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

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Tony Zhao – GE Energy
Lubomir Sevov - GE Digital Energy

Abstract **- This paper gives an overview on the practical considerations when IEC61850 GOOSE messaging based Zone Selective Interlocking (ZSI) scheme is applied in industrial applications. Considerations are extended from normal instantaneous overcurrent (IOC) protection elements coordination, to timed overcurrent (TOC) protection elements coordination for both phase and ground protection, from one voltage level to multiple voltage levels, from ZSI schemes to fast bus tripping schemes. When transformer feeders are involved with a ZSI scheme, avoiding nuisance trip caused by transformer inrush current is a major concern that makes timed overcurrent protection to be used over IOC only. When motor feeders are involved with a ZSI scheme, motor lockout current need be considered, so timed overcurrent is also used instead of IOC element. The impact of different protection devices used in different motor circuits, breaker or contactor fuse combination is also discussed in the paper.**

Communication network plays an important role in IEC61850 GOOSE messaging based ZSI schemes. In consideration of ZSI blocking time, all influencing factors have to be taken into account. This includes breaker or contractor opening time, relay I/O response time and messages traveling time in the communication network. Reducing and separating network traffic by using advanced network technology is a key for the success. Communication network redundancy needs to be carefully considered and implemented as an important step in each stage of the project: in the early planning, the setup and the execution. Detailed arrangement and configuration of the switchgear and the motor control center is another factor to consider, in terms to accommodate the number of intelligent electronic devices (IEDs), which communicate using the technology available today.

Keywords: Radial Feeder Protection, Instantaneous Overcurrent, Timed Overcurrent, Protection Coordination, Peer-To-Peer Communication

I. OVERVIEW OF CURRENT ZSI SCHEME

ZSI schemes are widely used in industrial applications. The main purpose of using ZSI is to optimize protection sensitivity and decrease clearing time, by making a downstream feeder breaker trip only the faulted part of the power system while avoiding tripping of the upstream breakers. It does not eliminate the relay coordination requirements, but enhances the pre-designed coordinated distribution system by reducing the fault clearance time, with no intentional time delay, hence reducing the stress on the system. In a simple radial network with one source and several feeders (Fig, 1), this can be explained with the trip of the feeder breaker closest to the fault, and isolate it from the entire system.

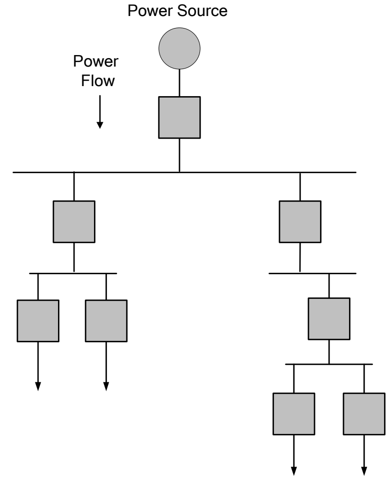

Fig.1 Simple radial power network

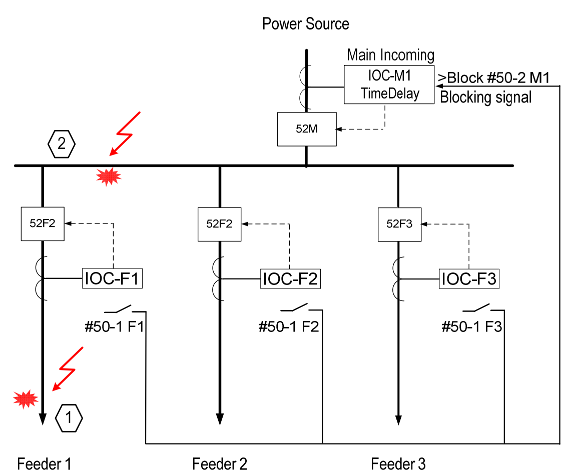

Fig. 2 ZSI in a simple radial power network

Basic principle is described as below. As shown in Fig. 2, when a fault occurs at the load side of the feeder breaker (fault location 1, Fig. 2), both the feeder relay at the faulted feeder, and the main relay detect the fault. The feeder relay sends a blocking signal to block tripping the main breaker and avoid loss of power for the whole bus. After the feeder fault is cleared, fault is not detected any more. If after a reasonably preset time delay, the main relay and the feeder relay still sense the fault, the main relay will trip the main breaker as a backup protection.

When a fault occurs on the bus (fault location 2, Fig. 2), only the main relay detects the fault, while feeder relays do not sense the fault, indicating the fault is on the bus. The main relay does not receive any blocking signal from any of the feeder relays, and will trip the main breaker right away.

