# Low-Cost Fast Bus Tripping Scheme Using High-Speed Wireless Protection Sensors

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# Low-Cost Fast Bus Tripping Scheme Using High-Speed Wireless Protection Sensors

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***Abstract*—Blue Ridge Electric Cooperative (BREC) has implemented a fast bus tripping scheme using high-speed wireless protection sensors as an alternative to a hardwired protection scheme.**

**The fast bus tripping scheme, also known as a zone interlocking scheme, is widely used in radial distribution substations. These substations use an overcurrent relay on either the high-voltage or low-voltage side of the transformer as the primary protection for bus faults. They use overcurrent relays on distribution feeders to provide protection for feeder (out-of-bus-zone) faults. In the fast bus tripping scheme, the bus overcurrent relay trips for an overcurrent condition unless blocked by a downstream feeder relay. A short time delay is used to ensure dependable blocking for downstream feeder faults.**

**For this scheme to work, each feeder relay must be able to rapidly communicate a block signal to the bus relay using either hardwired control circuits or high-speed communications via copper or fiber-optic cables. This mechanism allows the overcurrent relay on a faulted feeder to issue a block signal to the bus relay while protecting the feeder using standard time-coordinated overcurrent elements. However, adding cables to retrofit existing substations for a fast bus tripping scheme can be expensive.**

**This paper describes the characteristics, dependability, and security of a high-speed wireless protection sensor system and its capability for sending block signals. The paper then provides details on how BREC used this technology in a fast bus tripping scheme in a substation with protection devices from multiple manufacturers and reduced costs by avoiding equipment replacement and field wiring changes while improving worker safety. Finally, the paper presents a summary of the incident energy level reduction achieved by adopting the low-cost fast bus tripping scheme.**

## I. INTRODUCTION

Although a bus differential protection scheme is one of the best protection schemes for bus faults, it is not always used in distribution substations because of the additional equipment and maintenance requirements. As an alternative, a fast bus tripping scheme is an economical solution for providing protection to substation buses in radial electric power distribution systems [1]. This solution requires coordination between feeder relays and bus protection to determine whether a fault is internal (bus fault) or external (feeder fault) to the bus. If a fault occurs on the bus, the bus protection trips the bus circuit breaker, clears the fault, and leaves all feeders that are fed by the bus de-energized. If a fault occurs on one of the feeders, the bus relay expects the feeder relay to clear the fault. If the fault is not cleared because of feeder relay or breaker failure, the bus relay can act as a time-overcurrent backup [2].

To make this scheme work, the feeder relays must send fault indications to the bus relay. Traditionally, the feeder relays use hardwired I/O contacts or dedicated communications to send fault indications. Unfortunately, there are situations where neither hardwiring nor dedicated communications are feasible. Although most microprocessor-based relays or recloser controls have communications capabilities and I/O contacts, adding cabling from the feeder relays to the bus relay can be expensive.

This paper proposes an economical fast bus tripping scheme using high-speed wireless protection sensors that do not require the installation of cables between the feeder relays and the bus relay. The scheme uses the same traditional fast bus tripping principles, but the fault indication comes from wireless protection sensors installed on the overhead feeder distribution lines or substation feeder getaway conductors. When the wireless protection sensor system receiver (which can be installed next to the bus relay) receives the fault indication, it immediately sends the indication to the bus relay using high-speed serial communications.

This paper also describes in detail the benefits of a wireless fast bus tripping scheme and how such a scheme helped Blue Ridge Electric Cooperative (BREC) implement a low-cost and noninvasive solution.

## II. FAST BUS TRIPPING SCHEMES

### *A. Overview*

A fast bus tripping scheme, also known as a zone interlocking scheme, is used to protect substation buses when a fault occurs. In a radial distribution system, this scheme is more economical than differential bus protection and can achieve a minimum clearance time for bus faults close to that of bus differential schemes [1].

The fast bus tripping scheme consists of a relay installed on each feeder for feeder protection and a relay (bus relay) installed on the low side of the transformer as primary protection for bus faults (see Fig. 1). The bus relay and feeder relays are usually equipped with both the instantaneous/definite-time (fast tripping) element (50T) and overcurrent element (51).

If a fault occurs on a feeder, the feeder relay detects the fault and immediately issues a signal to block the fast tripping element of the bus relay. If the fault occurs on the bus, no feeder relay will detect the fault to block the fast tripping element of the bus relay. In this case, the bus relay trips the circuit breaker using its fast tripping element. To avoid race conditions, a short delay is set on the fast tripping element of the bus relay to provide the coordination required between feeder relays and the bus relay.

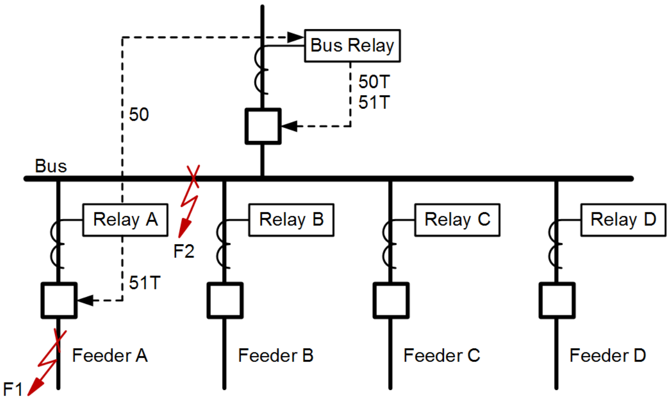

Fig. 1. Fast Bus Tripping Scheme

### 1) *Feeder Faults*

When a fault occurs on the outgoing Feeder A (F1 in Fig. 1), the bus relay elements (50 and 51) may pick up if the fault current is high enough. The Feeder A relay element (51) also picks up, and Relay A immediately sends a block signal to the bus relay. Once the bus relay receives the block signal, it blocks its element (50T) from tripping. This element remains blocked until the feeder relay clears the fault on the feeder.

