Zone Selective Interlocking

Contents

Powering Business Worldwide

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What is Zone Selective Interlocking?

Zone Selective Interlocking (ZSI) is a communication scheme used with electronic trip units and electronic protective relays for circuit breakers to improve the level of protection in a power distribution system. This is achieved through communication between the downstream and upstream devices in a power distribution system. The zones are classified by their location downstream of the main circuit protective device which is generally defined as zone 1.

This document will review Eaton protective devices that utilize zone interlocking protection, connections and common practices.

What is the purpose of Zone Selective Interlocking?

The purpose of ZSI is to speed up tripping for some faults without sacrificing the coordination of the system and interjecting nuisance trips into the system. Zone selective interlocked devices can communicate across distribution zones to determine whether or not a device sees a fault condition. The device that is closest to the fault will trip without a time delay therefore reducing the fault clearing time and reducing the damage to the equipment.

Is there such a thing as ZSI on Instantaneous protection?

The short answer is no. ZSI is applied to short time protection or ground fault protection where there is a time delay on the protection when short delay is active. To speed up tripping for some faults without sacrificing the coordination of the system and interjecting nuisance trips into the system. Zone selective interlocked devices can communicate across distribution zones to determine whether or not a device sees a fault condition.

Is it applied around the world?

Yes, Zone Selective Interlocking (ZSI) is used in many applications around the world and is described in the published technical report *IEC/TR 61912-2 Low voltage switchgear and controlgear – Overcurrent protective devices – Part 2: Selectivity under overcurrent conditions*. This document describes ZSI as a method of controlling circuit breakers in order to provide selectivity with very short delay times, irrespective of the number of grading levels (zones) and the location of the fault in the distribution system. The ZSI unit may be integral to the circuit breaker or a separate unit. Interlocking may be applied to the faults between phases or earth-faults or both.

The IEEE© standard C37.234-2009 "IEEE Guide for Protective Relay Applications to Power System Buses" describes Zone Interlocking schemes in section 7.2.

How does it work?

Zone selective interlocking monitors phase and ground faults between devices in separate zones using a three wire scheme. The three wire scheme has one output, one input and a common. An older scheme but still compatible with Eaton's ZSI systems today used five wires which had two inputs (one for phase and one for ground), two outputs (one for phase and one for ground) and a common.

An example of a load fault is shown in zone 4 of Figure 1. If the fault exceeds the short time pick up of the trip unit of the Branch MCCB in zone 3 the trip unit will send a zone out signal upstream to the Feeder breaker in zone 2. This will tell the Feeder breaker that the Branch breaker sees the fault below it.

The Feeder breaker also sees the fault current and therefore will send a zone output signal to the Main breaker in zone 1. The Feeder breaker acknowledges the ZSI input from the Branch breaker by restraining its tripping and continuing to do its time delay. Similarly if the fault current is over the Main breaker's Short Time protection level the Main breaker will be restrained by continuing to do its time delay and send a zone output signal to the protective relay EDR-5000 in zone 1.

The zone 3 Branch breaker does not get a ZSI input signal because it is the last breaker in the distribution network. The Branch breaker will initiate tripping immediately because it is the closest breaker to the fault. With proper selective coordination the Branch breaker should clear the fault before the Feeder or Main breakers finish their trip time delays, therefore maintaining power to the rest of the system.

In a ZSI system, if the downstream device that is closest to the fault fails to clear the fault, the next upstream device will finish its timing and clear the fault. Maintaining selectivity is another benefit of zone interlocking. If a major fault occurs then the device closest to the fault will be given the opportunity to clear the fault condition without disrupting service to other areas of the facility. The ZSI feature enhances the coordination of the system without sacrificing protection.

If a bus fault were to occur as shown in Figure 2, then none of the Branch breakers would see the fault and the Feeder breaker would not get a ZSI input signal. The Feeder breaker would see the fault on the bus and send a ZSI signal to the Main breaker. Since the Feeder breaker does not get a ZSI input signal, because it is the closest breaker to the fault, it will trip immediately without doing its time delay. This immediate reaction by the Feeder breaker prevents the condition from getting worse as would occur by delaying the trip to its coordinated short time setting.

This dramatically reduces the amount of energy consumed by the fault, and reduces the damage to the equipment and personnel near the fault. See in Figure 3 how the coordinated breakers are shown and the Feeder breaker would normally take approximately 300ms to clear, but as shown in Figure 4 the ZSI system allows the Feeder breaker to trip immediately because it is the closest breaker to the fault. The resulting time difference is shown in Figure 4.

The Eaton Zone Selective Interlocking system is self-powered and therefore requires no external power supplies to function. This system also requires no external modules. Most of Eaton's electronic trip units or protective protective relays have the ZSI circuit built inside the unit.

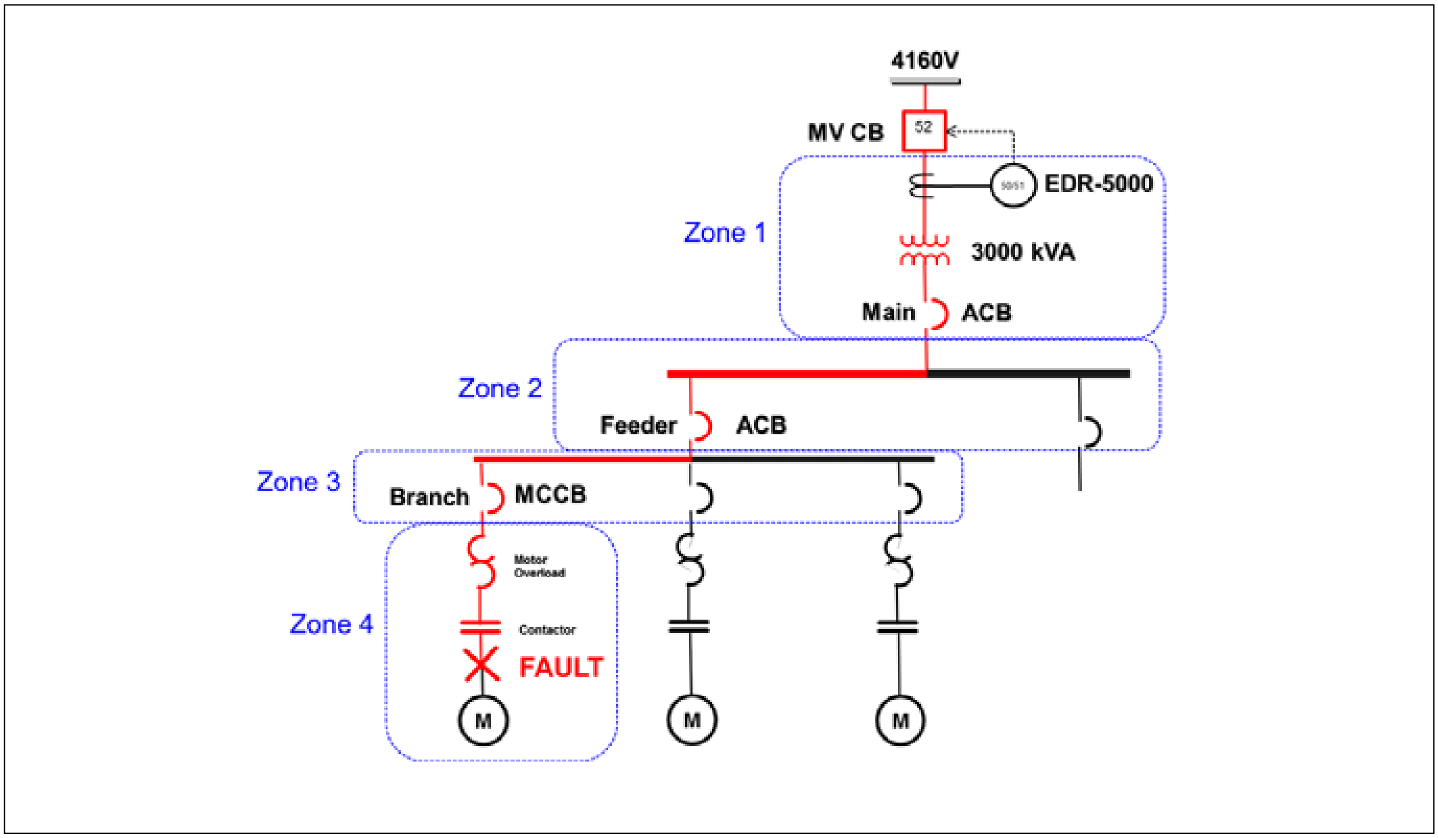

Figure 1. One Line Diagram – Example of Fault at Load.

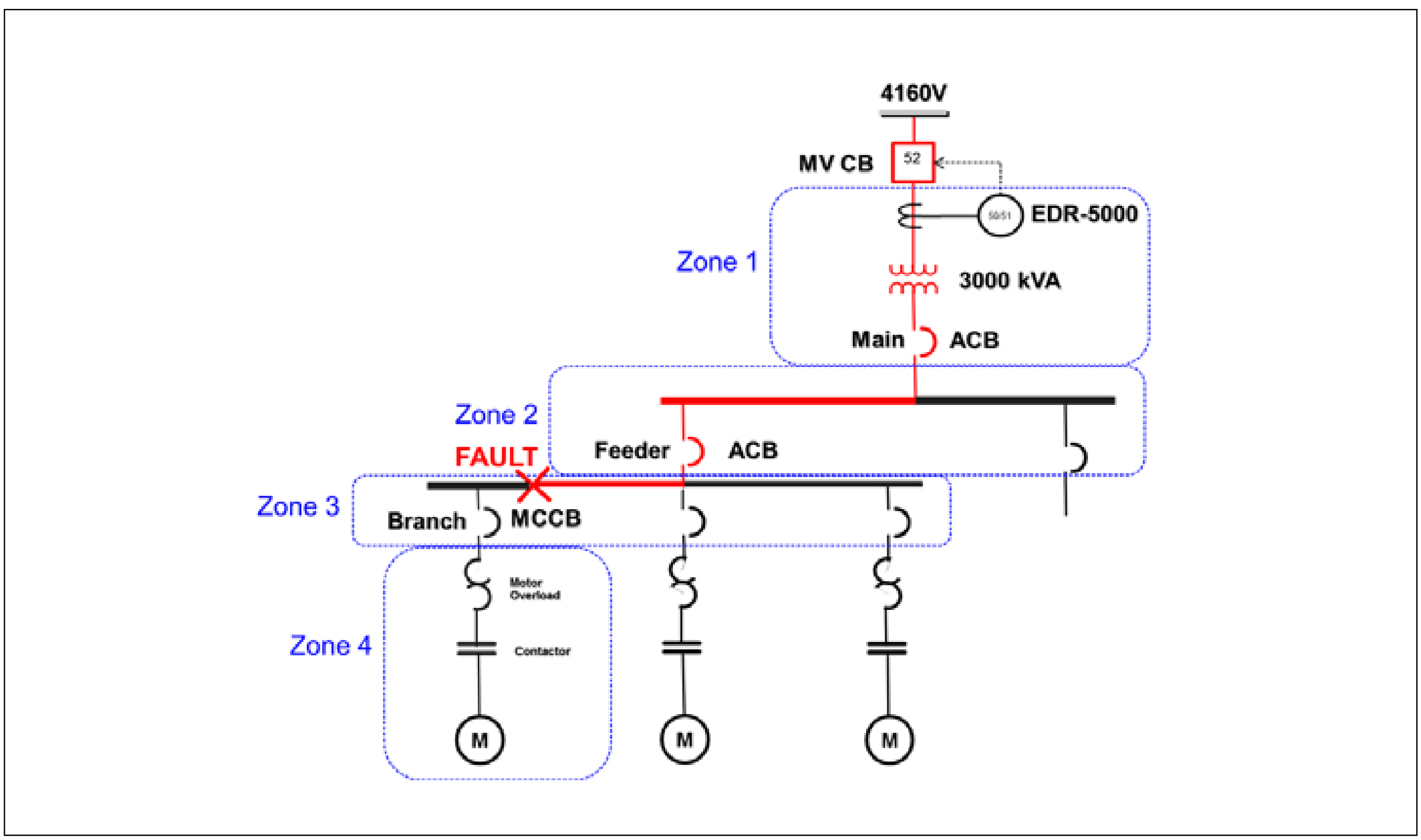

Figure 2. One Line Diagram – Example of Fault at Line.

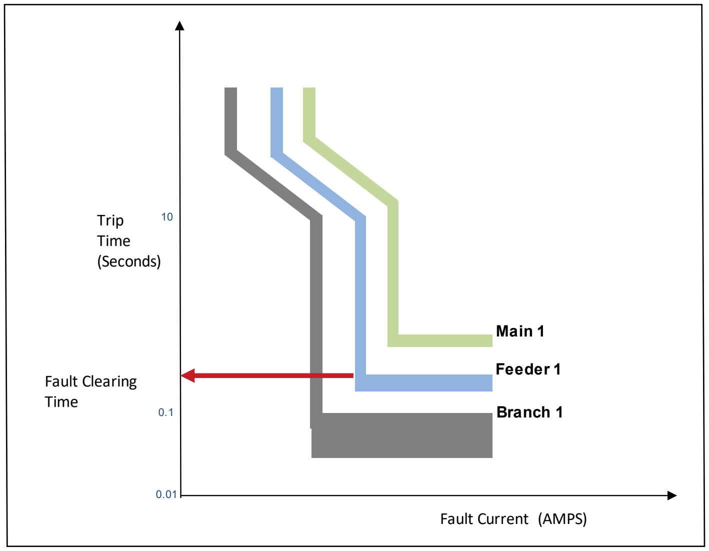

Figure 3. Time Current Curve Example - Branch Bus Fault with No ZSI.

