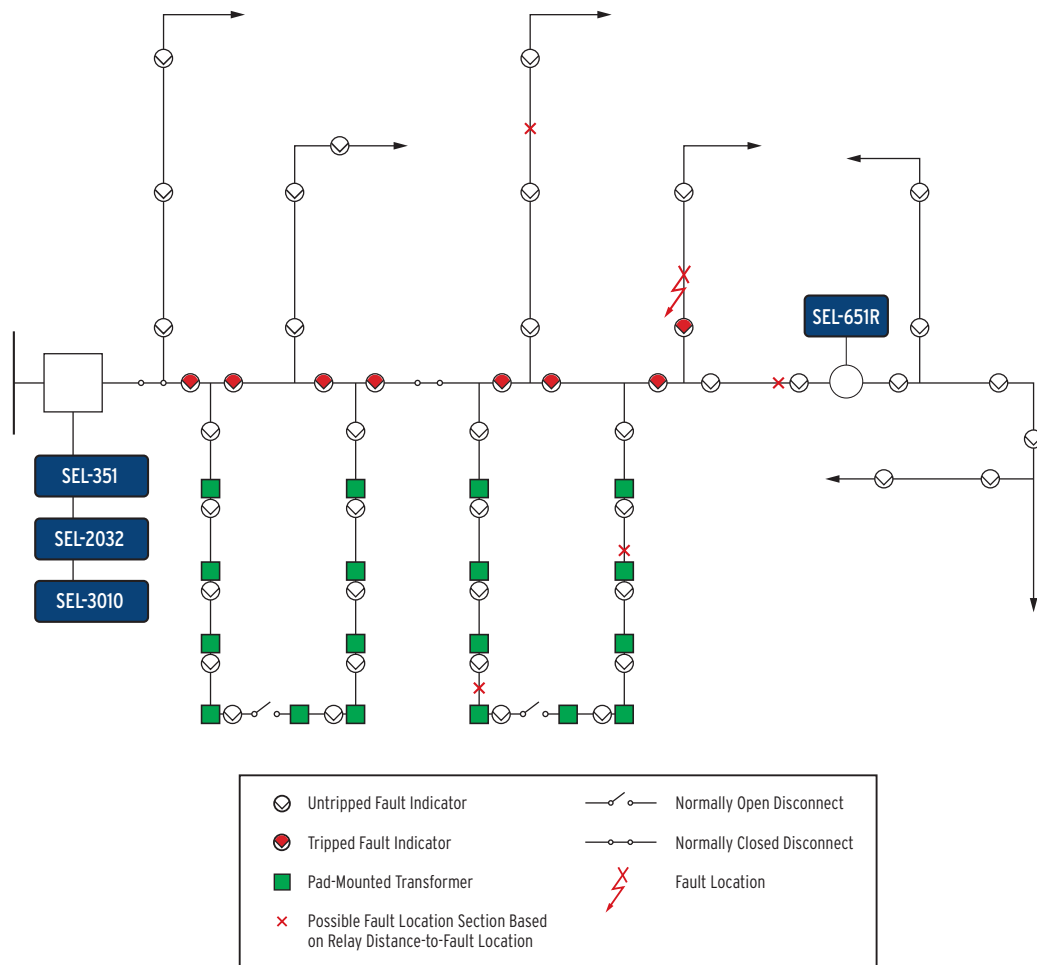
RadioRANGER Wireless Fault Indication Systems with test point fault indicators provide another solution for wind farms!

## Section 6 How do fault indicators fit with other equipment on a distribution system?

Modern distribution relays and recloser controls (such as SEL-351, SEL-351S, SEL-451, SEL-751A, SEL-351R, and SEL-651R) have distance-to-fault location ability. Substation relays determine the fault location as the distance from the substation to the fault.

Because most distribution feeders have multiple taps and multiple conductor sizes and types, the relay distance-to-fault information indicates multiple possible fault locations. Therefore, the line crew is unable to determine which tap to follow to find the fault.

Think back to this diagram:



Combining fault location information from the SEL relays and recloser controls, and fault path information from the FCIs, provides crews with the information they need to promptly

find the faulted section. This combination of technology expedites line repair, reduces cost, and improves reliability indices.



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