Practical Considerations of Applying IEC61850 GOOSE Based Zone Selective Interlocking Schemes in Industrial Applications

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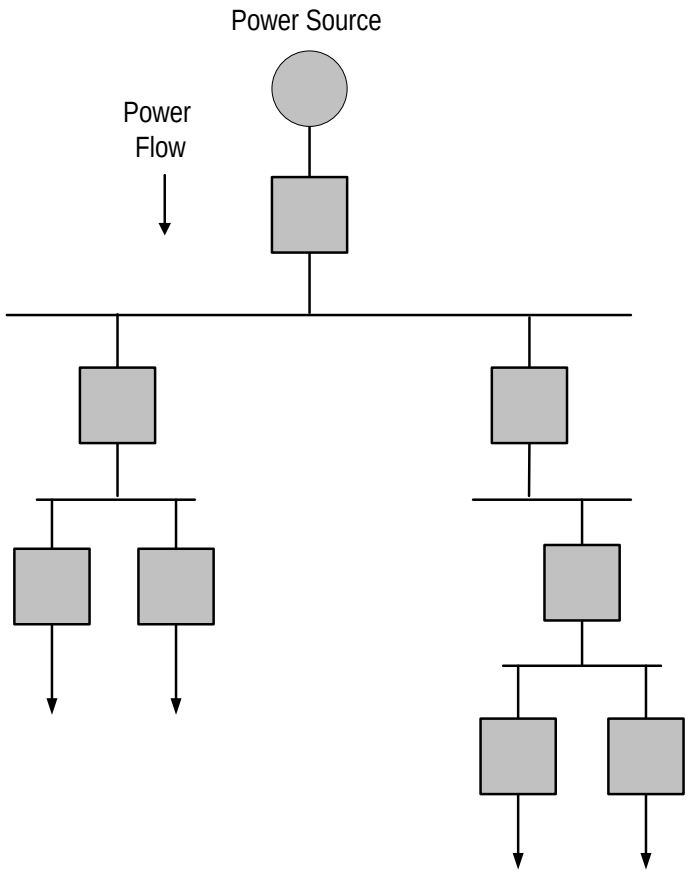
Purpose of ZSI Application

- Optimize protection sensitivity
- Decrease clearing time
- Reducing upset in the power system
- Reduce arc flash hazard
  - A downstream feeder breaker trips only the faulted part of the power system, avoiding tripping of the upstream breakers
  - Enhances the pre-designed coordinated distribution system by reducing the fault clearance time, with no intentional time delay



Simple radial power network

Traditional Way To Do Protection Coordination Between Feeder Relays And Main Relays

- Review of Buff Book for relay coordination summary of CTI (Coordination Time Interval) requirement
- Coordination Time Interval (CTI) between upstream static relay and down stream static relay: >=200ms
- Main breaker should not use 50 function in order to coordinate with feeder breaker overcurrent protection
- Do not enable the instantaneous overcurrent element (50) on main breaker relays

Bus Relays (Main Breaker or Partial Differential):
Pickup set between 100% and 125% FLA (150% FLA maximum)
Set to coordinate with transformer primary protective relaying

Table 15-3—Minimum CTIs[a]

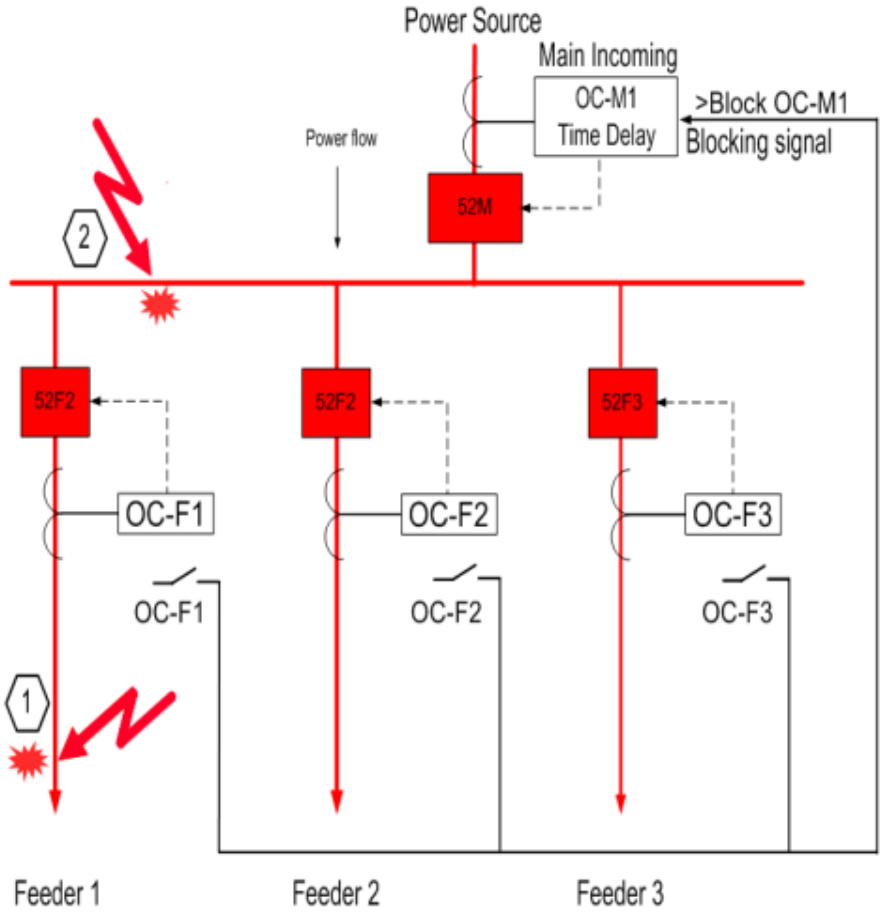
Downstream	Upstream			
	Fuse	Low-voltage breaker	Electro-mechanical relay	Static relay
Fuse	CS[b,c]	CS	0.22 s	0.12 s
Low-voltage circuit breaker	CS[c]	CS	0.22 s	0.12 s
Electromechanical relay (5 cycles)	0.20 s	0.20 s	0.30 s	0.20 s
Static relay (5 cycles)	0.20 s	0.20 s	0.30 s	0.20 s

[a]Relay settings assumed to be field-tested and -calibrated.
[b]CS = Clear space between curves with upstream minimum-melting curve adjusted for pre-load.
[c]Some manufacturers may also recommend a safety factor. Consult manufacturers' time-current curves.

