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

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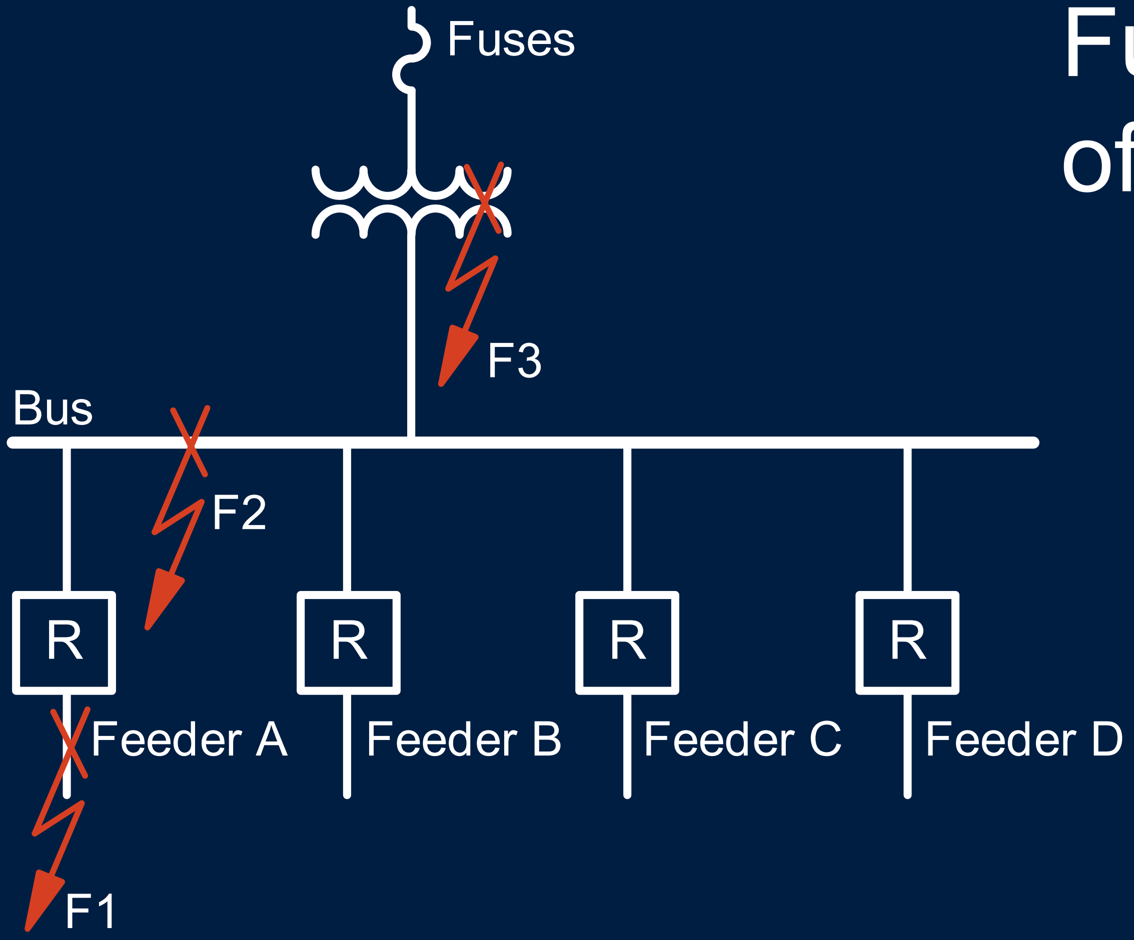
Distribution Substation Bus Protection

Common Small Substation Schemes

- Fused high-side protection
- Bus overcurrent protection
- Fast bus tripping scheme

