Zone Selective Interlocking On Instantaneous (I-ZSI)

&

Waveform Recognition (WFR)

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Introduction

The primary design requirement of an electrical distribution system is safety. Electric shock and arc flash hazards are the two major components of electrical safety. NFPA70E [1] and Z462 [2] detail methods for protecting against these two hazards. Healthcare, data centers and some industries require very high reliability in addition to safety. Redundancy might appear to be a solution for reliability, but NEC [3] has indicated that even redundant systems must be selective. Safety and selectivity use to be an either/or option, but now they must be ensured at the same time, preferably all the time. Annex O – Safety-Related Design Requirements in NFPA70 and Z462, recommend certain technologies for arc energy reduction. Zone-selective interlocking (ZSI) is one such technology. While zone selective interlocking has been in use for many years, it was primarily used to improve protection in the zone between cascaded circuit breakers. The instantaneous protection had to be disabled for zone selective interlocking to work and this does not help reduce the arc flash energy. A newer technology like GE's zone selective interlocking with Instantaneous protection (I-ZSI) enabled all the time has been developed to provide safety and selectivity at the same time, all the time. Zone selective interlocking schemes are limited to circuit breakers that are a short distance of each other. Selectivity between a circuit breaker and its downstream current limiting device without control signal connections between the two was also developed. GE's waveform recognition (WFR) algorithm extends the zone of selectivity from the low voltage switchgear down to the low voltage MCCs, panelboards and any other equipment and at the same time reduces the arc flash energy at this equipment to a low level. This feature has no distance limitation.

Zone Selective Interlocking (ZSI) – Current Technology

Zone selective interlocking currently used in the industry requires the following to be implemented (Figure 1);

1. Connect the trip units of the downstream feeder circuit breakers to the upstream main circuit breaker using twisted pair copper conductors to provide the restraint signal.
2. Set the trip unit of the main circuit breaker to the normal settings.
    a. This means staggering the time current curves on long time (L), short time (S) and ground (G) to provide selectivity under through-fault conditions.
    b. Disable the instantaneous protection (I) on the main trip unit.
    c. These settings will be in effect as long as a downstream feeder circuit breaker trip unit sends a restraint signal.
    d. Arc flash hazard analysis does not use these settings.

3. Set the trip units of the feeder circuit breakers as follows;
    a. Set the feeder circuit breaker to be selective with the main circuit breaker's normal setting.
    b. The time current curves of the main and feeder circuit breaker must not overlap.
    c. If selectivity is required between the feeder circuit breaker and the downstream MCCB/MCP in the LV MCCs and panelboards, disable the instantaneous protection (I) on the feeder circuit breaker.

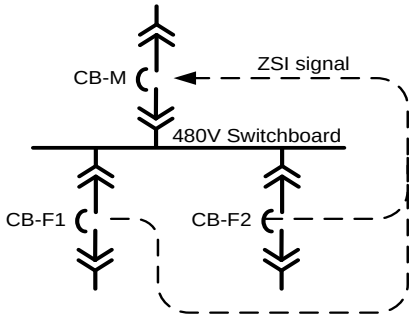

Figure 1: Zone selective interlock connections.

4. Any time the feeder circuit breaker picks up on short time and ground fault, it will send a restraint signal to the main circuit breaker.

For a fault downstream of a feeder circuit breaker, the trip unit of this feeder circuit breaker will send a restraint signal to the trip unit of the main circuit breaker and then trip to clear the fault within the programmed short time delay.

For a fault within the equipment, between the main and feeder circuit breakers, there would be no restraint signal from any of the trip units on the feeder circuit breakers and the short time delay and the ground fault delay of the trip unit on the main circuit breaker would automatically reduce from the set value to the minimum possible delay of 100ms. The main circuit breaker would clear the fault in 183ms.

The current technology of ZSI will give you complete selectivity but because the instantaneous protection must be disabled, the reduction in arc flash energy is minimal.

Zone Selective Interlocking on Instantaneous (I-ZSI) – GE's Technology

Zone selective interlocking scheme currently used by GE requires the following to be implemented (Figure 1);

1. Connect the trip units of the downstream feeder circuit breakers to the upstream main circuit breaker using twisted pair copper conductors to provide the restraint signal.
2. Set the trip unit of the main circuit breaker to the normal non-restraint settings.
    a. This means the short time pick-up (STPU), ground fault pick-up (GFPU) and the instantaneous pick-up (IPU) must not overlap.
    b. The short time delay (STD), ground fault delay (GFD) and instantaneous can overlap under normal conditions (Figure 2 – Non-Restraint).
    c. Enable the instantaneous protection (I) on the main trip unit.
    d. These settings will be in effect until a downstream feeder circuit breaker sends a restraint signal.
    e. Arc flash hazard analysis uses these settings.
3. Set the trip unit of the main circuit breaker to the ZSI restraint setting as shown in Figure 2 – Restraint.
    a. The short time delay (STD) in the restraint mode should be set to ride-over the downstream feeder's normal short time delay.
    b. The instantaneous protection will move to ride-over the downstream feeder's instantaneous protection. This is automatic and does not require a setting.

c. These settings will come into effect automatically when the feeder circuit breaker sends a restraint signal because the fault is downstream of the feeder circuit breaker.