Transitional CTI is defined by IEEE Standard 242 Buff book, Table 15-3, Minimum CTIs

Principle of Zone Selective Interlocking (ZSI) Application

- If a fault occurs at Location 1, both feeder 1 relay and the main relay sense the fault, a blocking signal is sent from the feeder 1 relay to the main relay to let the feeder 1 be tripped first to clear the fault
- If a fault occurs at Location 2, only the main relay senses the fault, the fault is on the bus. The main relay would clear the fault without any delay
- Side note:
  - Very easy to adopt ZSI to a fast bus trip scheme to replace the dedicated bus differential scheme in some less important bus applications

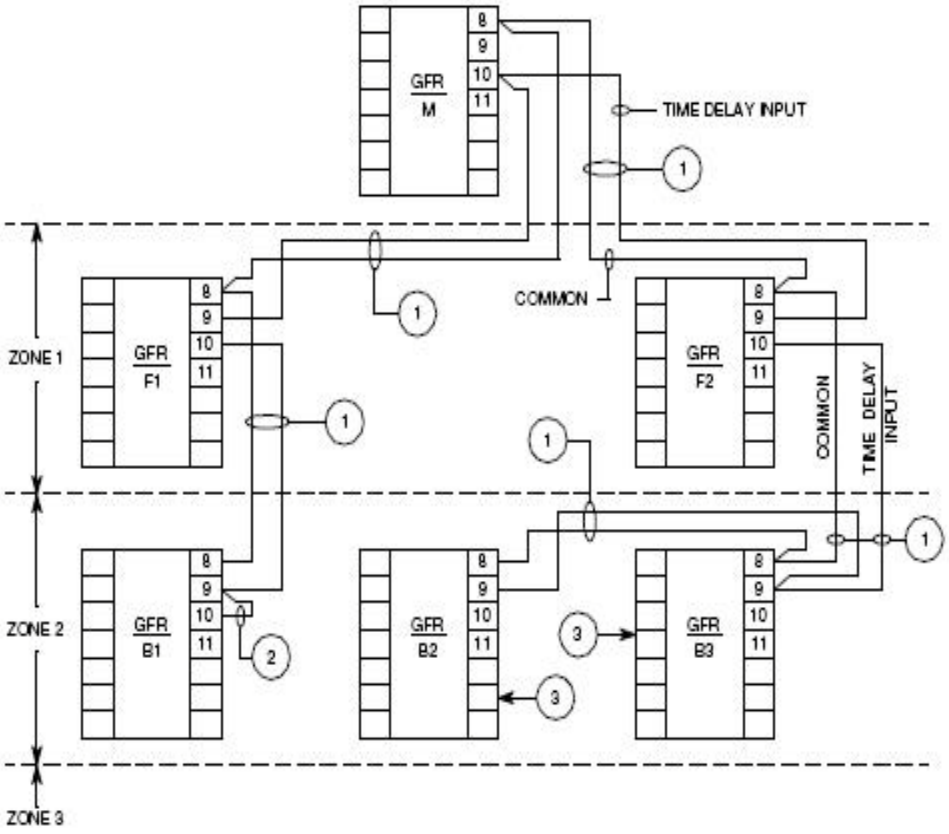


ZSI in a Simple Radial Power Network

Method to Achieve ZSI Application

1. Hardwired Based

- Used in LV applications exclusively
- Most LV intelligent breakers have hardwired ZSI as a built-in feature
- Hardwire connections between downstream and upstream devices
- Setting are done through LV trip units

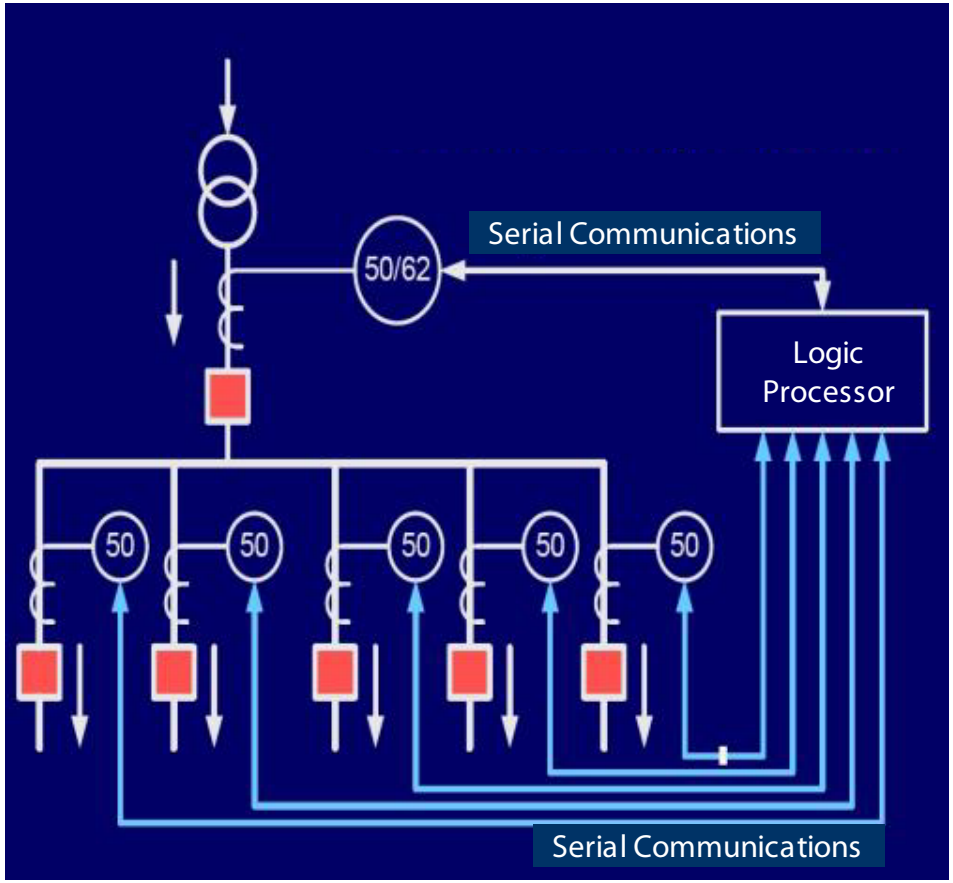


Hardwire Based ZSI Connection Setup

Method to Achieve ZSI Application

2. Serial Port Based Peer to Peer Communications

- Used in either MV or LV applications
- Is a proprietary technology. Not interchangeable with other vendors' IEDs
- Usually offers one to one communication channel only
- In order to do ZSI, a logic processor needs to be in place to overcome one to one communication channel limitations
- Need an additional dedicated serial cable network



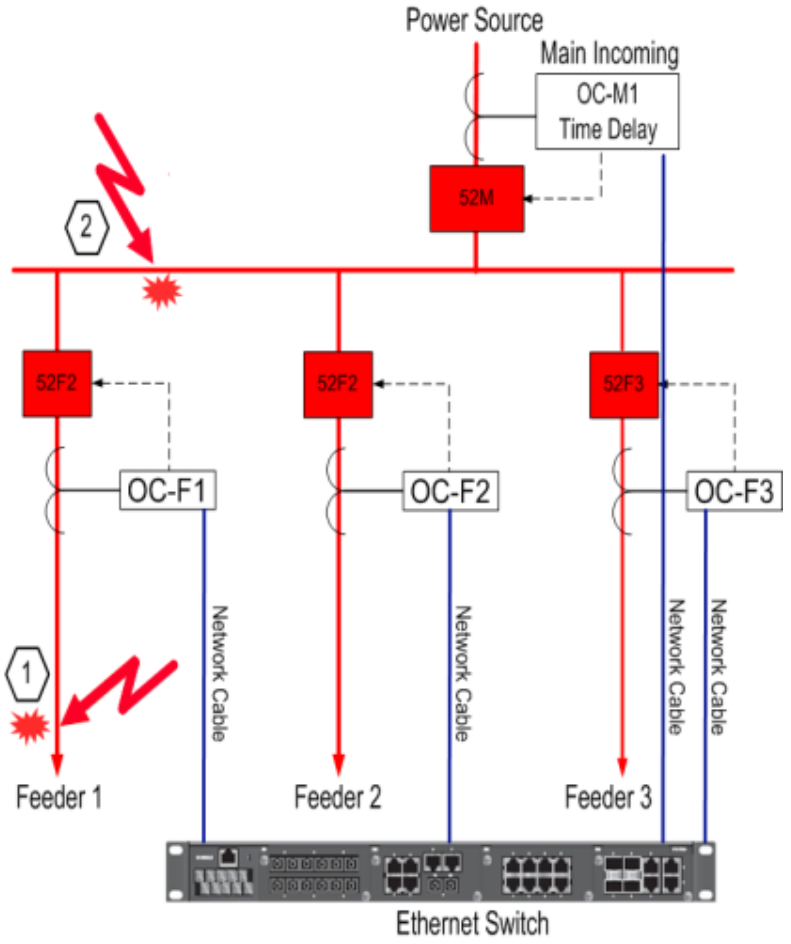
Serial Port Based ZSI Communication Setup

