A Current Based, Communication Assisted High Speed Protection System to Limit Arc Energy

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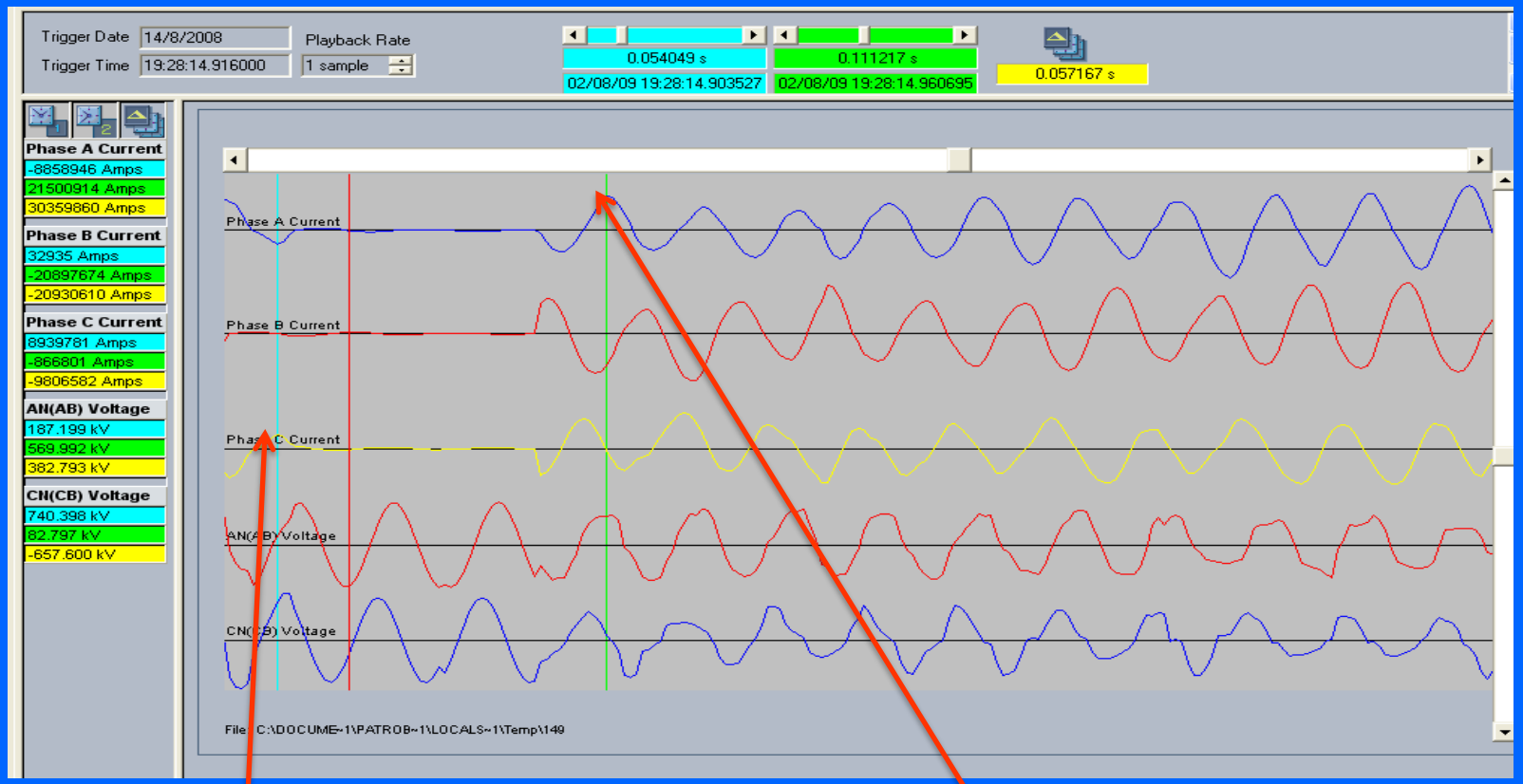
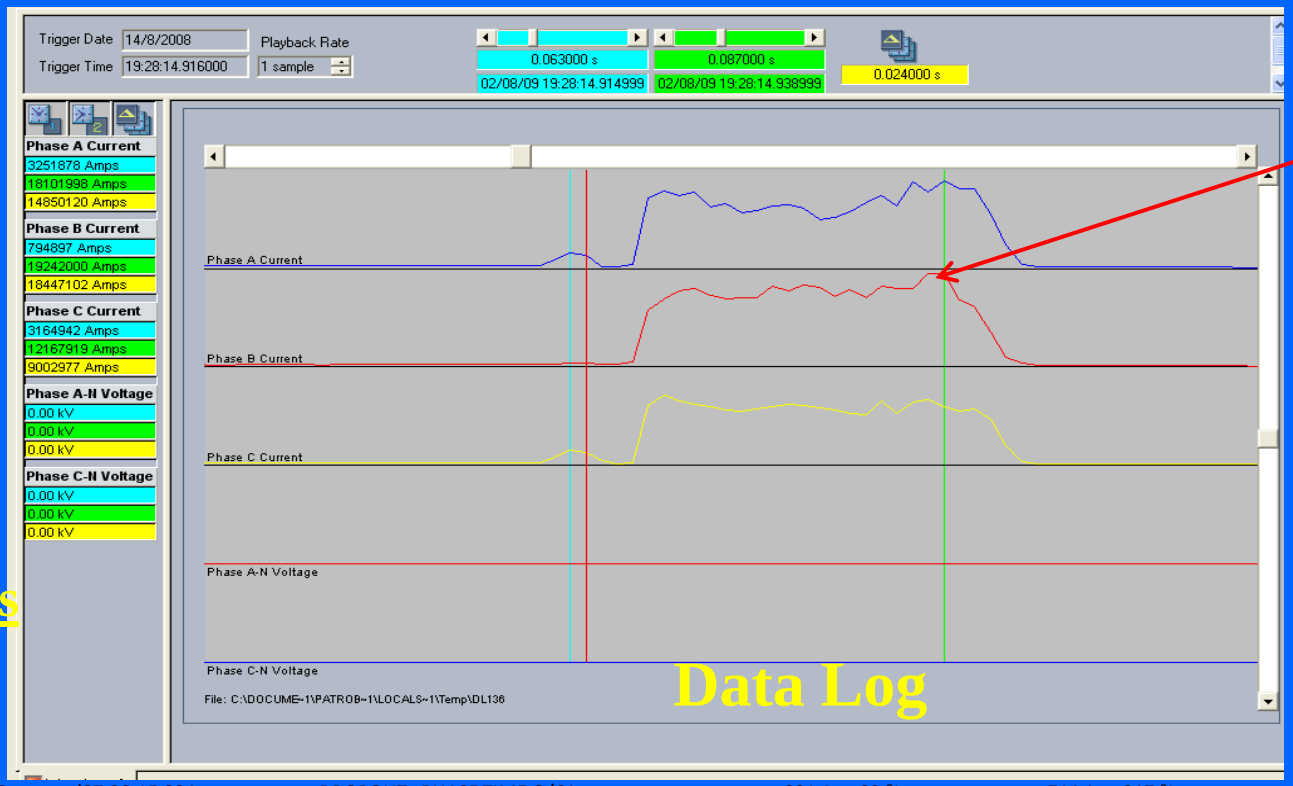
Captured Arcing Fault Event



Arc begins as phase A-C, 8ka peak, dies out then re-strikes 2 cycles later as 3 phase, 20+ka peaks. Fault extinguished itself, no protective device operated. Incorrect settings