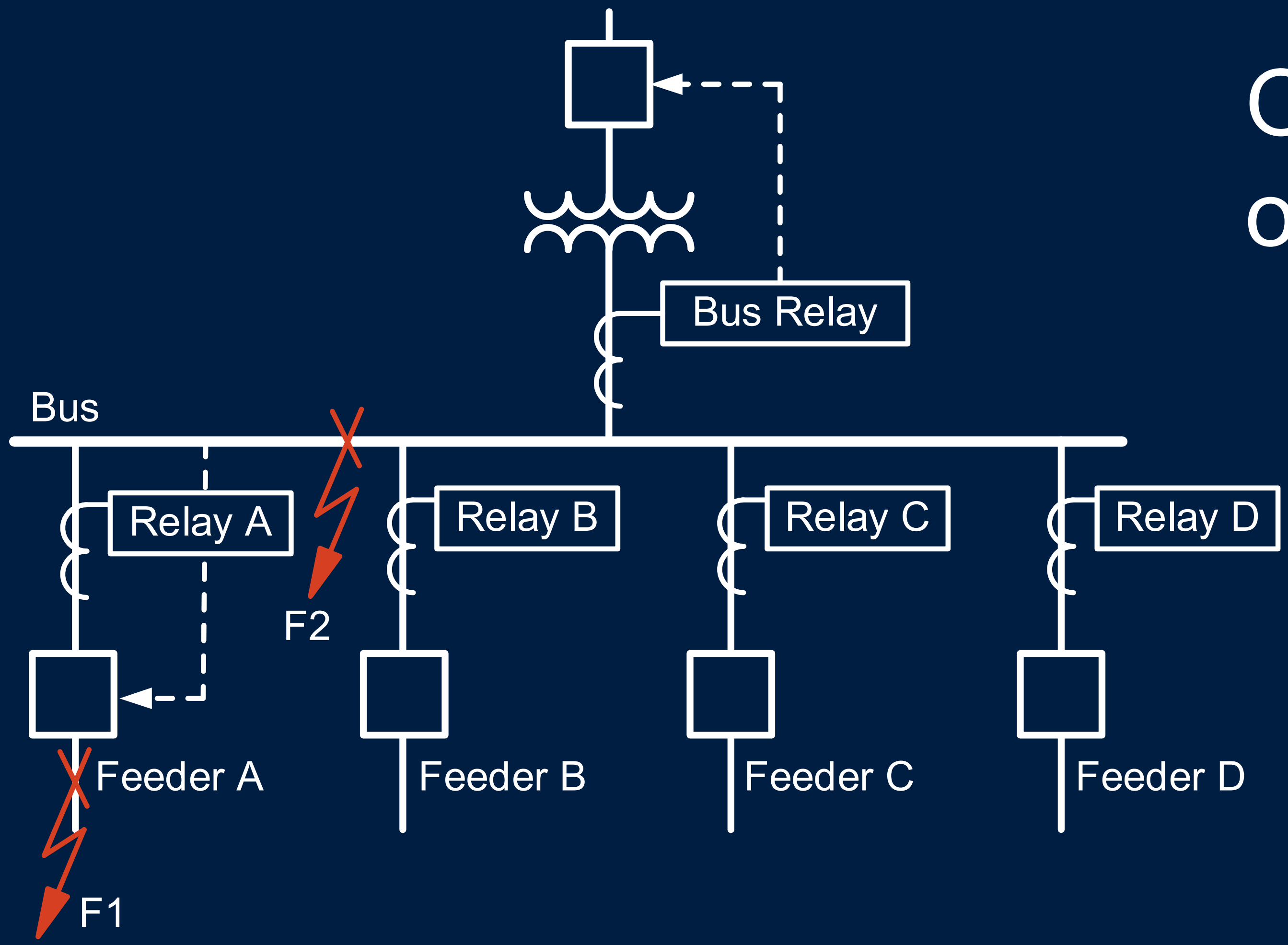
Fuse-Based Bus Protection



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



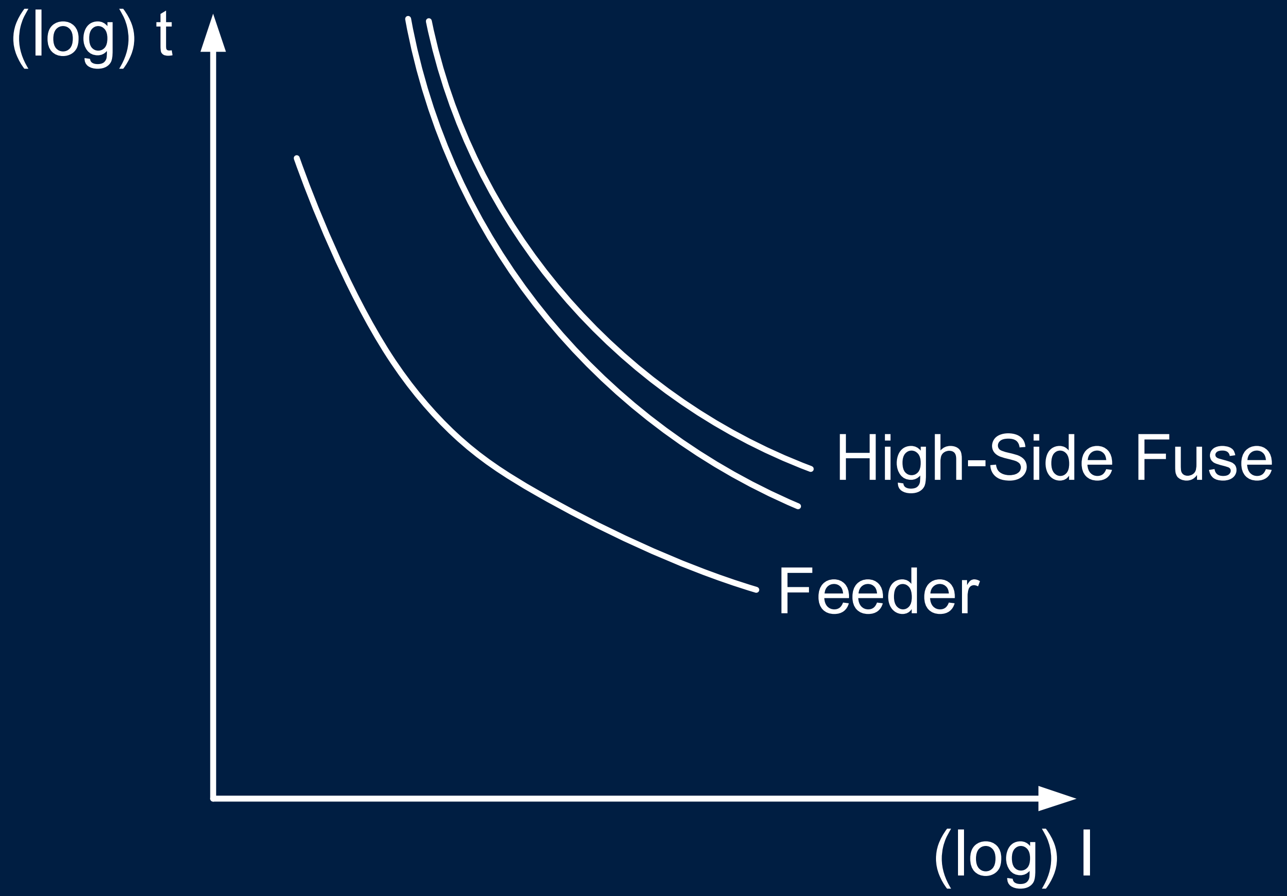
Overcurrent relay on bus provides

- 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

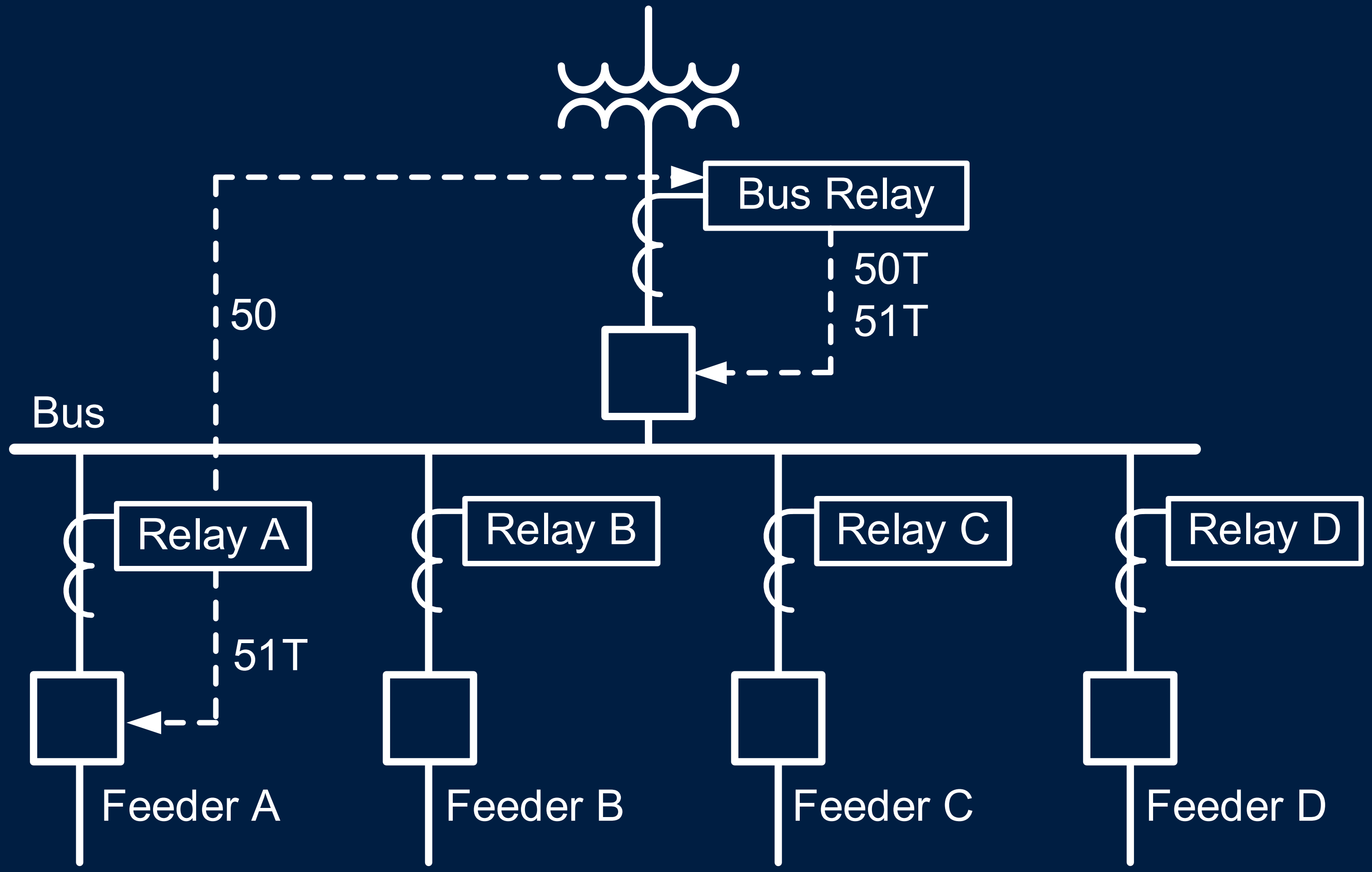


How Can Utilities Maximize Worker Safety in Substation Yard?

- Utilities should limit arc-flash incident energy exposure for bus faults
- NESC requires cumbersome PPE for arc-flash incident energy >8 cal / cm^2
- Fast bus scheme is proven method to reduce bus fault duration
- Typical fast bus scheme reduces arc-flash incident energy to <2 cal / cm^2