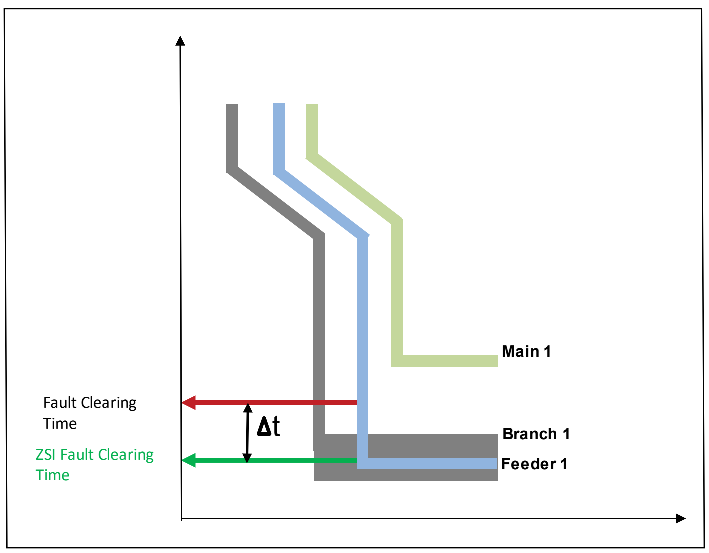

Figure 4. Time Current Curve Example - Branch Bus Fault with ZSI.

Tables 1 and 2 compare the effect of tripping time of the coordinated system for the Figure 2 example with and without zone selective interlocking and the effect on the value of Incident energy in calories per cm squared. Using ZSI the trip time goes from 300ms to 75ms and therefore the incident energy is reduced from 13.8 cal/cm^2 to 2.1 cal/cm^2.

Table 1. Branch Bus Fault Energy Example - Calculations without ZSI

Device	Ir – rated current	Short Delay trip time setting	Time to Trip	Incident Energy cal/ cm²
Feeder Breaker	1000 A	300ms	300ms	13.8
Main Breaker	3200 A	800ms	NA	NA

Table 2. Branch Bus Fault Example - Energy Calculations with ZSI

Device	Ir – rated current	Short Delay trip time setting	Time to Trip	Incident Energy cal/ cm²
Feeder Breaker	1000 A	300ms	75ms	2 .1
Main Breaker	3200 A	800ms	NA	NA

Note: Incident energy calculations are relative for the example using IEEE© 1584 calculated formulas and the following assumptions; system voltage 480V, gap distance 25mm, distance factor = 1.641, ungrounded system, 10kA bolted fault current, distance from arc to possible person = 455mm.

Connection Requirements

Conductor

The ZSI wire recommended is 14 gauge, stranded tinned copper, twisted pair, 600V insulation, 90°C rated, and UL type SIS class XL approved. Smaller gauge wire can be used for short runs but long runs will increase the impedance and reduce the signal strength. Install the wiring in metal compartments, conduit or other facilities used to physically separate control circuits from current-carrying power circuits. On older systems that have the 5 wire interface, use a separate twisted pair for each interlocking circuit of phase and ground.

The stated limitation of connection distance is 75 meters (~ 250 feet). This is the length of wire distance from the first device in the zone to the last device connected to that run. Each device has a load impedance and the conductor cables are transmission lines. The total impedance that the signal driver sees is the length of the cables and the number of devices connected. See Figure 5 for an example of wiring using 2 wire twisted cable.

Some devices such as the E Series protective relays have an extra terminal for the shield so that shielded wire can be used. The common should not be connected to the shield terminal.

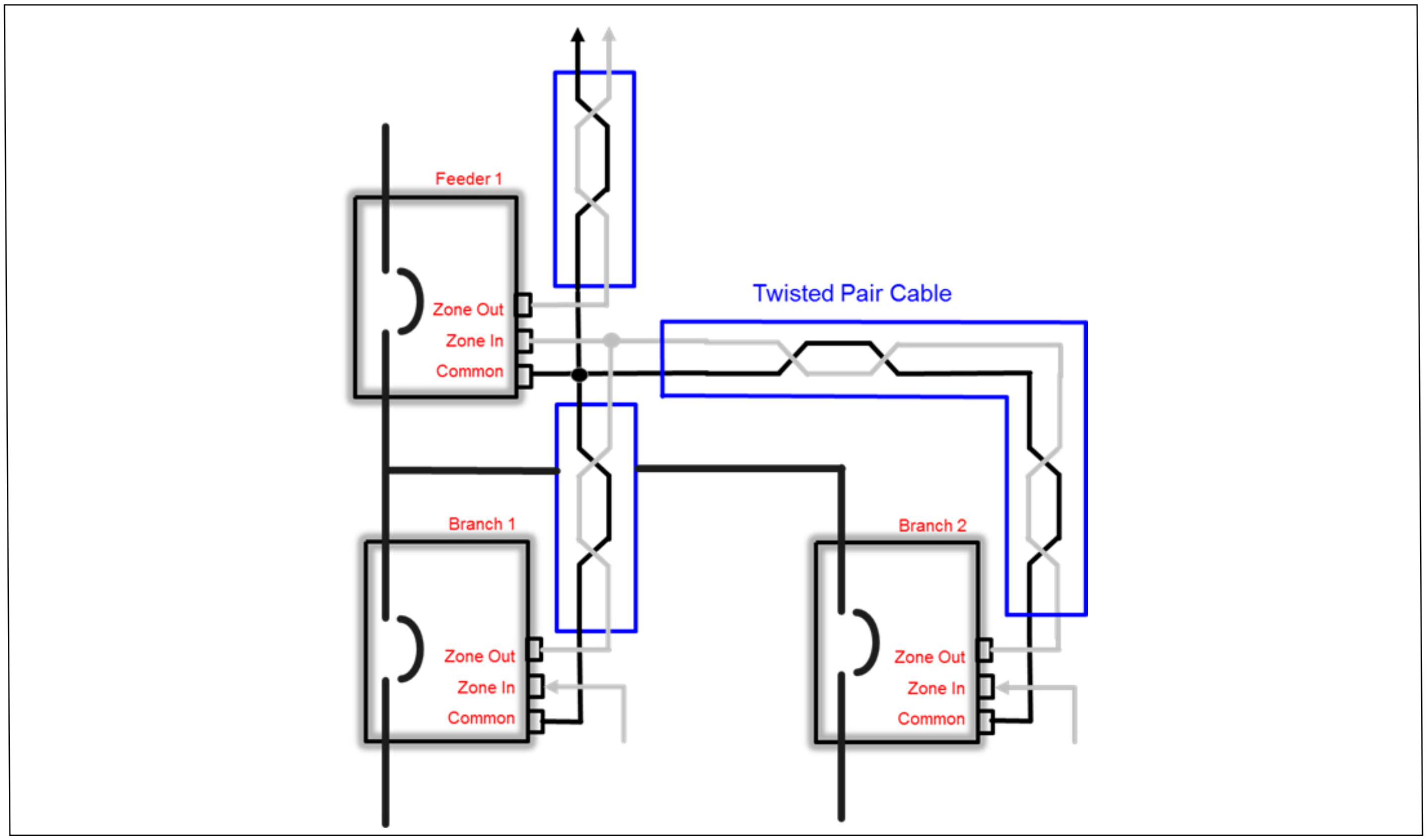

Figure 5. ZSI wiring example using twisted pair wire.

⚠ WARNING

DO NOT CONNECT THE ZONE INTERLOCK COMMON TO EARTH GROUND. THIS IS A DIGITAL GROUND AND MUST BE ISOLATED FORM THE SYSTEM GROUND (EARTH).

Devices

There is a limit to the number of devices that can be connected to a run of cable from several outputs to an input. A high level signal may not get over the threshold limit for a valid high at the end of the run because of the loading impedance seen on the transmission line from one end to the other. Figure 6 shows 4 trip units with their Zone outputs wired to a Zone input of an upstream trip unit. One of the trip units has its input wired to its output which is called self-interlocked. The Z impedance looking down the line the input from the trip unit is variable when all of the connections are paralleled to the common ground. For the example in Figure 6, the total loading for the number of devices = 1A out + 2A out + 3A out + 4A out + 4A in + 1B in = 6 total device loads.

Another limitation is the output driver signal strength. There is a limit to the current that the driver can source to support a voltage signal at the high level signal through the impedance load to the end of the cable. Table 3 shows several different products and how many device loads they can support. When excessive loads are applied to the signal lines steering/blocking diodes can be used to block the look back impedance seen by the upstream breakers.

If you have a product that has separate ground and phase output signals and you tie them together to interface with a product that has the two signals logically combined, then that tied together output should be considered two loads.

Signal integrity should be confirmed by testing the sending and receiving of the zone interlocking signals before or during commissioning.

Table 3. Device load table

Protective Device	PXR trip unit	Digitrip trip unit	EDR5000 protective relay	FP5000 protective relay	GFR ground fault relay
# OF DEVICE LOADS	20	20	20	11	10

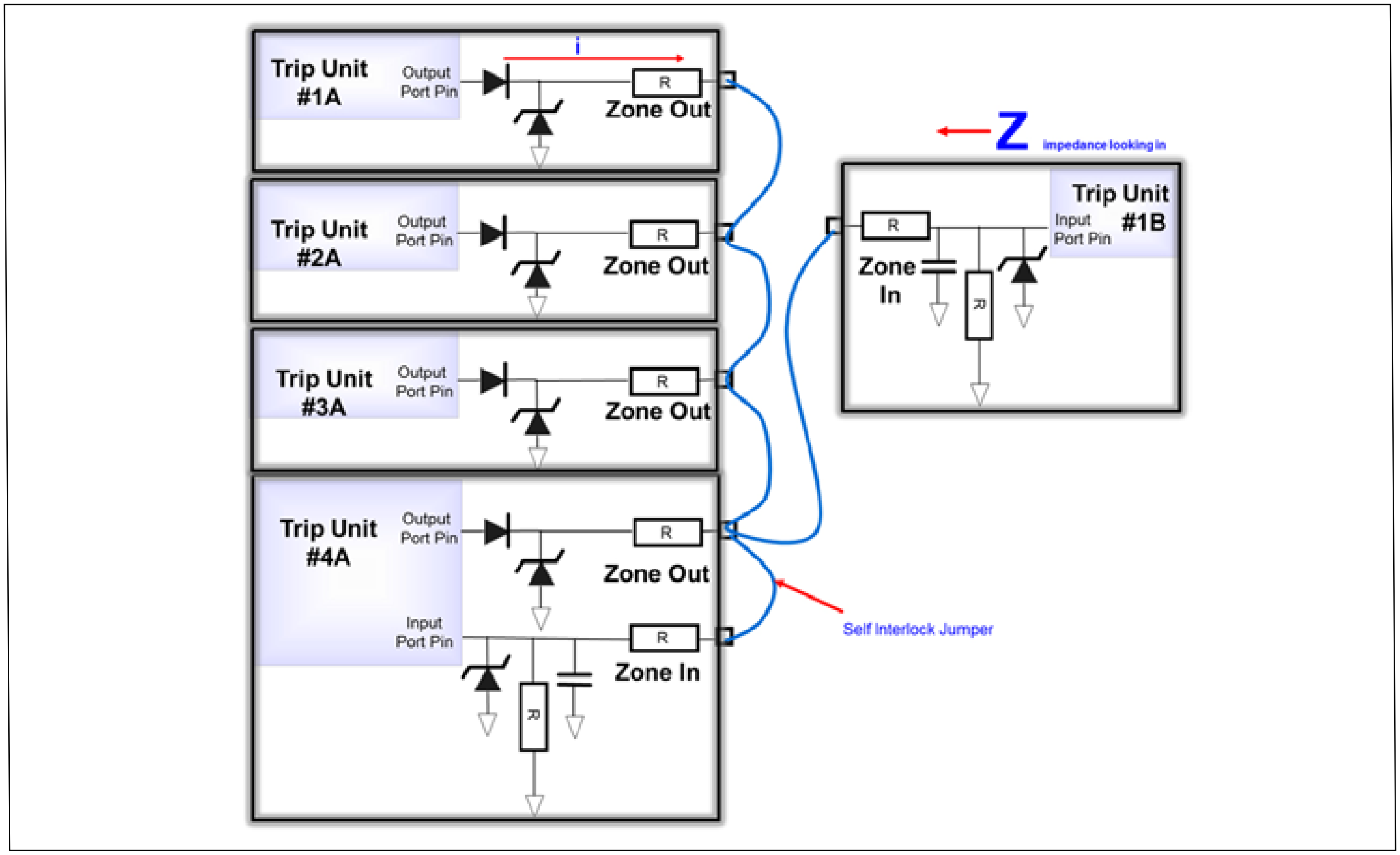

Figure 6. ZSI impedance wiring and loading example.