Method to Achieve ZSI Application

3. IEC61850 GOOSE Based Peer to Peer Communications

- Used in either MV or LV applications
- Ethernet communication network based
- Worldwide recognized standard, open architecture, and common technology, interchangeable with any vendor's IED
- No need for any additional network, network cable or components

IEC61850 = Communication networks and systems in substations
GOOSE = Generic Object Oriented Substation Event
Specified in IEC61850 standard



IEC61850 GOOSE Based ZSI Communication Setup

Advantages of Using GOOSE Based ZSI

- Replace the conventional hard wiring connections between IEDs, lower installation cost
- No need to have additional serial port on protection relays
- Comply IEC61850 standard, compatible with any IEC61850 capable IEDs from any vender
- One to one, one to many, many to one and many to many communication channels
- Use the existing or must-to-have Ethernet network in a plant
- Other communication-assisted applications can be achieved in the same IEDs and the same network
- Easy to modify and expand when system configuration changes

Blocking Time Considerations

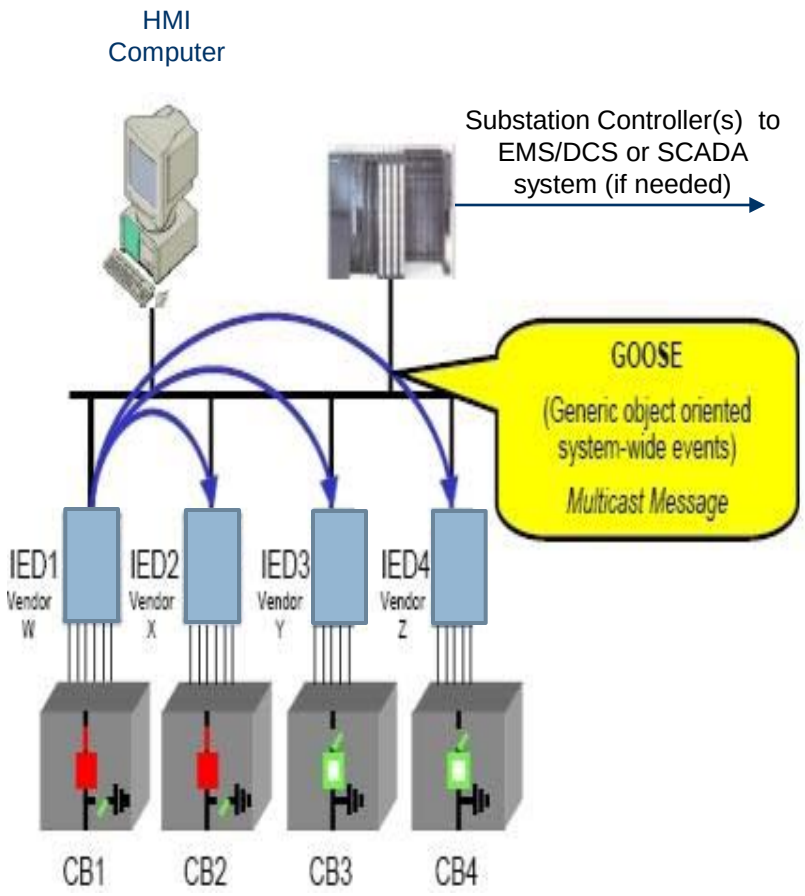
BLOCKING TIME DETERMANATION:

- If the blocking time is too long, the goal of reducing CTI cannot be not met
- If the blocking time is too short, mis-operation may occur.

- Initial blocking time estimate with the following conditions:
  - Well designed and configured network
  - LAN communication travelling time is initially estimated not over a cycle of 16ms (worst case scenario)
  - Three cycle breakers are used in ZSI scheme

Downstream relay logic execution:		2ms
LAN communication travelling:		16ms
Upstream relay logic execution:		2ms
Upstream relay output responding	:	4ms
Three-cycle breaker opening time:		50ms
Total:		74ms

- Final blocking time should be determined by the test, For most cases, not more than 100ms



Other Considerations

COMMUNICATION FAILURE

- If communication is failed between a feeder relay and the main relay, a traditional CTI with intentional time delay in the main relay should be restored for that particularly feeder as a backup

BREAKER OPEN FAILURE

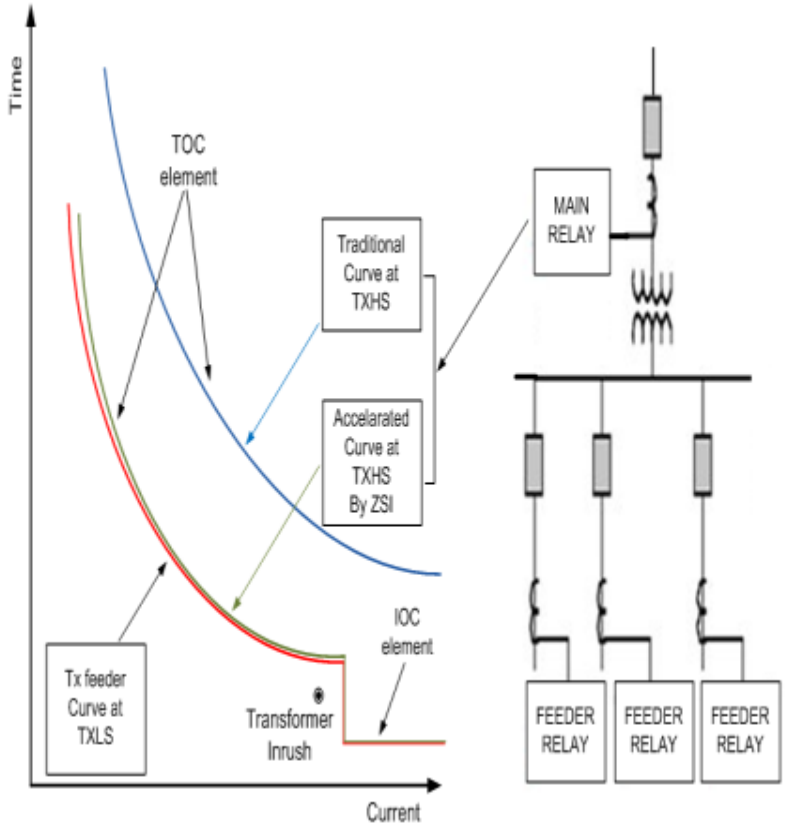
- Breaker open failure detection should be involved in the ZSI applications and the Breaker Failure Initiate (BFI) logic should be programmed in the feeders relays and supervised with communication failure. If a feeder breaker gets breaker open failure, the main breaker should be tripped right away as a backup