The bus relay is the feeder protection backup. If the feeder relay fails to clear the feeder fault, the bus relay trips on its 51 element, which is coordinated with the feeder relays so they have time to operate first.

### 2) *Bus Faults*

When a fault occurs on the bus (F2 in Fig. 1), the bus relay elements pick up, but none of the feeder relays pick up. Because the bus relay does not receive a block signal, it trips on its definite-time element (50T) after time-out.

## B. *Implementations*

### 1) *Traditional Hardwired Scheme*

The traditional hardwired fast bus tripping scheme uses a relay output contact of the feeder relay 50 element to send a block signal to the bus relay, as shown in Fig. 2. The feeder relay 51 element is used for tripping.

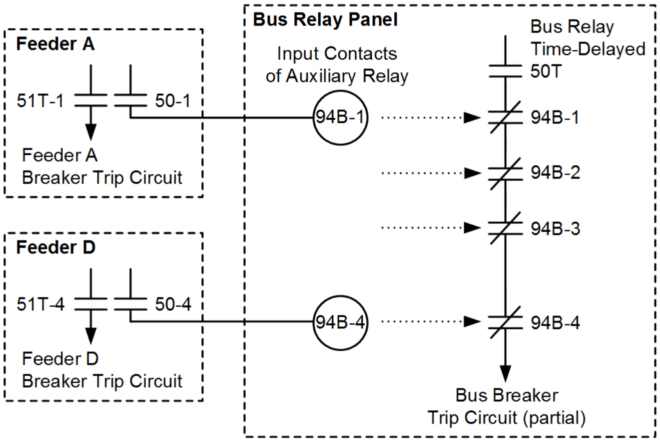

Fig. 2. Example Hardwired Implementation

On the bus relay panel, auxiliary relays can be used to receive the block signals and provide a normally closed contact to be wired in series with the 50T tripping circuit, as shown in Fig. 2. If none of the feeders provide a block signal, the 50T circuit is available to trip the bus circuit breaker when 50T closes. If any feeder provides a block signal, the 50T circuit is interrupted and not able to trip the bus circuit breaker. The bus relay uses a short definite-time delay to avoid race conditions and to provide time for the feeder elements to pick up and the auxiliary relays to open. Similar implementations exist, such as those described in [3].

For microprocessor-based relays, the panel wiring (see Fig. 2) can be avoided by using the internal logic functions of the relays. In this design, an output contact from a feeder relay, assigned to follow the 50 element, sends a hardwired block signal to the bus relay. The bus relay 50T element can then be disabled by activating the block signal input on the bus relay using internal logic.

### 2) *Communications Scheme*

#### a) *High-Speed Serial Communications*

Instead of using hardwired control circuits, fast bus tripping schemes can use high-speed serial communications. The principle behind this scheme is the same as that of the hardwired application. The electricians install serial cables between feeder relays and the bus relay panel (one serial cable from each relay). The serial cables can be either copper or fiber-optic. This implementation uses a serial communications logic processor or another intelligent electronic device (IED) at the bus relay panel to aggregate block signals from multiple feeder relays. The processor output is a single block signal over a serial connection with the bus relay serial port, as shown in Fig. 3.

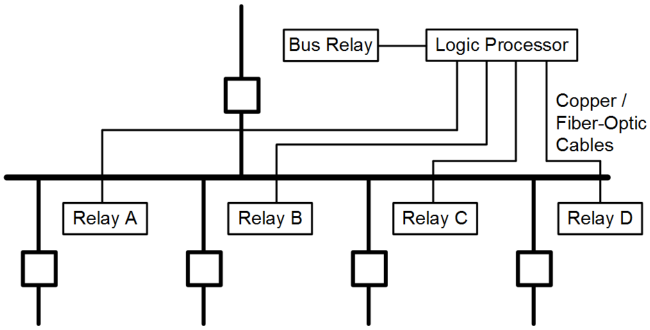

Fig. 3. High-Speed Serial Communications Implementation

### b) IEC 61850 Communications Protocol

IEC 61850 is a standard for substation automation and control communications system design. The principle of a fast bus tripping scheme using IEC 61850 is the same as that of a hardwired application. However, the virtual, high-speed peer-to-peer Generic Object-Oriented Substation Event (GOOSE) messages provide the block signal to the bus relay instead of physical relay I/O contacts.

This implementation requires an IEC 61850 network system in which information is exchanged by IEDs through an Ethernet network, as shown in Fig. 4. GOOSE message transmission is event-driven and any relay can publish messages when an event such as a fault detection occurs. Any device on the same network can be configured to subscribe to specific GOOSE transmissions. In the fast bus tripping scheme, the feeder relays publish GOOSE transmissions containing the block signal and the bus relay is configured to subscribe to these transmissions. Further details of IEC 61850 communications systems and protocols are beyond the scope of this paper.