Traditionally, protection coordination is achieved by using instantaneous overcurrent (IOC) element for feeder breakers and timed overcurrent (TOC) element for a main breaker. The minimum Coordination Time Interval (CTI) has to be followed between the downstream and the upstream protection devices. Per IEEE, for static relays used in both downstream and upstream protection devices, CTI must be at least 200ms[2], as shown in Fig. 3. By using ZSI schemes, the CTI between the downstream and the upstream protection devices could be greatly reduced, that, resulting in tremendously reduces arc flash hazard in industrial applications. In addition, the upstream protection device could also use IOC element, instead of using TOC element that makes the relay coordination job much easier.

This kind of ZSI functionality can be achieved by using any of the following three ways.

- Method 1, Hardwired connections among the intelligent trip units of LV downstream feeder breakers and the upstream breakers.
- Method 2, Serial channel based peer to peer communication among the downstream feeder relays and the upstream relays.
- Method 3, IEC61850 GOOSE based peer to peer communication among the downstream feeder relays and the upstream relays through Ethernet network.

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.

Fig. 3 Transitional CTIs defined by IEEE

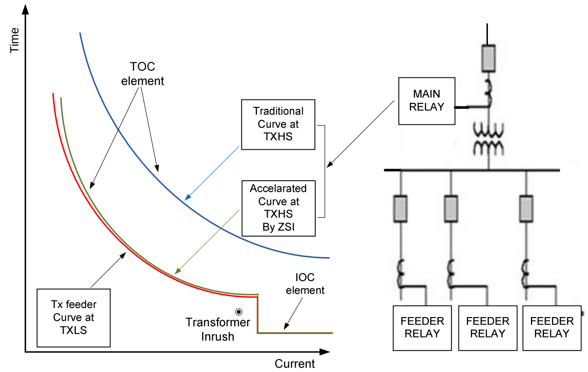

Fig. 4 Transformer feeder with ZSI

IEC 61850 GOOSE based ZSI scheme has many advantages over the other two methods. For an existing plant that already has an Ethernet network available, the existing network can be used without any additional equipment and new installation. For any new plant, the Ethernet network in most cases is a must-to-have design, and there is no need to add a separate Ethernet network for this purpose. The GOOSE messaging can be easily configured, transmitted and received among the protective relays, and it is to implement, modify and expend, when needed, without adding any additional hardware.

Compared to Method 1, the IEC61850 GOOSE based ZSI scheme does not need any additional hardwire connections that would save tremendously on material and installation cost.

Since IEC61850 GOOSE based ZSI scheme uses Ethernet network as the communication media, the involved protective relays do not need to be equipped with any additional serial ports, and do not need any serial cables as dedicated connections. The serial commutation is a proprietary technology of a particular vendor and would cause a lot of IED interoperability problems. Usually the serial communication only offers one-to-one communication mode, which makes it not useful for ZSI applications. The ZSI applications, involve multiple relays where each need to communicate with the rest of the others. In addition, in order to overcome the distance limitation by serial communication, a fiber over serial converter must be installed at each end of the serial communication channel, and a fiber cable in between has to be in place that further increases the cost and installation time.

II. PROTECTION CONSIDERATIONS

In most current applications, the ZSI schemes are limited to be used between the downstream feeder breakers and the upstream main breaker in one voltage level with no transformers and motors involved. This makes perfect sense for adopting IOC elements as the major protection function among these devices. However, when transformer feeders are involved, and the ZSI scheme is extended to multiple voltage levels, avoiding nuisance trip caused by transformer inrush current calls for timed overcurrent protection instead of IOC protection only. In this case, the ZSI scheme may be composed as two parts: the first part is at a relatively low current level with TOC part of Time Overcurrent Coordination (TCC) curve, using ZSI to accelerate the breaker tripping process but it is set above the transformer inrush point. The second part is passed at a relatively high current range, where the transformer high side upstream relay may have the same IOC curve as the one from the transformer low side downstream relay, which is the secondary part of ZSI scheme in transformer feeder applications.

Figure 4 shows the concept of this application. The shape of the transformer high side protection curve is almost the same as the one at the transformer low side relay, but ZSI blocking time should be added for selectivity to achieve accelerated breaker tripping function. It should be noted that transformer feeder ZSI application only applies to the transformers that do not have a dedicated transformer differential protection. This is due to the fact that the speed of the dedicated transformer differential protection is much faster than the ZSI scheme.

Moreover, when motor feeders are involved with ZSI schemes, motor lockout current has to be taken into account, so again timed overcurrent element has to be used instead of IOC element only. Similar to transformer feeder ZSI protection scheme, the ZSI may be applied to two parts of the current pick curve as well.