Captured Arcing Fault Event



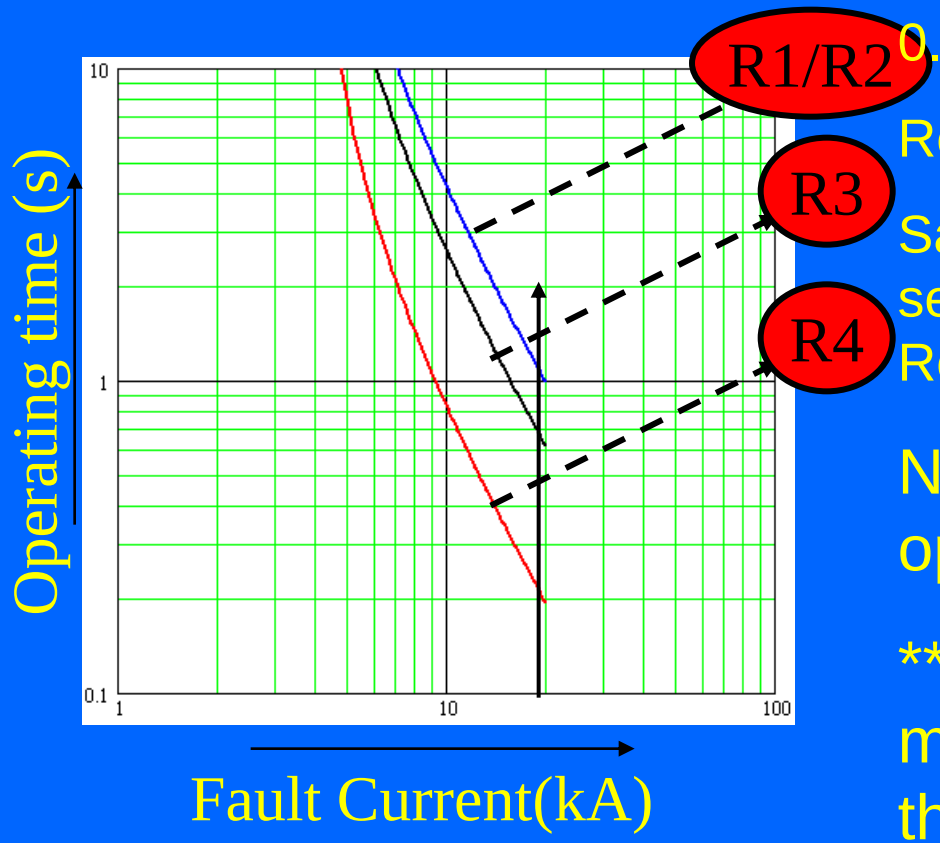
19.2KA RMS MAX

Total event Time 470ms

Data Log

'08/14/2008	'07:28:15.384 pm	DROPOUT: PHASE TIME O/C1	891 A at 92 °Lag	714 A at 217 °Lag	753 A at 323 °Lag
'08/14/2008	'07:28:14.984 pm	PICKUP: ABC PHASE TIME O/C1	14409 A at 36 °Lag	11787 A at 160 °Lag	12456 A at 267 °Lag
'08/14/2008	'07:28:14.949 pm	DROPOUT: PHASE TIME O/C1	480 A at 37 °Lag	597 A at 179 °Lag	360 A at 307 °Lag
'08/14/2008	'07:28:14.916 pm	TRIGGER DATA LOGGER	2676 A at 81 °Lag	894 A at 179 °Lag	2679 A at 280 °Lag
'08/14/2008	'07:28:14.916 pm	TRIGGER TRACE MEM	2676 A at 81 °Lag	894 A at 179 °Lag	2679 A at 280 °Lag
'08/14/2008	'07:28:14.915 pm	PICKUP: AC PHASE TIME O/C1	2676 A at 81 °Lag	894 A at 179 °Lag	2679 A at 280 °Lag

Limitations of Traditional Co-ordination



Circuit breaker opening time (3-5 cycles) 0.05-0.08 s

Relay overshoot and timing errors 0.10 s

Safety factor for CT errors and saturation, setting errors on Electromechanical Relays, Variables

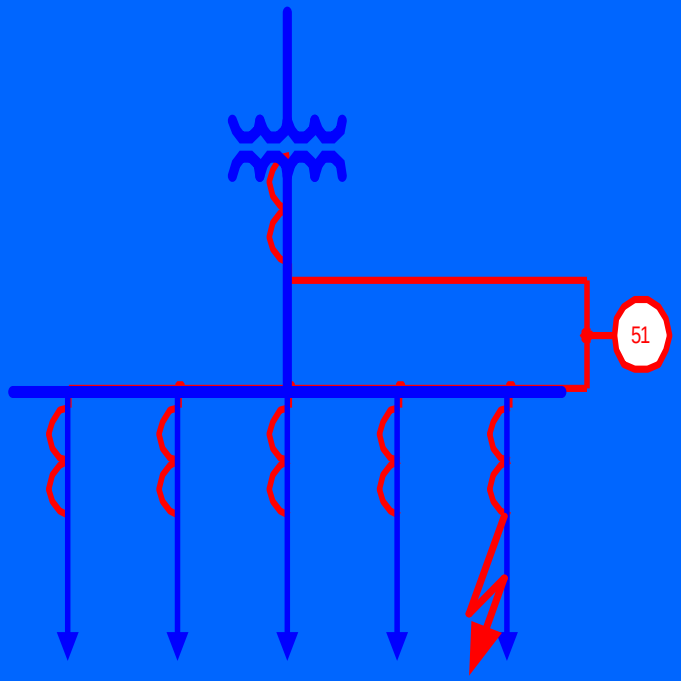
Normally 0.3-0.5s minimum operate time

***Note that proper co-ordination may not have made a difference to the fault shown on previous slides

Arc Energy Reduction

- Arc Flash Energy (AFE) protection is a major concern for both new and existing installations
- Many new installations are using arc-resistant or arc-proof gear
- While faults cannot be eliminated completely, the goal is to reduce the amount of time they are present when they do occur

Traditional Bus Protection ANSI Device 87B



- Percent characteristic and special algorithms are used to cope with CT saturation
- PRO - Does not require coordination with other protection devices, has low pickup and is independent of load current
- CON - Not traditionally used at plant distribution levels due to the ***cost*** factor

This approach typically only covers the electrical apparatus

Arc Detection via Light Sensitive Devices

- Many devices exist which can operate on the light emitted by an incipient arc, but light can be from other sources
- Solution has been to supervise with an IOC current detector, ANSI device 50
- Published operate times are typically 1-3 cycles
- However, operate time is based on the fault current exceeding the pickup
- Pickup must be set higher than the short term maximum allowable current load
- All faults are different, evolve differently
- Fault inception to exceeding 50 element pickup can be many cycles, essentially indeterminate depending on fault type, 50 operates 1-3 cycles after that point is reached
- Operate time determined by current element operation regardless of speed of light detection element

Arc Energy Reduction – Maintenance Switches

- One solution possible with Multifunction Digital Relays (MDRs) is to use a maintenance switch to temporarily modify settings
- PRO-This setting group has much lower trip operate values resulting in much lower arc energy values at that point in the system when a fault occurs
- CON-If a fault occurs anywhere downstream during this period, an uncoordinated trip results in a major plant outage
- Requires operator intervention

Zone Interlocking via Hardwiring

- An ideal system will be in operation all the time and require no user intervention to arm, but will not compromise plant operational integrity
- Zone Interlocking systems have been done via hardwiring using early generation MDRs
- Scheme decreases fault clearing time vs traditional coordinated protection
- This application is limited in scope due to the requirement for control wire connections between devices