TEST MODE

- Test mode needs to be setup for each individual feeder

Protection Considerations

- Most ZSI applications involve downstream loads are of all feeder lines within one voltage level, 50 (IOC) elements are used both in feeder relays and upstream main relays
- When transformer feeders are involved, transformer inrush current has to be considered
  - At relatively lower current part, use accelerated 51 (TOC) element to avoid transformer inrush current
  - At relatively higher current part, use accelerated 50 (IOC) element
- Same principle applies to motor feeders to avoid motor lockout current at motor starting
  - Majorly used for motor breaker circuit, not used for motor contractor-fuse combination circuit applications
- Apply ZSI schemes for both phase and ground elements
- Ground element ZSI usage:
  - High Resistance Grounding (HRG), no need for ZSI Ground fault is for alarm only, not for tripping
  - Low Resistance Grounding (LRG), no need for ZSI Ground fault current is limited to a fixed low magnitude
  - Solidly grounded (SG) system, apply ground ZSI scheme



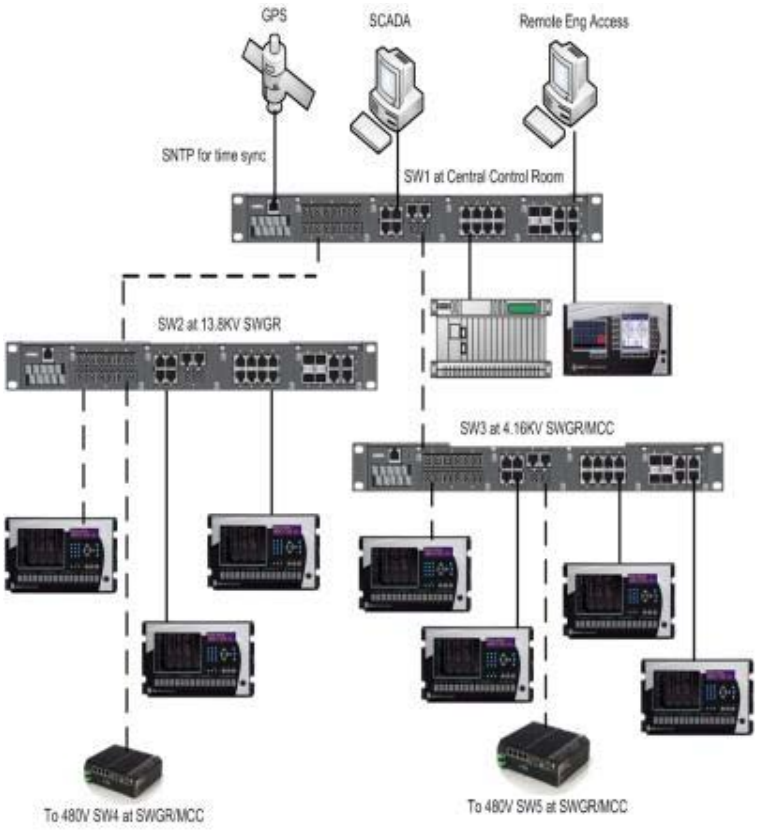
Transformer Feeder with ZSI

Network Considerations

REQUIREMENTS:

- Reliable communications
  - Redundancy is needed
    - Redundancy at network (Ethernet switch) level
    - Redundancy at node (IED/protection relay) level
  - Fast retransmit profile is needed

- Fast speed
  - Separate communication traffic is needed
  - Tag prioritizing. Critical data should be passed first



Communication Network with No Redundancy

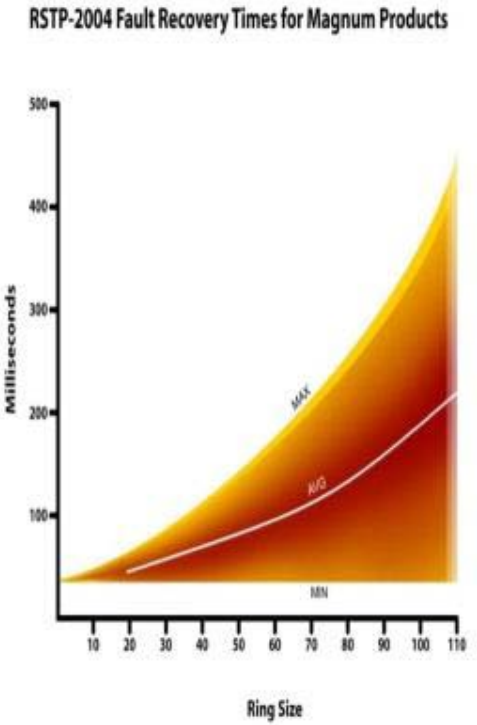
Network Considerations

REQUIREMENTS:

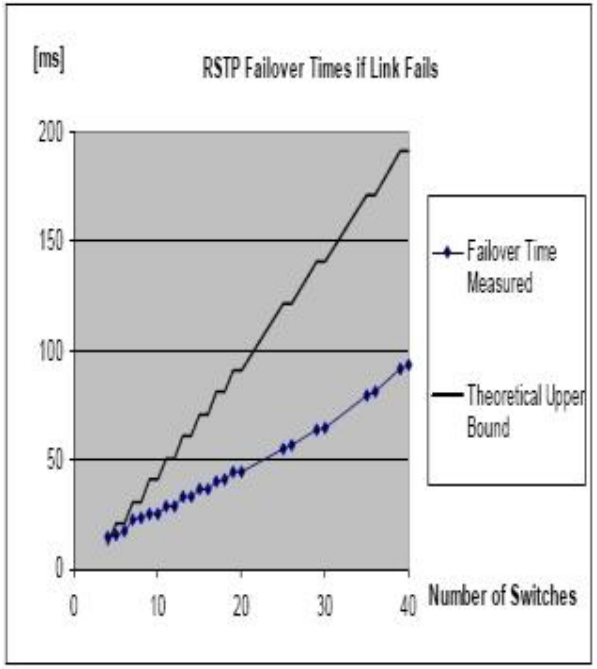
- Reliable communications
  - Redundancy is needed.
    - Redundancy at network (Ethernet switch) level
    - Redundancy at node (IED/protection relay) level

- RSTP = Rapid Spanning Tree Protocol defined in IEEE 802.1W-2004
- RSTP ring is set up as a physically a closed loop for possible quick recovery but a logically open loop to avoid data broadcast storm that results in the network unusable
- RSTP automatically recovers from a link fault without the need of any operation interaction
  - The time RSTP protocol needs to realize the fault and find an alternate path is called protocol convergence time (Recovery Time, Failover Time, etc.)
  - Convergence time varies depending on how many switches in an RSTP ring. The more switches in a ring, the slower the convergence time.
  - Typically, maximum number of Ethernet switches in an RSTP ring: 40

Typical recovery time vs. number of switches in an RSTP ring



Measured vs. theoretical RSTP failover time in a ring network if the root bridge fails.