Self Interlocking

Self interlocking is a method to force the circuit breaker to restrain itself and force the full short time or ground fault time delay when a fault is detected. As shown in Figure 6 on Trip Unit #4A the jumper wire is placed between the ZSI output terminal and the ZSI input terminal connection. When the trip unit or protective relay detects a fault, they will first send a ZSI output signal. The devices will then check their ZSI input for a restraining signal. Therefore if the device sees its own output signal as a ZSI input and then it will do its full time delay and not do a quick trip of the circuit breaker. Typically the self-interlocking wring is done for the breaker on the last zone or it is done on a breaker that may have thermal magnetic trip unit breakers below them in the distribution system that do not have the capability to do ZSI.

⚠CAUTION

THE SELF-INTERLOCKING JUMPER MUST BE INSTALLED IN THE DEVICE OF THE LAST ZONE OR SELECTIVE COORDINATION COULD BE LOST.

Steering (or Blocking) Diodes

With different applications such as a Main-Tie-Main scheme there can be connections where the output of one group of interlocked circuit breakers is not intended to be sent to an upstream circuit breaker. Figure 7 shows a M-T-M scheme where the ZSI output signal of the feeder breakers are self-interlocked and have blocking diodes. This example shows a fault under the Feeder 11 breaker. The example was done with both Main breakers closed and the Tie closed. The red bus indicates where fault current flows. The Feeder 11 breaker sends a ZSI output signal (blue lines). The Feeder breaker 11 is self-interlocked with the jumper from its input to its output, so it will do its full time delay before tripping. Since these feeder breakers are the last in the distribution system their time delays in the coordination study were set low. The ZSI signal is then sent out and passes through the diode D1 and is sent along the ZSI wiring. The signal is blocked by all of the feeders by D2, D3 and D4 and will not be seen by the ZSI input circuitry for those breakers. The Feeder 11 ZSI output signal goes to the ZSI input of the Tie breaker and passes through the diode D5 so it is seen by the inputs to the Main 1 and Main 2 circuit breakers. The D5 steering or blocking diode is very important to prevent the ZSI output signal of the Tie breaker from going back to its input. Steering/blocking diodes can also help to block the electrical loading seen by the ZSI input circuit in upstream breakers. Typical steering diodes are type IN5408 or equivalent.

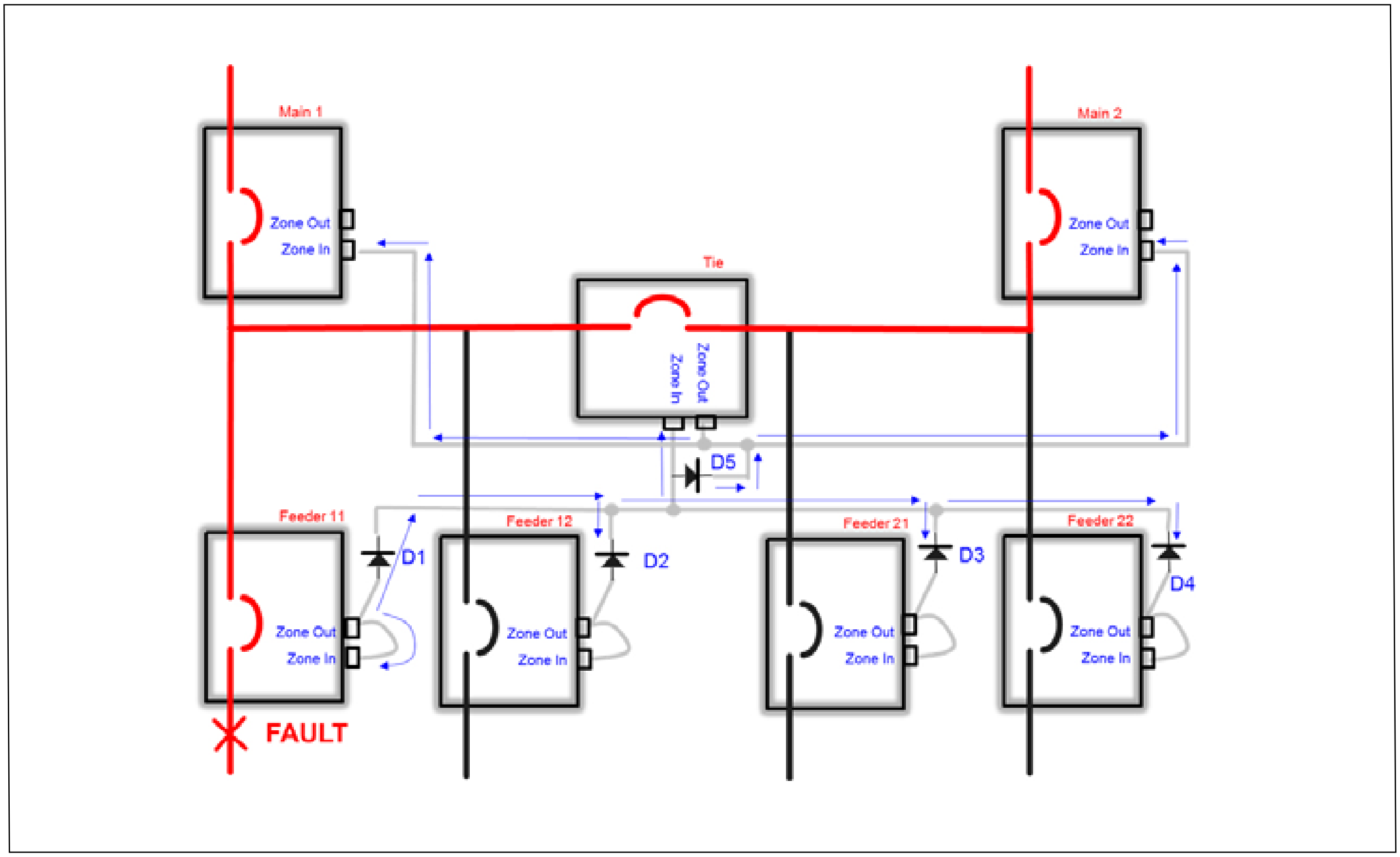

Figure 7. Main-Tie-Main example with steering diodes.

An alternative use of the diode blocking scheme is shown in Figure 8. This scheme was developed by Robert Holse and is described in US patent #9379537. This scheme uses more steering diodes to separate the Main 1 feeder ZSI signals from the Main 2 feeder ZSI signals. In the Figure 8 example the Feeder 11 breaker sees the fault current from the fault below the breaker. The small blue arrows indicate the ZSI signal from the Feeder 11 breaker. The signal from Feeder 11 is only needed by the Main 1 breaker because only the Main 1 source is feeding the fault. The Main 2 source is not feeding the fault because its breaker is either open or the Tie breaker is open. The Feeder 11 ZSI output signal is blocked by diode D7 and prevents it from back feeding into the Feeder 21 and 22 breaker ZSI wiring. Diode D10 also blocks the Feeder 11 ZSI signal from getting to the Main 2 breaker Zone input. Also note in this example that the self interlock jumpers are not used on Feeder 12 and 21 breakers because they have breakers below them that have ZSI output signals. Therefore the blocking diodes D2 and D3 to the Zone Input were not needed and removed.

The next example in Figure 9 shows a fault on the Main 2 bus. In this example the Main 1 breaker is closed and the Main 1 source is feeding the fault. The Tie breaker is closed but the Main 2 breaker is open. The feeder breakers do not see any fault current and they do not send out any ZSI signals. The Tie breaker sees the fault current and it sends a ZSI output to the Zone input of the Main 1 breaker. These signals will then allow the Tie to quickly interrupt the fault and keep the Main 1 breaker closed and still powering the Feeder 11 and 12 breakers.

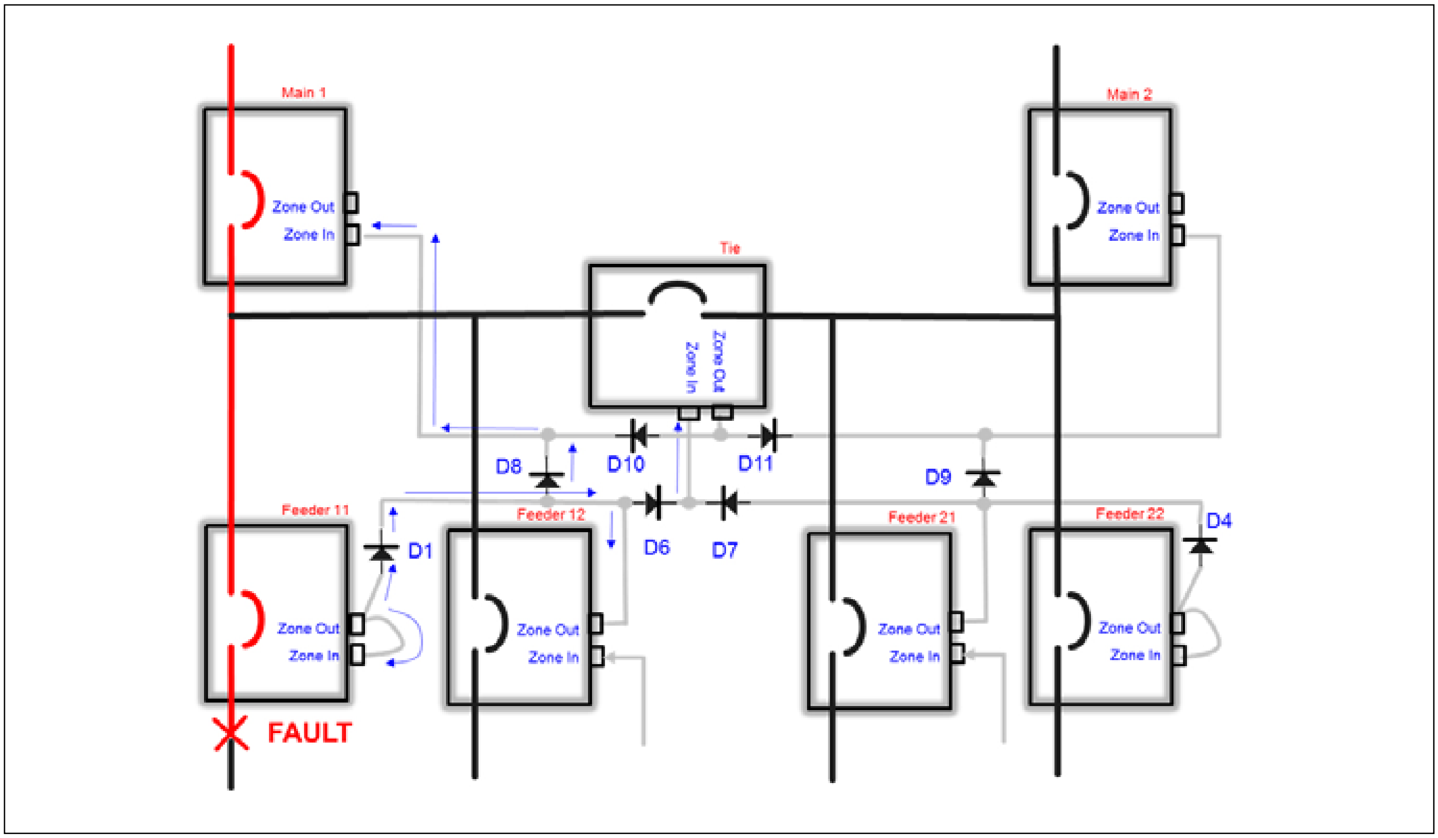

Figure 8. Main-Tie-Main with separate feeder steering diodes.