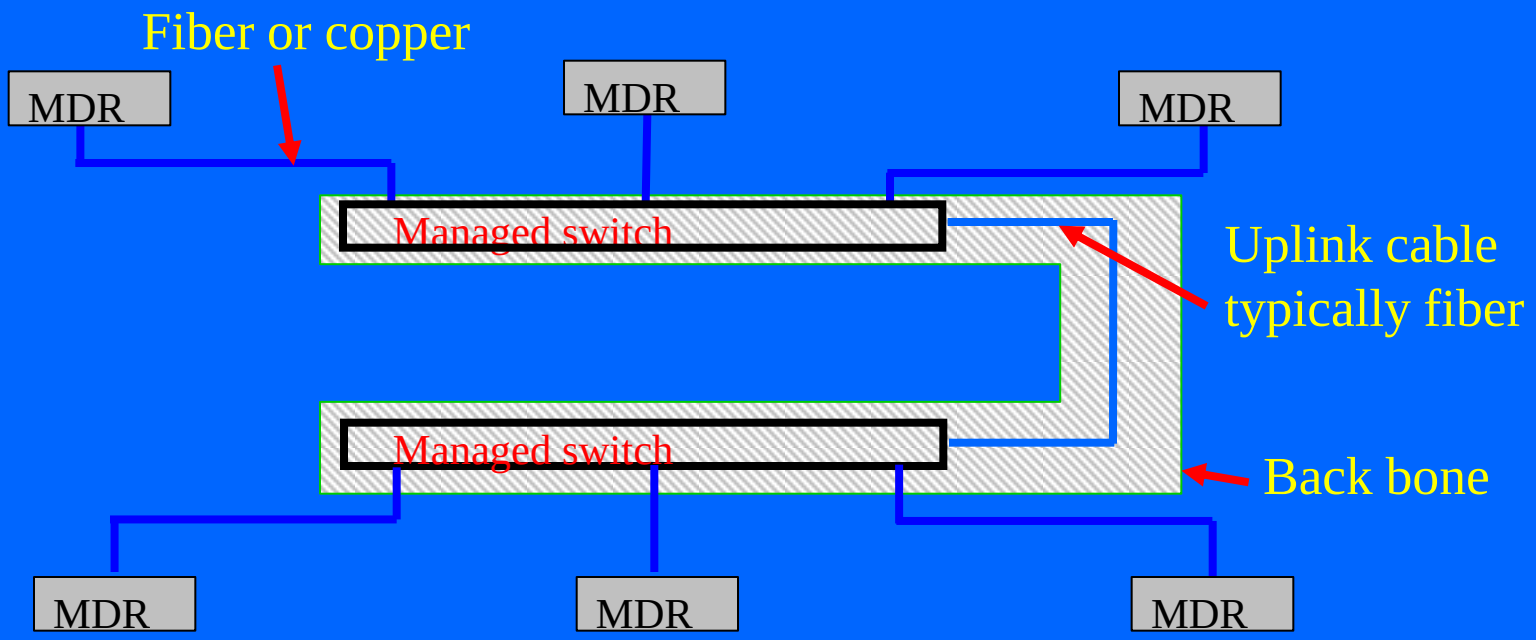
New Solution for Zone Interlocking

- Most newer MDRs include Ethernet communications
- These devices may also include an option for the **IEC61850** protocol
- Within this protocol is a subset of functions called “GOOSE” messaging, ‘Generic Object Oriented Substation Event’
- GOOSE allows for extremely fast peer-to-peer communications between **any** MDRs, regardless of manufacturer, location or distance between them as long as they are located on the same LAN.

Step One - Implement a Traditional Coordinated System

- As per standard protection practices, a suitable MDR is installed to protect every feeder, transformer, generator, motor, and connected to the plant LAN
- Fault studies are performed, MDR settings are calculated
- The MDRs provide traditional coordinated fault clearing using 50/51 elements, phase and ground
- The difference in this modern solution is that all of the MDRs have IEC 61850 protocol enabled

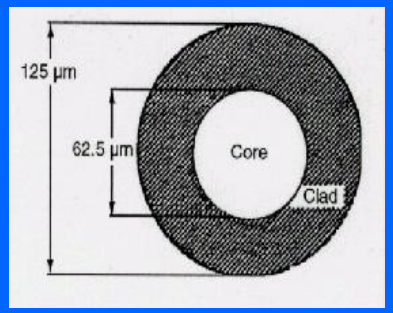
Step Two – Design IEC61850 Compliant Station Bus LAN Architecture



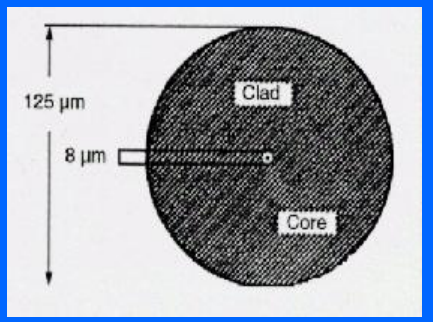
- Managed switches are used to connect devices together and form the LAN.
- The connection of several higher speed uplink ports to produce a higher speed path between switches is referred to as a backbone.

Design IEC61850 Compliant Station Bus LAN Architecture

MultiMode
62.5/125µm
50/125µm*



SingleMode
9/125µm

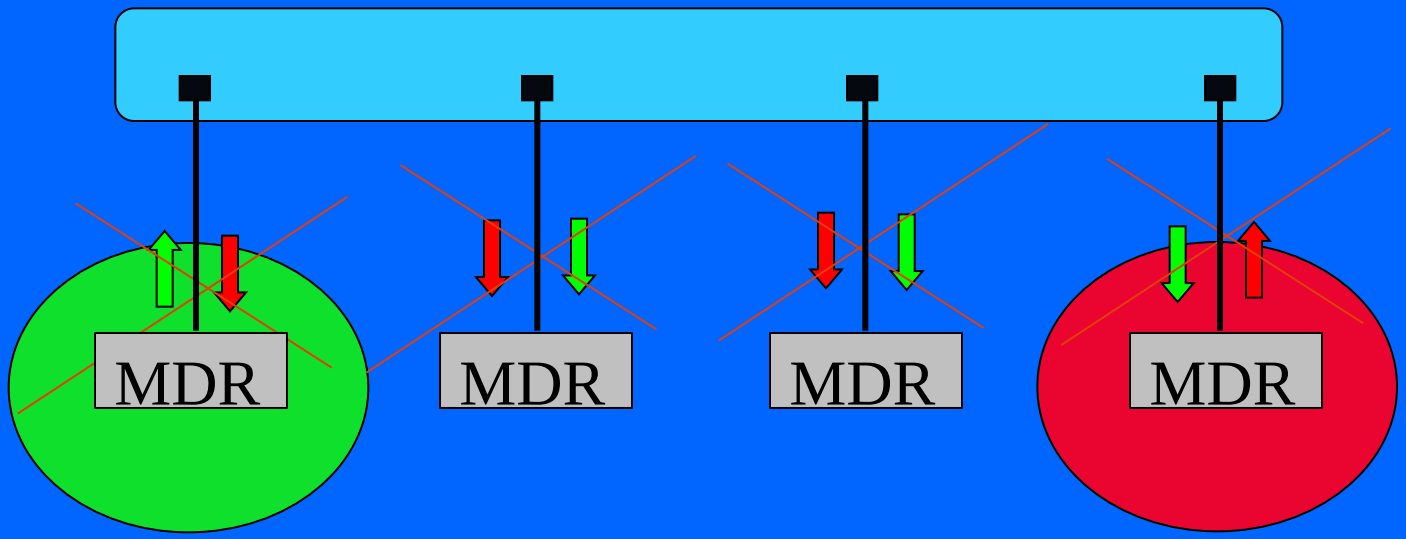


- There are two main classes of fiber optic cable; multimode and single mode cable.
- Multi mode fiber, with the much larger aperture is a much more robust media for applications within substations
- Single mode generally used for longer distances

Design IEC61850 Compliant Station Bus LAN Architecture

Ethernet hub operation:

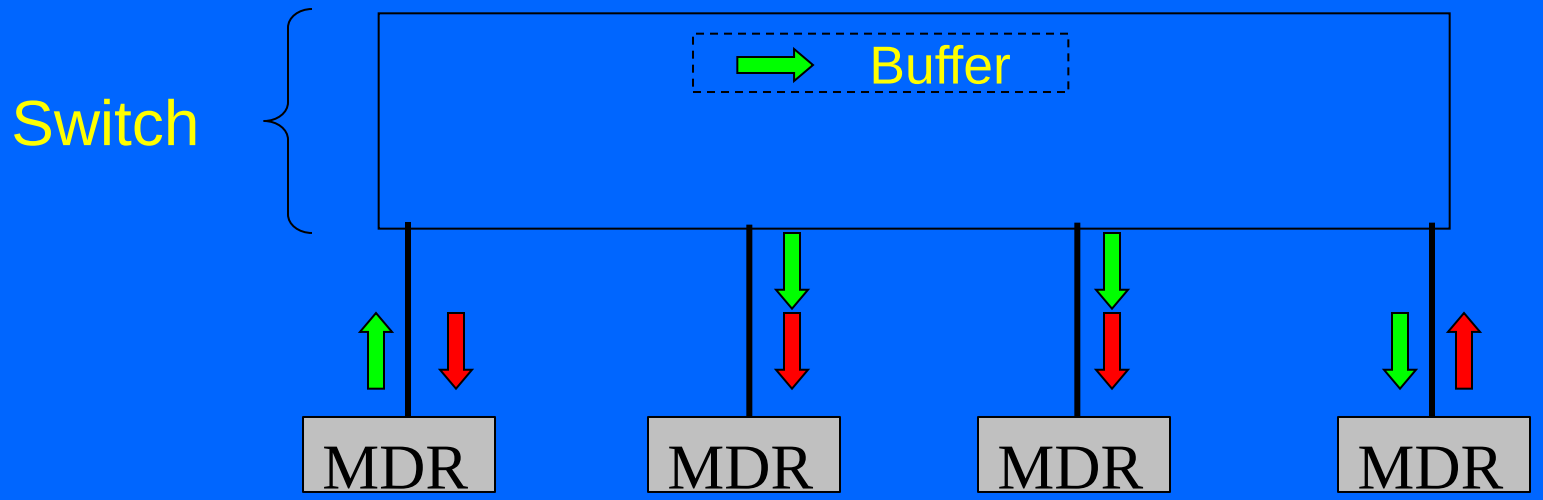
HUB (unmanaged switch)



HUBs operate at layer 1: All devices are in the same collision domain; therefore they compete for the same bandwidth

Design IEC61850 Compliant Station Bus LAN Architecture

Managed Ethernet switch operation:



In a modern Ethernet LAN architecture, managed switches are used exclusively due to:

- Ability to buffer messages eliminating media contention
- Each connection to a single device is it's own collision domain allowing the network to operate in full duplex.

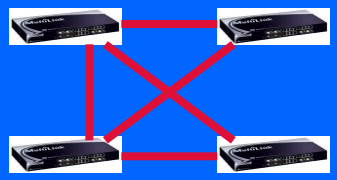
Design IEC61850 Compliant Station Bus LAN Architecture

Star Topology

- Easy to install and trouble shoot
- No redundant path: a single point of failure will cause loss of communications between sections of the LAN

Full Mesh Topology

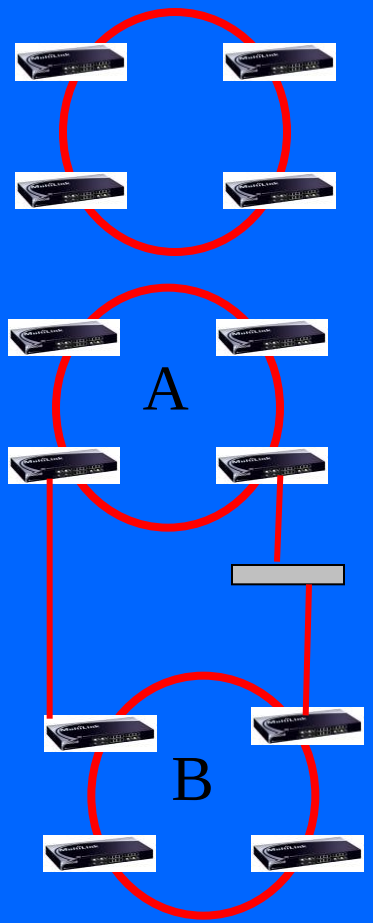
- All devices connected to each other
- Multiple Points of failure required before loss of communications
- Additional fiber cables required
- Difficult to troubleshoot



Partial Mesh Topology

- At least one device maintains multiple connections to other devices without being fully meshed.
- Reduces installation cost

Design IEC61850 Compliant Station Bus LAN Architecture



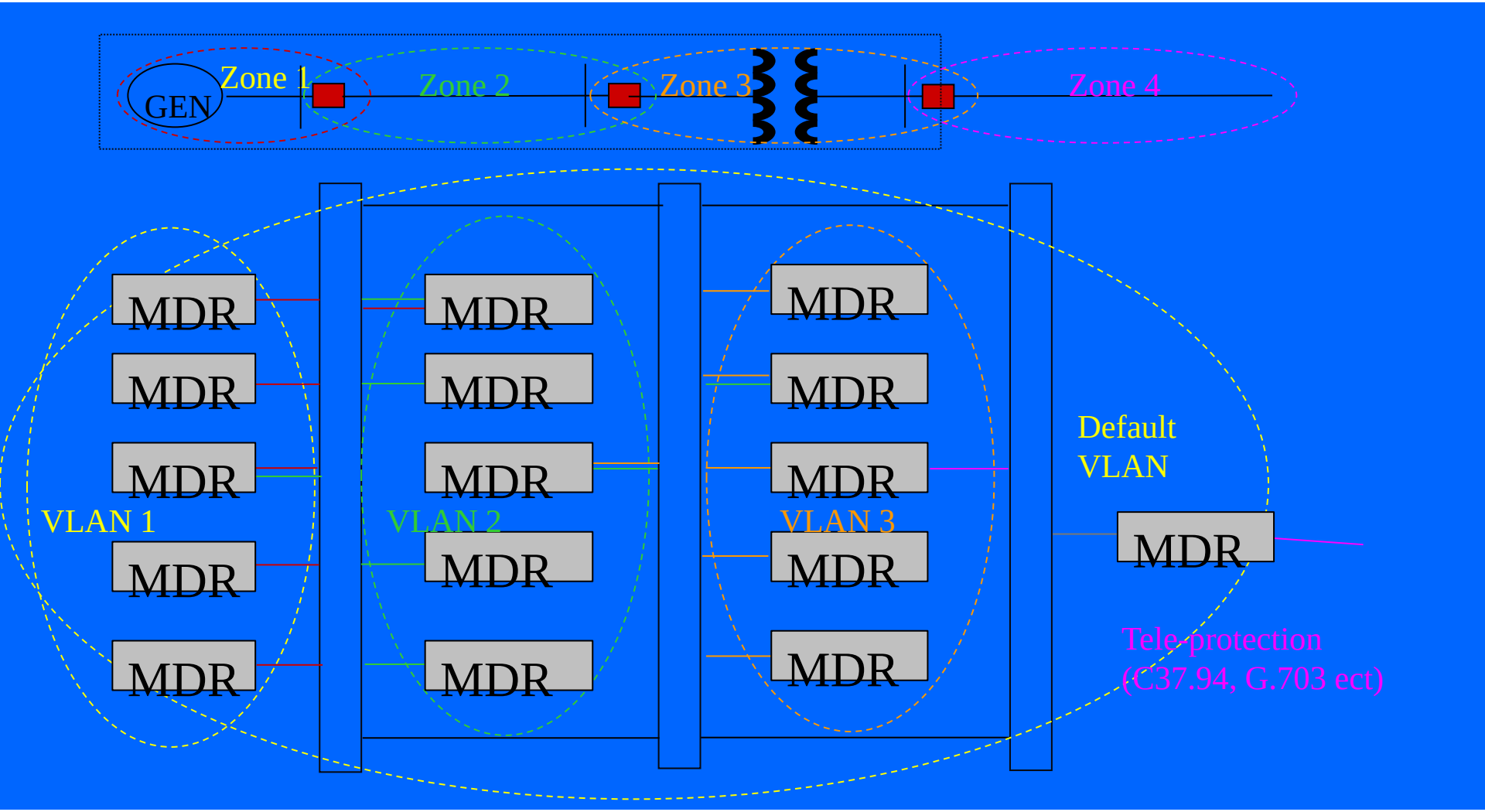
Ring Architecture

- Easy to install and troubleshoot
- Predictable recovery time
- Full Network Redundancy
- Fastest network recovery (5ms per switch)