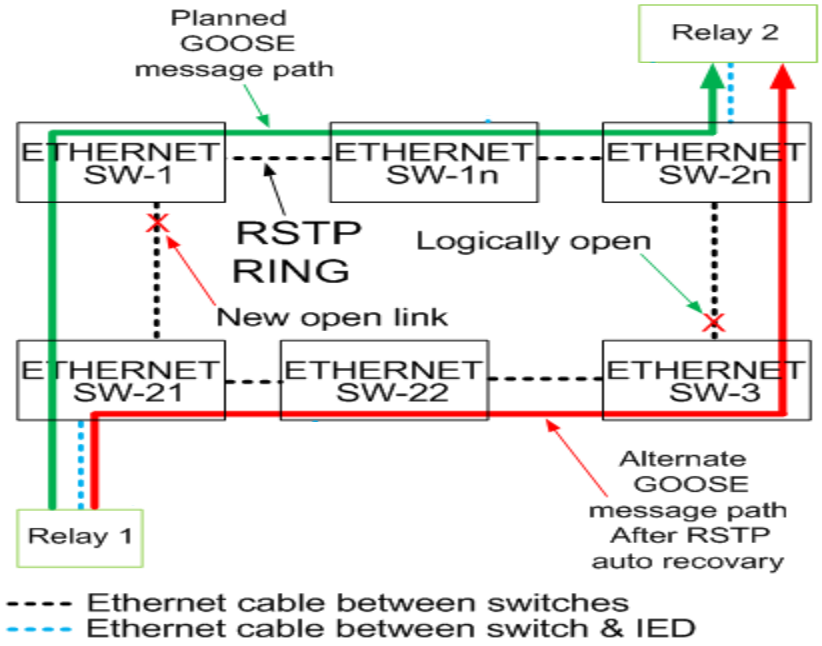


Source:
Left: From GarrettCom literature.
Right: From: Performance of the Rapid Spanning Tree Protocol in Ring Network Topology
By Michael Pustylnik, Mira Zafirovic-Vukotic, Roger Moore, RuggedCom, Inc.

Network Considerations

REQUIREMENTS:

- Reliable communications. Redundancy at network level and at node level is needed



Method 1:

Communication redundancy achieved at network level by one RSTP ring and at node level by using two ports at each node

Which method is better? Method 2 is better. Why?

Less number of Ethernet switches in each RSTP ring so recovery time is shorter

Network Considerations

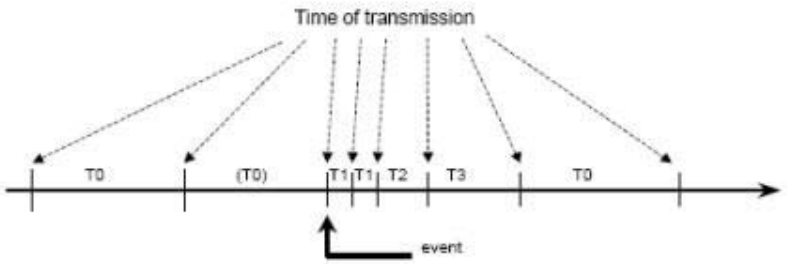
REQUIREMENTS:

- Reliable communications
  - Fast retransmit profile is needed

IEC61850 PART 8-1 , GOOSE RE-TRANSMISSION RULE

18.1.2.5 SendGOOSEMessage

The GOOSE service model of 61850-7-2 ".. provides the possibility for a fast and reliable system-wide distribution of input and output data values." This SCSM uses a specific scheme of re-transmission to achieve the appropriate level of reliability. When a GOOSE server generates a SendGOOSEMessage request, the current data set values are encoded in a GOOSE message and transmitted as T-DATA on the multicast association. The event that causes the server to invoke a SendGoose service is a local application issue as defined in IEC 61850-7-2. Additional reliability is achieved by re-transmitting the same data (with gradually increasing SqNum and retransmission time). How this will be done is shown in Figure 7.



T0	retransmission in stable conditions(no event for a long time).
(T0)	retransmission in stable conditions may be shortened by an event.
T1	shortest retransmission time after the event.
T2, T3	retransmission times until achieving the stable conditions time.

Figure 7 – Transmission time for events

Table 5–1: GOOSE RETRANSMISSION SCHEMES

SCHEME	SQ NUM	TIME FROM THE EVENT	TIME BETWEEN MESSAGES	COMMENT	TIME ALLOWED TO LIVE IN MESSAGE
Aggressive	0	0 ms	0 ms	Event	2000 ms
	1	4 ms	4 ms	T1	2000 ms
	2	8 ms	4 ms	T1	2000 ms
	3	16 ms	8 ms	T2	Heartbeat * 4, 5
	4	Heartbeat	Heartbeat	T0	Heartbeat * 4, 5
	5	Heartbeat	Heartbeat	T0	Heartbeat * 4, 5
Medium	0	0 ms	0 ms	Event	2000 ms
	1	16 ms	16 ms	T1	2000 ms
	2	32 ms	16 ms	T1	2000 ms
	3	64 ms	32 ms	T2	Heartbeat * 4, 5
	4	Heartbeat	Heartbeat	T0	Heartbeat * 4, 5
	5	Heartbeat	Heartbeat	T0	Heartbeat * 4, 5
Relaxed	0	0 ms	0 ms	Event	2000 ms
	1	100 ms	100 ms	T1	2000 ms
	2	200 ms	100 ms	T1	2000 ms
	3	700 ms	500 ms	T2	Heartbeat * 4, 5
	4	Heartbeat	Heartbeat	T0	Heartbeat * 4, 5
	5	Heartbeat	Heartbeat	T0	Heartbeat * 4, 5
Heartbeat	0	0 ms	0 ms	Event	2000 ms
	1	Heartbeat	Heartbeat	T1	2000 ms
	2	Heartbeat	Heartbeat	T1	2000 ms
	3	Heartbeat	Heartbeat	T2	Heartbeat * 4, 5
	4	Heartbeat	Heartbeat	T0	Heartbeat * 4, 5
	5	Heartbeat	Heartbeat	T0	Heartbeat * 4, 5

Conclusion: Use "Aggressive" profile for ZSI blocking signal

Network Considerations

REQUIREMENTS:

- Fast speed
  - Separate communication traffic is needed

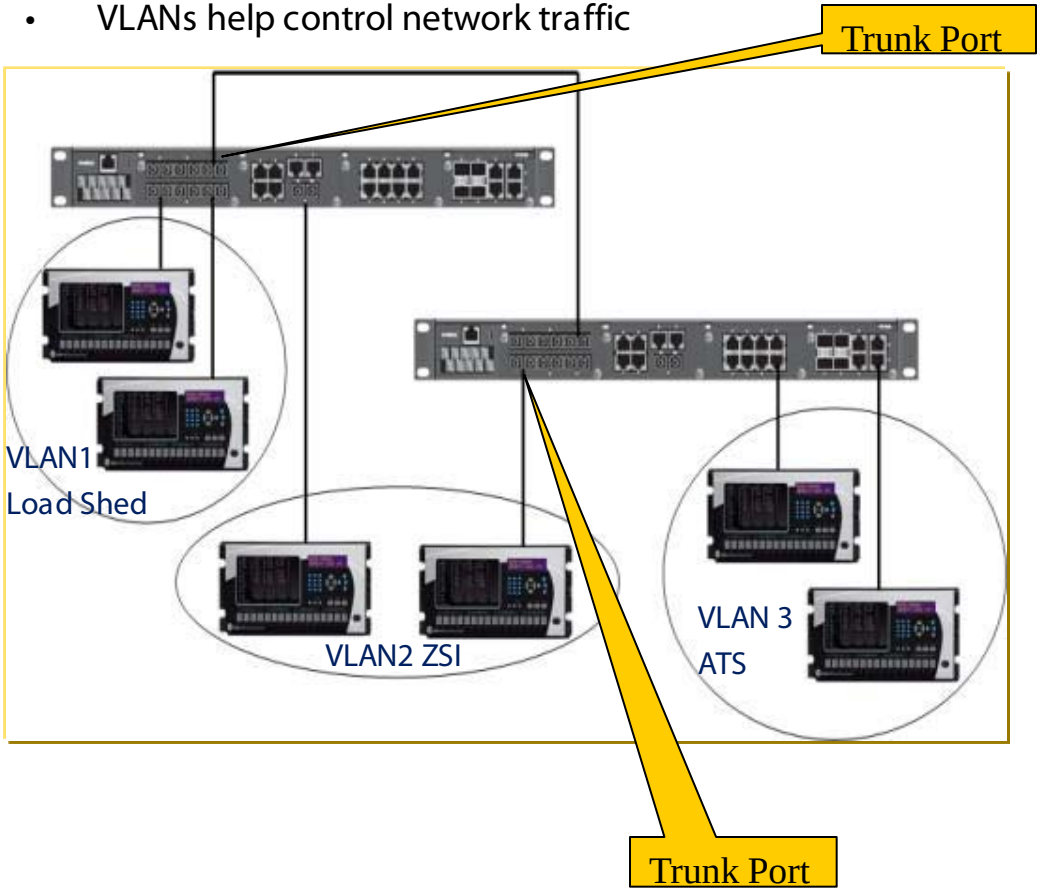
- A VLAN is a Virtual LAN . It is a group of devices that can be located anywhere on a network, by which communicate as if they are on the same physical segment. With VLANs, you can segment your network without being restricted by physical connections