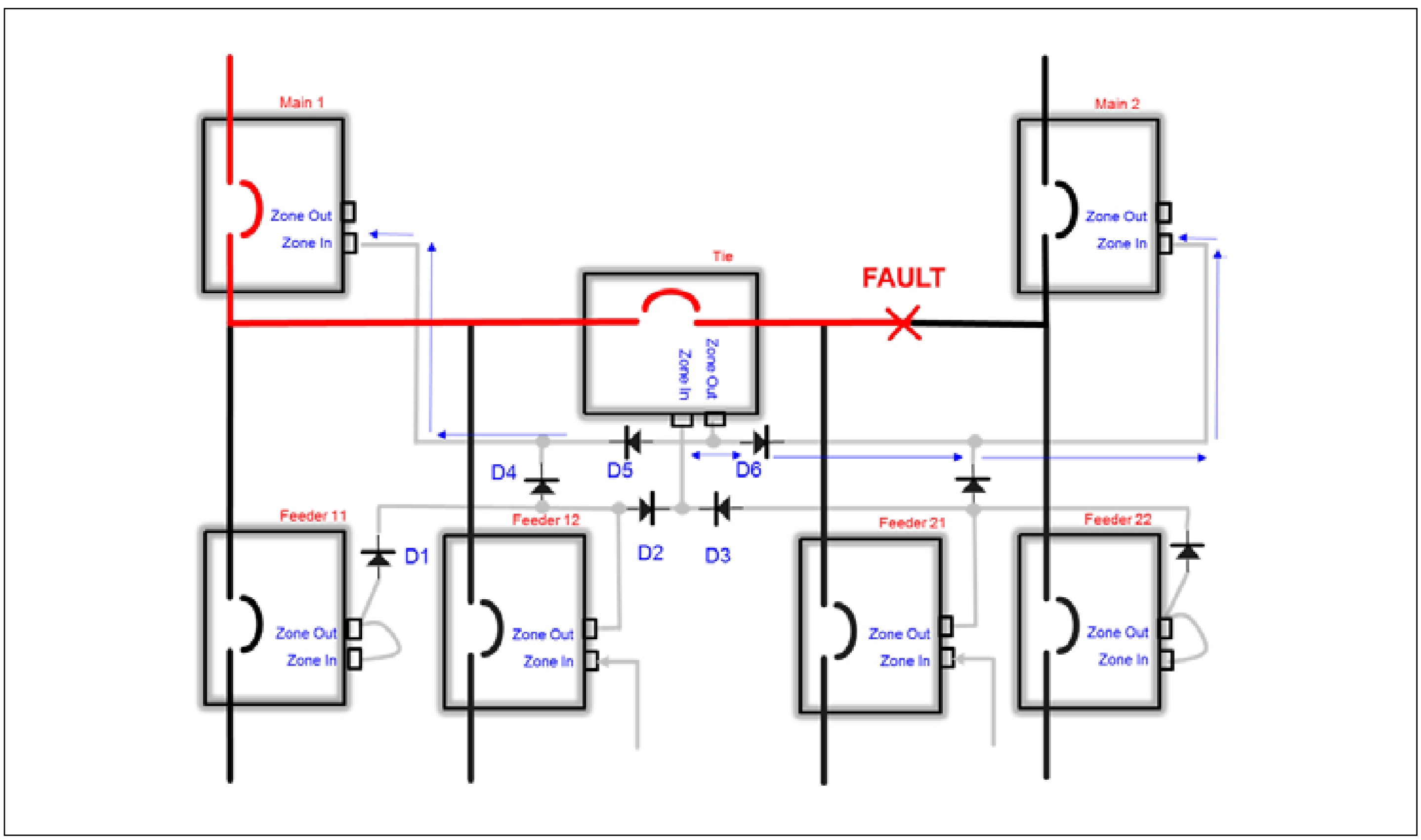

Figure 9. Main-Tie-Main with fault on main 2 bus.

Phase and Ground Outputs / Inputs

Zone input and output interlock connections may be combined on the same terminal for phase and ground or have separate connections. Figure 10 shows an example of a mixture of 5 wire, separate phase and ground, and 3 wire combined phase and ground devices. The 5 wire OPTIM 1050, the 3 wire PXR 25 and the 3 wire Magnum DS 1150+ trip unit are all interlocked to the input of the 3 wire EDR 3000 protective relay. The EDR 3000 provides 2 common connection points and a terminal for landing the shield, if used. Combining the phase and ground outputs or inputs on the same terminal reduces the number of conductors required for adding zone interlocking to a power distribution system. Some applications may want only ground or only phase to be interlocked. The Eaton E Series relays provide programming to enable or disable one or the other or both functions. The New Eaton PXR trip units also provide the ability to enable or disable ZSI through programming. Table 6 shows which products have the zone interlock signal combined or independent for phase and ground.

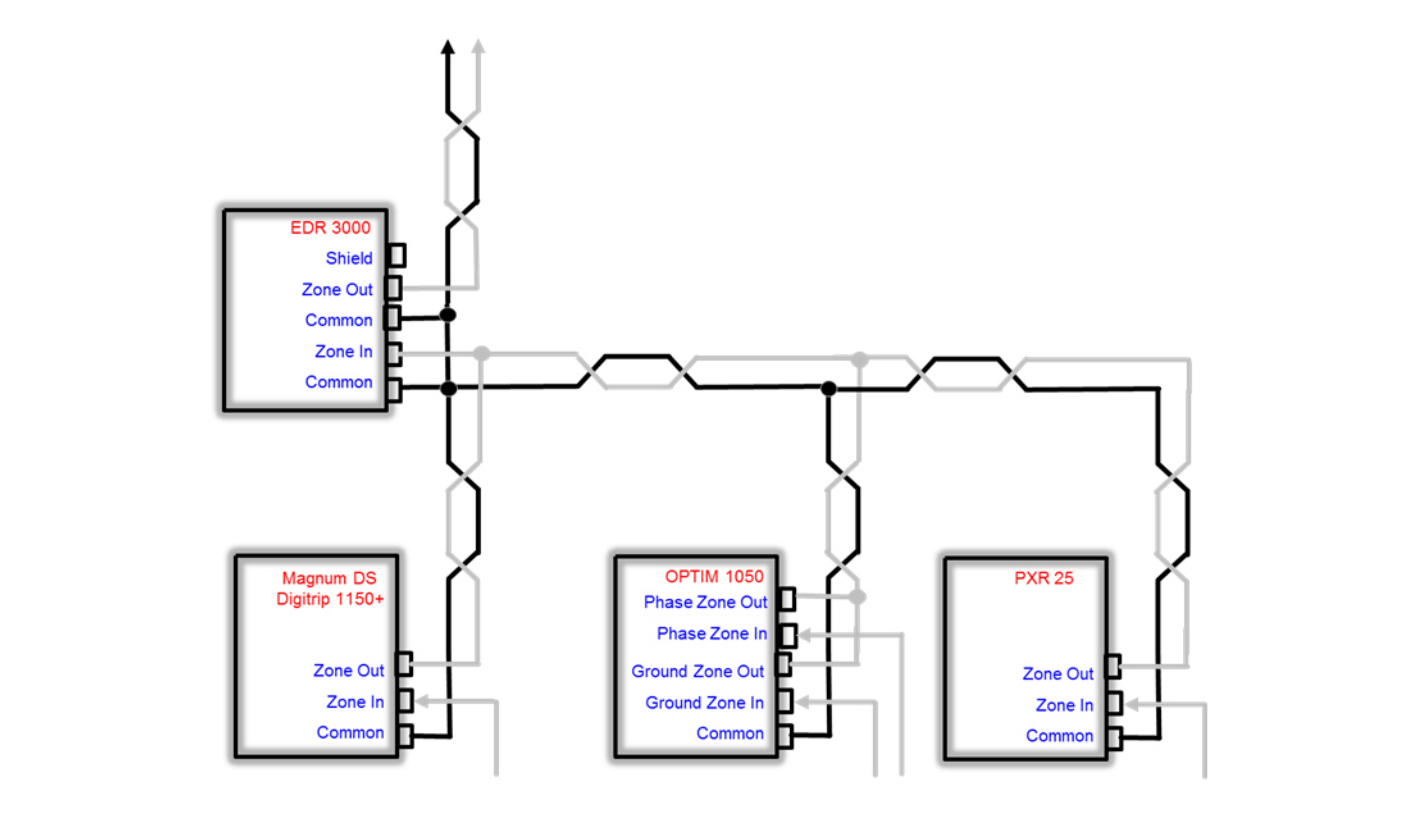

Figure 10. Wiring for 3 and 5 wire ZSI devices.

Table 4. List of devices and configurations

Devices	ZSI Phase and ZSI Ground Connections
NRX breakers - PXR 20, PXR 25	Combined
MCCB breakers – PXR 20, PXR20D,PXR 25	Combined
NRX breakers – Digitrip 520, 1150	Combined
Magnum DS/SB – Digitrip 520, 520M, 520MC, 1150	Combined
MCCB breakers – OPTIM 550, 750, 1150	Independent
MCCB breakers – 310+	Combined
EDR 3000, EDR 5000	Combined
DT 3000	Independent
FP 5000	Combined
SPB/DS/RD breakers - Digitrip 510, 610, 810, 910	Independent

ZSI Logic

The flow diagram in Figure 11 shows the logic flow of a typical protective unit with the ZSI function. Not all units have the same logic.

The protection routine is entered at the top. The first test is to see if a ZSI output signal should be sent out. The test for the fault current over 2X is used to determine the next step. If there is no fault current then all of the flags are cleared to make sure a clean start for the next time through the loop. If the fault current is detected, the ZSI output is enabled. The next test is to see if the Ground Fault or Short Delay protection is picked up. If it is not then the routine is exited. If either the GF or SD protection is picked up, meaning that the value of fault current is over its setting, then the next test is to see if the protection has timed out. If the timing on the protection is done then the breaker should be tripped and this is done. If the timing is not expired then there is a check of the ZSI input signal. If there is a ZSI input signal exit and continue to do protection timing. If there is no ZSI signal then check to see if this is the first time through the routine. If it is the first time, then the ZSI Zone Flag is set. If the logic gets to this point again the Zone Flag will have been set from the previous pass and there was no ZSI input signal, therefore the ZSI protective function will now do a quick trip of the circuit breaker. The 2 passes are important to make sure that transients or false signals are not interpreted as true signals to prevent any nuisance tripping or false blocking.

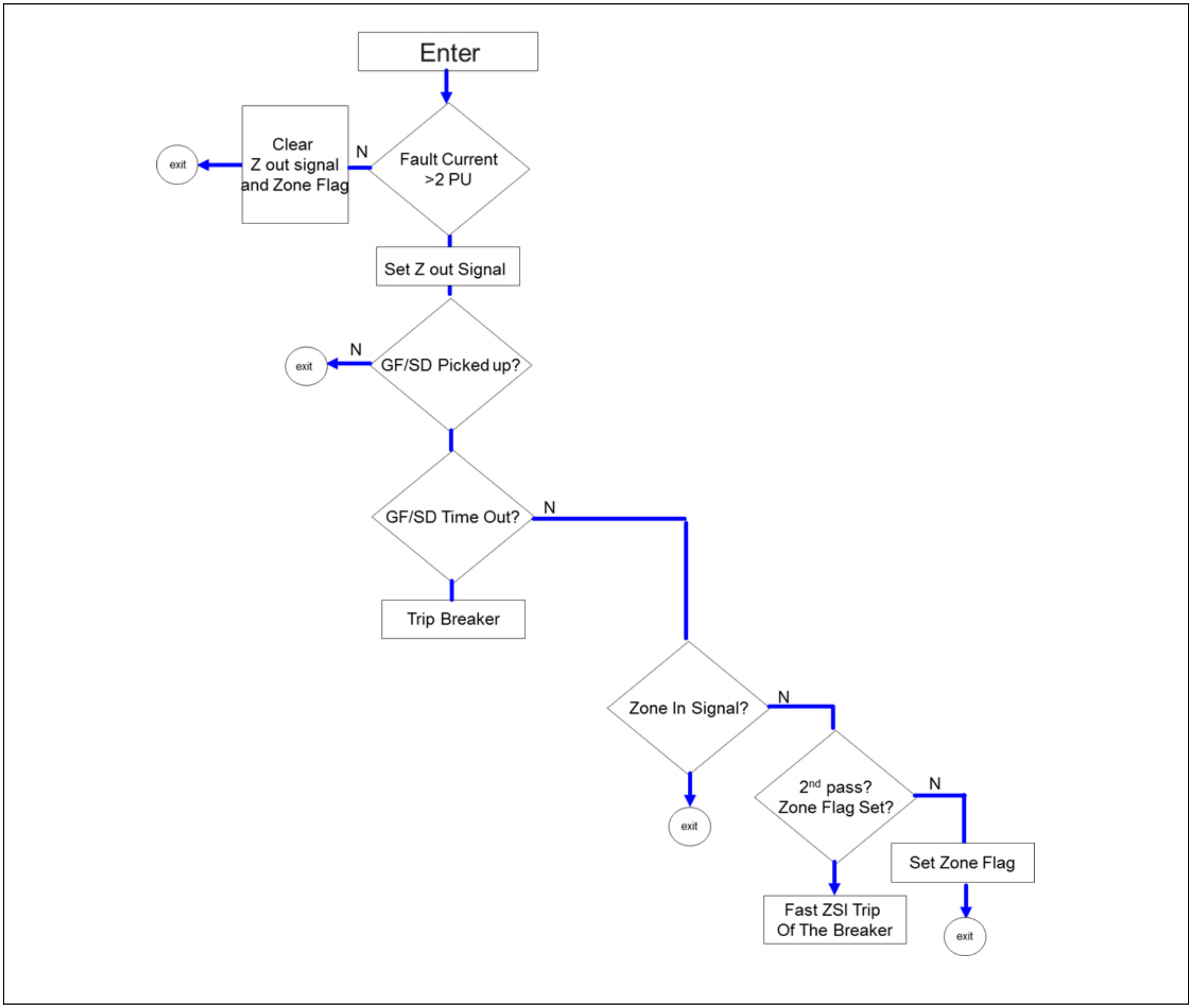

Figure 11. ZSI internal logic flow chart.