Dual Ring Architecture

- Most secure: convergence of one ring does not affect other ring
- Easy to trouble shoot
- Easy to install
- Fastest network recovery

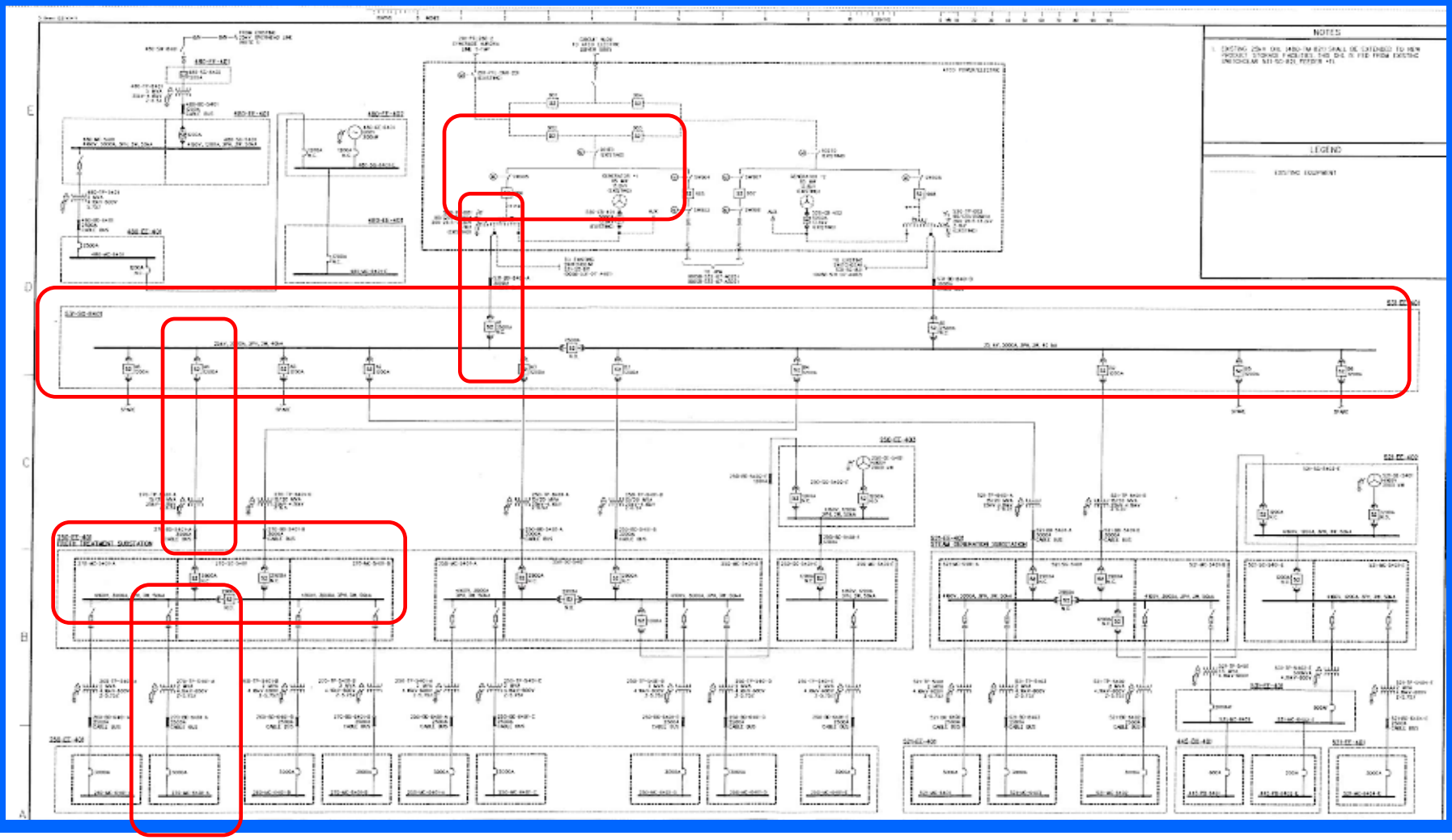
IEC61850 compliant Station Bus LAN architecture



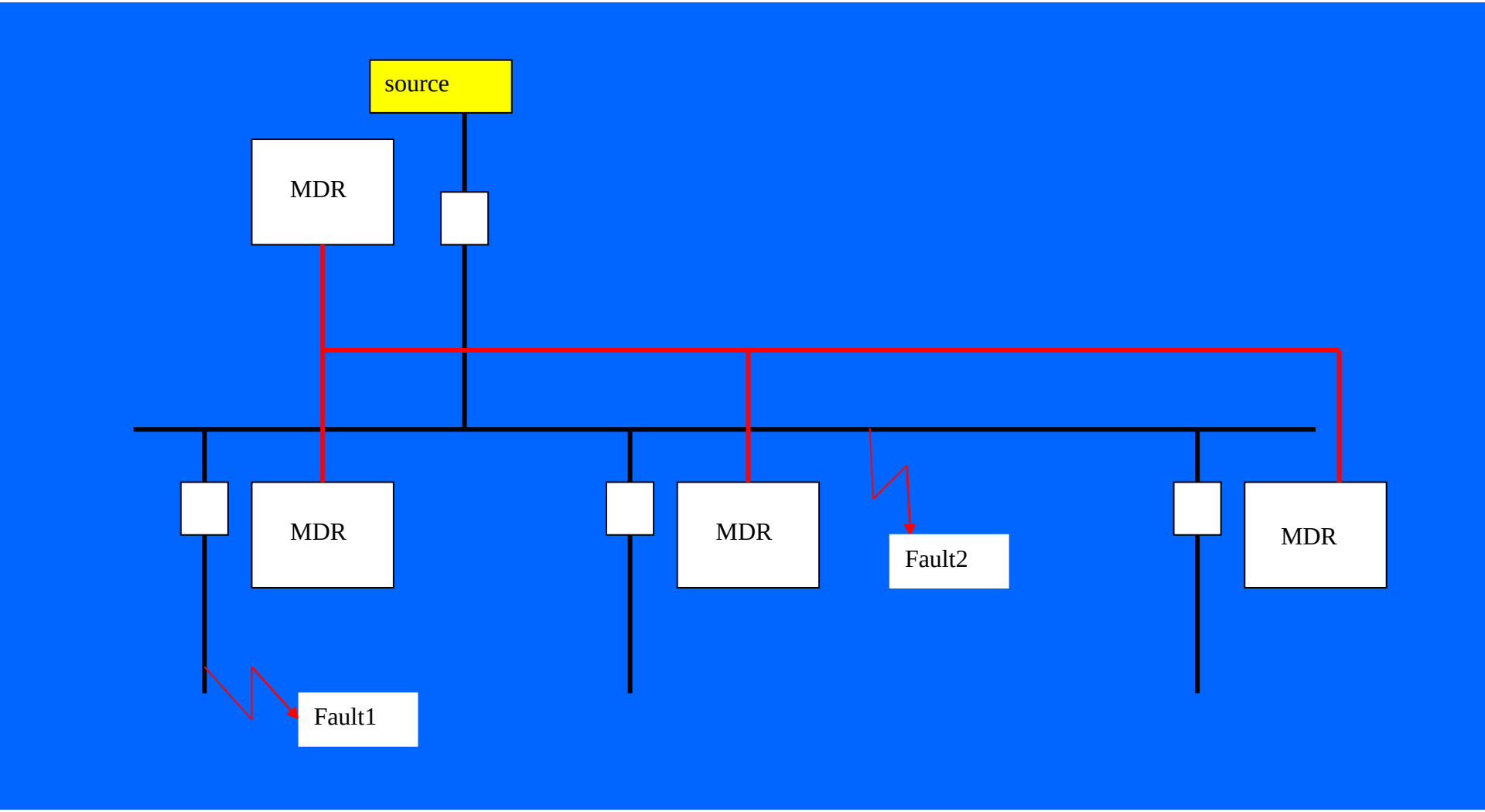
Step 3 - Enable High Speed System

- Upstream IOC element set at a **minimum** operate time
- Supervised by the **pickup** signal of the downstream IOC element, pickup settings are determined by the fault study min fault level
- Helps prevent the element seeing faults farther down in the system
- Fault in the zone, no block signal is sent upstream, the upstream relay trips extremely fast
- Can be implemented for both phase and ground elements, including high resistance grounded systems, 70% of initial faults being phase to ground