Wired Fast Bus Trip Scheme

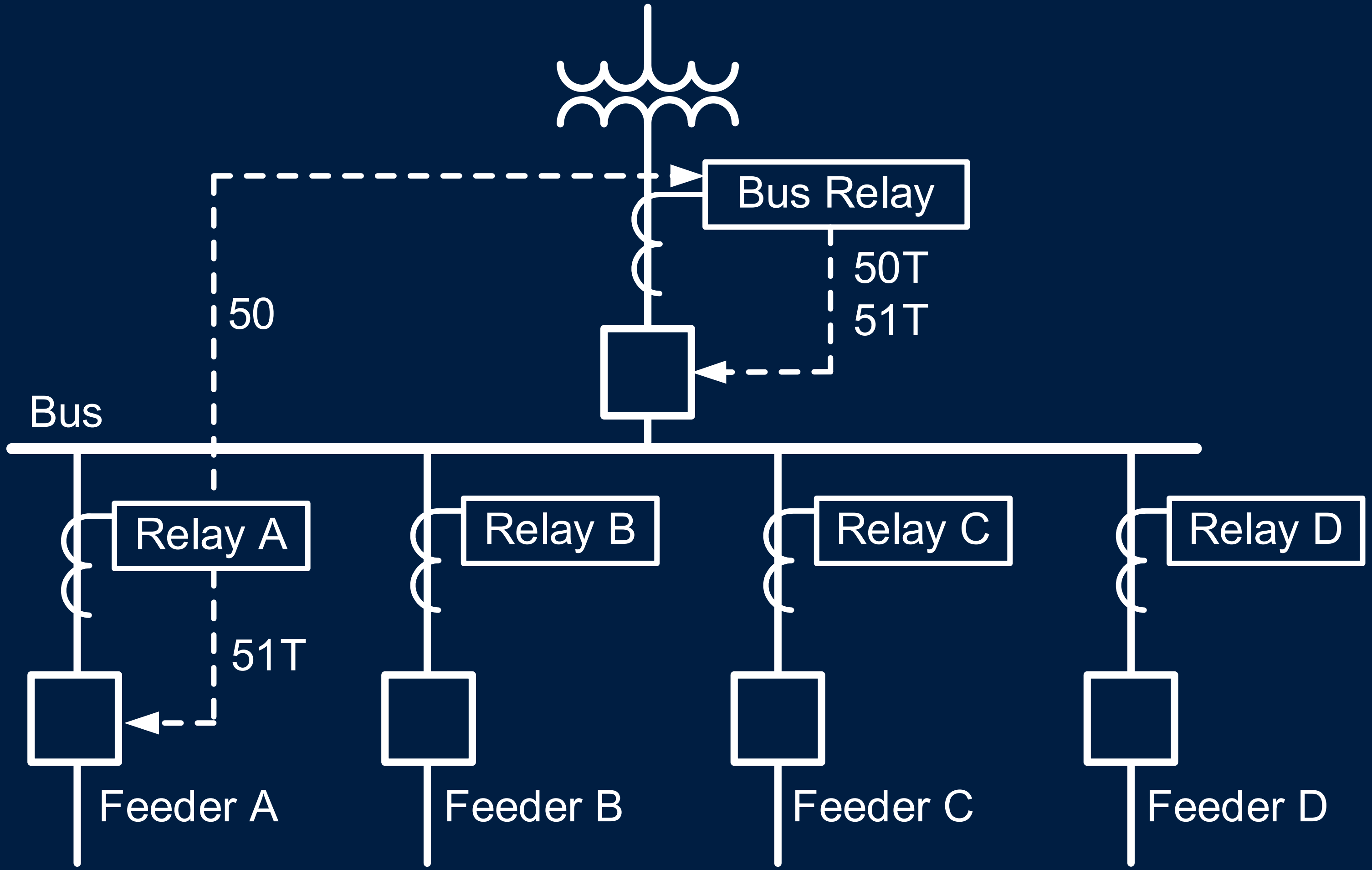
Feeder Relay



- 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

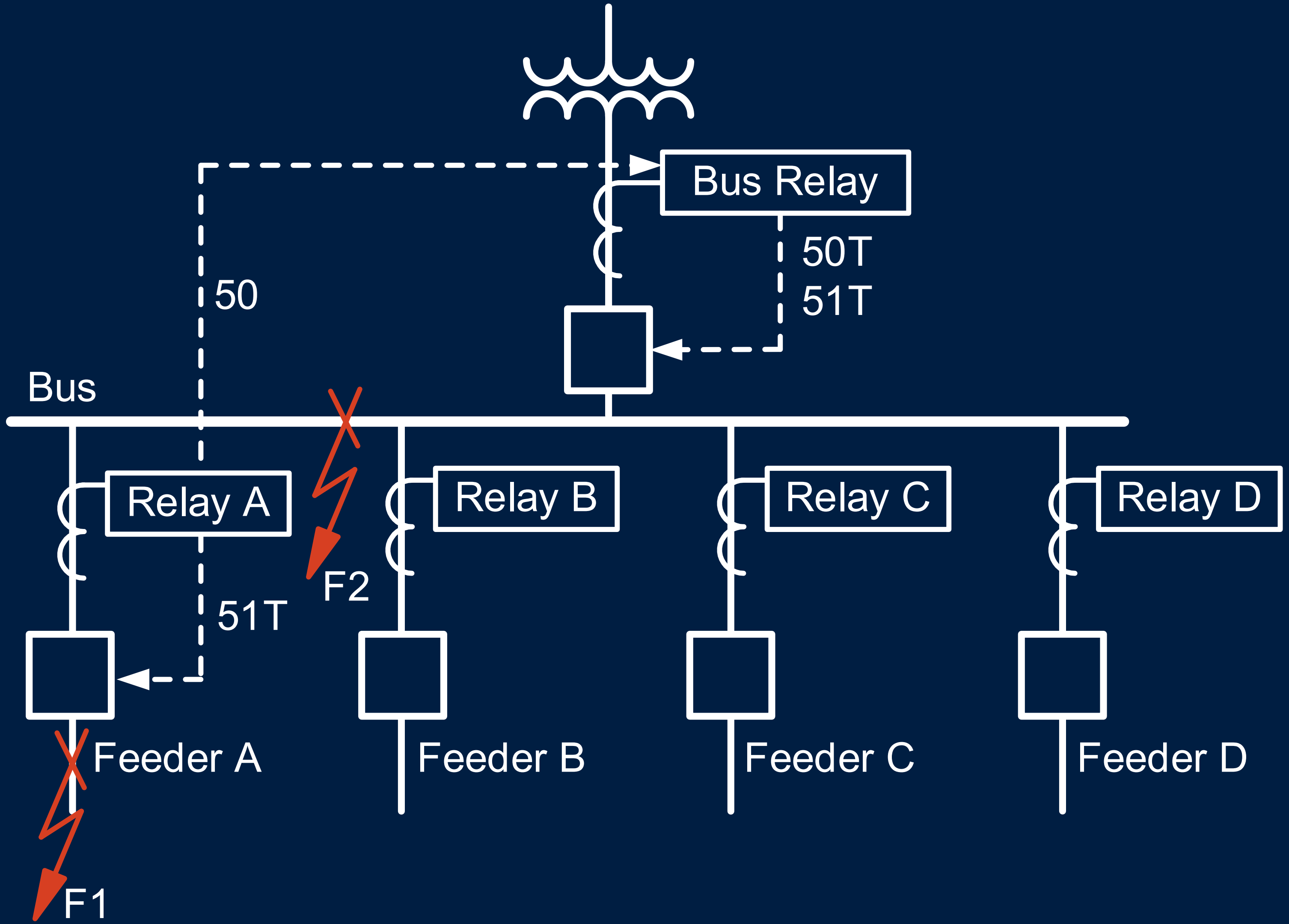
Bus Relay



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

Wired Fast Bus Trip Scheme

Feeder Fault (F1)

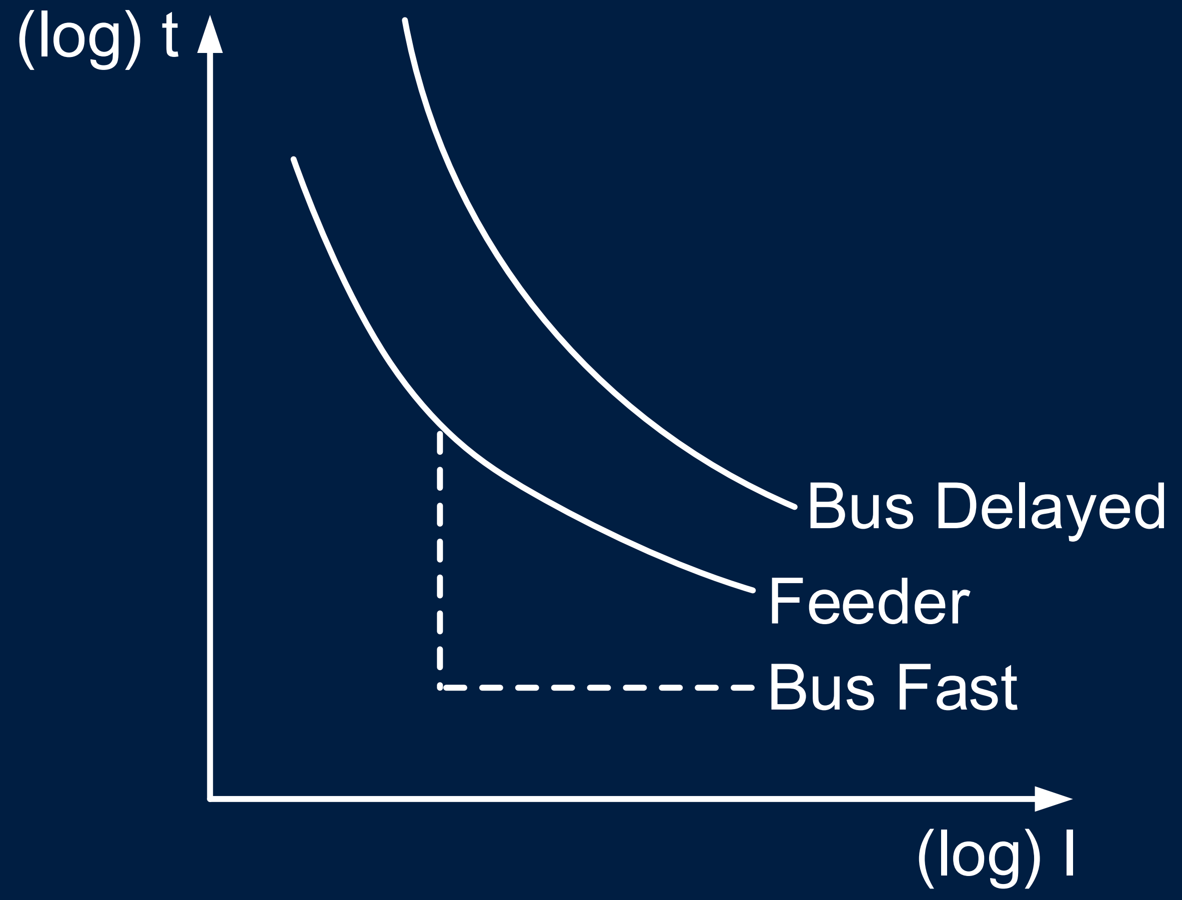


- 50T in bus relay is blocked
- Feeder relay trips on 51T
- Bus relay trips on 51T if feeder breaker fails to clear fault