ZSI Clearing Time

Each product and some manufacturer's differ on the total clearing time for ZSI enabled products. The product's literature should be checked for the actual time specified to clear the fault. The following are some of the factors that influence the clearing time:

1. The time at where in the protection software code does the fault happens is one factor. As can be seen in Figure 11, if the fault happens right when the ZSI routine is entered the ZSI output and flags will be set right away. If the fault happens at the end of the routine it may be several milliseconds before the routine is entered again.
2. If the trip unit is not powered up when the fault occurs. It could take a millisecond for other checks to happen in the power up process before the ZSI routine is entered.
3. If the system frequency is 60Hz (16.67ms per cycle) vs. 50Hz (20ms per cycle) could make a difference if the Short Time protection routine needs to take a full cycle of samples or even sample at the peak maximum before declaring a fault.
4. As shown in Figure 11 the input signal needs to be verified several times to make sure there will be no nuisance tripping on false signals and that sampling time adds to the delay time.

All of these extra time delays can have an effect on the total clearing time when ZSI is used.

New Advances in ZSI with PXR Electronic Trip Units

The new Power Xpert Release (PXR) electronic trip units provide a new level of ZSI capability. The PXR trip units can now electronically disable or enable ZSI protection as a setpoint. In the past a self-interlocking ZSI jumper on the terminal block was used to disable the quick trip function. A self-interlocking jumper placed between the zone input and the zone output terminals will still force the trip unit to read its own output and execute full timing delays. But with the PXR trip unit a programmed setpoint will do the same function. The display on the trip unit or the Power Xpert Protection Manager software on a laptop connected to the USB port of the trip unit can be used to access the setpoints and enable or disable the ZSI feature.

When the ZSI function is enabled in PXR trip units with a display, the ZSI letters will appear on the display as shown in Figure 12. This is your confirmation that the trip unit understands that ZSI function is active. The PXR trip units also show a √ 'check mark' on the display to acknowledge when the trip unit has seen a ZSI input signal. This mark will stay on the display as long as there is auxiliary power to the trip unit. The check mark can then be reset, cleared from the display, by pressing the reset pushbutton.

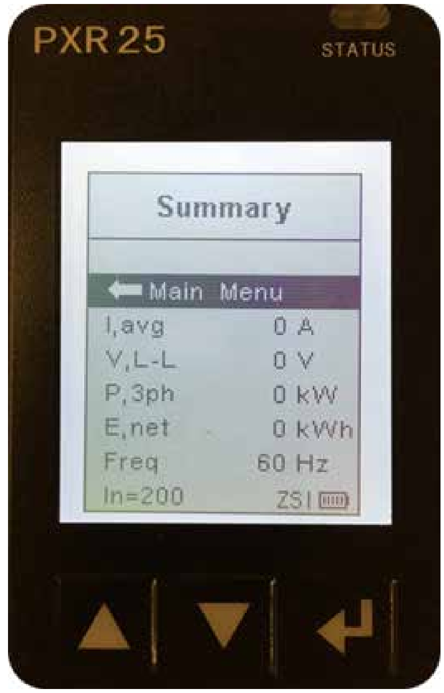

Figure 12. PXR display with ZSI indication (lower right).

Testing ZSI with PXR trip units

The ZSI function and wiring can be easily tested for the PXR trip units. The example shown in Figure 13 is a Main 1 breaker with 3 feeder breakers connected to its load side. The 3 feeder breakers have their ZSI outputs connected to the ZSI input of the Main 1 breaker. The Feeder 11 breaker is the last breaker before its load and the self-interlock jumper is used between its ZSI out and ZSI input terminals. Feeder breakers 12 and 13 have ZSI input signals coming from branch breakers farther downstream in their distribution network. In the example, Feeder 11 breaker is tested using primary injected current or tested with secondary injected current from the trip unit using PXPM software connected to the USB port to initiate the test. The current injected, 4560A in phase B, is over the short delay setting value and the short time protection is now active. The ZSI function in the Feeder 11 breaker will send a signal from its ZSI output terminal. The display on the Feeder 11 breaker shows the check mark next to the letters ZSI. The check means that it saw a ZSI input signal. Because this breaker is self-interlocked, it should see that ZSI input signal and the correct wiring of the jumper is confirmed as correct. The Main 1 breaker did see a ZSI input signal from the Feeder 11 breaker and the display on the Main 1 breaker shows the check mark. This confirms that the wiring from Feeder 11 output to the input of Main 1 breaker is correct. The Feeder 12 breaker display shows no check mark. This is correct. The Feeder 12 breaker did not see the test fault current, it did not see a ZSI input signal and therefore shows no current on its display and no check mark next to the ZSI letters. The display on the Feeder 13 breaker is next checked. It has a check mark on the display next to the ZSI letters. There should NOT be a check mark because this breaker is a feeder breaker on the same bus as the tested breaker, Feeder 11. The wiring is checked and it is found that the ZSI signal from the branch breakers below Feeder 13 was wired to the ZSI output terminal. The ZSI input terminal was mistakenly wired to the ZSI outputs of all the other feeder breakers. The ZSI wiring error was found and corrected. The test was repeated and the correct wiring was verified. The test was next performed on Feeder 12 breaker and then on Feeder 13 breaker. With the new PXR trip units verifying ZSI wiring is easy and thorough.

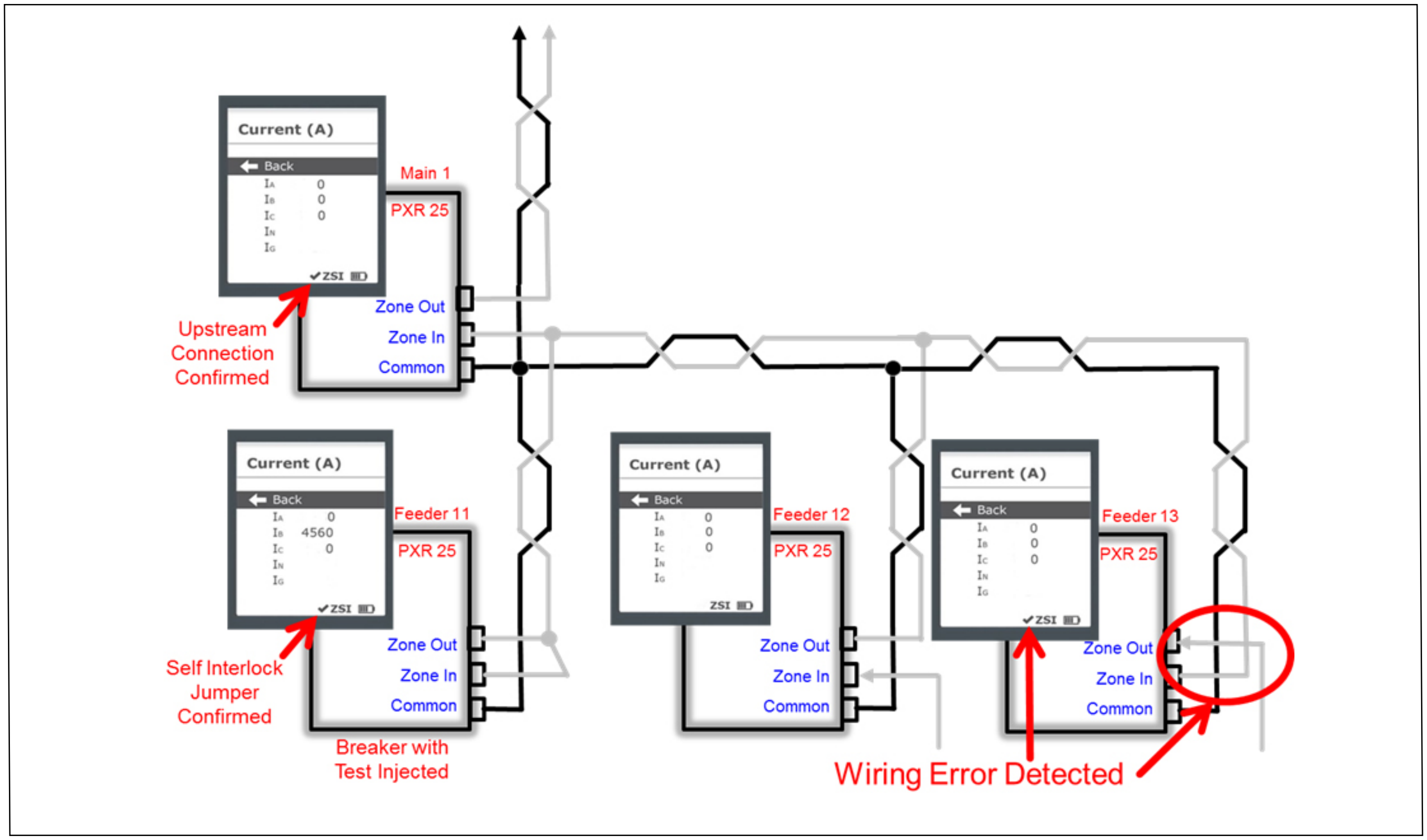

Figure 13. PXR displays for ZSI testing examples.

E Series Protective Relay Timing and Logic

The E Series protective relays offer an advanced level of logic with multiple outputs and several different inputs that can produce the zone selective interlocking function.

The E Series can be configured using 3 groups. The GENERAL group, which comprises the settings used to control the general usage of the zone interlocking module. The other two groups are the OUTPUT group and the TRIP group. The timing and logic are shown for both the output and the trip group.

Figure 14. EDR-5000 protective relay.

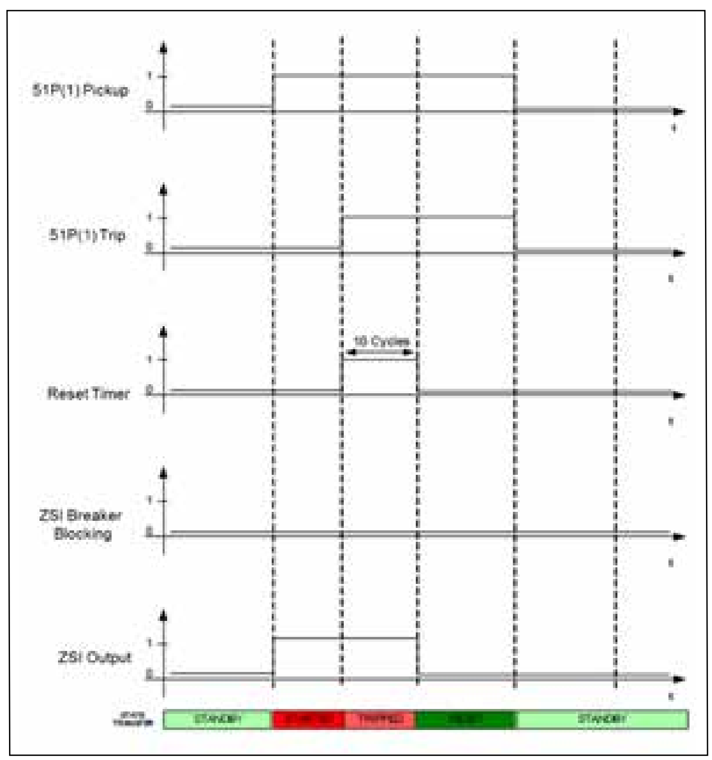

Figure 15. EDR output timing.

Example: EDR 3000 protective relay Zone Selective OUTPUT timing

The OUTPUT group comprises the settings to configure the zone interlocking output logic in Figure 16. If the zone interlocking application for the device is used as a downstream device, the settings in OUTPUT group should be programmed accordingly. If the zone interlocking application for this device is only used as an upstream device (main breaker or Zone 1), the setting Zone Interlock Out within the OUTPUT group should be disabled.

The logic can be used to program which input signals to use to trigger the outputs. There are logic outputs for either ground or phase or both, and there is a common ground/phase hardware output signal to the upstream device.