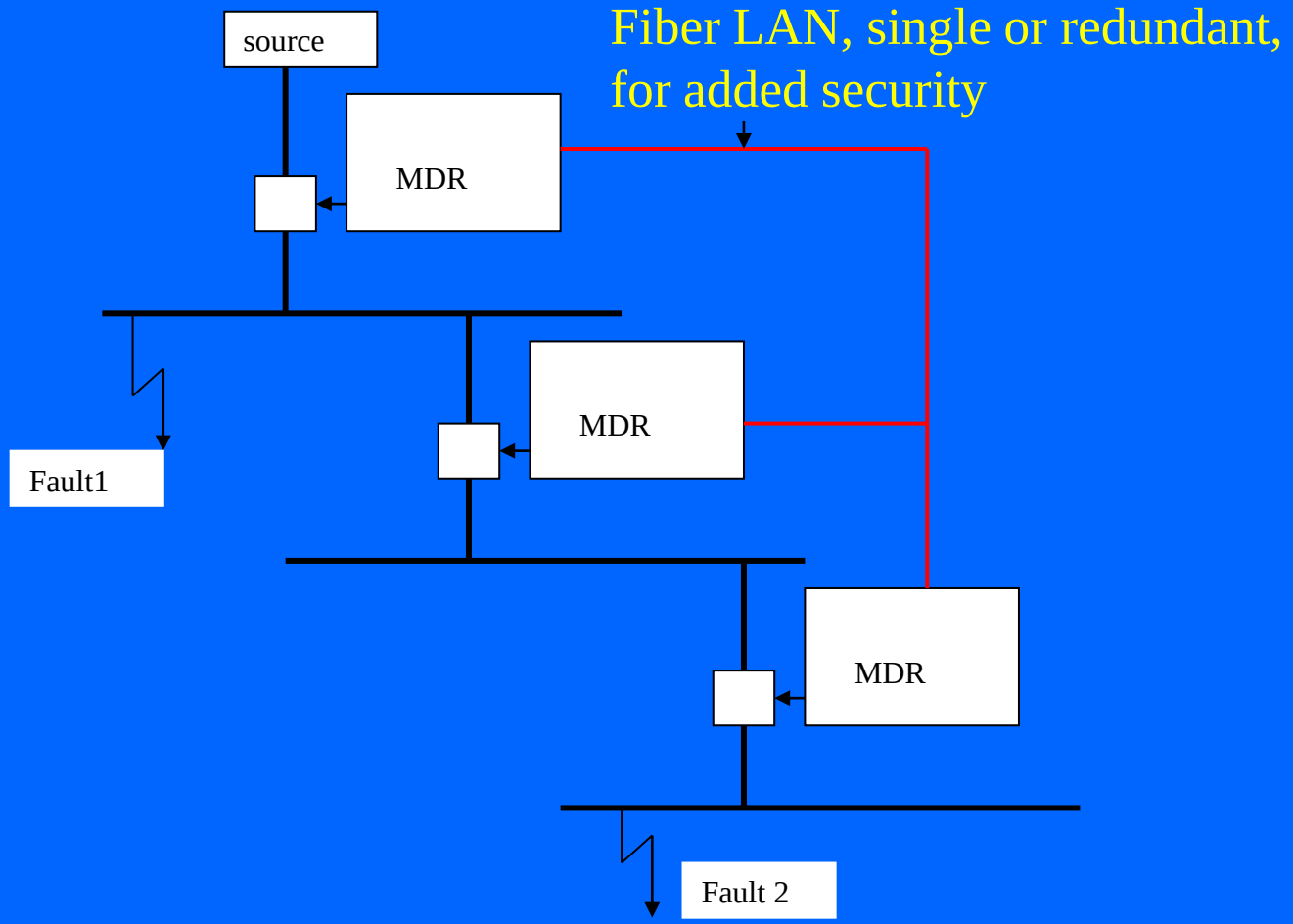
Typical Industrial Plant Distribution - Zones



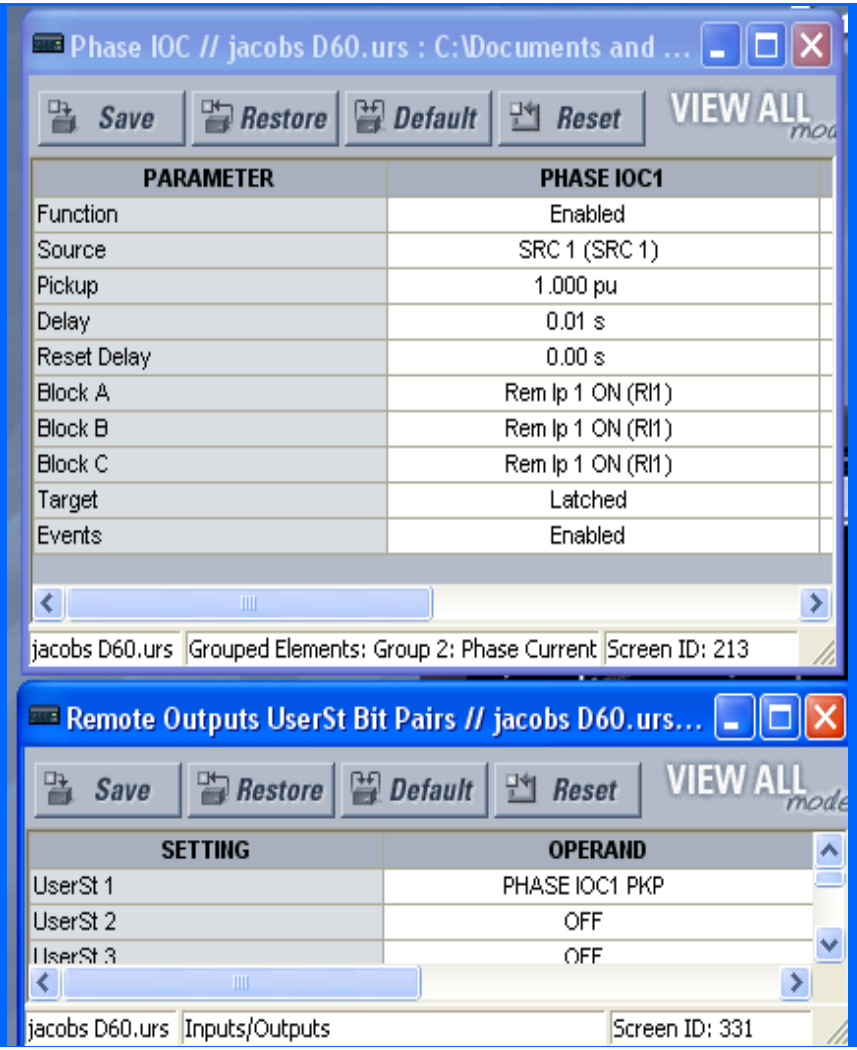
MDRs Connected Via Managed Switch LAN For Bus Protection