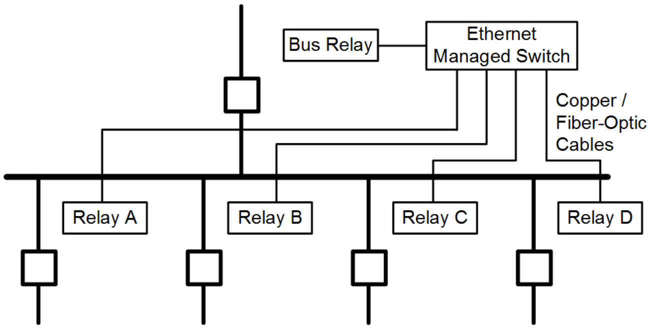

Fig. 4. IEC 61850 Implementation

## C. Wireless Fast Bus Scheme Principles

As mentioned previously, fast bus schemes work well when all the protective relays in the scheme can communicate block signals via hardwired connections between contact I/O or high-speed digital channels. There are, however, situations where hardwiring is not feasible and high-speed digital communication is not available. For example, some or all the feeder relays could be electromechanical relays with no communications. Another example is a substation with microprocessor-based relays with communications capabilities but no dedicated communications cabling between the bus relay and the feeder relays. Adding communications cabling or hardwiring between relays can be difficult and expensive.

For example, in Fig. 1, if one or all the feeder relays do not have communications cabling or hardwiring to the bus relay, it is not possible to implement a fast bus scheme without upgrading equipment. In this scenario, the bus relay time-overcurrent curves are set to coordinate with the feeder relays so that the bus relay does not trip for feeder faults. This comes at the price of slow tripping on bus faults, which could impact safety, equipment life, power quality, and reliability.

A high-speed wireless protection sensor system can help in this situation. This system consists of a line-powered current sensor that detects fault currents based on a set threshold and communicates this information to a receiver device. The fault detection and system communications latency are short enough to make the system viable for protection applications such as a fast bus tripping scheme. Fig. 5 shows how the high-speed wireless protection sensor system can be applied to enable a fast bus trip scheme.

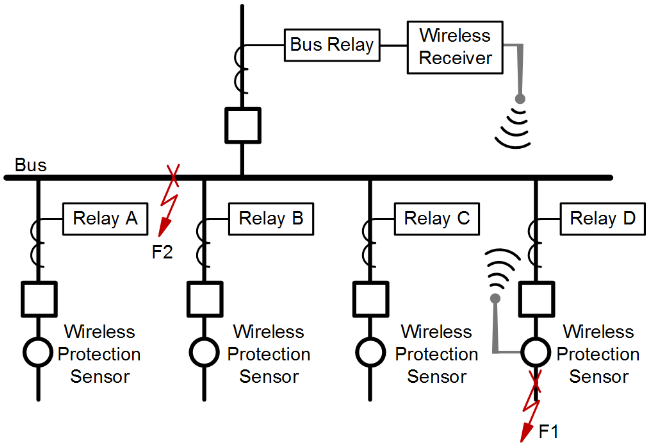

Fig. 5. Wireless Fast Bus Tripping Scheme

In Fig. 5, the high-speed wireless protection sensors are installed on each feeder and communicate with the wireless receiver connected to the bus relay. The wireless sensors are line-powered and can be set to pick up on fault currents based on each individual feeder. In Fig. 5, F1 is detected by both Relay D and the wireless sensor on the feeder. Relay D trips for this fault, and the high-speed wireless protection sensor sends a fault indication signal to the wireless receiver confirming the feeder fault. This signal is used to block the fast bus trip overcurrent elements on the main breaker.

When a fault occurs on the bus (F2 in Fig. 5) in the fast bus trip scheme, the wireless protection sensor detects no fault current and restrains its blocking signal. Accordingly, the bus instantaneous elements are not blocked. Coordination of instantaneous elements between the feeder and the main breaker is achieved by setting a time delay of a few cycles on the instantaneous elements of the main breaker relay. The actual time delay is selected to provide adequate margin for the block signal to be received in time to block the fast trip during worst-case conditions.

To provide backup for the feeder breaker, a slow-acting time-overcurrent element is always enabled in the bus relay. This element covers cases where a feeder block signal is received but no feeder breaker trips.

### D. High-Speed Wireless Protection Sensor System Application Guidelines

The following principles must be considered when applying a high-speed wireless protection sensor system in fast bus protection schemes [4]:

- The protection devices should not make protection decisions based solely on fault data from the wireless protection sensor system. The protective relay must never trip a circuit breaker (nor a recloser control trip a recloser) based solely on sensor information. Instead, the protection device must sense a fault using overcurrent elements before acting on the additional sensor information.
- Protection devices should revert to a backup scheme in the absence of sensor data. This fail-safe principle covers cases when the wireless sensors are unable to provide fault information to the protection devices. Because data loss can occur in any radio system, the fast bus protection scheme discussed in this paper should include logic to monitor the sensor system data and identify problems early.
- The protection device should only use the sensor fault information to augment existing schemes when the system has been fully designed, commissioned, and enabled. Because the wireless protection sensor system gives more visibility into the distribution power system, the protection devices can use the sensor fault data to improve protection decisions.

## III. BENEFITS AND LIMITATIONS OF WIRELESS FAST BUS SCHEMES

In this section, we discuss the benefits of a wireless fast bus scheme compared with a traditional fast bus tripping scheme and the benefits of applying a wireless scheme for bus protection. Wireless schemes also have certain limitations compared with traditional fast bus tripping schemes, so this section also presents techniques to overcome these limitations.