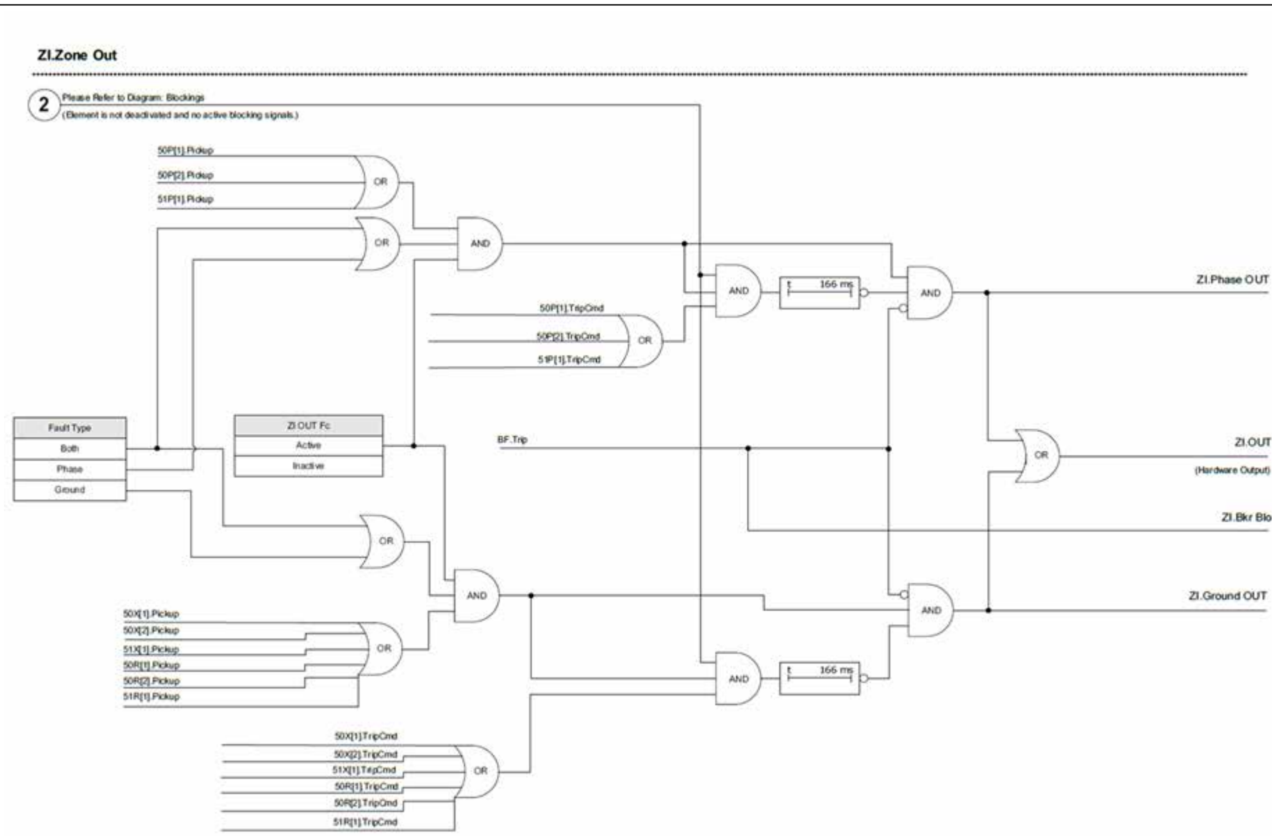

Figure 16. EDR Output Logic.

Example: EDR 3000 protective relay Zone Selective TRIP timing

The TRIP group comprises the settings to configure the zone interlocking tripping logic in Figure 18. The TRIP group comprises the settings used to configure the zone interlocking TRIP logic. If the zone interlocking application is applied to an upstream device, main breaker or Zone 1, the settings in the TRIP group should be programmed accordingly. If the zone interlocking application is only used for a downstream device (feeder breaker or Zone 2), the setting Zone Interlock Trip in TRIP group should be disabled.

The logic can be used to program which input signals to use to block the trip signals. There are logic outputs for either ground or phase, or both. Refer to the EDR instruction manuals for more information.

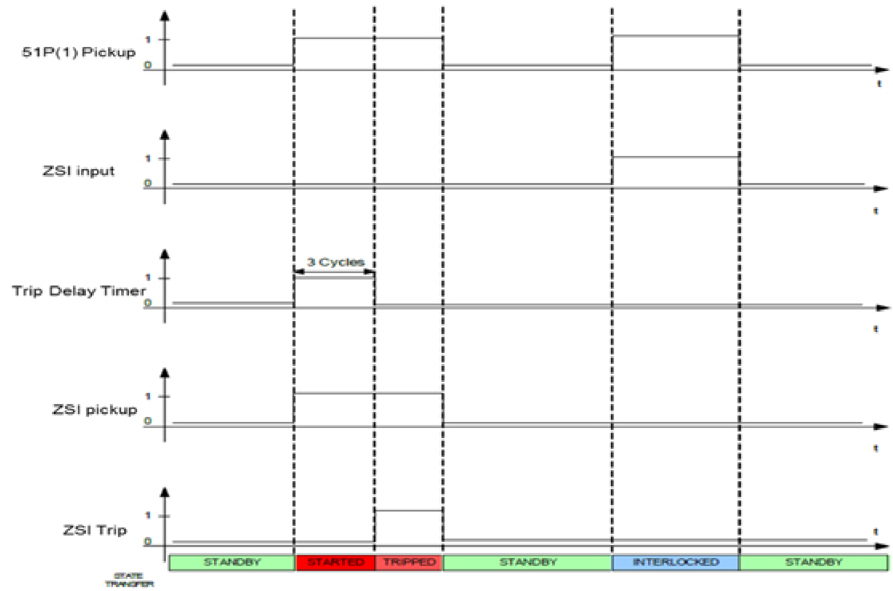

Figure 17. EDR Trip Timing.

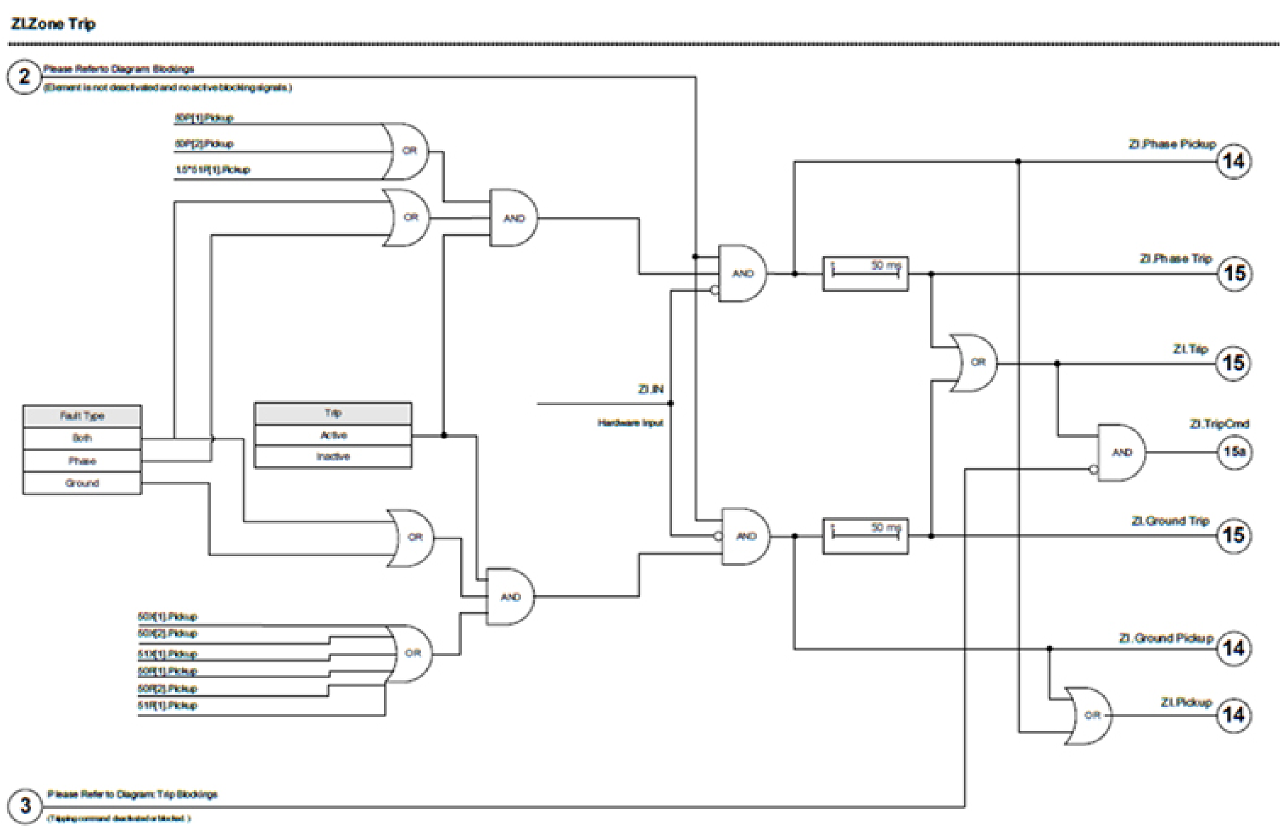

Figure 18. EDR Trip Logic.

Advanced Applications

Arc-Flash Limiter (AFL)

An Arc-Flash Limiter is a medium voltage hybrid approach to provide substation primary and secondary short circuit protection and to lower incident energy on the secondary LV side of the transformer. A medium voltage vacuum breaker (Eaton VCP-T) is retrofitted in the fuse section of a medium voltage fused switch. The Medium Voltage primary protection is provided by a protective relay ED3000 or DT3000 as shown in Figure 19 and primary mounted CT's. The Low Voltage secondary protection is provided by an integral VCP-T trip unit (Digitrip 520MVC or 1150V) with transformer secondary stab mounted low voltage sensors.

For transformer secondary arc flash incident energy reduction, the VCP-T integral trip unit uses the low voltage sensors and built-in ARC Flash Reduction Maintenance Switch (ARMS). When the ARMS circuit is engaged, the arc flash incident energy is significantly reduced on the transformer low voltage secondary bus, hence lower incident energy at the low voltage switchgear.

The VCP-T breaker contains a Digitrip 50/51 relay that has a ZSI capability. The one line in Figure 20 shows how the low voltage to medium voltage ZSI interlocking can be done. In this scheme the Digitrip unit is sensing current on the load side of the transformer while the EDR 5000 relay is sensing transformer primary current. Both protective units have the ability to trip the breaker. The ZSI interlocking gives the Digitrip the ability to be restrained if any of the feeders see the fault. Should the fault be on the 480V bus or on the secondary connections from the transformer the Digitrip will be unrestrained from the Feeder breakers and will trip MV VCP-T breaker with no delay. This quick tripping action greatly limits the fault damage without sacrificing coordination.

Figure 19. PXR display with ZSI indication (lower right).

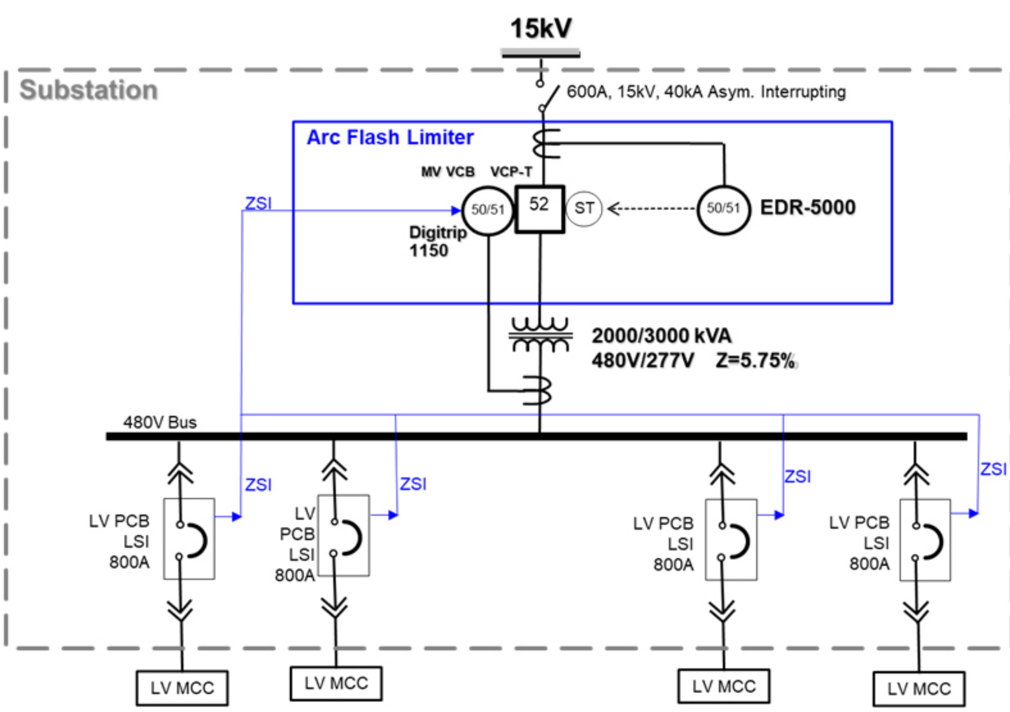

Figure 20. Arc Flash Limiter Substation One-line.

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Transformer Inrush

Applying zone interlocking on the primary side of a transformer may cause false trips due to high transformer inrush currents that may be greater than 12X the FLA rating of the transformer with the secondary open. In order to prevent the breaker on the primary side from tripping in a nuisance condition a self-interlocking jumper should be installed during the energizing of the transformer, which can last from 10 cycles to several minutes.

This may be accomplished by using a timer that closes a contact during the inrush period of the transformer across the zone interlock output and input terminals of the device. If a harmonic restrain unit that monitors the 2ND order harmonics is available; a contact closure from the harmonic restraining unit can be used as a self-interlocking jumper. The self-interlocking jumper would allow the device to trip according to preset coordinated time current curves and temporarily disable the instantaneous zone interlock feature.