MDRs Connected Via Managed Switch LAN For Radial Feeder Protection

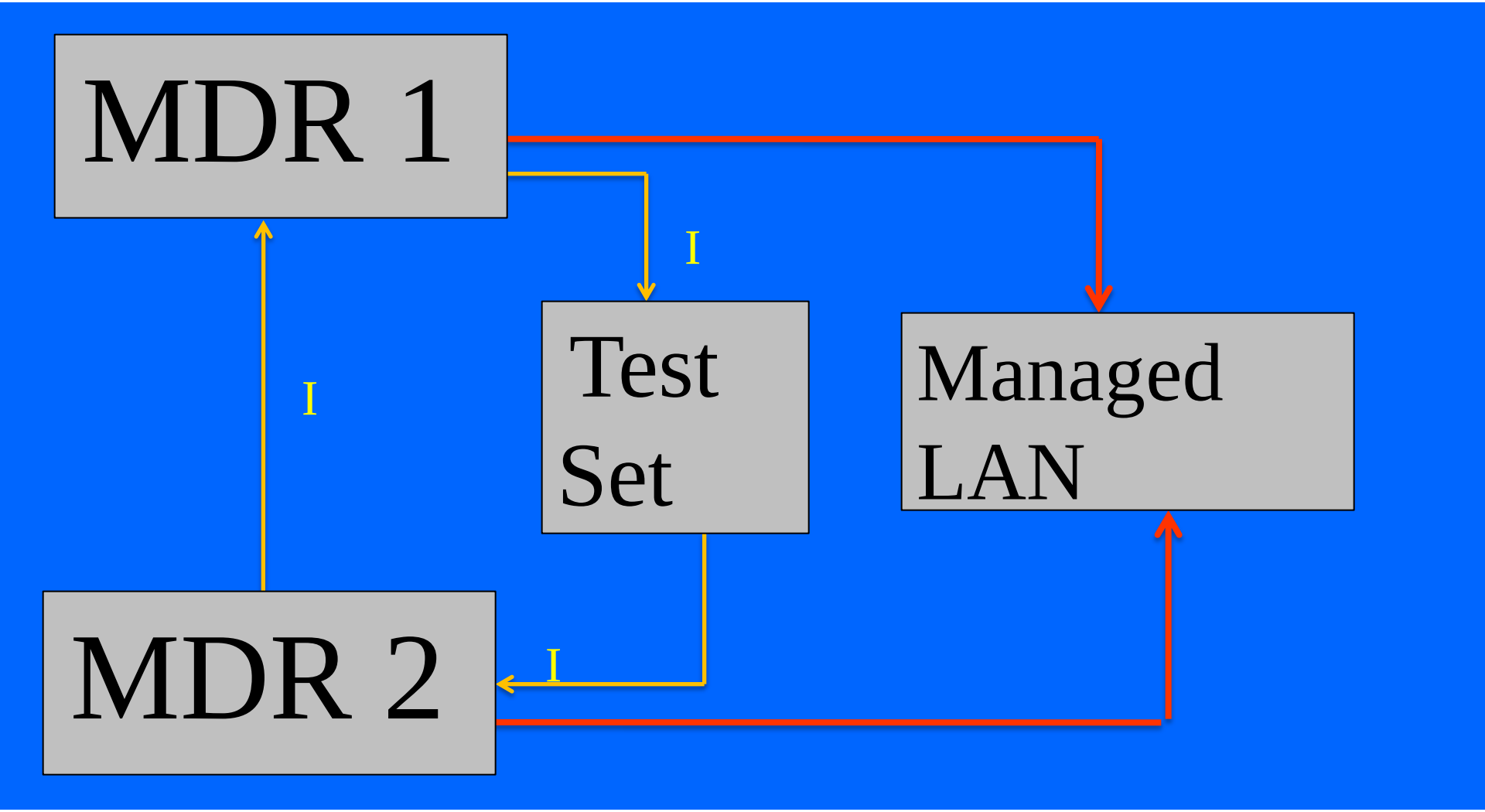


Injection Test of the Scheme Speed

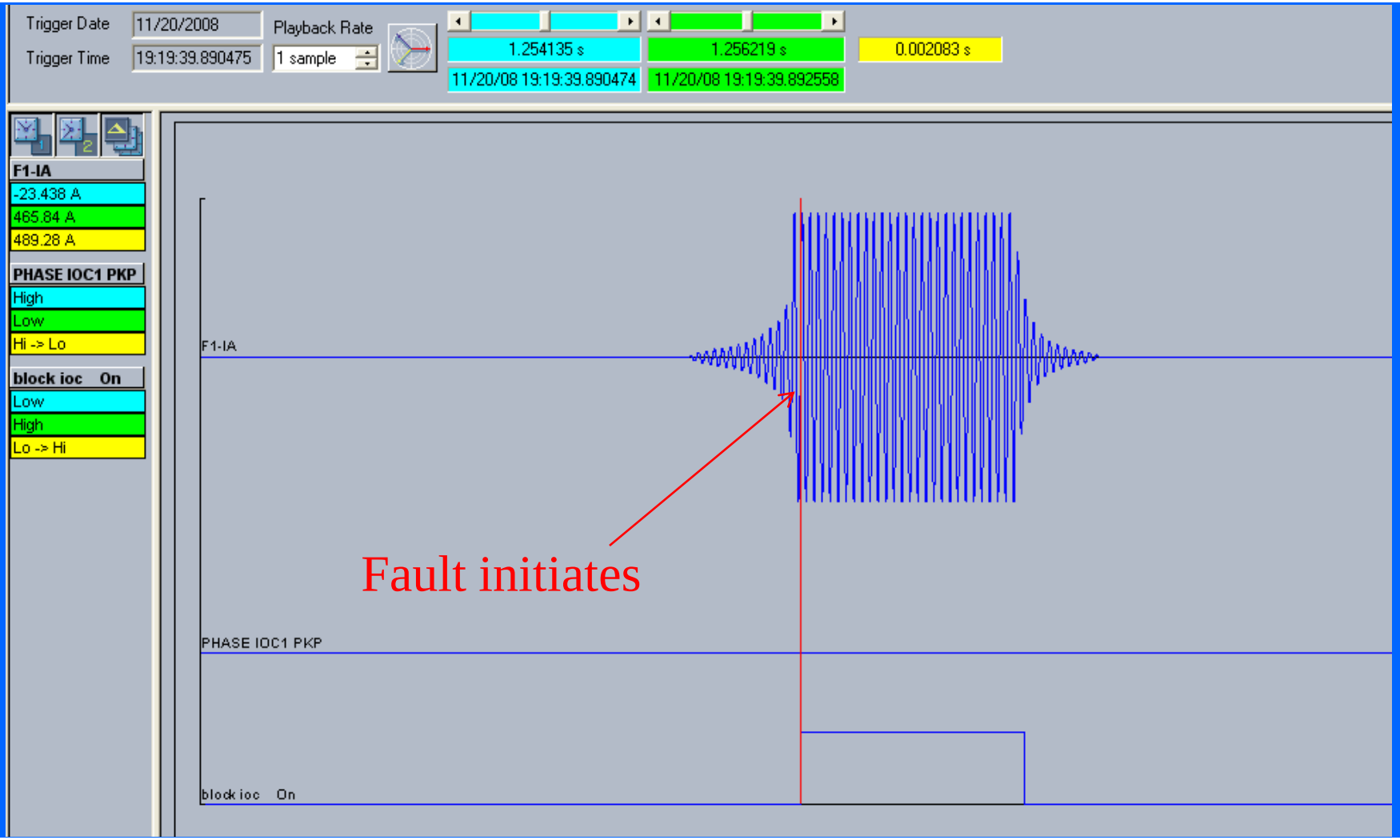


- Injection set series connected to both MDRs
- IOC trip elements with 10ms operate delay
- Downstream MDR initiates GOOSE on IOC PICKUP
- Upstream MDR receives blocking signal
- If the fault was within the zone, no blocking signal would be sent, trip initiates within 10ms