### A. Benefits

#### 1) Easy Installation

One of the key advantages of a wireless fast bus scheme is its easy installation. The wireless fast bus tripping system requires neither installing hardwired or communications cables nor building an Ethernet communications network. It does not require digging holes in the ground, making trenches, installing conduits, pulling cables, covering trenches, terminating wires in terminal blocks, or routing wires and cables from the terminal blocks to the destination via I/O contacts or a physical communications interface. A high-speed wireless protection sensor installation offers a substantial cost savings for relays installed in the substation switchyard.

Installation of the wireless sensors can be performed with a hot stick and can take as little as 15 minutes. Traditional installations can take days to implement depending on the number and length of the cable runs and crew availability.

Another advantage is that the installation of wireless sensors is noninvasive. Installing a wireless fast bus scheme requires fewer modifications to existing equipment than traditional fast bus schemes, whether it is a retrofit system or a new installation. It only requires making changes in the bus relay. The only physical interface between the wireless receiver and the bus relay is a serial cable connection. The length of the cable can be short because the wireless receiver can be installed very close to the bus relay. This can significantly reduce installation time and costs.

#### 2) Ability to Overcome Legacy Feeder Relay Limitations

The electric power system today is protected by relays of varying age and capabilities. Some relays provide limited capabilities for supporting fast bus scheme design. Once the fast bus scheme has been designed the first time, a wireless protection sensor fast bus scheme can be implemented as a “bolt-on” solution, saving valuable engineering resources in future installations.

Some electromechanical feeder relays do not include a 50 element and therefore have no ability to initiate a block signal. Even for electromechanical feeder relays that do include a 50 element, the protection engineer may wish to configure the element for instantaneous tripping of high-current faults rather than to initiate a block signal.

While most modern microprocessor-based relays offer programmable contacts and high-speed communications, there are some solid-state analog and digital relays still in service and available for purchase today that do not offer programmable output contacts and that may not offer enough 50 elements to support a traditional fast bus scheme design. Some of these legacy relays also lack support for high-speed digital communications.

Some distribution substations are built using reclosers in place of feeder breakers. Hydraulic recloser designs were never intended for integration with other systems and, as a result, provide no output signaling.

Finally, there may be devices connected to the bus that are protected with fuses, such as capacitor banks, station service transformers, or Automatic Meter Reading (AMR) signal injection transformers. Fuses, of course, have no ability to report a block signal to the bus relay for faults in their zone.

For any of these cases, the wireless protection sensor provides a simple solution. The wireless protection sensor system has its own pickup settings and can be used as a bolt-on 50 element set specifically to detect the presence of a fault and provide the block signal to the bus relay. This solution overcomes a lack of available protection elements and output signaling in an easily installed package and allows users to economically include fuse-protected apparatus on the bus in the fast bus scheme.

### *B. Limitations*

#### *1) Loss of Communications*

Loss of communications can occur in a wireless fast bus scheme for various reasons. The availability of wireless communications is not always 100 percent. An availability of 99.99 percent translates to 52.56 minutes of communications outage per year. If this outage occurs when a fault occurs, the bus relay will not receive the block signal and therefore will trip on its fast tripping element. However, the probability of the outage and fault occurrence at the same time is very low.

Another cause for loss of communications is interference. The system can suffer interference any time, although a well-designed installation minimizes interference. The interference could impair the wireless receiver's ability to decode the fault indication from the wireless sensors. One possible solution is to choose a frequency channel that experiences the least amount of interference in the area.

#### *2) Problems With Inrush and Transients*

A key difference between the block signals sent by high-speed wireless sensors and a feeder relay is that wireless sensors are susceptible to inrush, other transients, and other power system disturbances. It is possible that the wireless sensors would pick up under these conditions and send a block signal to the bus relay. However, if the bus relay supervises the block signal that comes from the sensors with protection elements such as 50 or 51, it is possible to overcome this issue (see Section IV, Subsection B).

#### *3) Momentary Output*

Because of the line-powered nature of the sensors, the wireless protection sensor system may not transmit fault signals for the duration of a fault, making the wireless receiver deassert the fault bit. The protection logic design must account for a momentary block signal. If the duration of the block signal is shorter than the duration of a fault, then the relay bus will trip after the block signal is discontinued. This leads to a bus trip that leaves all feeders de-energized. One way to resolve this problem is to seal or latch the block signal received until the fault is cleared. Section IV, Subsection B provides more details regarding this implementation.

#### *4) Multifeed Issues*

When distributed generation is connected to a feeder or when the feeder serves a large industrial load, these connections can provide fault current to faults on the bus or upstream of the bus. Additionally, if there is a grounding bank on a distribution feeder, the bank can provide fault current to ground faults on the bus or upstream of the bus. To apply fast bus tripping schemes on these multifeed systems, feeder and main relays must use directional overcurrent elements. The directional overcurrent element in the bus relay determines whether the fault is upstream of or potentially on the bus, and the element will trip for faults in the bus direction unless blocked. The directional elements in the feeder relays determine whether the fault is on the feeder and, therefore, whether to send the block signal to the bus relay.

Because the wireless protection sensors are typically nondirectional overcurrent devices, the wireless fast bus tripping scheme is not applicable to multifeed systems.