Main Tie Main Applications

The following applications are for main tie main (M-T- M) configurations. M-T-M configurations which are commonly used to maintain a reliable backup source of utility power should the primary fail. As discussed earlier in this paper there can be other configurations using steering diodes, shown here is one example.

Scheme 1: Main-Tie-Main with ZSI

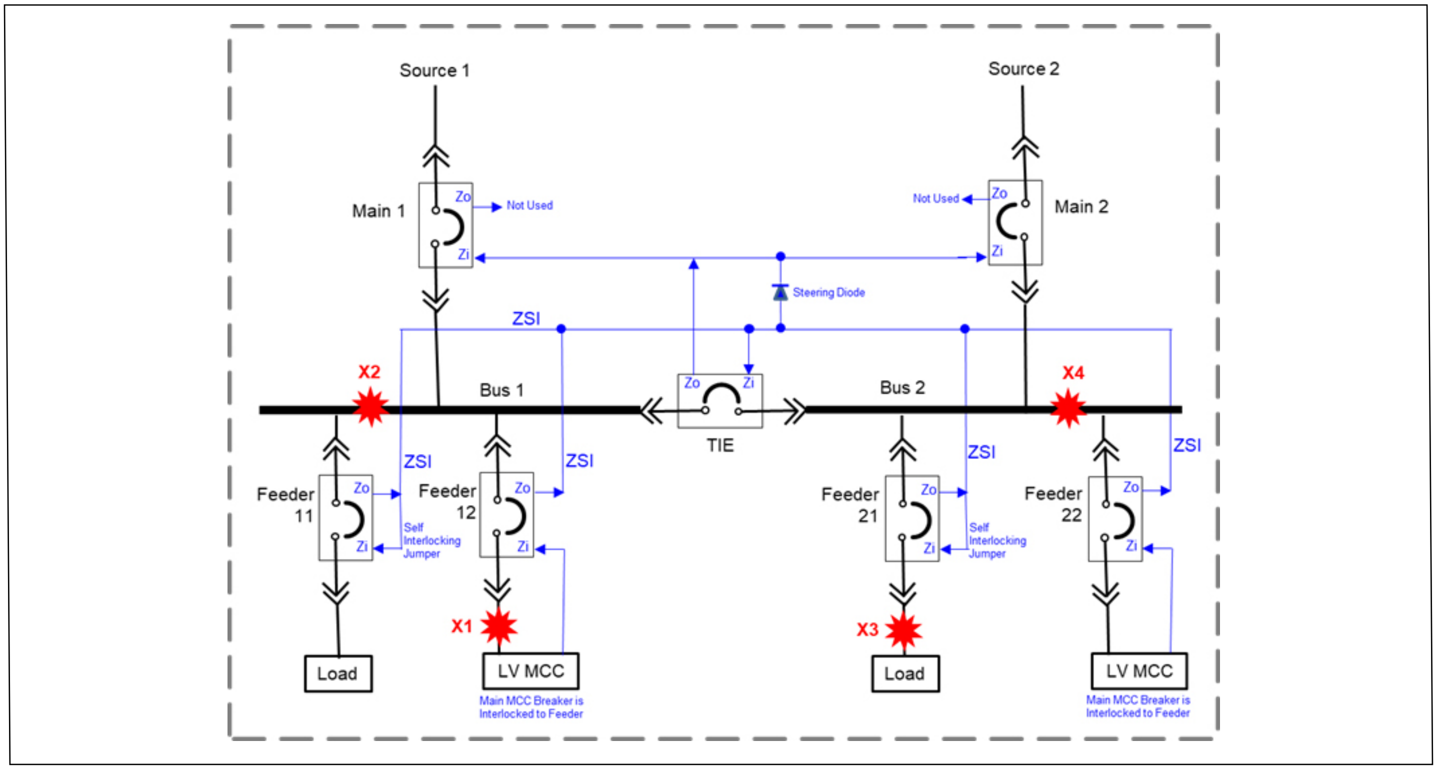

Figure 21. Scheme 1 Main-Tie-Main.

a) TIE Circuit Breaker Open, Main 1 Closed, and Main 2 Closed

Fault at X1

Feeder 12 will see the fault current and send a zone output signal to Main 1, Main 2 and TIE protective devices. The signal does not have an effect on the Feeder 22 breaker since the signal goes to its input. The TIE breaker is also unaffected because the breaker is open and not carrying any current. The steering diodes D2 and D3 prevent the signal, from Feeder 12, to go through the self-interlocking jumper into the zone input on Feeders 11 and 21 and therefore will have no effect on them. The Feeder 12 breaker will not get an input from LV MCC main breaker since the MCC does not see the fault current. Therefore the Feeder 12 breaker will clear the fault instantaneously, bypassing its time delay.

Fault at X2

This fault is on the bus below the Main 1 breaker which will not receive zone signals from the Feeder breakers because they do not see the fault current. The TIE breaker is open and therefore the Main 2 breaker does not supply fault current. The Main 1 breaker will clear the fault instantaneously, bypassing its time delay.

Fault at X3

Feeder 21 will provide send a zone output signal to Main 1, Main 2 and TIE protective devices. The signal does not have an effect on the Feeder 22 and 12 breakers since the signal goes to their inputs. The TIE breaker is also unaffected because the breaker is open and not carrying any current. The steering diode D2 prevents the signal, from Feeder 21, to go through the self-interlocking jumper into the zone input on Feeder 11 and therefore will have no effect. The Feeder 12 breaker is the last breaker before the load and has a self-interlocking jumper on its input. Because the Feeder is the last breaker there is no need for further coordination and its short time delay is at the lowest or instantaneous setting. Therefore Feeder 12 will trip fast and clear the fault.

Fault at X4

This fault is on the bus below the Main 2 breaker which will not receive zone signals from the Feeder breakers because they do not see the fault current. The TIE breaker is open and therefore the Main 1 breaker does not supply fault current. The Main 2 breaker will clear the fault instantaneously, bypassing its time delay.

b) TIE Circuit Breaker Closed, Main 1 Closed and Main 2 Closed

Fault at X1

Both sources will feed into this fault. Feeder 12 will see the fault current and send a zone output signal to Main 1, Main 2 and TIE protective devices. The signal does not have an effect on the Feeder 22 breaker since the signal goes to its input. The steering diodes D2 and D3 prevent the signal, from Feeder 12, to go through the self-interlocking jumper into the zone input on Feeders 11 and 21 and therefore will have no effect on them. The Feeder 12 breaker will not get an input from LV MCC main breaker since the MCC does not see the fault current. The TIE breaker will see fault current from Source 2 and produce a zone out signal to Main 1 and Main 2 breakers. Since the two Main breakers and the TIE breaker are restrained, the Feeder 12 breaker will clear the fault instantaneously, bypassing its time delay.

Fault at X2

Both sources will feed into this fault. This fault is on the bus below the Main 1 breaker which will not receive zone signals from the Feeder breakers because they do not see the fault current. The TIE breaker will see fault current from Source 2 and produce a zone out signal to Main 1 and Main 2 breakers. The TIE breaker will not receive a zone input signal from any of the feeder breakers therefore it will trip instantaneously, bypassing its time delay. The Main 1 breaker will be doing its time delay trip until the TIE breaker opens instantaneously and removes its zone out signal. With the TIE breaker open the Bus 2 service power will be maintained. Once the TIE breaker has removed its zone out signal the Main 1 breaker will see no zone restraining signals and trip instantaneously to clear the fault by bypassing the rest of its time delay.

Fault at X3

Both sources will feed into this fault. Feeder 21 will see the fault current and send a zone output signal to Main 1, Main 2 and TIE protective devices. The signal does not have an effect on the Feeder 22 breaker since the signal goes to its input. The steering diode D2 prevents the signal, from Feeder 21, to go through the self-interlocking jumper into the zone input on Feeder 11 and therefore will have no effect on it. The Feeder 21 breaker is the last breaker before the load and has a self-interlocking jumper on its input. Because the Feeder is the last breaker there is no need for further coordination and its short time delay is at the lowest or instantaneous setting. The TIE breaker will see fault current from Source 2 and produce a zone out signal to Main 1 and Main 2 breakers. Since the two Main breakers and the TIE breaker are restrained, the Feeder 21 breaker will clear the fault instantaneously, bypassing its time delay.

Fault at X4

Both sources will feed into this fault. This fault is on the bus below the Main 2 breaker which will not receive zone signals from the Feeder breakers because they do not see the fault current. The TIE breaker will see fault current from Source 1 and produce a zone out signal to Main 1 and Main 2 breakers. The TIE breaker will not receive a zone input signal from any of the feeder breakers therefore it will trip instantaneously, bypassing its time delay. The Main 2 breaker will be doing its time delay trip until the TIE breaker opens instantaneously and removes its zone out signal. With the TIE breaker open the Bus 1 service power will be maintained. Once the TIE breaker has removed its zone out signal the Main 2 breaker will see no zone restraining signals and trip instantaneously to clear the fault by bypassing the rest of its time delay.

c) TIE Circuit Breaker Closed, Main 1 Closed and Main 2 Open

Fault at X1

Feeder 12 will see the fault current and send a zone output signal to Main 1, Main 2 and TIE protective devices. The signal does not have an effect on the Feeder 22 breaker since the signal goes to its input. The TIE breaker is also unaffected because the Main 2 breaker is open and therefore not supplying any current through the TIE to the fault. The steering diodes D2 and D3 prevent the signal, from Feeder 12, to go through the self-interlocking jumper into the zone input on Feeders 11 and 21 and therefore will have no effect on them. The Feeder 12 breaker will not get an input from LV MCC main breaker since the MCC does not see the fault current. Therefore the Feeder 12 breaker will clear the fault instantaneously, bypassing its time delay.

Fault at X2

This fault is on Bus 1 below the Main 1 breaker which will not receive zone signals from the Feeder breakers because they do not see the fault current. The TIE breaker is closed but the Main 2 breaker is open and therefore not supplying any current through the TIE to the fault. The Main 1 breaker will clear the fault instantaneously, bypassing its time delay.

Fault at X3

Feeder 21 will provide send a zone output signal to Main 1, Main 2 and TIE protective devices. The signal does not have an effect on the Feeder 22 and 12 breakers since the signal goes to their inputs. The zone signal to the TIE breaker restrains it as it is supplying fault current from the Main 1 source to Feeder 21 and to the fault. The steering diode D2 prevents the signal, from Feeder 21, to go through the self-interlocking jumper into the zone input on Feeder 11 and therefore will have no effect. The Feeder 12 breaker is the last breaker before the load and has a self-interlocking jumper on its input. Because the Feeder is the last breaker there is no need for further coordination and its short time delay is at the lowest or instantaneous setting. Therefore Feeder 12 will trip fast and clear the fault.

Fault at X4

This fault is on the Bus 2. The Main 2 breaker is open and all of the fault current will come from the Main 1 breaker through the TIE breaker. The TIE breaker will not receive zone signals from the Feeder breakers because they do not see the fault current. The TIE breaker does see the fault current and sends a zone out signal to the Main 1 breaker restraining it. The Tie breaker will clear the fault instantaneously, bypassing its time delay.

d) TIE Circuit Breaker Closed, Main 1 Open, Main 2 Closed Fault at X1

Feeder 12 will see the fault current and send a zone output signal to Main 1, Main 2 and TIE protective devices. The signal does not have an effect on the Feeder 22 breaker since the signal goes to its input. The zone signal to the TIE breaker restrains it as it is supplying fault current from the Main 2 source to Feeder 12 and to the fault. The steering diodes D2 and D3 prevent the signal, from Feeder 12, to go through the self-interlocking jumper into the zone input on Feeders 11 and 21 and therefore will have no effect on them. The Feeder 12 breaker will not get an input from LV MCC main breaker since the MCC does not see the fault current. Therefore the Feeder 12 breaker will clear the fault instantaneously, bypassing its time delay.

Fault at X2

This fault is on the Bus 1. The Main 1 breaker is open and all of the fault current will come from the Main 2 breaker through the TIE breaker. The TIE breaker will not receive zone signals from the Feeder breakers because they do not see the fault current. The TIE breaker does see the fault current and sends a zone out signal to the Main 2 breaker restraining it. The Tie breaker will clear the fault instantaneously, bypassing its time delay.

Fault at X3

Feeder 21 will provide send a zone output signal to Main 1, Main 2 and TIE protective devices. The signal does not have an effect on the Feeder 22 and 12 breakers since the signal goes to their inputs. The TIE breaker is closed but the Main 1 breaker is open and therefore not supplying any current through the TIE to the fault. The steering diode D2 prevents the signal, from Feeder 21, to go through the self-interlocking jumper into the zone input on Feeder 11 and therefore will have no effect. The Feeder 12 breaker is the last breaker before the load and has a self-interlocking jumper on its input. Because the Feeder is the last breaker there is no need for further coordination and its short time delay is at the lowest or instantaneous setting. Therefore Feeder 12 will trip fast and clear the fault.

Fault at X4

This fault is on Bus 2 below the Main 2 breaker which will not receive zone signals from the Feeder breakers because they do not see the fault current. The TIE breaker is closed but the Main 1 breaker is open and therefore not supplying any current through the TIE to the fault. The Main 2 breaker will clear the fault instantaneously, bypassing its time delay.