- It is virtual because the VLAN is artificially/virtually created and the nodes need not be physically located on the same switch or even reside in the same physical location

- Use VLAN to separate network traffic between different IED to IED communications (GOOSE) and Server to IED communications (Clint-Server architecture)

- Configure VLAN, trunk port and priority in Ethernet switches

- VLANs allow for easy network changes
- VLANs enhance network security
- VLANs help control network traffic

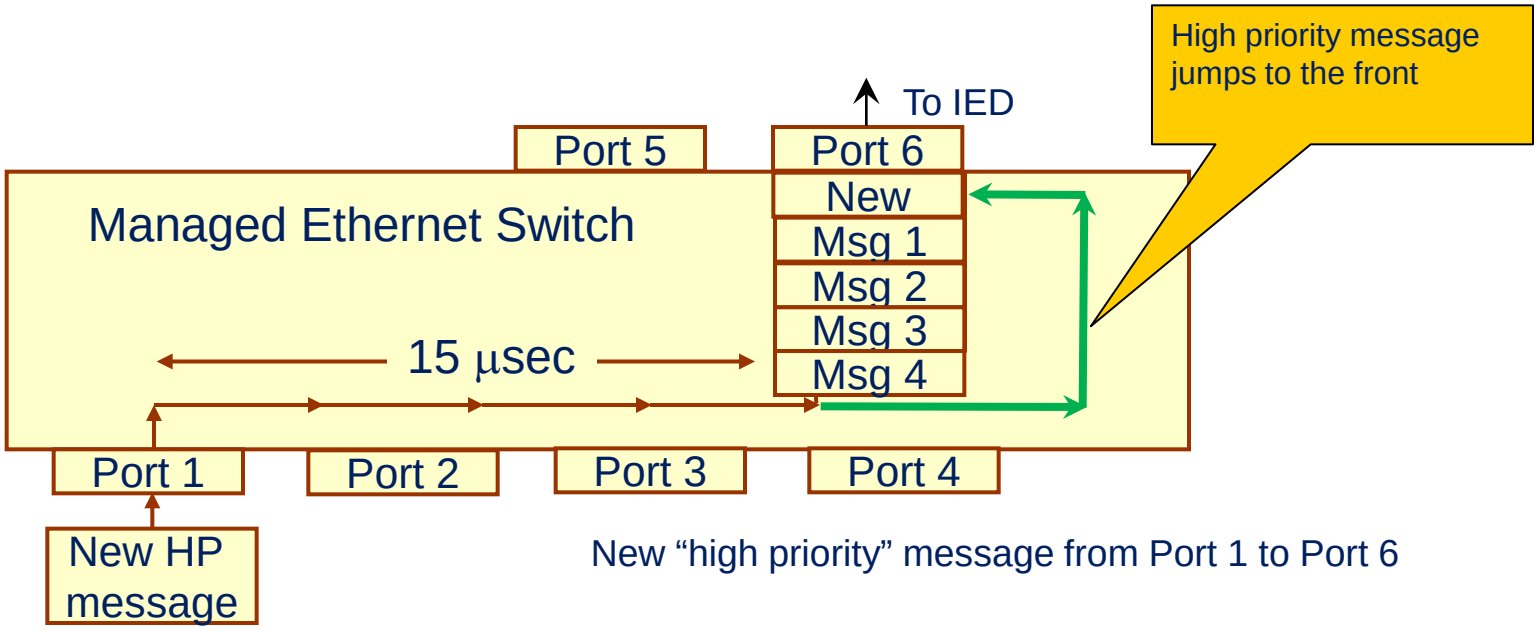


Network Considerations

REQUIREMENTS:

- Fast speed
  - Tag prioritizing. Critical data should be passed first

- GOOSE provides a priority setting with 8 levels of priority (0 to 7 where 7 is the highest)
- IEEE 802.1Q/P standard provides 3 bits for each frame to prioritize the traffic level
- When processed in a managed Ethernet switch, the message with the highest priority is moved to the front of the queue



Conclusion: Set ZSI related GOOSE message blocking signal as priority 7 to get it processed first

Setup and Programming Considerations

EXTEND ZSI TO A FAST BUS TRIP SCHEME

- Fast bus trip scheme may replace some dedicated bus differential schemes in less important and lower voltage level application, due to the speed of fast bus trip is not quick enough.

Comparison of commonly used bus differential schemes

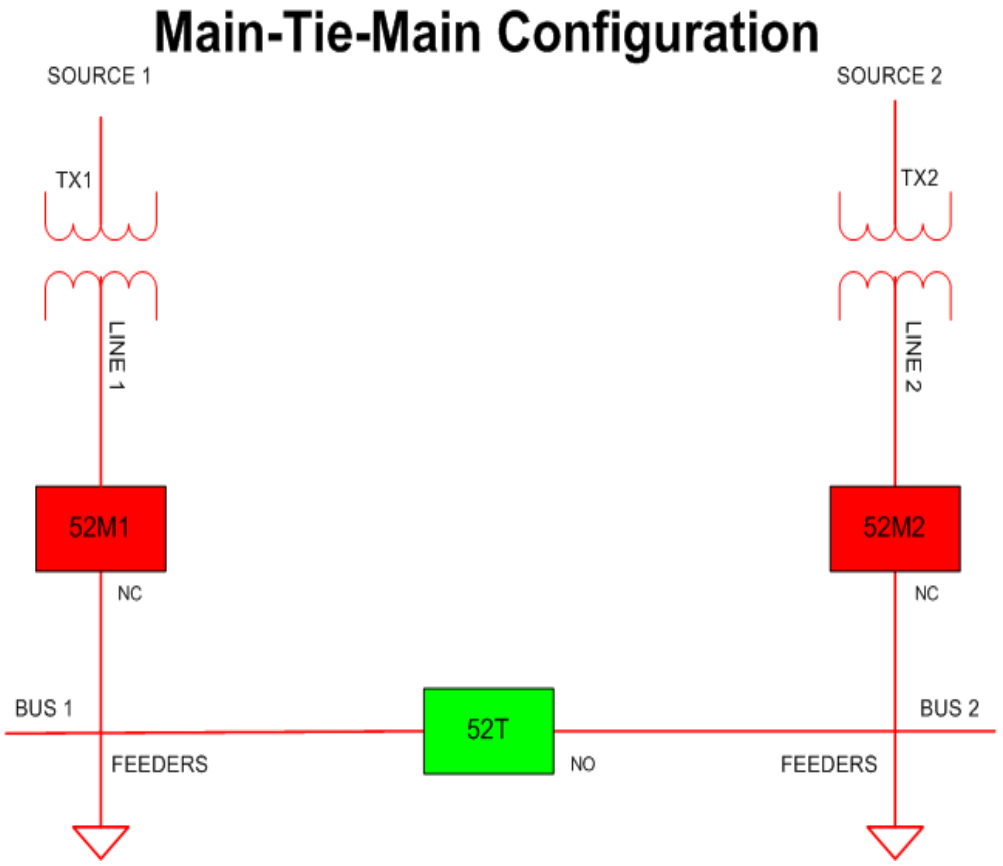
Item	LOW IMPEDANCE	HIGH IMPEDANCE	FAST BUS TRIP
Dedicated CT	Must	Must	Not needed
CT ratio and performance match	Not needed	Must	Not needed
Speed	Fast	Fast	Slow
Program complex level	High	Low	High
Flexibility	High	Low	High
Space taking	More	More	No need
Communication needed	No	No	Yes
Cost	High	Low	Low
Easy to communicate with other IEDs	Depends	Depends	Definitely
Skill needed	High	Low	High
Popularity	Low	High	New Technology