It is recommended in graphical representation of relay protection coordination study, TCC curves are still plotted as usual, like the ones without ZSI interlocking timer, but an additional text box needs to be inserted nearby. In this box, add some words there to indicate ZSI is involved for these curves. The proposed interlocking timer (in milliseconds) should be in the box as well. Although by doing so the downstream curve and the upstream curve may overlap together, but the text box would give a clear indication for ZSI involvements so relay programmers would program them accordingly without confusion.

The decision on whether or not to apply ZSI schemes should be very carefully estimated for situations where the motors are equipped with contactor-fuse combination, which is quite common for industrial applications, particularly for medium voltage Motor Control Centers (MCCs). In most cases, fuses are used for short circuit protection and relays for overload protection. This is in consideration of short circuit current magnitude often exceeds the low-interruption capacity of the motor contactors, and then overcurrent protection, either IOC or TOC, (ANSI code 50 or 51) is out of relay service. By this reason, motor ZSI applications are majorly used for motor breaker circuit, but not for contactor-fuse combination applications.

ZSI schemes can apply to both phase and ground protection elements. However, if a system neutral is either Low Resistance Grounded (LRG) or High Resistance Grounded (HRG), it does not make sense to use a ZSI scheme for these systems since their ground current is limited to a certain preset level. Moreover, a ground fault occurred in a HRG system is supposed to get alarmed only, not even result in tripping any device.

III. NETWORK CONSIDERATIONS

For any communication-assisted tripping or blocking scheme, reliability has to be placed in first place. If communication fails among any ZSI application involved IEDs, the fault cannot be cleared and isolated at the location closest to the fault. The benefit of using ZSI schemes can be compromised. There are two major thoughts related to communication failure for ZSI schemes related applications. The first thought is to maximally avoid communication failure that makes redundancy on the top of the table. And the second thought is, if communication fails what we should do as a backup plan.

In order to avoid communication failure at the Ethernet switch level, IEEE power system relaying committee issues the following guideline for using IEC61850 in critical applications [6]:

"Connect multiple switches in a ring, so that there are at least two paths from any switch port used by a relay to any other such switch port. Ethernet switches include the failover service called rapid spanning tree protocol (RSTP) by which the switches discover and use a normal or default message path without circulating messages forever in a loop – one link in the loop is blocked to achieve this. If the ring suffers a break or if one switch fails, the switches can detect the path loss and immediately set up new routing of messages by unblocking the spare path to maintain communications."

Network ring topology with Rapid Spanning Tree Protocol (RSTP) is defined in IEEE 802.1W-2004. A well planed and configured ring is physically set as a closed loop to make the ring automatic recovery possible, but logically open to avoid data broadcasting storm inside. Refer to Fig. 5 below.

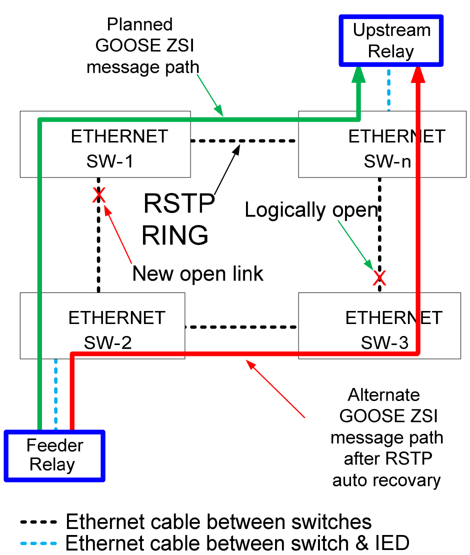

Fig. 5 RSTP for redundancy at network level

In normal operations, GOOSE blocking signals are published from the downstream feeder relays and subscribed by the upstream relays through SW2-SW1-SWn path (solid green lines in Fig. 5). If a new broken link occurs in the ring by some reasons, the ring automatically recovers itself to make a new communication path of SW2-SW3-SWn (solid red lines in Fig. 5). The RSTP recovery time varies depending on how many Ethernet switches in an RSTP ring. Fig. 6 gives the trend of recovery time vs. number of Ethernet switches in a ring. The maximum number of Ethernet switches in an RSTP ring is 40 [3].

RSTP ring solves the communication redundant problem at Ethernet switch level but could not solve the redundancy problem at the node level. Assuming the link between an IED (protective relay) to an Ethernet switch is broken, as it is shown in a dotted blue line of Fig. 5, the whole GOOSE messaging path is broken. In order to get the communication redundancy at the node level, PRP protocol and HSR protocol specified in IEC62439 may be used. These protocols provide seamless communication redundancy at node level without even losing a single bit. However, at the current market place, the protection relays with these advanced protocols are not widely available.

There are two convenient methods that can be used as a work around to solve the problem.