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

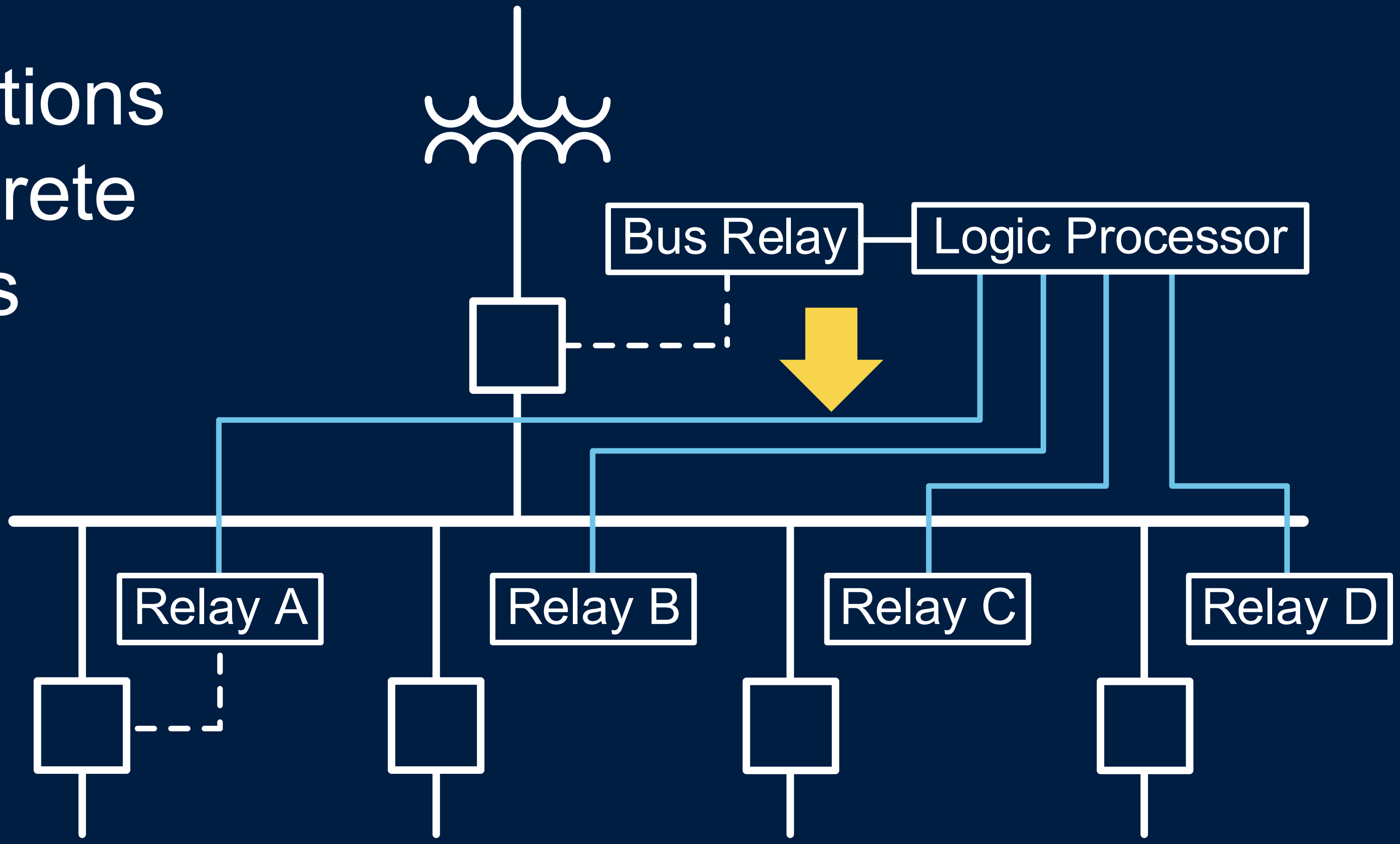


Bus faults are now cleared quickly

Communications-Based Fast Bus Trip Scheme

Similar in Concept to Wired Scheme

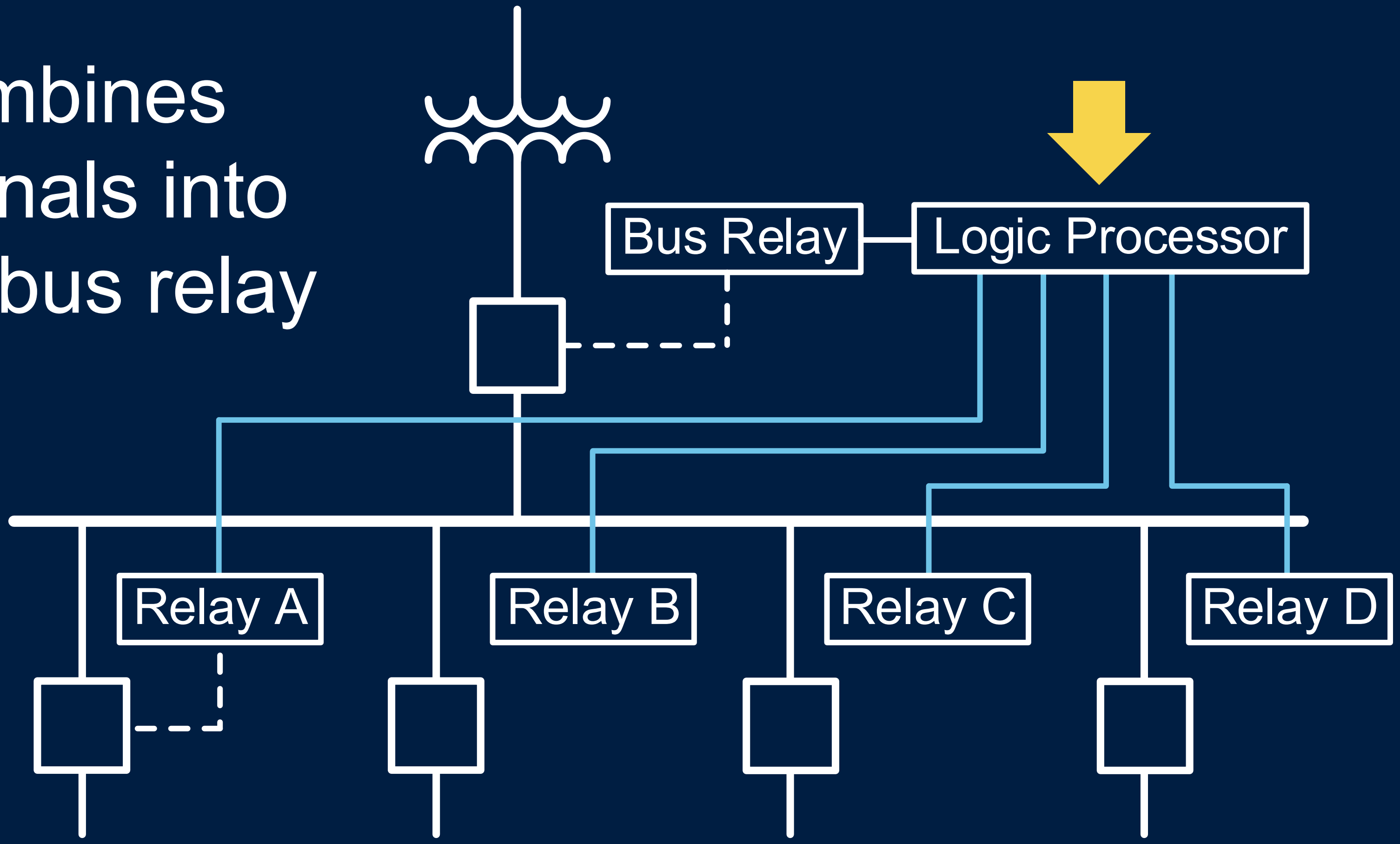
Serial communications links replace discrete control circuits



