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

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Distribution Substation Bus Protection
Common Small Substation Schemes

- Fused high-side protection
- Bus overcurrent protection
- Fast bus tripping scheme
Fuse-Based Bus Protection

Fuses on high-voltage side of transformer provide:

- Transformer protection (F3)
- Bus protection (F2)
- Backup protection (F1) – must coordinate with feeder relay
Bus Overcurrent Protection

Overcurrent relay on bus provides

- Bus protection (F2)
- Backup protection (F1) – must coordinate with feeder relay
Fuse-Based and Overcurrent Bus Protection

Bus Faults Take Long Time to Clear

- High arc-flash incident energy for bus faults
- High through-fault stress on transformer
How Can Utilities Maximize Worker Safety in Substation Yard?

- Utilities should limit arc-flash incident energy exposure for bus faults.
- NESC requires cumbersome PPE for arc-flash incident energy >8 cal/cm².
- Fast bus scheme is proven method to reduce bus fault duration.
- Typical fast bus scheme reduces arc-flash incident energy to <2 cal/cm².
Each feeder relay sends block to bus relay when 50 element picks up.

Signal provided by dry contact to input on bus relay.
Wired Fast Bus Trip Scheme

Bus Relay

- Trips on 50T element if no block is received
- Also trips on 51T as backup, coordinated with feeder relay 51T
50T in bus relay is blocked.

Feeder relay trips on 51T.

Bus relay trips on 51T if feeder breaker fails to clear fault.
Wired Fast Bus Trip Scheme
Bus Fault (F2)

- Bus relay receives no block from any feeder relay
- Bus relay trips on 50T for bus faults

Bus faults are now cleared quickly
Serial communications links replace discrete control circuits.

Communications-Based Fast Bus Trip Scheme
Similar in Concept to Wired Scheme
Communications-Based Fast Bus Trip Scheme
Similar in Concept to Wired Scheme

Logic processor combines feeder relay block signals into single block signal for bus relay
Communications-Based Fast Bus Trip Scheme

Feeder Relay

- Each feeder relay sends block to bus relay via logic processor when 50 element picks up
- Signal provided by high-speed communications
Fast Bus Trip Scheme With Reclosers
Reclosers Often Installed as Feeder Breakers

- May not have programmable output contact for wired schemes
- May not support compatible protection speed digital protocol
- May prove difficult to install cable runs from yard to control house
In this example, only Feeder D has a recloser.

If Recloser D cannot provide compatible blocking signal, are we stuck?
Sensors provide block signals that we are unable to create with incompatible or remotely mounted equipment.
Install sensors on each feeder breaker or recloser egress.

Existing substation with no fast bus tripping scheme.

**Equipment Needed for Wireless Scheme**

- Bus
- Bus Relay
- Wireless Receiver
- Relay A
- Relay B
- Relay C
- Relay D
- Wireless Protection Sensor
Equipment Needed for Wireless Scheme

Install wireless receiver and antenna at control house
Connect wireless receiver to bus relay or logic processor.
Wireless Protection Sensor Overview

- Introduction
- Characteristics
- Use in fast bus tripping scheme
Wirelessly “Connect” Fast Bus Scheme
Program Bus Relay to Use Feeder Pickup Status to Block Fast Element

- No physical connection required between bus relay and feeder relays or recloser controls
- Wireless receiver provides pickup status from each feeder

Fast bus tripping scheme can truly be implemented without wires
Wireless Protection Sensors Attach Directly to Primary Conductor

- One sensor required per phase conductor
- Sensors are line-powered (no power connections)
- Fault messages transmitted regardless of pre-fault current levels
- Unique communications addressing used
- Overcurrent pickup level is settable
Wireless Receiver Located in Control House or Outdoor Enclosure

- Supports up to 4 three-phase feeders
- Requires outdoor antenna
- Is dc powered
- Monitors received signals from associated sensors
- Provides status from each sensor in high-speed serial communications format
System Health Monitoring and Loss-of-Communications Detection

• While powered up, each sensor transmits periodic link test message to prove radio path continuity

• Receiver maintains status register for each sensor
  ▪ When receiving link test messages, sensor status bit is set (LINK up)
  ▪ When successive link test messages have not been received, sensor status bit is cleared (LINK down)
System Health Monitoring and Loss-of-Communications Detection

LINK down state is expected during light load conditions when there is insufficient line current to power sensor electronics and sensor can no longer transmit link messages.