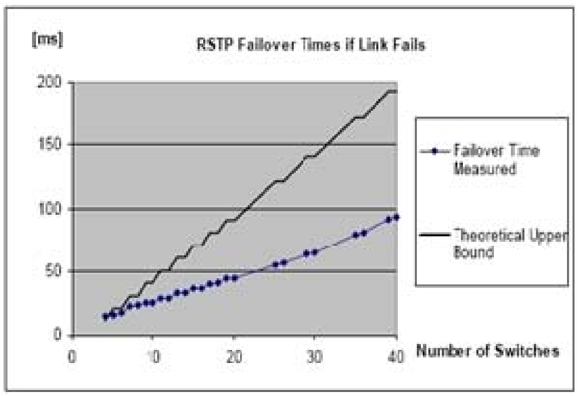

Fig. 6 Recovery time vs. # of switches [3]

Figure 7 shows each port of each relay goes to two different Ethernet switches but in a common RSTP ring. Alternately, Fig. 8 shows each port of each protection relay goes to two different Ethernet switch residing in two different RSTP rings. In either method, each protective relay should be equipped with two Ethernet ports either running at the same time or at least at a failover mode. Both methods achieve the node level redundancy but Method 2 is a preferred one. This is due to the total number of Ethernet switches in each RSTP ring is less than that in Method 1. In most cases it can be less than 40, which is the limitation in a single RSTP ring. Consequently, the recovery time in each RSTP ring is shorter (refer to Fig 6) than that in a single RSTP ring.

Blocking timing is always a concern for IEC61850 GOOSE based ZSI applications. The benefit of using GOOSE based ZSI schemes is to use interlocking technique to reduce CTI to the minimum. In order to achieve this, the blocking time period would need to be as short as possible. On the other hand, the feeder breaker opening time and communication network traffic have to be considered to avoid nuisance tripping of the upstream breakers that requires the blocking time period long enough to let the feeder breakers operate first when a feeder fault occurs.

In order to reduce the network traffic time, some modern communication network techniques should be adopted. There are basically two types of commutation paths found in a plant Ethernet network. One is SCADA communication that is basically IEDs (relays, meters, controllers, etc.) to server communication for SCADA/HMI need. It is usually a server-client, or master-slave relationship with Modbus communication protocol for industrial plant applications. The other one is peer to peer communication without going to the SCADA server, for which GOOSE messaging belongs to.

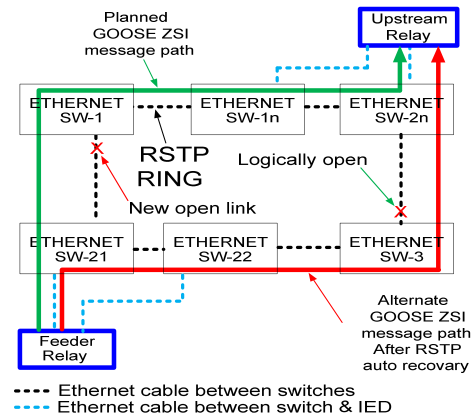

Fig. 7 Redundancy at node level Method 1

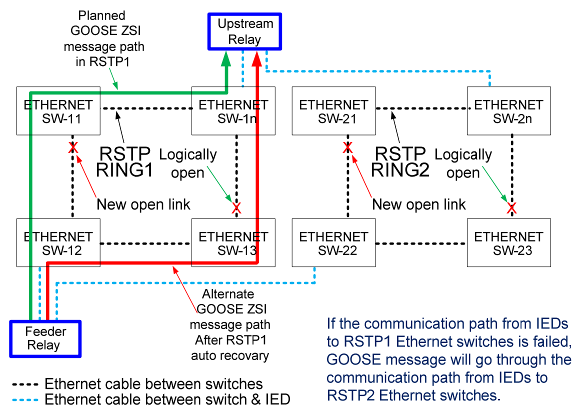

Fig. 8 Redundancy at node level Method 2

A VLAN, defined in IEEE 802.1Q, is an administratively-configured Virtual Local Area Network segment that limits the communication traffic in multiple broadcast domains. Instead of physically arranging or reconnecting a device to a different LAN, network administrators can accomplish this task by configuring VLAN-compliant Ethernet switches, usually fully managed Ethernet switches, to create some logical network segments. By using VLAN technology, IED to server communication traffic can be separated from GOOSE peer to peer communication traffic making them in separated paths. Each GOOSE messing is securely confined in its belonging VLAN and not interfered by IED to server SCADA communication traffic or GOOSE messaging belonging to a different VLAN. For example, SCADA, as well as remote engineering access, related communication traffic might be confined in VLAN1, ZSI schemes related communication traffic might be confined in VLAN2, automatic transfer schemes related communication traffic might be confined in VLAN3, inter trip related communication traffic might be confined in VLAN4, load shed related communication traffic might be confined in VLAN5, etc.

Also, if the relays equipped with an additional RS485 port, traffic may be separated by arranging RS485 port for SCADA/HMI purpose whereas Ethernet ports are used for peer to peer communications.