Communications-Based Fast Bus Trip Scheme

Similar in Concept to Wired Scheme

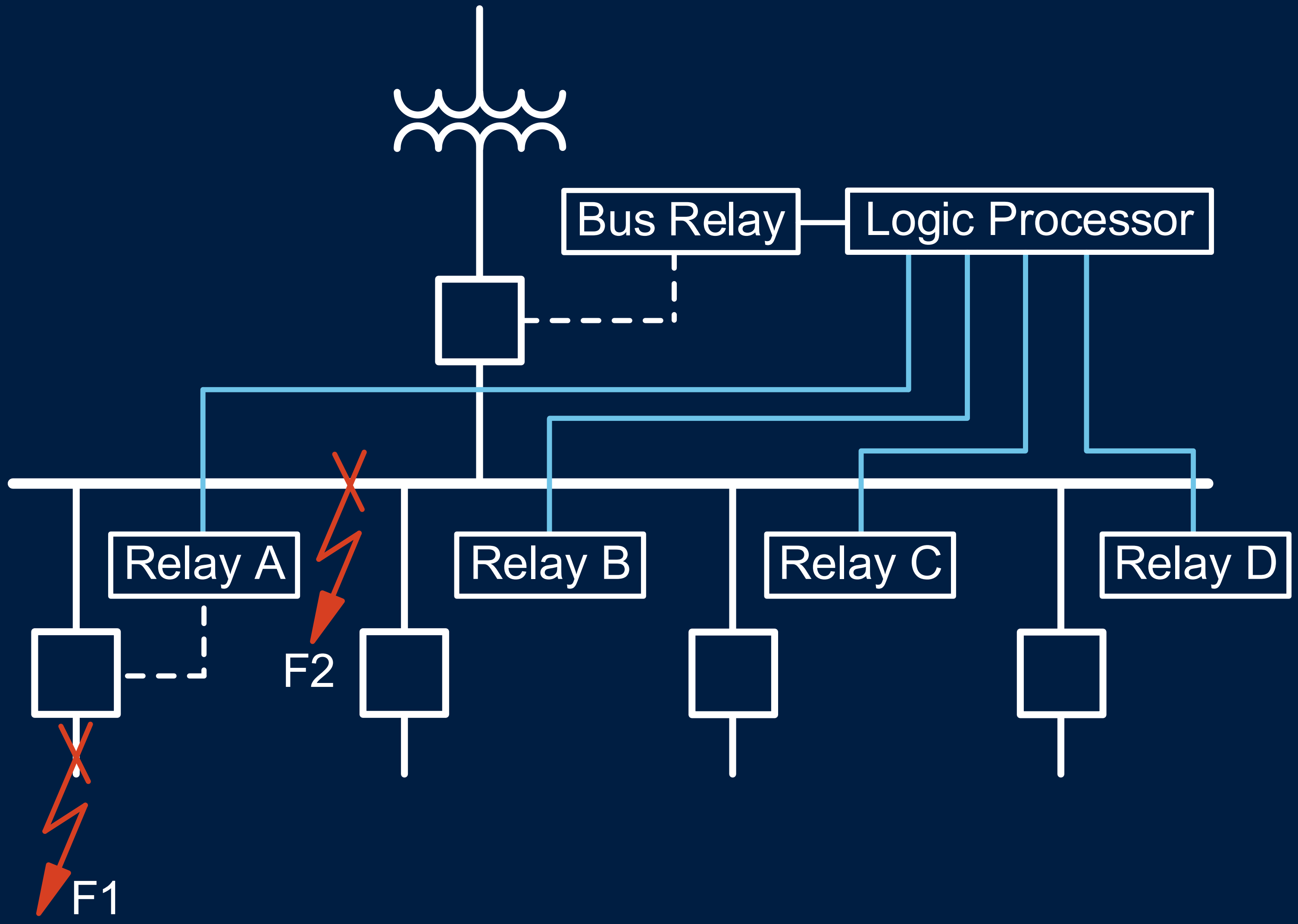
Logic processor combines feeder relay block signals into single block signal for bus relay



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



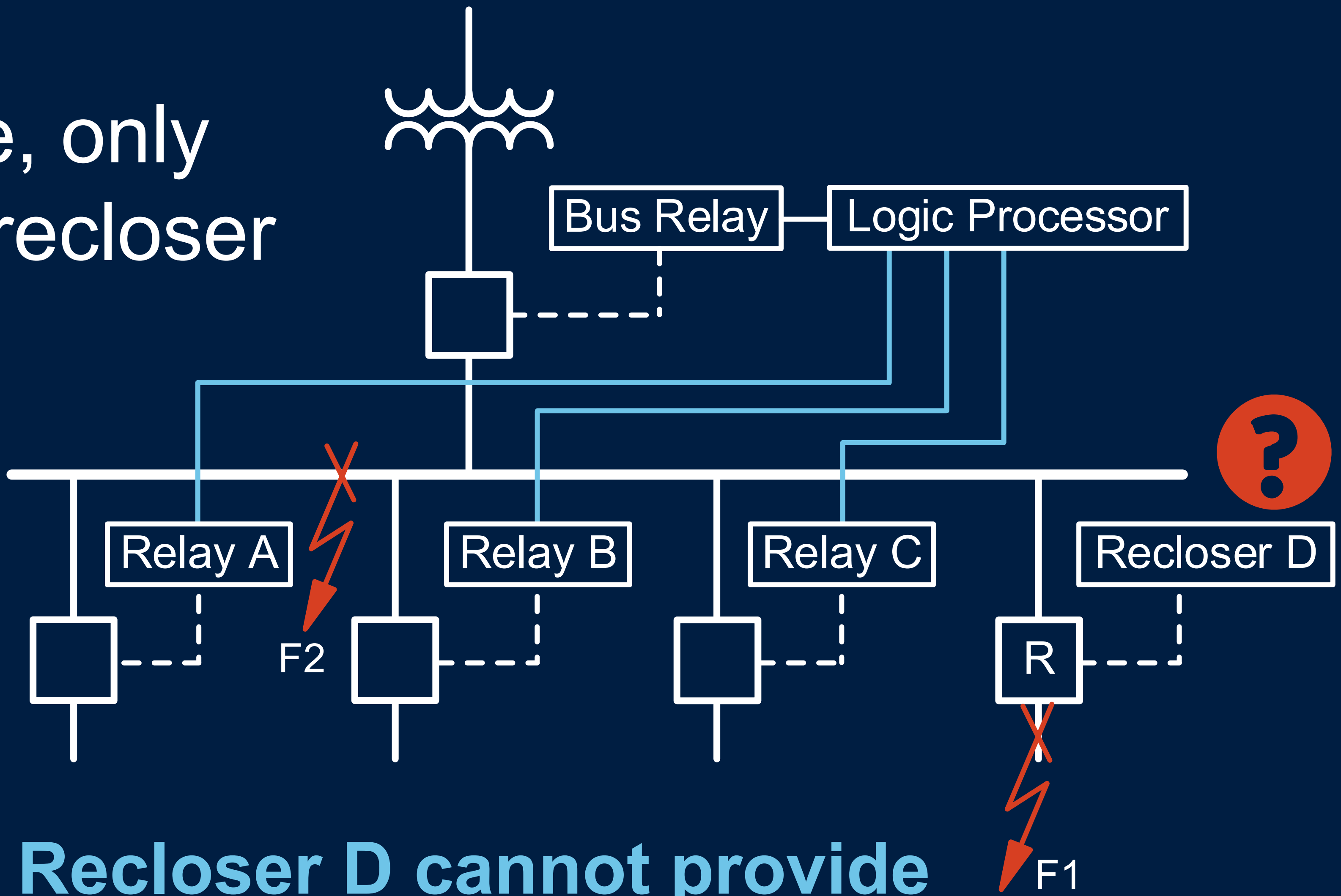
Fast Bus Trip Scheme With Reclosers

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

Fast Bus Trip Scheme With Reclosers

In this example, only Feeder D has a recloser



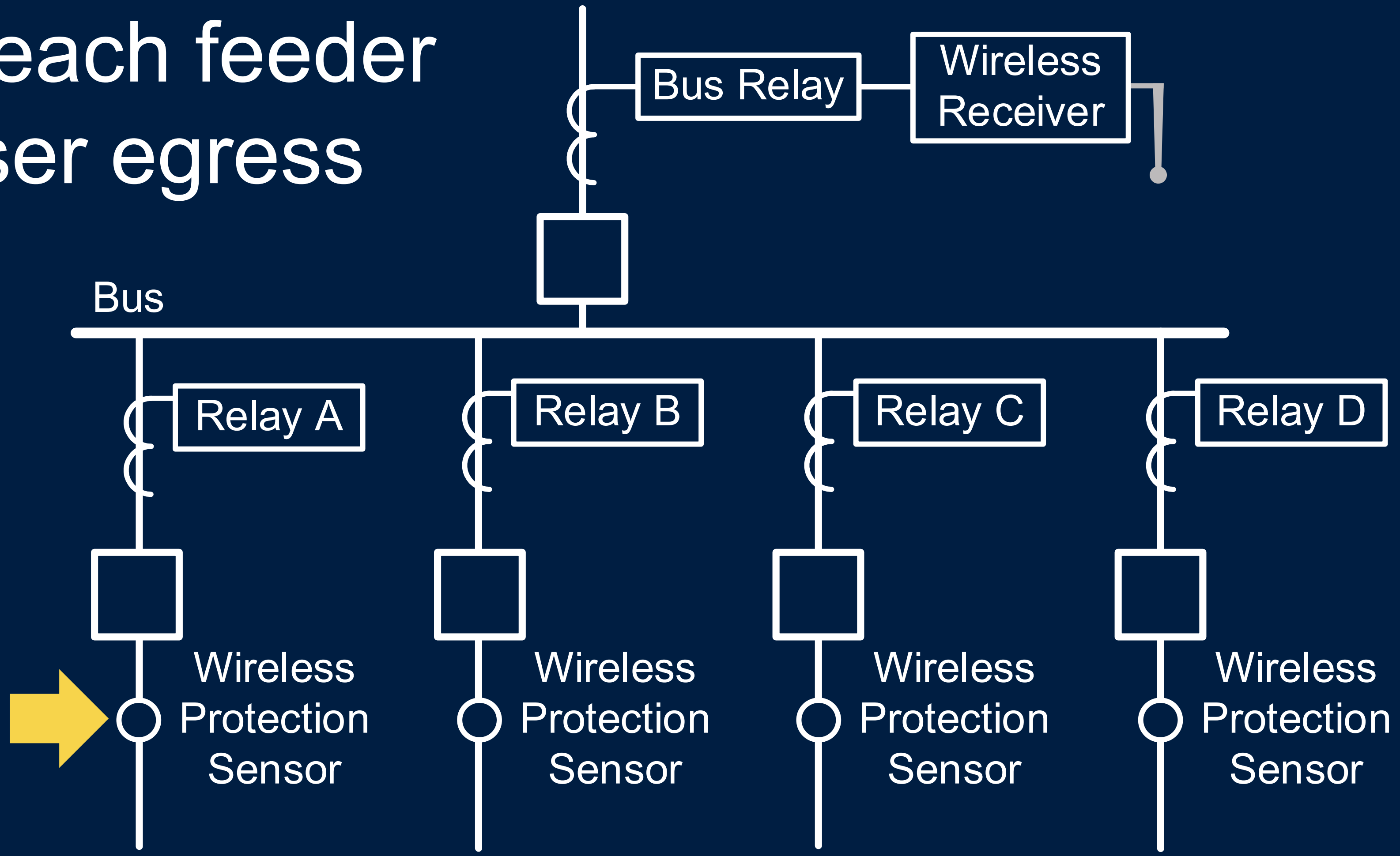
If Recloser D cannot provide compatible blocking signal, are we stuck?