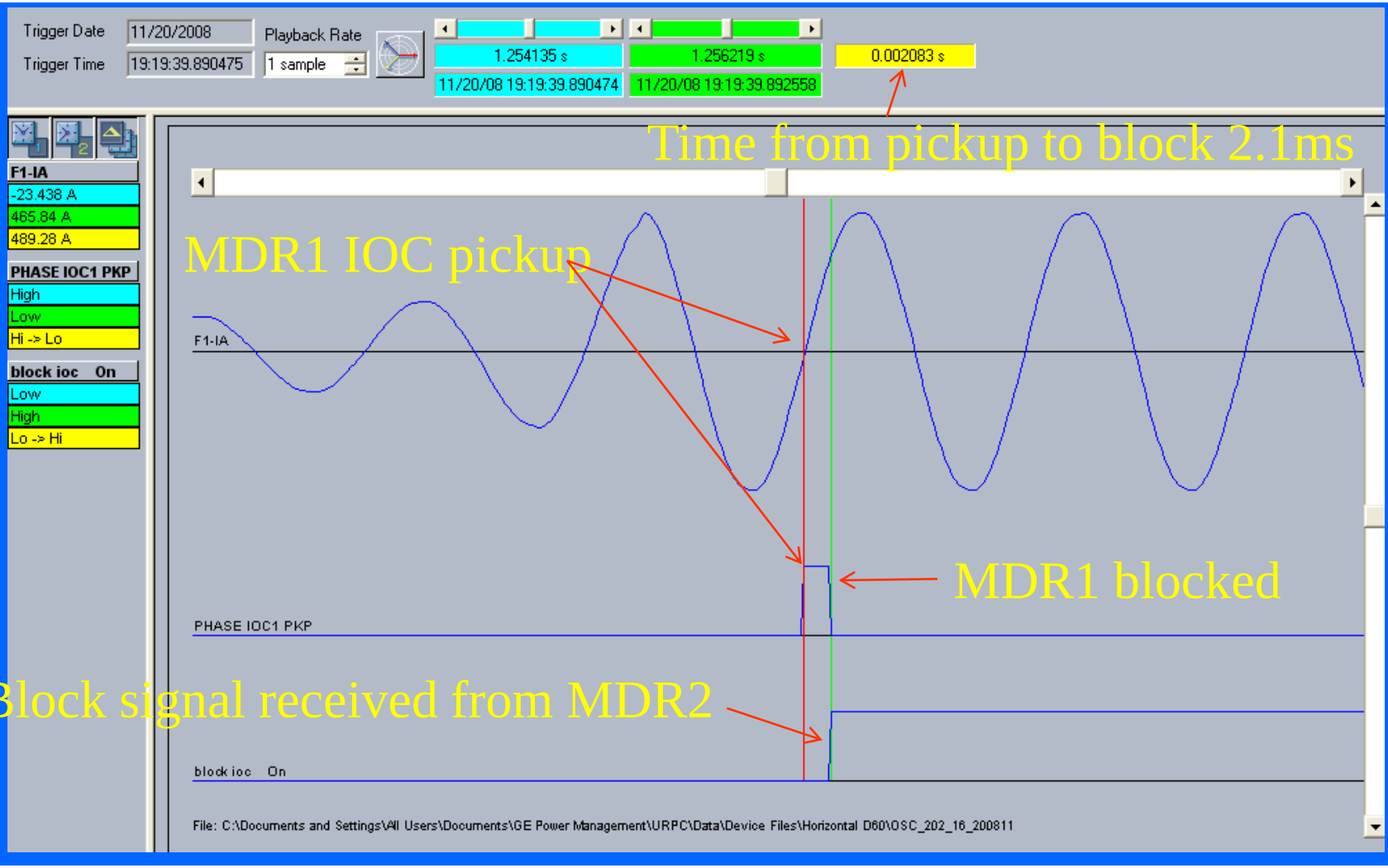
Injection Test of the System



Injection Test of the System



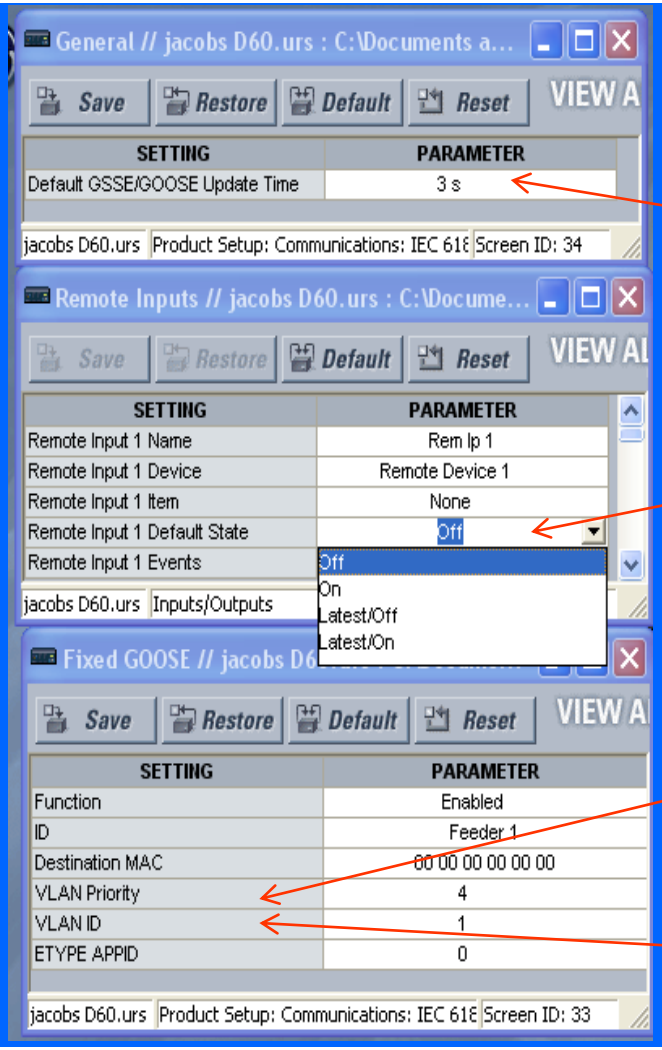
Injection Test of the System-Magnified



Injection Test of the System

- This 2.1ms is essentially the scan time of the MDR
- The network transmission time is only measurable in microseconds
- True managed switches '**manage**' the traffic
- Virtual LANs (VLAN) effectively route GOOSE traffic within a LAN reducing network congestion, speeding relay response
- Unlikely that with an MDR scantime of 2ms that the delay from detection at one relay to reception of GOOSE message at other relay would be > 4ms

System Security



- GOOSE settings allow greater security than traditional hardwired solutions
- Update time defines how often signal must be sent if no change detected, “heartbeat”
- Default to “ON” means block >security, time coordinated protection in effect, “OFF” means don’t block - >safety- fast clearing
- User selectable operation
- Priority ensures GOOSE messages go to the high priority buffer within the switch.
- VLAN tag enables the LAN to route messages to specific MDRs.

Conclusion

- 61850 peer-peer messaging can significantly reduce arc incident energy for the **entire** electrical distribution system
- Customer retrofit application found a reduction from 68 to 3.9 cal on the 5kv bus using a **30ms** IOC operate delay
- Accomplished with no additional equipment cost, just implementation of GOOSE settings
- **Best case –** secure, minimal clearing time with no user intervention
- **Worst case** - if LAN is down the electrical system still has traditional independent coordinated protection, alarm can be generated to warn personnel
- Remedial systems can then be employed