Prioritizing traffic into different classes is also important to ensure critical data is processed first. IEEE 802.1Q/P standards provide 3 bits in each frame to prioritize the traffic. The values of these bits represent different priority levels ranging from 0 to 7, where 7 is the highest. Taking the advantage of priority tagging, in order to speed up ZSI related tripping or blocking related GOOSE messaging tags, they should be set at a priority level 7.

Whenever possible, ZSI schemes related GOOSE messaging retransmitting profile should be set at an aggressive mode that makes it retransmit quickly to ensure reliability.

It is worth to emphasize that all of the above-mentioned advanced communication network techniques apply not only to the ZSI schemes, but also apply to other GOOSE related applications, like inter trip, automatic transfer scheme and load shedding, etc.

IV. BLOCKING TIME CONSIDERATIONS

Blocking time may need to be further elaborated. For most of the relays the internal logic execution time from overcurrent element picked up to the moment of sending a GOOSE messaging, is not more than 2ms, and the internal logic execution time from receiving a GOOSE messaging to the moment of blocking the upstream breaker tripping, is also less than 2ms. The upstream relay's contact output responding time would need to be added too. This time, depending on what type of output contact is, is in range of 4-8ms. Three-cycle breakers are widely used in medium voltage industrial applications that would add another 50ms (60Hz system) in the total blocking time. Depending on how the network architecture is designed and how well is configured, GOOSE message travelling time varies. This time could be as fast as 1ms in the situation of all feeder relay and main relay physically located in the same Ethernet switch with a well configured VLAN, or as slow as 100ms or more if these relay are far away and several Ethernet switches in between and VLAN is not well designed and configured resulting in a lot of traffic existed in the network.

By adopting a well-designed VLAN and not more than three Ethernet switches involved in the ZSI scheme, an initial estimation of one cycle time would be reasonably assumed. In order to avoid the upstream breaker nuisance tripping, feeder breaker's opening time needs to be added, that makes the following total blocking time:

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

For some slow medium voltage 5-cycle breakers, the total blocking time would roughly be 2 + 16 +2 + 4 + 83.3 = 108ms. Accordingly, the blocking timer in the upstream relay should be set as 80ms and 110ms, respectively. The final blocking time should be determined by the real test under simulated or real conditions in factory, or in the field. In both cases, it is still much quicker than traditional 200ms CTI requirement defined by IEEE standard, and leads to a fast response time and reduced arc flash hazard.

In applying ZSI scheme, when overcurrent element is picked up by any of the feeder relays, the relay should send a blocking signal right away to the main relay. This blocking signal should block the upstream main relay from tripping the main breaker in a blocking timer of 80ms (for 3-cycle 60Hz breakers) or 110ms (for 5 cycle 60Hz breakers). Blocking signal should be released after the blocking timer expires.

Considerations must be given for what we should do if communication fails between a particular feeder relay and the upstream relay. Communication failure flag should be a part of ZSI logic. In order to avoid mis-coordination of de-selectivity, a traditional CTI with a properly pre-defined intentional time delay for that particular feeder should be restored as a backup. This is actually another advantage of GOOSE based ZSI schemes over hardwired based ZSI schemes, usually seen in trip unit of low voltage breakers, where it is almost impossible to get two independent sets of overcurrent settings by the technologies currently available.

Fault related Breaker Failure Initiate (BFI) logic should also be programmed in any of the feeder relays involved in ZSI schemes. BFI must be supervised by communication failure status. After the associated feeder breaker receives a tripping signal but does not get the breaker tripped, a BFI signal from the feeder relay should be sent through GOOSE messaging to the upstream main relay to force it to trip the main breaker as a backup protection, regardless if the blocking timer has expired or not.

If communication gets failed between a feeder relay and the upstream main relay, the related ZSI protection setting in the upstream main relay for the associate feeder should be abundant but restore back to the traditional one as backup overcurrent protection.

V. SETUP AND LOGIC PROGRAMMING CONSIDERATIONS

It is easy to configure and extend ZSI scheme to a fast bus trip scheme though GOOSE application. Refer to Fig. 2, the fault location at 2 is a bus fault where no feeder relays can sense the fault, but the upstream main relay can. So no blocking signals will be received in the upstream main relay. By using this judgment, the main relay trips the main breaker right away. Comparing to the traditional bus differential scheme, it does not need any dedicated CTs in each feeder to achieve bus protection and does not need any dedicated bus differential relays. By using the fast bus scheme a lot of material and installation cost can be saved by substituting a communication-assisted control logic system. This thereby eliminates the need for the dedicated CTs and their space requirement and installation cost. Although the fast bus trip scheme has almost the same effect as dedicated bus differential protection, due to the time delays in commutation path, and the time needed for internal logic execution, the speed of these schemes is much slower, than that of a dedicated bus differential scheme. That is why the fast bus trip schemes are only applied to some less important buses at relatively lower voltage levels.