No Longer a Problem Using Wireless Protection Sensors

Sensors provide block signals that we are unable to create with incompatible or remotely mounted equipment

Equipment Needed for Wireless Scheme

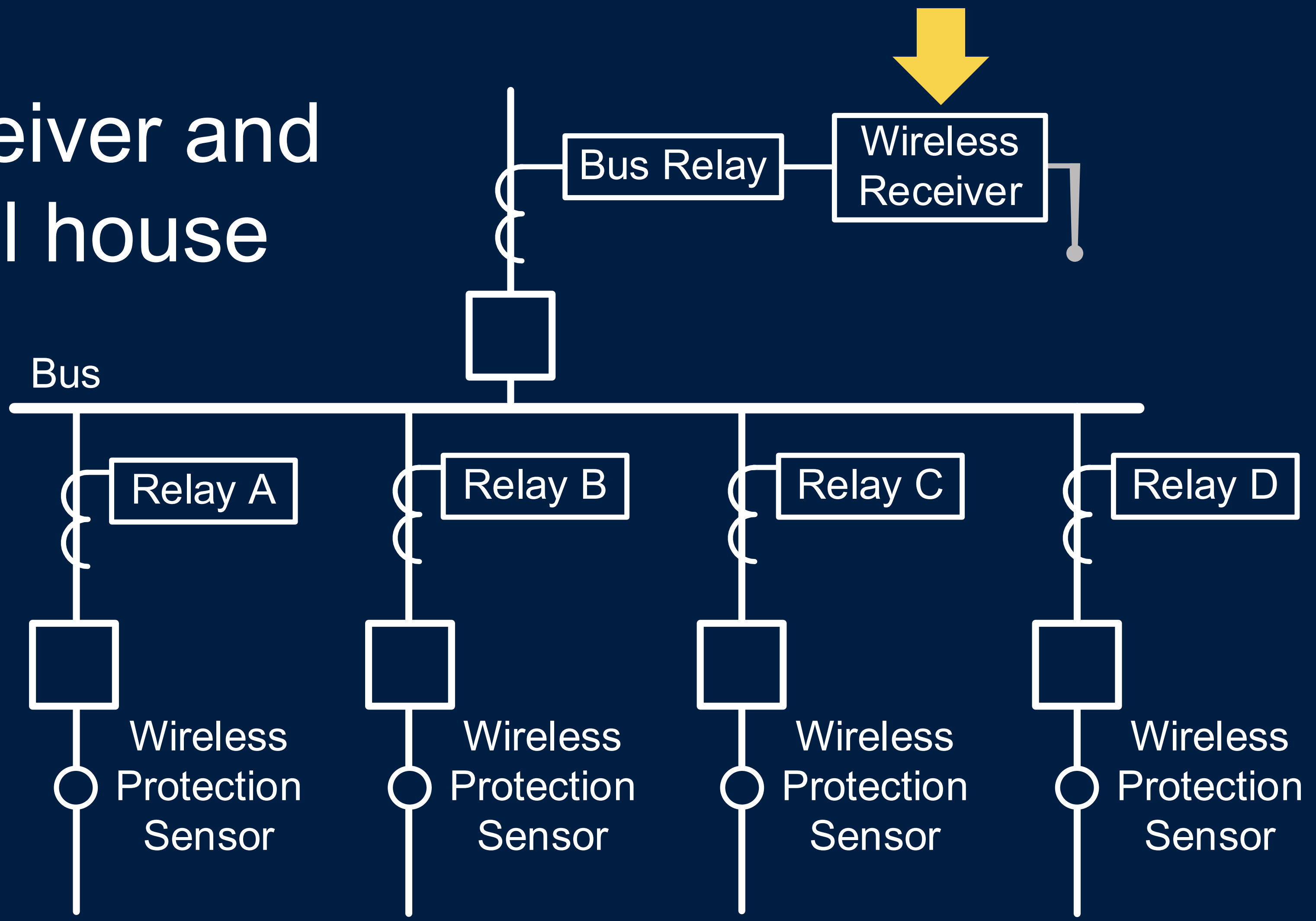
Install sensors on each feeder breaker or recloser egress