## IV. WIRELESS FAST BUS SCHEME DESIGN

### *A. Installation*

Installation requirements for a wireless fast bus scheme are typically very easy to meet because of the close wireless range of a substation environment. However, it is worth the time to consider these requirements methodically to ensure proper operation. The deployment of any high-speed wireless sensor system involves the phases discussed in the following subsections.

#### *1) Research*

Research includes installation site selection, antenna selection for the receiver, and a wireless link budget estimate. For short-range applications such as a fast bus tripping scheme, the sensors are usually near the receivers. A deployment is considered short range if the sensors are physically visible from the receiver antenna and there are no obstructions between them. Short-range systems do not require extensive system planning, but a simple link budget estimation should be performed. A wireless link budget accounts for all losses and gains in a radio link from the transmitter and the receiver. Link budget calculations are used to determine the amount of link margin available for a given radio link. For a reliable link, the receive power must be greater than the effective receive sensitivity. The link margin is the difference between received power and effective receive sensitivity.

Fig. 6 shows a sample link budget for a wireless system:

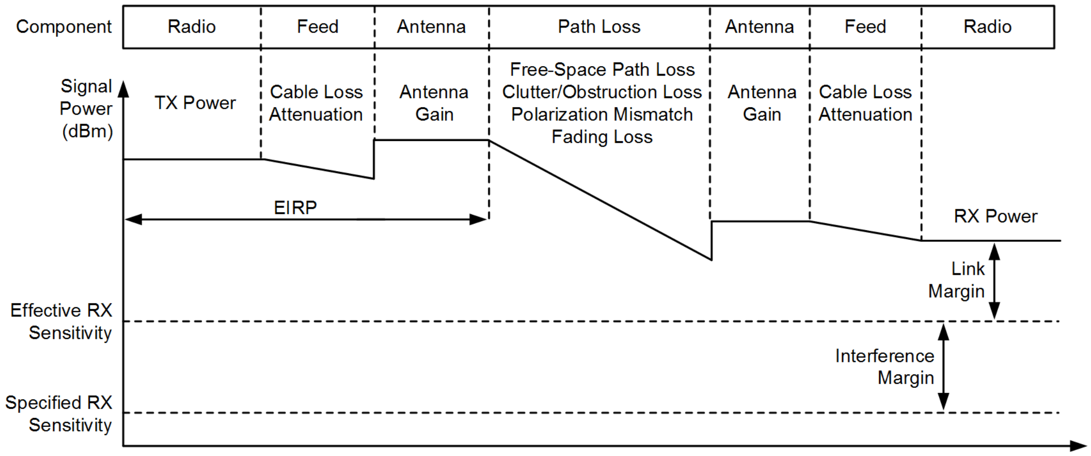

Fig. 6. Link Budget Analysis

### 2) *On-Site Survey*

If the sensors are in the line of sight of the receiver antenna, no path study is required. An onsite precommissioning test can simplify the wireless fast bus tripping scheme deployment. For the test, place a temporary antenna at the proposed antenna installation site, connect a receiver, and then position a wireless protection sensor at a safe location (near the proposed feeder installation). Manually trigger faults on the sensor using a test current source, such as a handheld current loop.

If the receiver detects the manual fault indications from the sensor, this provides confidence that the wireless protection sensor system will work for the wireless fast bus tripping scheme. If the receiver cannot detect the fault indications from the sensor, relocate the receiver antenna, sensor, or both until the receiver consistently receives fault indications from the sensor. The wireless receiver may also include a function that measures the received signal strength, which can be used to fine-tune the system.

### 3) *Physical Installation*

Wireless sensors can be installed by using an industry-standard hot stick. The device orientation after the installation is important for a reliable wireless link. A hot stick can be used to orient the device so that the internal antenna in the wireless sensor is positioned for the best signal propagation.

The wireless receiver typically communicates with multiple sensors and requires an external omnidirectional antenna for the best communications link. Using a low-loss radio frequency (RF) cable reduces the signal loss, further improving the link budget. Typically, the wireless receiver is installed in a relay building or a cabinet in the substation yard. To protect the receiver device from lightning and other transients that could potentially damage the electronics, it is important to install a surge protector between the antenna cable and the receiver. The surge protector should be bulkhead-mounted to a properly grounded metal surface.

## B. *Wireless Sensor and Receiver Settings*

High-speed wireless sensors require some configuration prior to installation. The protection behavior is defined by a fault detection overcurrent pickup threshold, which needs to be set according to the specific feeder and substation characteristics. When the current sensed exceeds these setting values, the sensor communicates the fault signal to the receiver via high-speed wireless link [4]. The overcurrent pickup should be calculated based on the system protection scheme and other protective relays in the system. In general, the overcurrent pickup should be set as low as possible (to maximize sensitivity) while allowing an ample security margin above the peak steady-state load. If the wireless protection sensor picks up transiently for inrush or switching conditions, this is of minimal concern because the bus relay will take no action on the transient block signal.

The wireless system requires unique sensor identifiers and network settings to ensure the wireless receiver recognizes messages from the wireless protection sensor, and to allow more than one system to be used in the same substation without conflict. Fig. 7 shows an example of a system that comprises two high-speed wireless sensor systems installed in the same substation. These systems are expected to operate independently. Because the RF communications between these systems cannot be isolated from each other, the equipment of each network requires a network identifier to allow co-located operation.