Usually ZSI scheme applies to buses with one single source and several radial feeders. For typical industrial plants or platforms, the Main-Tie-Main configuration is very common with two incoming power sources. The feeder relays from the ZSI scheme should coordinate with the tie relay in order to trip the tie breaker first in a single ended situation, if the fault is at the far end of the bus. ZSI between the tie breaker relay and the main breaker relay should be incorporated as well, to take the maximum benefit of reduced CTI between the tie breaker, and the main breaker.

Each feeder should have a provision to be set in test mode. When a particular feeder relay or breaker is under test, while other breakers are in service, any tripping command to the upstream relay should be blocked. Thus, any protection element pick up at the under-test feeder relay should not trip the upstream breaker even if the blocking timer is expired. Any breaker failure should not initiate the upstream relay tripping as well. In addition, the testing process for this feeder should not interfere with the operations and protection functions of the other in-service feeders and upstream breakers in the system. The test mode may be enabled at the upstream relay. Its status should be noticed locally to the upstream relay itself and noticed remotely to the associated feeder relay though GOOSE messaging published from the upstream relay. This way, the number of remote points received in the upstream relay would be reduced to the minimum.

Other communication-assisted schemes may be merged in the ZSI involved protections. These schemes may include, but not limited to, automatic transfer scheme, inter trip, load shedding, breaker local and remote manual operations, etc. Detailed descriptions for these schemes are out of the scope of this paper.

Most protection relays have a limitation of how many remote devices (virtual devices) and how many remote points (virtual bits) they can communicate to. In switchgear and MCC arrangement, it should layout in a way to maximally reduce the number of remote devices and remote inputs for the upstream relays. For example, if a MCC is directly tied to a switchgear bus without a feeder breaker in between, the number of remote devices and remote points may exceed the limitation of the upstream relay's peer to peer communication capability due to so many motor relays may be existed in the MCC. Rearranging the layout by adding a feeder breaker in the middle between the switchgear bus and the incoming cubicle of the MCC could significantly reduce the number of remote devices involved in ZSI scheme. In this way, a complete ZSI scheme could be conveniently arranged in two areas. One area involves all the motor feeders and the incoming feeder breaker to the MCC inlet, and the other area involves all switchgear feeder breakers, including the feeder breaker feeding the MCC, and the upstream main and tie breakers.

Protective relays and Ethernet switches should be carefully selected to meet the project requirements. This includes enough CT/PT inputs, appropriate and enough protection functions, dual Ethernet ports running at the same time or at failover mode, enough inputs and output contacts, IEC61850 capability etc. Caution should be made to select relay fast output contacts whenever available. All Ethernet switches should be managed type switches, and preferably from the same manufacture, in terms to get the best RSTP and VLAN performance possible.

VI. EXAMPLARY LOGIC DIAGRAM

Figure 9 illustrated below shows a typical logic diagram for the logic used in the upstream main relay in a popular Main-Tie-Main configuration. It also considers ZSI between the tie breaker and the main breaker. Similar diagram applies to the tie breaker logic by taking out the tie breaker logic in the picture with some minor modifications.

In the figure, O/C represents overcurrent protection elements (ANSI code 50 or 51 or both), either phase or ground, or both. The final output of the logic drives a contact output which energizes an 86 lockout relay to trip the breaker and block it from closing. Alternatively, this output may drive a latch bit inside the relay logic and output of the latch bit is used to energize the trip coil of the breaker and lock it out to prevent it from closing.

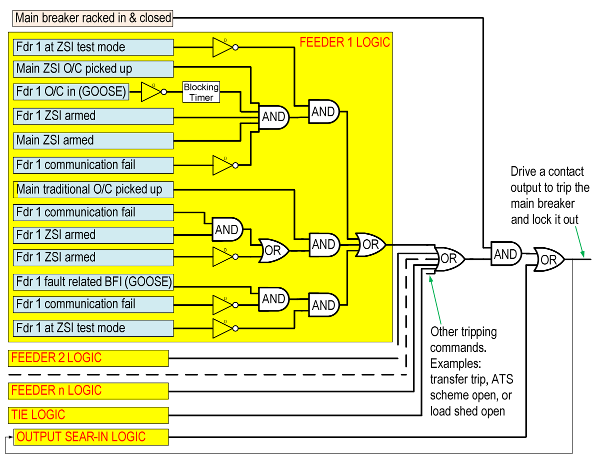

Fig. 9 Typical logic diagram of the upstream main relay

As a summary, the diagram considers everything discussed in Section V of this paper with appropriate logical expressions. This diagram may be easily translated in the relay logic programming language accordingly. The upstream relay's front panel pushbuttons or relay's physical digital inputs in local mode, or some virtual inputs in remote mode, may be configured as enable/disable ZSI functions and test mode for each relay. They may be setup in the upstream relays in order to reduce the number of GOOSE remote points transmitted from the feeder relays to the upstream relays.