Setup and Programming Considerations

MAIN-TIE-MAIN CONSIDERATION

ZSI needs to be implemented in each of the following configurations:

- In normal double-ended operation mode where the tie breaker is open
  - Between feeder breakers and the main breaker
- In single-ended operation mode where the tie breaker is closed
  - Between feeder breakers and the tie breaker
  - Between the tie breaker and the main breaker



Setup and Programming Considerations

Reduce text

FEEDER IN TEST MODE

When doing ZSI related test for a specific feeder, the other in-service feeders should not be interfered for normal operations. A test flag should be raised for this particular feeder.

The test mode may be set:

- Method 1: At each feeder relay and use GOOSE to inform the upstream relay that the corresponding feeder is at-test mode status
- Method 2: At the upstream relay and use GOOSE to inform the related downstream relay that the corresponding feeder is at-test mode status

Method 2 is better because it reduces the requirement of total number of remote points communicating from the downstream relays to the upstream relay

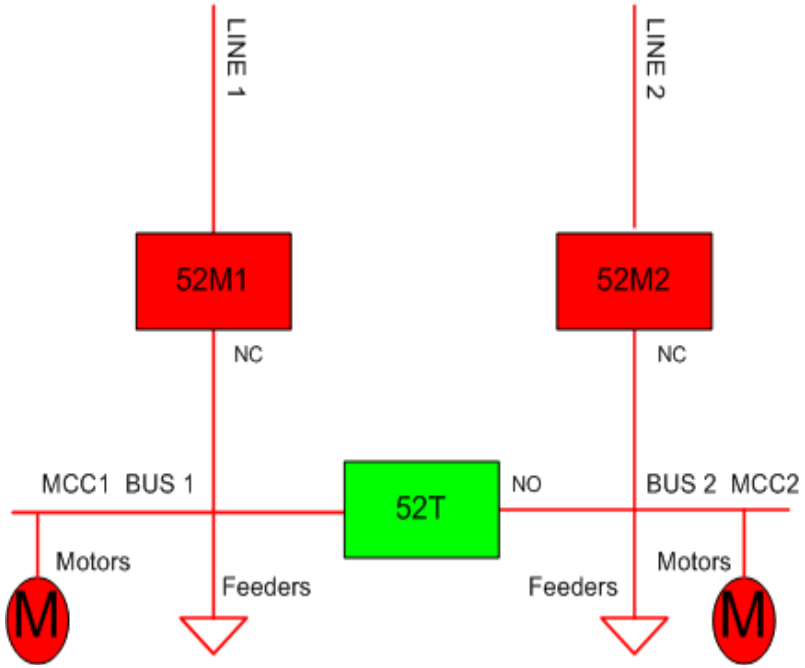
Example shown below is an arrangement of using upstream relay's four relay front pushbuttons to set each of 16 feeders in test mode individually

Feeder No. / PB No.	PB01	PB02	PB03	PB04
Feeder 1 in test mode	0	0	0	1
Feeder 2 in test mode	0	0	1	0
Feeder 3 in test mode	0	0	1	1
Feeder 4 in test mode	0	1	0	0
Feeder 5 in test mode	0	1	0	1
Feeder 6 in test mode	0	1	1	0
Feeder 7 in test mode	0	1	1	1
Feeder 8 in test mode	1	0	0	0
Feeder 9 in test mode	0	0	0	1
Feeder 10 in test mode	0	0	1	0
Feeder 11 in test mode	0	0	1	1
Feeder 12 in test mode	0	1	0	0
Feeder 13 in test mode	0	1	0	1
Feeder 14 in test mode	0	1	1	0
Feeder 15 in test mode	0	1	1	1
Feeder 16 in test mode	1	1	1	1

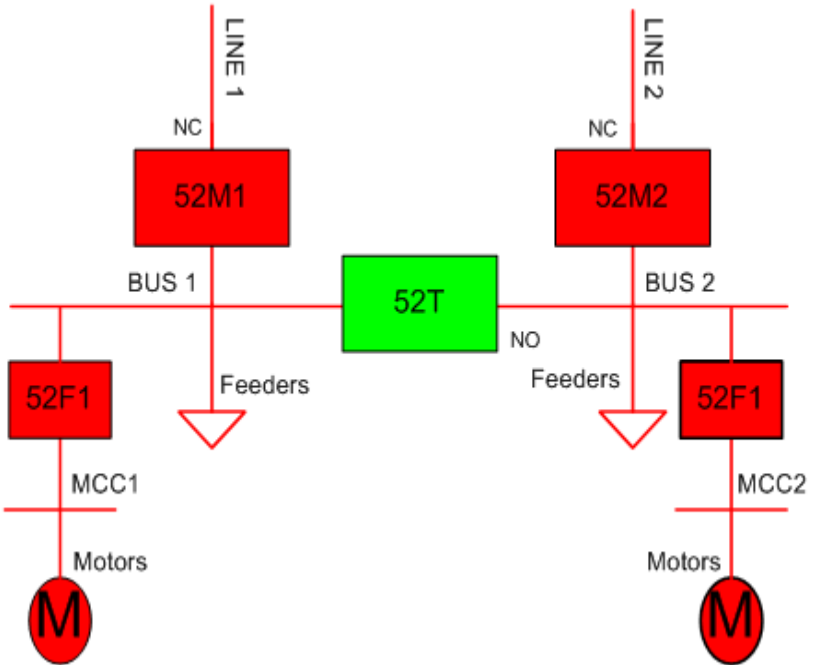
Setup and Programming Considerations

REDUCE NUMBER OF REMOTE DEVICES AND REMOTE POINTS

Re-arrange switchgear and Motor Control Center (MCC) configuration by adding a breaker between the switchgear and the MCC to reduce the total number of remote devices and remote points for each level of ZSI