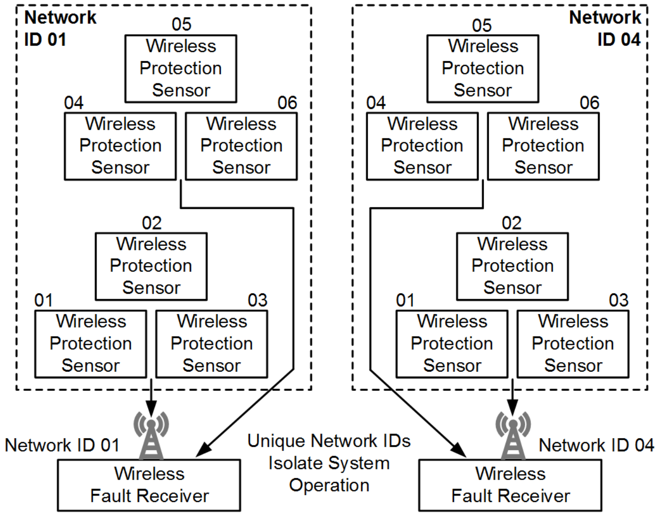

Fig. 7. High-Speed Wireless Protection Sensor System

In the example in Fig. 7, one system has a network ID of 01 while the second system has a network ID of 04. Note that the wireless sensor and the receiver on the same network must be set to have the same network ID.

Finally, the serial communications interface ports of the wireless receiver require bits per second (bps) and addressing settings that are compatible with the peer device, whether it is a logic processor or another IED.

### *C. Integrating High-Speed Wireless Protection Sensors Into an Existing Fast Bus Scheme*

Consider an example substation with three feeders using a serial communications-based fast bus trip scheme similar to the scheme described in Section II, Subsection B. To this substation, we add a fourth feeder equipped with a recloser control that is not capable of providing a high-speed serial communications connection.

Because the Feeder 4 fault pickup signal cannot be sent directly from the recloser control to the bus relay, the fast bus trip scheme is missing the information it needs to properly function. If the scheme was enabled anyway, it would work correctly for bus faults and feeder faults on Feeders 1, 2, or 3. However, a fault on Feeder 4 would appear to be a bus fault, and the bus protection would operate.

To overcome this shortcoming, high-speed wireless protection sensors can be installed on the load side of the Feeder 4 recloser (as shown in the expanded system in Fig. 8). These sensors wirelessly transmit fault information to a receiver in the substation control house. The sensor installation cost is minimal because the sensors do not require a power source nor wiring.

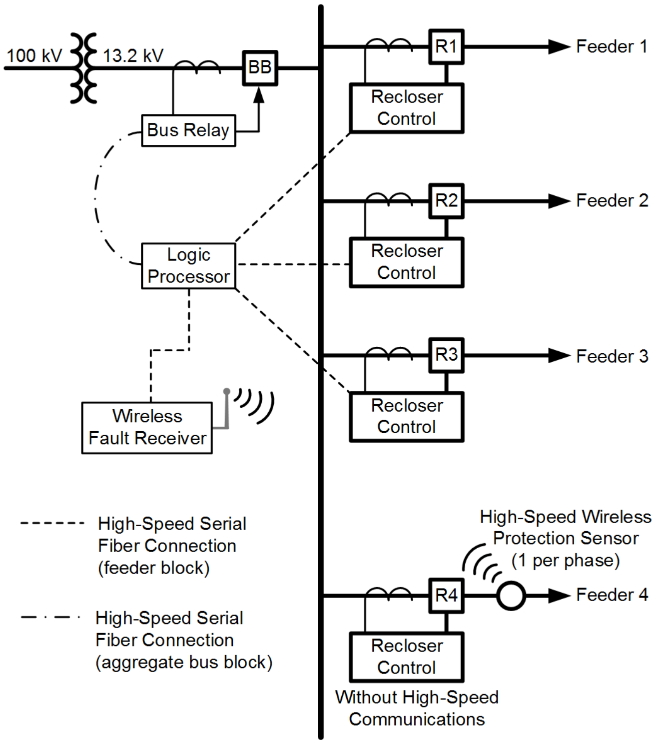

Fig. 8. Traditional and Wireless Fast Bus Tripping Schemes Combined

The wireless receiver qualifies the incoming protection sensor signals and encodes the result in a logic bit indicating the fault status on Feeder 4. This bit is transported over a high-speed serial communications link that is compatible with the logic processor. The logic processor combines the Feeder 4 fault pickup signal with the Feeder 1, 2, and 3 pickup signals, and the single block signal is then communicated to the bus relay.

#### *1) Seal-In Logic*

For a fault on Feeder 4, the high-speed wireless protection sensor detects the instantaneous overcurrent condition and communicates the fault state to the wireless receiver. The wireless receiver logic provides a fault signal of finite duration, which may drop out while the fault is still present. Because of this, the feeder fault pickup signal must be sealed in by the bus relay. This seal-in function also covers the pickup signals from Feeders 1, 2, and 3, which are encoded in the same Any_Feeder_Faulted signal by the logic processor.

The logic diagram in Fig. 9 shows the seal-in function. Note that the internally derived block signal is only unsealed when the 51 element fully resets. This prevents a premature dropout of the block signal for faults that intermittently assert the overcurrent element pickup.