The logic diagram (Fig. 9) may be slightly modified to suit specific and different project needs for different applications or may be merged with other breaker control functions together.

VII. TEST CONSIDERATIONS

For GOOSE messaging testing purpose, even IEC61850 standard specifies a quality flag, a test flag and a test mode included in LLNO logical node, the usage of qualify flag for testing purpose is not feasible at the current phase. The required individual logical node must be placed in TEST or TEST/BLOCKED mode or the entire device is through LLNO, which is not feasible at current relay offers. On the other hand, support of TEST mode and qualify flag varies among different devices and protection relay vendors. In overcoming this, we used a simple test-mode-enabling tag as an indication of test mode, (Fig. 9). The following outlines the testing considerations during a Factory Acceptance Test (FAT), or a Site Acceptance Test (SAT).

For new installations, ZSI schemes could be tested in normal mode during FAT. For switchgear or MCC that is already energized, test mode for the feeder under the test needs to be enabled first during SAT before actual testing can be carried out.

- Although secondary current injection is a preferred way to perform a throughout test for ZSI schemes, primary current test is recommended at the start up as the first step to ensure all components and wiring are functioning correctly.
- Test needs to be done to determine the blocking timer. The major purpose is to determine GOOSE messaging traffic time. Some network traffic injection tool, like GOOSE blaster or Agilient N2X, may be used to carry out the test [4][5], then by using some of the network traffic capture software, like Wireshark, to analyze and determine the blocking timer.
- If RSTP is implemented in the ZSI scheme, after communication network is carefully configured, RSTP functioning test should be carried out. It may or may not be necessary to conduct RSTP performance test but RSTP functioning test is a must.
- VLAN should be verified to make sure all communication paths are properly separated and fine tuned. No communication leaking should be out of each dedicated belonging VLAN domain.
- Conduct ZSI function and performance test by injecting secondary fault current to all ZSI involved protection relays individually to verify ZSI performance with healthy communication path and failed communication path, respectively. The first test should be carried out by injecting currents to both the upstream relay and one of the feeder relays. This would simulate the fault at the load side of the feeder line and observe the feeder breaker gets tripped. The upstream breaker should have no action due to GOOSE blocking signal. Here the upstream breaker means the main breaker if no tie breaker gets involved or, both the tie and main breakers if the switchgear has a Main-Tie-Main configuration. This test should repeat for every breaker. Then inject current to the upstream relay only to simulate a fault is on the bus, the upstream relay should trip the upstream breaker, either the tie breaker or the main breaker, quickly per the ZSI overcurrent setting, which is quicker than the traditional overcurrent setting.
- Break the communication cable from each feeder relay to Ethernet switch (disconnect both Ethernet cable when two ports are running at redundant channels), verify the upstream relay can restore the protection settings to the traditional one.
- Break the connection wire to the trip coil of each downstream under-test feeder breaker, test BFI function with healthy communication path and failed communication path, respectively.
- Disarm ZSI for each relay, verify traditional overcurrent setting will take place.

VIII. EXAMPLE PROJECT OUTLINE

Three IEC61850 GOOSE based ZSI schemes have been applied in a refinery plant. One scheme has been applied to 25KV switchgear for a neutral solidly grounded system and two schemes have been applied to 4.16KV switchgear and MCC, each of them is of LRG system so no ground ZSI scheme is needed. They are all Main-Tie-Main configurations with ZSI settings also applied between the tie breaker and the main breakers. The following two tables describe how ZSIs are applied for this project.