Scheme 2: Two Mains, Two Ties, with ZSI

In this scheme, redundant TIE breakers are used. Usually this system has two separate switchgear sections and may be in different locations. The use of two TIE breakers are an added safety feature for maintenance workers that can confidently know the other source is isolated from the switchgear that is being worked on. This scheme is treated just like the one TIE design with the Zone input and output connections paralleled on the two TIE breakers. The unique condition where there is a fault in the bus or cable between the TIE breakers as shown as X2 in Figure 22. This scheme also shows an example of the use of a dual diode assembly to accomplish the signal steering necessary. The diodes used in this example are designed for utility use and are from E-MAX Instruments, Inc. type #911A002.

a) TIE 1 and 2 Circuit Breakers Closed, Main 1 and Main 2 Closed

Fault at X1

With both Main breakers closed and TIE breakers closed the fault is feed from both sources. Both TIE breakers will see the fault current and trip immediately because there will be no Zone input signals from the feeder breakers. The Main breakers will start their time delay because they get Zone input signals from the TIE breakers. When the TIE breakers trip and have removed their zone out signals then the Main 1 breaker will see no zone restraining signal and trip instantaneously to clear the fault by bypassing the remaining time of its delay. The Main 2 breaker never trips since the TIE breakers have opened and removed the flow of fault current from the Main 2 Source.

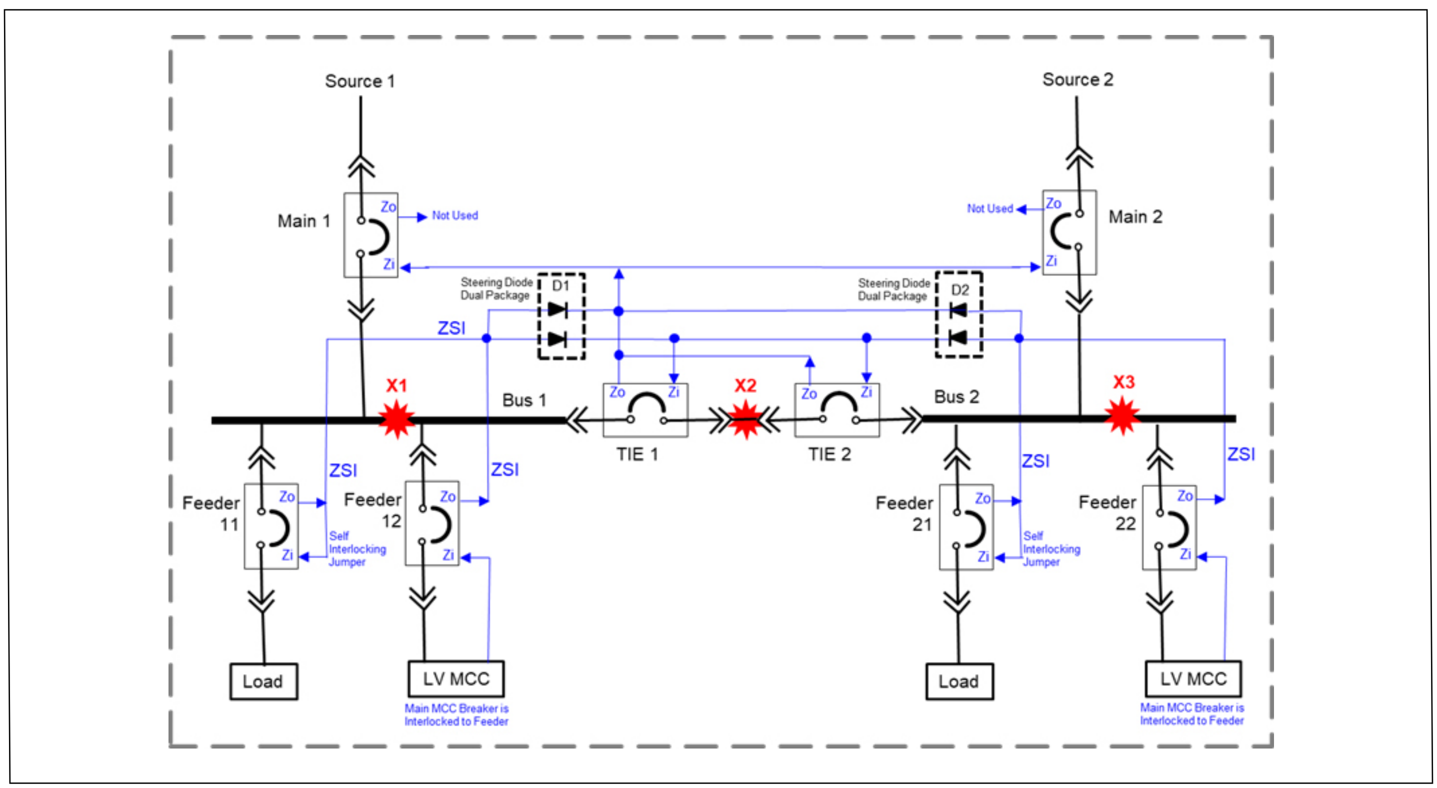

Figure 22. Scheme 2 with Redundant TIE Breakers.

Fault at X2

In the X2 fault both TIE breakers will see the fault current since it is feed from both Main 1 and Main 2 sources. The TIE breakers send zone out signals to the Main breakers. The TIE breakers will not get a Zone input signal from any of the Feeder breakers since they do not see the fault current. Therefore the two TIE breakers will clear the fault instantaneously, bypassing their time delays. When the TIE breakers are open, then both Main breakers will not see fault current anymore and will remain closed.

Fault at X3

This condition is just like the fault at X1 only with Main 2 eventually clearing the fault after the TIE breakers have cleared.

b) TIE 1 and 2 Circuit Breakers Closed, Main 1 Closed and Main 2 Open

Fault at X1

Only Main 1 breaker is closed and both TIE breakers are closed so the fault current is only feed from Source 1. Neither TIE breaker will see the fault current and will remain closed. Main 1 breaker will not get any Zone input signals from the TIE breakers or Feeder breakers. Since the Main 1 breaker will not see any zone restraining signals it will trip instantaneously to clear the fault.

Fault at X2

For the X2 fault the current will only come from Main 1. TIE 1 sees the fault current but TIE 2 does not see the fault current. TIE 1 breaker will send a zone out signal to the Main breakers. TIE 1 breaker will not get a Zone input signal from any of the Feeder breakers since they do not see the fault current. Therefore the TIE 1 breaker will clear the fault instantaneously, bypassing its time delay.

Fault at X3

For the X3 fault, both TIE breakers will see fault current and send out zone output signals to the Main breakers. Neither of the TIE breakers will get a zone input signal from any of the Feeder breakers because they do not see the X3 fault current. Therefore the two TIE breakers will clear the fault instantaneously, bypassing their time delays. When the TIE breakers are open, then the Main 1 breaker will not see fault current anymore and will remain closed.

c) TIE 1 and TIE 2 Circuit Breakers Closed, Main 1 Open and Main 2 Closed

This fault condition is similar to the b) condition where the Main 1 Source is feeding the fault. In this condition the Main 2 Source is feeding the faults and the operation will mirror the b) condition only with the Main 2 breaker eventually clearing the fault in the X3 fault.

Scheme 3: Three Mains, Two Ties, with ZSI

In this scheme, there are 3 sources of power supplied through 3 separate Main breakers and two TIE breakers separating the loads into 3 separate buses. For simplicity there is only one Feeder breaker on each bus and each one has its zone input coming from some load breakers that are not shown.

One option in a scheme like this would be to have the main breakers with differentially wired CT connections so that the non-faulted bus will not see the fault current fed from its source.

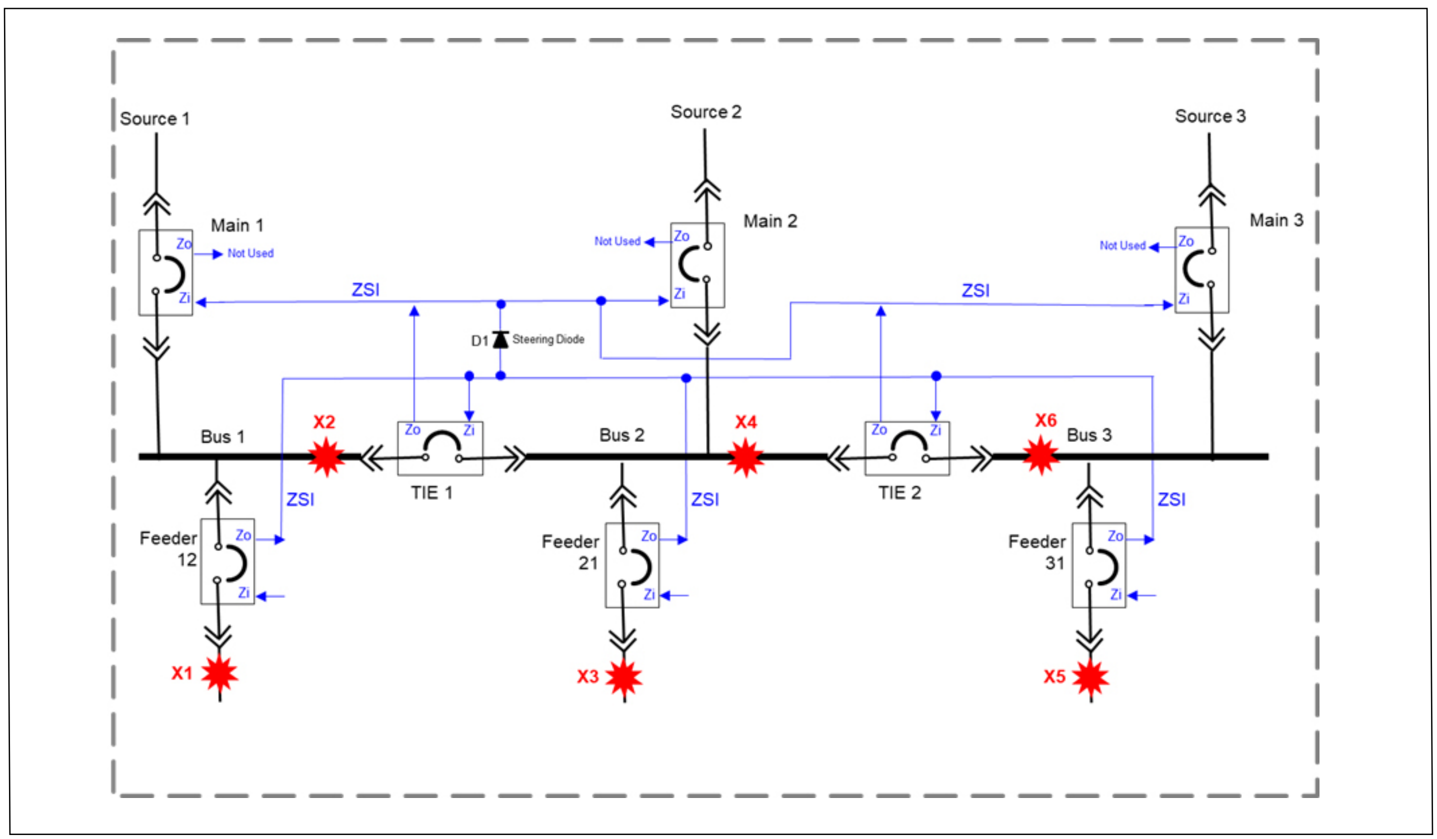

Figure 23. Scheme 3 with 3 Main Source Breakers and 2 TIE Breakers.

Electrical Specifications

⚠CAUTION

ONLY FOR ZONE INTERLOCK TRIPPING OUTPUTS (ZONE INTERLOCK, SEMI-CONDUCTOR OUTPUT): 5 VDC, <2MA FOR CONNECTION TO ELECTRONIC INPUTS ONLY.

Zone Out:	
Output voltage (High)	4.75 tp 5/25 Vdc
Output voltage (Low)	0.0 to +0.5 Vdc
Zone In:	
Nominal input voltage	+5 Vdc
Max. input voltage	+5.5 Vdc
Switching threshold ON	min. 4.0 Vdc
Switching threshold OFF	max. 1.5 Vdc
Galvanic isolation	2.5 kV ac (to ground and other IO)

Technical Resources

1. Arc-Flash Incident Energy Reductions using Zone Selective Interlocking, Authors: Donna Lee Hodgson and David Shipp, IEEE Transactions on Industry Applications, VOL 49, NO3, May/June 2010.
2. Arc-Flash Energy Reduction Techniques: Zone Selective Interlocking and Energy Reducing Maintenance Switching, Author: Christopher Walker, IEEE Transactions on Industry Applications, VOL 49, NO2, March/April 2013.
3. NEMA publication ABP 1-2010: Selective Coordination.
4. IEC Technical Report 61912-2 Low voltage switchgear and controlgear – Overcurrent protective devices Part 2: Selectivity under overcurrent conditions.

Eaton
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United States
Eaton.com

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