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

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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

Data Log

Total event Time 470ms

19.2KA RMS MAX
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.
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
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 its 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 troubleshoot
- Easy to install
- Fastest network recovery
IEC61850 compliant Station Bus LAN architecture

Substation

Default VLAN

Tele-protection (C37.94, G.703 etc)
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

Fiber LAN, single or redundant, for added security
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

MDR 1

Test Set

Managed LAN

MDR 2
Injection Test of the System

Fault initiates
Injection Test of the System-Magnified

Time from pickup to block 2.1ms

MDR1 IOC pickup

MDR1 blocked

Block signal received from MDR2
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 scan time of 2ms that the delay from detection at one relay to reception of GOOSE message at other relay would be > 4ms
• 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