Existing substation with no fast bus tripping scheme

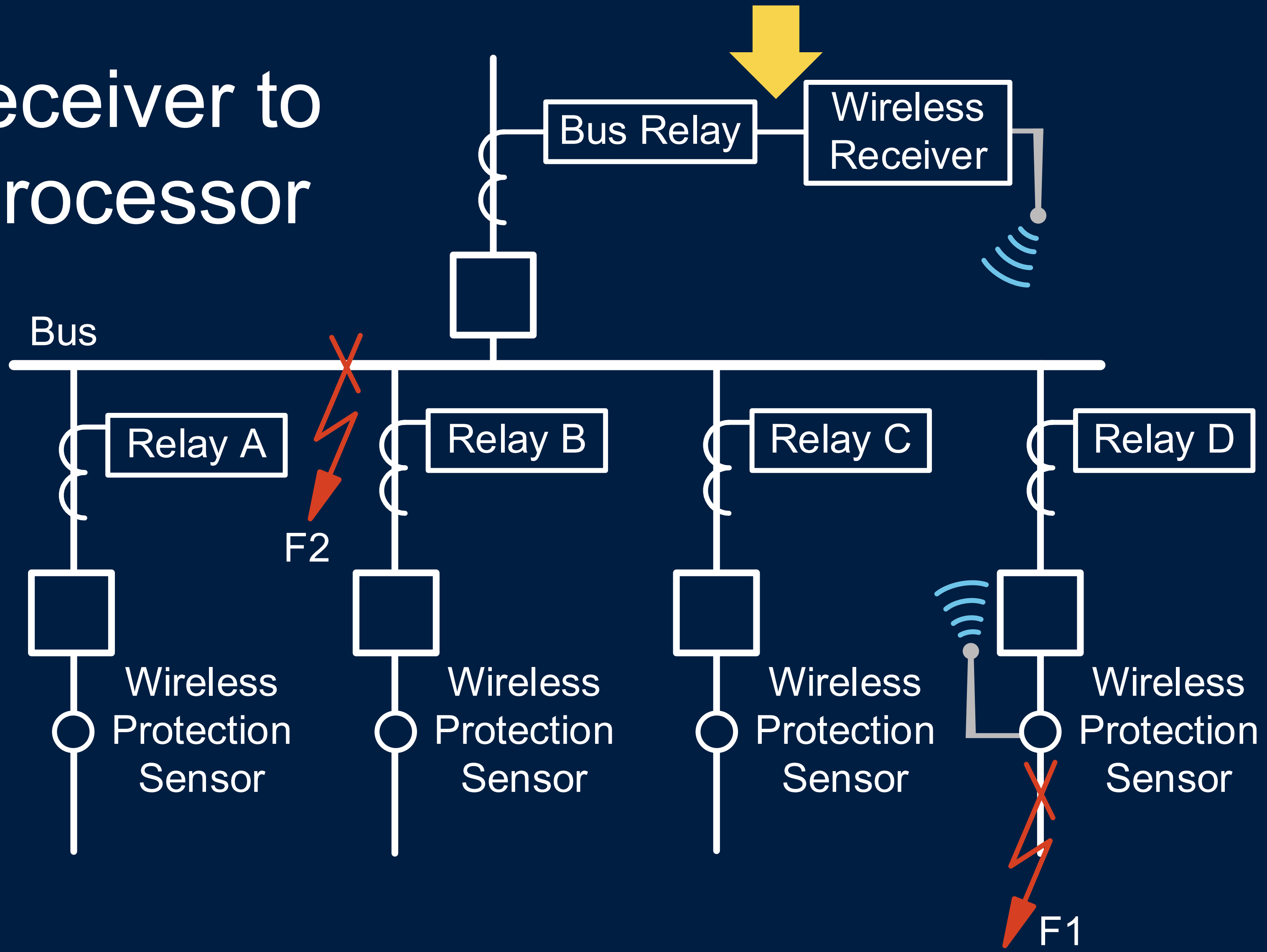
Equipment Needed for Wireless Scheme

Install wireless receiver and antenna at control house



Equipment Needed for Wireless Scheme

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

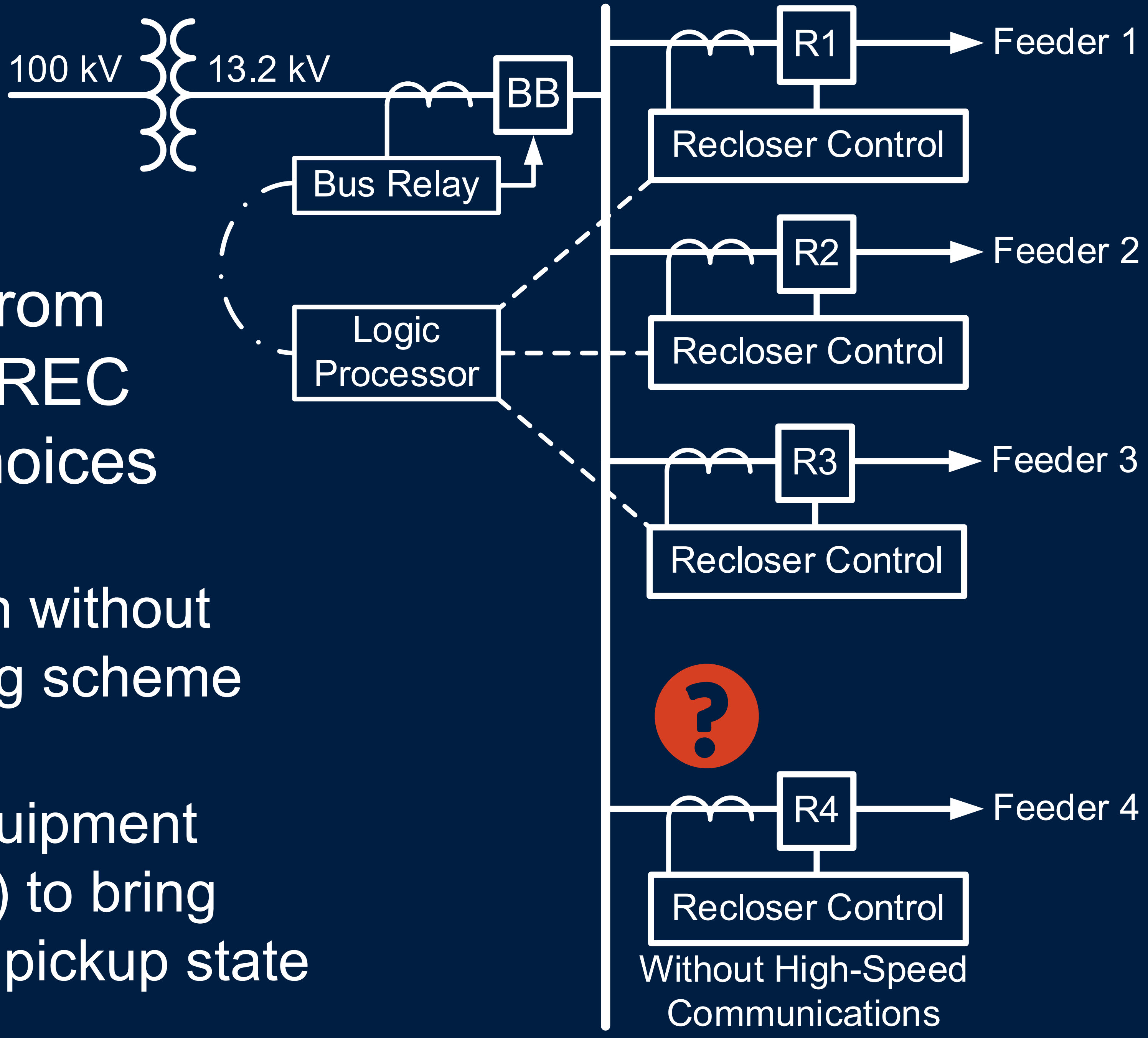
Incompatible Equipment

- 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

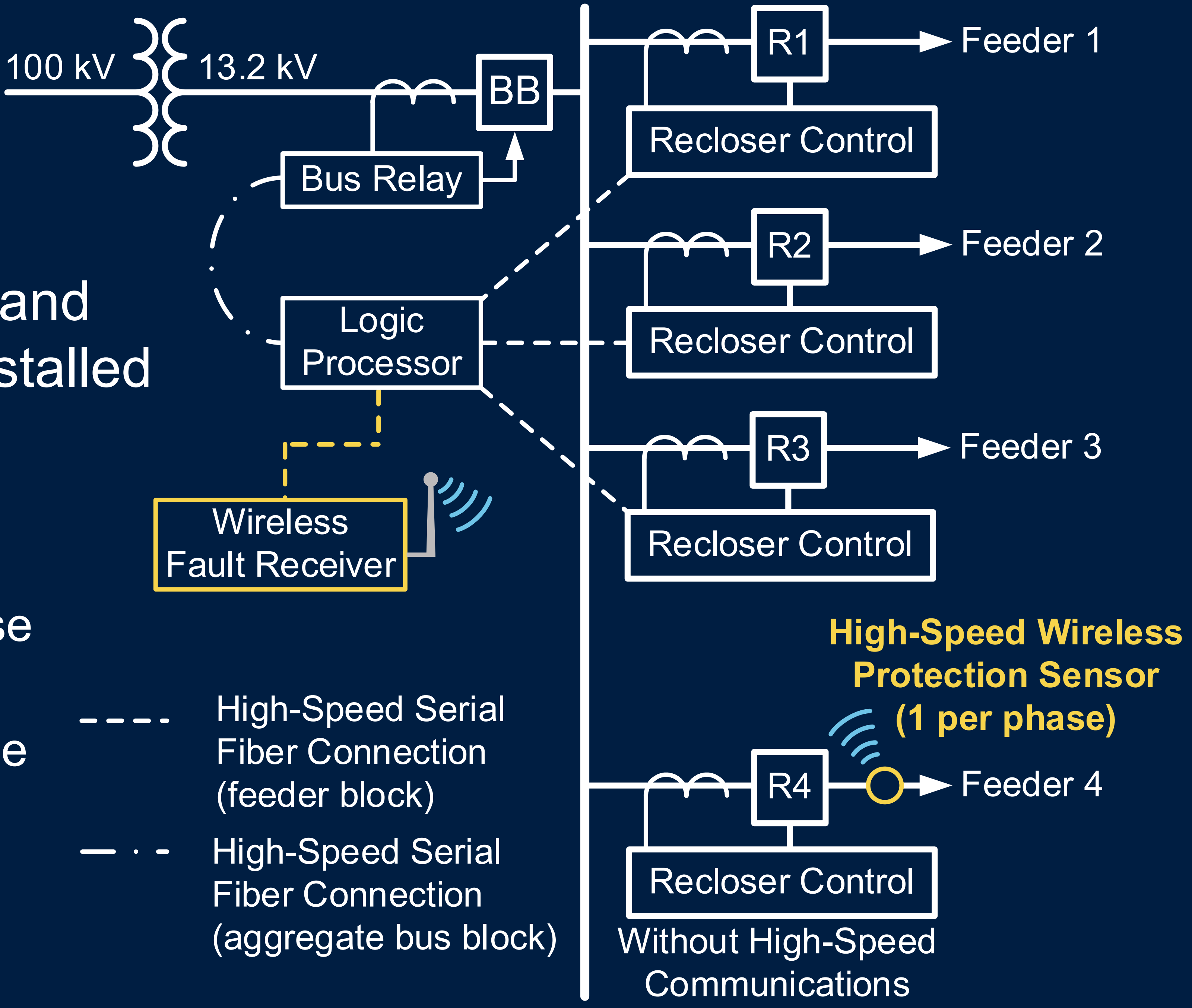
1. Operate station without fast bus tripping scheme
2. Install extra equipment (CTs and relay) to bring back Feeder 4 pickup state



Hybrid Fast Bus Scheme

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



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

No Outdoor Connections

- Sensors are installed on outbound jumpers of station-mounted recloser
- Other than antenna on control building, there were no outdoor cables to connect