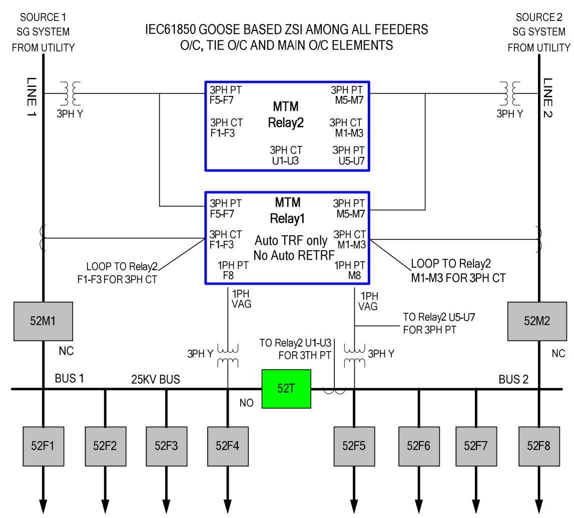

Fig. 10 25KV one line

INITIAL SOURCE	BLOCKING SIGNAL	UPSTREAM RELAY	BLOCKED ELEMENT
FEEDER RELAY	PKP of 50-2 (PH IOC2)	TIE	50-1
		INCOMER A	50-1 (PH IOC1)
		INCOMER B	50-1 (PH IOC3)
TIE RELAY	PKP of 51-2 (PH TOC6)	INCOMER A	51-2 (PH TOC2)
		INCOMER B	51-2 (PH TOC4)
TIE RELAY	PKP of 50-1 (PH IOC5)	INCOMER A	50-1 (PH IOC1)
		INCOMER B	50-1 (PH IOC3)

Fig. 11 25kV ZSI setup

An RSTP ring is designed and configured for all communication needs. Three-cycle breakers have been used for this project and the ZSI blocking timer has been setup as 70ms.

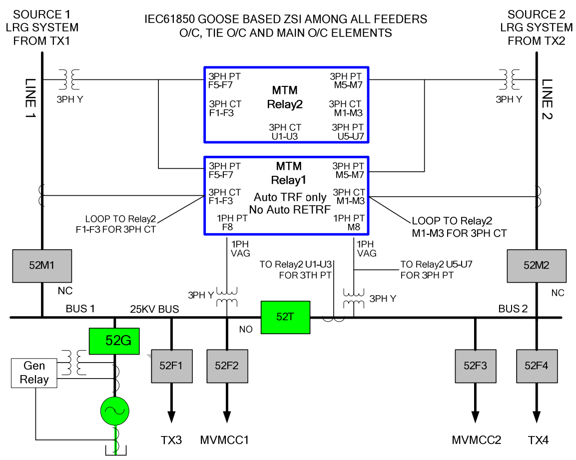

Fig. 12 4.16KV one line

INITIAL SOURCE	BLOCKING SIGNAL	UPSTTREAM RELAY	BLOCKED ELEMENT
MOTOR RELAY TYPE1	PKP of 50-1 (PH IOC1)	TIE	50-1 (PH IOC5)
		INCOMER A	50-1 (PH IOC1)
		INCOMER B	50-1 (PH IOC3)
MOTOR RELAY TYPE2	PKP of 50 (O/C)	TIE	50-1 (PH IOC5)
		INCOMER A	50-1 (PH IOC1)
		INCOMER B	50-1 (PH IOC3)
FEEDER RELAY	PKP of 50-2 (PH IOC2)	TIE	50-1 (PH IOC5)
		INCOMER A	50-1 (PH IOC1)
		INCOMER B	50-1 (PH IOC3)
TIE RELAY	PKP of 51-2 (PH TOC6)	INCOMER A	51-2 (PH TOC2)
		INCOMER B	51-2 (PH TOC4)
TIE RELAY	PKP of 50-1 (PH IOC5)	INCOMER A	50-1 (PH IOC1)
		INCOMER B	50-1 (PH IOC3)

Fig. 13 4.16KV ZSI setup

IX. CONCLUSIONS

With ZSI schemes, the breaker closest to the fault will override the intentional time delay settings and clear the fault quickly, resulting in a fast tripping time to reduce arc flash hazard and equipment damage while selective coordination is still well maintained.

In order to achieve the best IEC61850 based ZSI scheme performance, many factors have to be considered. These include good system planning and network design, proper components selections, careful logic programming, and appropriate testing procedures to work together as a whole.

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XI. VITA

Tony W. Zhao received his M.Sc. degree in High Voltage Engineering from China Electric Power Research Institute (CEPRI). After working for CEPRI for three years as a type testing engineer, he joined Shenzhen Nanshen Power Station Company in China as an electrical and control maintenance manager for gas-turbine generator sets. In 1997 he started with GE Instrument Transformer Inc. USA as an applications engineer. In 2001, he jointed Powell Electrical Systems Inc. as an R&D engineer in the beginning, and then worked as a senior power control systems engineer for relay programming, relay protection, system automation and integration. He joined GE Energy in 2012 working as a lead P&C engineer. He is a contributing and active member in the IEEE Houston Section's Continuing Education on Demand seminars and is an IEEE senior member.

Lubomir Sevov received his M.Sc. degree from Technical University of Sofia, Bulgaria in 1990. After graduation, he worked as a protection and control engineer for National Electric Company (NEC) Bulgaria. Mr. Sevov joined GE Multilin in 1998 as a relay test design engineer and in 2001 he was promoted to an application engineer. Mr. Sevov is a Senior Applications Engineer leading the design and development of protective relays for the medium and low voltage power systems. He is a member of the association of professional engineers Ontario, Canada, and a senior member of IEEE.