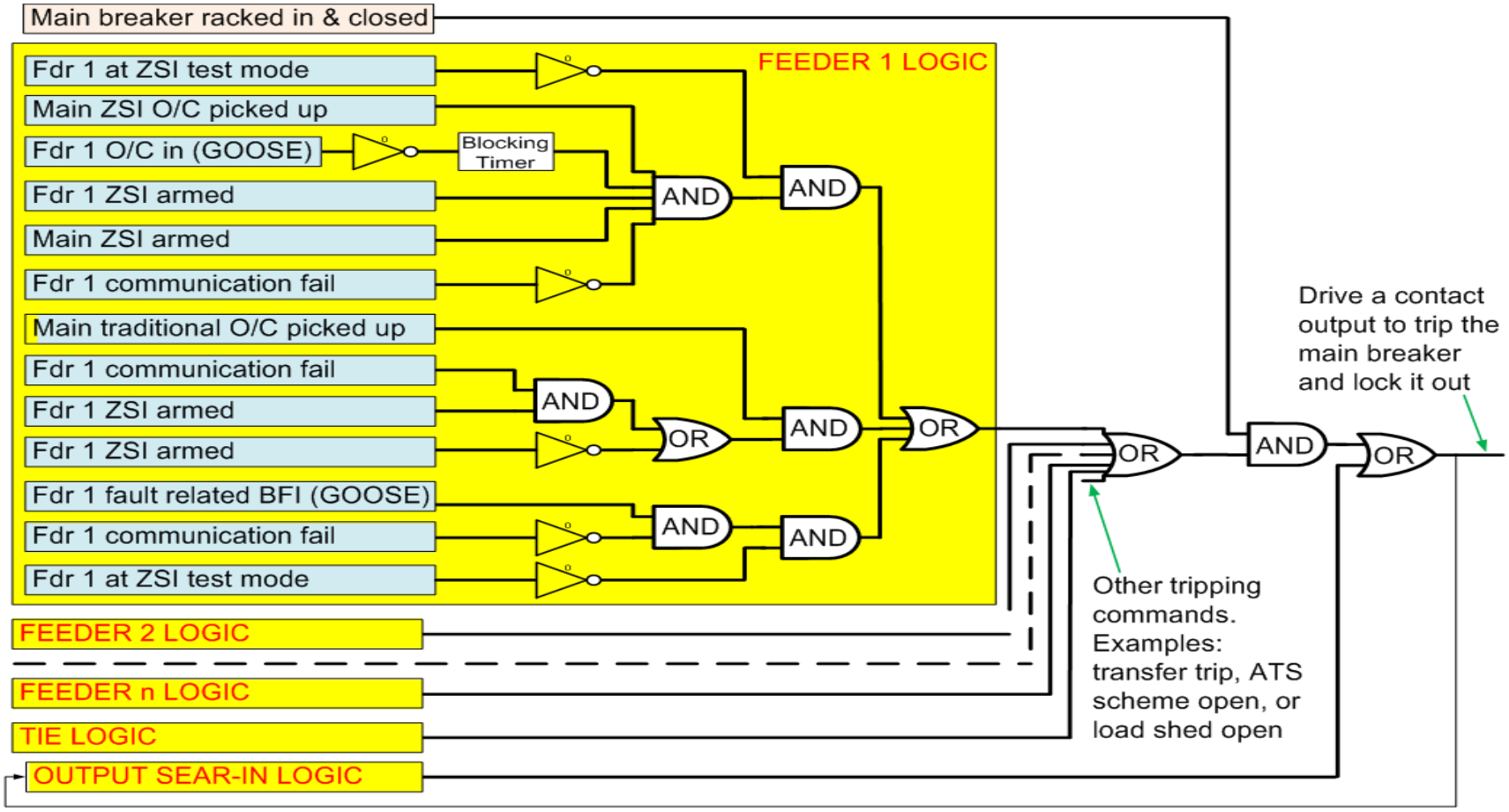
Require more remote devices and remote points capability in the upstream relays by the above setup



Require less remote devices and remote points capability in the upstream relays by the above setup

Example Logic Diagram

EXAMPLE LOGIC DIAGRAM USED IN THE UPSTREAM RELAY FOR MAIN-TIE-MAIN ZSI APLICATION



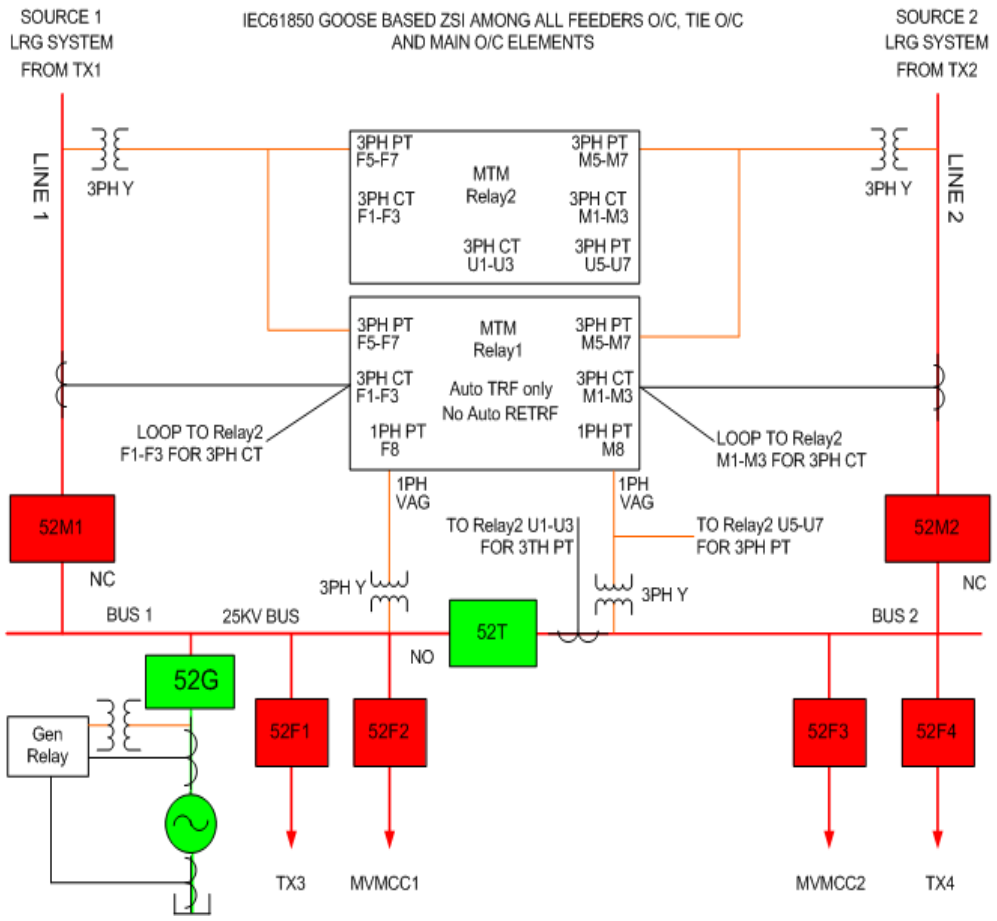
ZSI Test Considerations

TYPICAL TEST PROCEDURES

- Inject current from the primary side to check wiring and component integrity
- Determine ZSI blocking timer
- Test RSTP functionality
- Verify VLAN
- Current injection from the secondary side to test ZSI functionality and performance for each feeder
- Conduct communication failure test to verify alarms are properly flagged and upstream relay(s) is(are) back restored to normal CTI when communication failure occurs
- Conduct feeder breaker failure related test to verify upstream breaker could be tripped right away
- Disable ZSI, verify traditional CTI is in place

Project Outline

PROJECT OUTLINE – ONELINE DIAGRAM AT 4160V LEVEL



Development And Simulation Tests

Questions ?