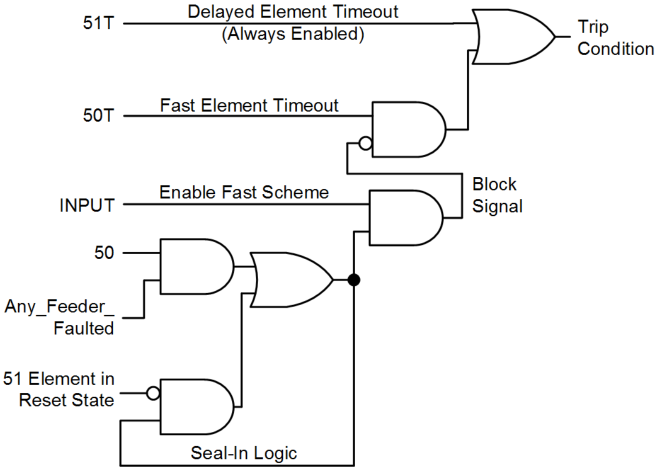

Fig. 9. Bus Relay Seal-In and Enable Logic

#### *2) Fast Bus Scheme Enable/Disable Control*

The Enable Fast Scheme input in Fig. 9 controls the blocking logic. When this input is deasserted, the block signal is disabled and only the 51T element remains in service. This time-delayed element must be coordinated with all feeder reclosers. Because it is unconditional, the 51T element is always able to initiate a bus trip for backup in case of feeder protection problems.

#### *3) Loss of Wireless Communications Detection*

The high-speed wireless protection sensors normally transmit a periodic link health signal, powered by the line current. In light feeder load conditions, one or more sensors may stop transmitting the link test signals. The wireless receiver monitors the link signals and provides a status point. A temporary loss of link caused by light feeder loading is not problematic for the fast bus scheme because the sensors still detect faults and transmit the wireless fault message. The scheme operation is not adjusted in this situation because of the fail-safe characteristic of the blocking scheme.

A longer signal outage may indicate a problem with the wireless system itself. The logic processor can monitor the link status and assert an alarm signal if a link is lost for a considerable period (e.g., 12 hours). This alarm can be monitored at a control center, and the system operator can dispatch a technician to investigate.

#### 4) *Local Monitoring and Targeting*

The wireless fault receiver can expose the individual phase fault indication and link status on a local user interface and through a digital status bit. This display facilitates testing, troubleshooting, and commissioning activities. Users can also use custom target logic or display logic in the bus relay to provide indication of a fast bus trip.

The logic processor can also monitor the wireless protection sensor fast bus trip scheme block signals and link status and populate a sequential events recorder. This information is valuable for post-event analysis.

## V. BLUE RIDGE ELECTRIC COOPERATIVE FAST BUS TRIPPING SCHEME

### A. *Installation*

BREC recently commissioned a rural 100 kV/13.2 kV substation. This distribution substation supplies customers via four feeders.

To maximize worker safety in the substation yard, bus fault duration must be minimized to limit the arc-flash incident energy exposure, per National Electrical Safety Code (NESC) guidelines. BREC frequently employs fast bus tripping schemes as a proven method for achieving quick bus fault clearing times. The short fault duration of a typical fast bus scheme typically reduces the arc-flash incident energy to less than 2 cal/cm$^2$, which is well under BREC's 8 cal/cm$^2$ standard rating for personal protective equipment (PPE). This ensures workers remain comfortable in their work environment and reduces the likelihood of human performance errors in hot conditions.

#### 1) *Standard Installation – Serial Connection*

Each feeder is protected by a microprocessor-based recloser control that communicates with a logic processor using a dedicated high-speed serial communications link. Each feeder recloser control is programmed to send a block signal to the logic processor when an overcurrent element has picked up and is timing on a feeder fault. In each recloser control, a communications channel monitoring system continuously tests the serial link and asserts an OK status bit when the link is active.

The logic processor qualifies each feeder block signal with its communications status bit, aggregates them into a single block element, and transmits the result to the bus protective relay over a dedicated high-speed serial link. The bus logic uses this input as a block signal for the fast bus tripping element.

#### 2) *High-Speed Wireless Protection Sensor Installations*

On one feeder, BREC specified a recloser control that does not support protection-speed communications and has no output contacts suitable for sending block signals. To meet the tight bus fault clearing speed requirement, the utility was faced with the prospect of installing a bus differential scheme. This would have been very expensive because it requires a larger substation footprint to accommodate the extra current transformers (CTs) in the feeder positions, plus additional design, wiring, testing, and maintenance efforts.

The commercial availability of high-speed wireless protection sensors vastly improved the picture. By installing the wireless sensors on the load side of the incompatible IED, it became possible to use the fast bus trip scheme. The high-speed protection sensors wirelessly transmit the fault status directly to a receiver module installed in the control house, independent of the protective IED.

When a feeder fault occurs, the high-speed sensor(s) on the faulted phase(s) detect the high-level through-current and transmit wireless messages to the receiver module. The receiver, in turn, sends a block signal to the protection logic processor using the same high-speed serial communications protocol as the standard feeder IEDs.

Because the wireless protection sensors required no power connections, the technicians could select a convenient location to install them. As shown in Fig. 10, the sensors are installed on the outbound jumpers from a station-mounted recloser.