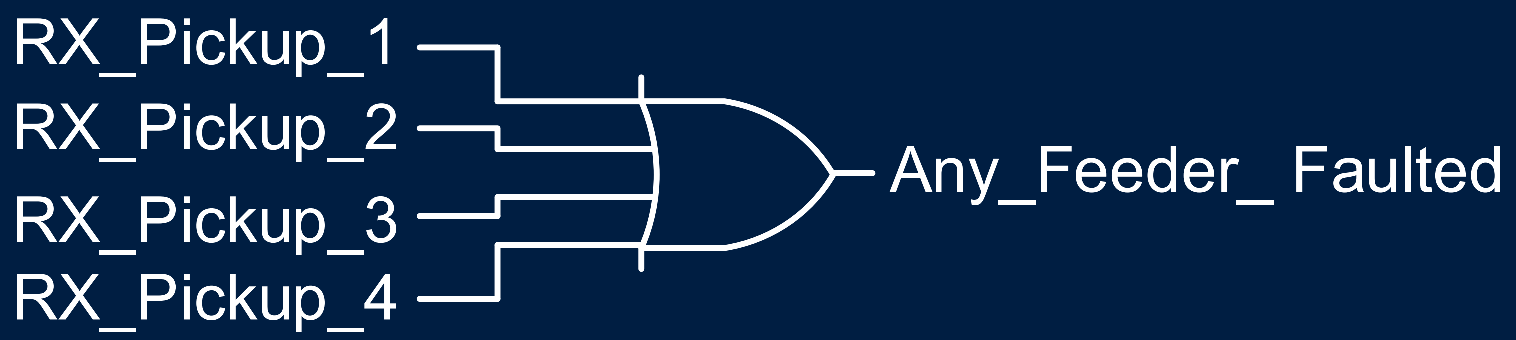
Logic Processor

Serial
Communications

Serial
Communications

Pickup Messages
From Each Feeder

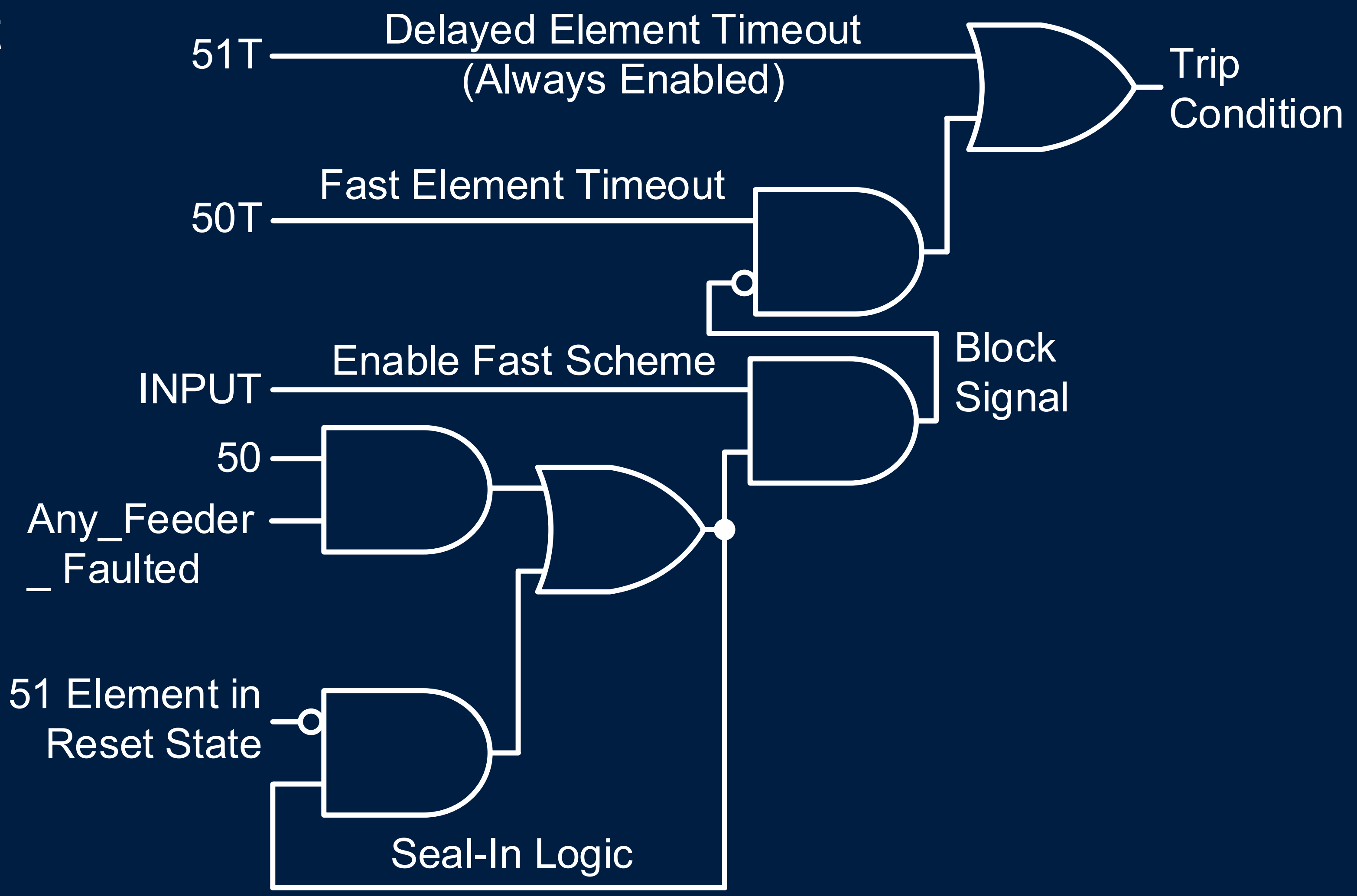
Combined Status
Message for Bus Relay



For feeder fault, logic processor asserts
Any_Feeder_Faulted signal and transmits it to bus relay

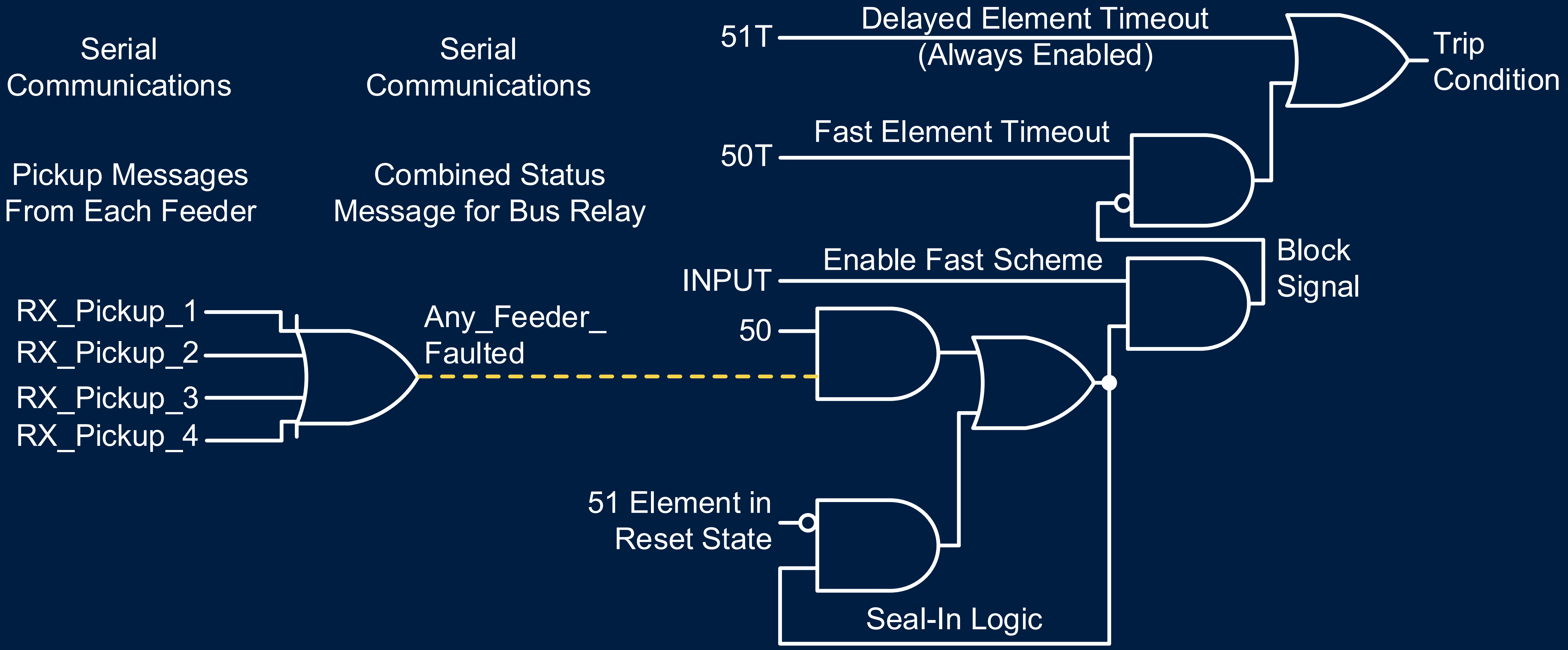
Seal-In Logic in Bus Relay

- 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



Logic Processor

Bus Relay 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 / cm^2 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 / cm^2 is well below BREC's 8 cal / cm^2 standard PPE rating

Questions?