In this situation, wireless protection sensor and receiver system still responds to faults.
System Health Monitoring and Loss-of-Communications Detection

LINK down state can also indicate issues with sensor itself, wireless signal path, or wireless receiver antenna

In this situation, wireless protection sensor and receiver system may not receive fault indication
Wireless Protection Sensor Health Monitoring

Bus Relay or Logic Processor Can Monitor LINK State for Each Sensor

- Isolated, temporary, or periodic LINK down states may be logged with no further action.
- If sensor LINK down states persist for extended period, disable fast bus trip scheme.
Wireless Fast Bus Scheme Advantages

• Saves on cost by avoiding cable runs to substation
• Avoids addition of standalone CTs when feeder protection is unable to provide pickup signal
• Can be used in hybrid scheme, where some feeders provide wired or communications-based pickup signal and others do not
Wireless Protection Sensor Considerations

• Radio system must be reliable, generally measured by availability of radio system — acceptable range is 95% to 99.95% for this type of application
  - 95% translates to 438 hours of link outage per year
  - 99.95% translates to 4.4 hours of link outage per year
• Sensors may respond to inrush current
• Sensor fault declaration may drop out during fault
• Sensors are nondirectional
Wireless Protection Sensor Best Practices

• Protection devices should not make decisions based solely on sensor operation.

  Overcurrent supervision should be used.

• Protection devices must have designed backup behavior in case sensor fails to operate.

• Protection schemes should use fully commissioned sensor system, which includes radio path survey, testing, and commissioning study.
Blue Ridge Electric Cooperative (BREC) Recently Constructed Rural Substation With Communications-Based Fast Bus Trip Scheme

- Scheme can improve worker safety by reducing incident energy level
- BREC is comfortable using communications-based scheme in other substations
Incompatible Equipment

• New substation has four feeders (three use familiar equipment)
• Fourth feeder topology led BREC to install different protection package
• Recloser control provides no digital or discrete output that can produce fast-acting pickup signal for fast bus blocking function
No Fast Bus Scheme

Missing pickup signal from Feeder 4 recloser left BREC with some unpleasant choices

1. Operate station without fast bus tripping scheme
2. Install extra equipment (CTs and relay) to bring back Feeder 4 pickup state
After investigating sensor and receiver system, BREC installed:

- Sensor on each phase of Feeder 4
- Antenna on control house
- Receiver in control house
- Serial communications cable from receiver and logic processor

Hybrid Fast Bus Scheme

Feeder 1: R1
Feeder 2: R2
Feeder 3: R3
Feeder 4: R4

Without High-Speed Communications

Serial communications cable and logic processor:
- High-Speed Serial Fiber Connection (feeder block)
- High-Speed Serial Fiber Connection (aggregate bus block)
How Fast?

BREC and Their Consultant Benchmarked System

• Technician measured worst-case average and peak delay between fault current application and block signal recognition in bus relay

• After 10 tests, longest measured time was 21 ms and average was 17 ms

• Performance fell within targeted 50 ms window for BREC fast bus trip scheme
• Sensors are installed on outbound jumpers of station-mounted recloser

• Other than antenna on control building, there were no outdoor cables to connect
For feeder fault, logic processor asserts Any_Feeder_Faulted signal and transmits it to bus relay.
• If bus overcurrent (50) element is asserted, incoming block signal state is sealed in, ensuring block function is maintained until fault is externally cleared.

• Seal-in allows pickup indication to drop out without causing unexpected bus trip.

• Seal-in is broken when bus relay time overcurrent element enters reset state.

Seal-In Logic in Bus Relay Diagram:

- 50T: Fast Element Timeout
- 51T: Delayed Element Timeout (Always Enabled)
- INPUT
- Any_Feeder_Faulted
- 51 Element in Reset State
- Seal-In Logic
- Block Signal
- Trip Condition

Enable Fast Scheme

Seal-In Logic in Bus Relay
Logic Processor

- Serial Communications
- Pickup Messages From Each Feeder
  - RX_Pickup_1
  - RX_Pickup_2
  - RX_Pickup_3
  - RX_Pickup_4

Bus Relay Logic

- Serial Communications
- Combined Status Message for Bus Relay
  - Any_Feeder_Faulted

- Fast Element Timeout
  - 50T
  - Any_Feeder_Faulted

- Delayed Element Timeout
  - 51T
  - (Always Enabled)

- Fast Element Timeout
  - 50T

- Enable Fast Scheme
  - INPUT

- 50

- 51 Element in Reset State
  - 51T

- Block Signal

- Trip Condition

Seal-In Logic
Maximize Worker Safety in Substation Yard

- Bus fault duration must be minimized to limit arc-flash incident energy exposure per NESC guidelines
- Fast bus tripping schemes are proven method for achieving quick bus fault clearing times
- BREC has 8 cal/cm² standard PPE rating
Conclusion

• Wireless protection sensor and receiver system enabled BREC to enjoy benefits of fast bus trip scheme without adding or replacing medium voltage substation equipment

• System required no new cabling between substation yard and control house

• Resulting open-air incident energy of 1.54 cal / cm² is well below BREC’s 8 cal / cm² standard PPE rating
Questions?