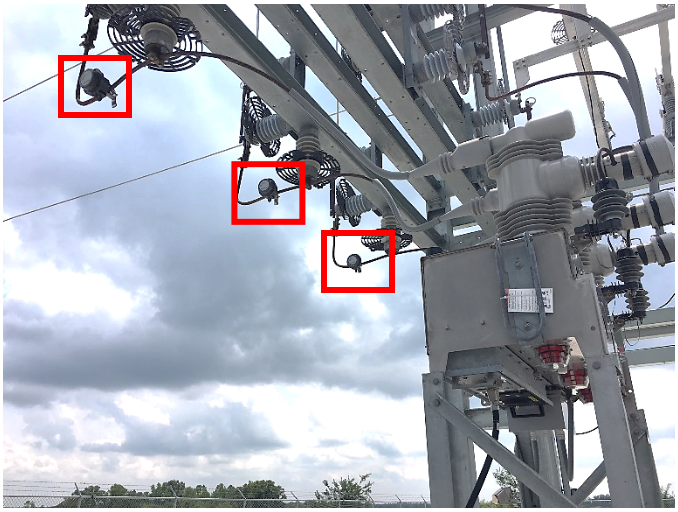

Fig. 10. High-Speed Wireless Protection Sensor Installation

### B. *Testing*

During the design phase, BREC arranged for speed tests to help determine the suitability of the high-speed wireless protection sensors for the application.

Their consultant performed end-to-end testing in a laboratory environment with a wireless protection sensor mounted on a conductor loop with a controllable current source. The wireless receiver module was connected to a logic processor, and the logic processor in turn connected to a bus relay of the same design used in BREC's standard fast bus tripping scheme. The logic processor settings were representative of the standard scheme.

The technician measured the worst-case average and peak delay between fault current application and block signal recognition in the bus relay. After ten tests, the longest measured time was 21 ms, and the average was 17 ms. This performance fell within the targeted 50 ms window for the BREC fast bus trip scheme.

### *C. Calculations*

High-speed bus protection improves worker safety by reducing the incident energy level for bus faults. The incident energy is directly proportional to the fault duration. For standard bus protection without a fast scheme, a 7.4 kA single-phase-to-ground bolted fault on the substation bus has a modeled open-air incident energy of 11.7 cal/cm$^2$, with a fault clearing time of 1,011 ms. For this same fault type, the fast bus tripping scheme reduces the clearing time to 133 ms, and the incident energy is reduced by a factor of 133/1011, to 1.54 cal/cm$^2$.

Using the same reduction factor for a three-phase fault, the open-air incident energy drops from 13.7 to 1.8 cal/cm$^2$. BREC implemented the low-cost fast bus tripping scheme in their substation, which reduced the open-air incident energy by 86.6 percent.

## VI. CONCLUSION

Fast bus tripping schemes are an economical solution for providing protection to substation buses in radial distribution systems when bus differential is not available. The traditional fast bus tripping scheme requires physical installations of cables (either copper or fiber-optic) for feeder relays to send the block signal to the bus relay. Because the proposed wireless fast bus tripping scheme using high-speed wireless protection sensors does not require these physical installations, the scheme offers substantial cost savings for feeder relays, especially ones that are installed in the switchyard.

Wireless fast bus tripping schemes also provide several benefits. Wireless protection sensors are very easy and quick to install. The installation uses a standard hot stick and can take just a few minutes. The installation is noninvasive because no setting changes are needed in feeder relays for retrofit systems and no special feeder relay programming is required for greenfield projects. This can significantly reduce installation time and costs. The fast bus tripping scheme can be an ideal solution for protective relays that do not have either I/O contacts or communications capabilities. It can also be used to integrate legacy or nonstandard devices into a fast bus scheme.

BREC's real-world application of the wireless fast bus tripping scheme discussed in the paper proves the scheme is effective in providing bus protection. Furthermore, it is a solution that can achieve similar performance to a traditional fast bus tripping scheme. One of the key reasons for using bus protection is to reduce the arc-flash PPE categories. BREC initially had the option of installing a new set of CTs and a new relay or installing the wireless protection sensors and system. Choosing the wireless option has significantly saved both installation costs and time. The wireless fast bus tripping scheme has also reduced the arc-flash category from 3 to 1.

## VII. REFERENCES

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## VIII. BIOGRAPHIES

**Eric McCollum** is the supervisor of power control and system reliability for Blue Ridge Electric Cooperative and is directly responsible for the collection and mitigation of outages on the system. He has over 30 years of experience with electric distribution systems. Eric has worked on outage data collection and actual restoration of the Blue Ridge system, and he has had similar responsibilities on sister systems in the Southeast.

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**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 hardware for power utility products. Shankar currently holds 14 SEL patents, and he is an inventor on several patents that are pending in the field of distribution sensors, precise timing, and wireless communications. He currently holds the position of engineering director for the distribution controls and sensors group at SEL.

**Jeremy Blair**, P.E., joined Schweitzer Engineering Laboratories, Inc. as an application engineer in 2013. Previously he worked for Entergy Corporation as a distribution planning engineer with responsibilities in distribution system planning, protection, power quality, and automation in Baton Rouge, LA. He also managed Entergy's Automatic Load Transfer and Sectionalization Program over its four-state territory. Jeremy earned his B.S.E.E. from Louisiana Tech University and his M.S.E.C.E. from Georgia Institute of Technology. He is a licensed professional engineer in the state of Louisiana.

**David Keckalo** received his B.S. degree in electrical engineering from the University of British Columbia in 1987. He joined Schweitzer Engineering Laboratories, Inc. (SEL) in 1998 and is a lead power engineer in distribution controls and sensors. In previous positions, he worked on the design and development of many of SEL's protective relay products, including product literature. Prior to SEL, David held various positions at BC Hydro, concluding 10 years of service as a senior distribution engineer. He holds one U.S. patent, is a registered professional engineer in British Columbia, and is a member of the IEEE.

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