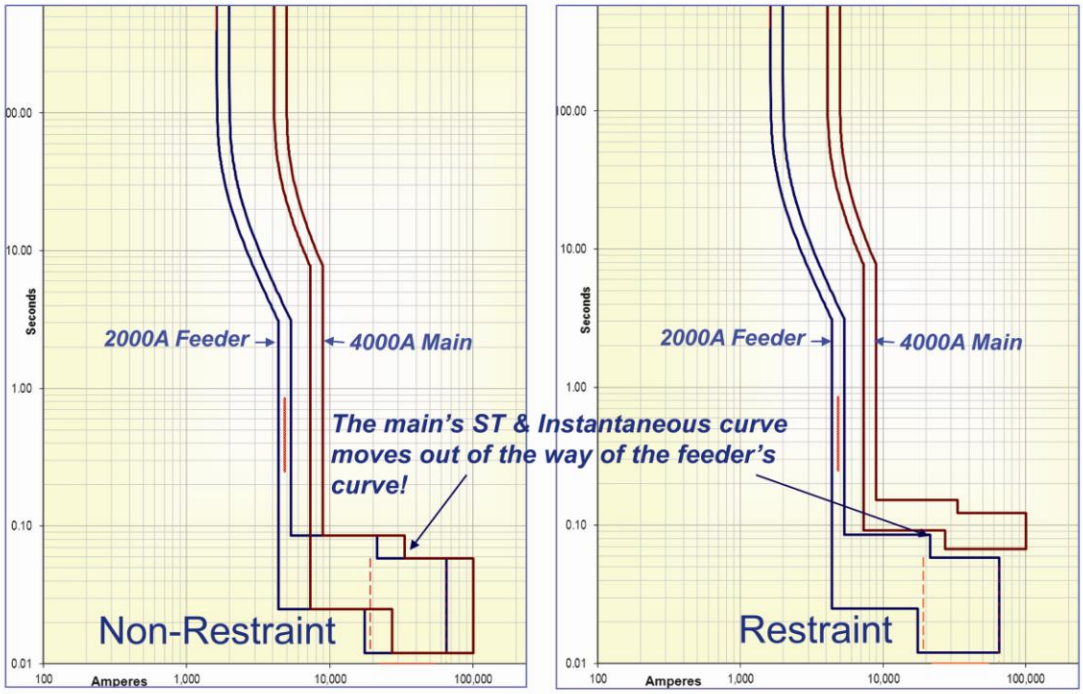

Figure 2: No fault (Non-Restraint) and fault (Restraint) conditions shown on TCC.

4. Enable the instantaneous protection (I) on the feeder trip unit.
   a. Selectivity is ensured between the feeder circuit breaker and the downstream current limiting MCCB/MCP in the LV MCCs and panelboards because of waveform recognition technology explained later.
   b. No additional settings are required on the trip unit of the feeder circuit breaker. Any time the trip unit on the feeder circuit breaker picks up on short time, ground fault and/or instantaneous, it will send a restraint signal to the trip unit of the main circuit breaker.

For a fault downstream of the feeder circuit breaker, the trip unit of this feeder circuit breaker will send a restraint signal to the trip unit of the main circuit breaker and will then trip to clear the fault within the programmed time. As the feeder circuit breaker had its instantaneous protection enabled, it will clear the fault within 50ms and reduce the arc flash energy at the downstream equipment. If the fault was further downstream, then the fault would be cleared by the downstream device nearest to the fault and because of waveform recognition, the trip unit on the feeder circuit breaker would not trip. The short time delay band on the trip unit on the main will move up to a pre-programmed time delay value. The instantaneous band will also move up to a pre-determined time delay value, thus moving out of the tripping region of the trip unit on the feeder closest to the fault (Figure 2 – Restraint). The main circuit breaker stays closed and the system's selectivity is maintained.

For a fault within the equipment, between the main and feeder circuit breakers, there would be no restraint signal from any of the trip units on the feeder circuit breakers. The short time, the

ground fault and instantaneous protection of the trip unit on the main circuit breakers would stay where they were programmed, at the minimum possible values and clear the fault. The main circuit breakers would clear the fault within 50ms. The reduction is arc flash energy is substantial.

This innovative technology of I-ZSI will give you complete selectivity and because the instantaneous protection is enabled all the time, the reduction in arc flash energy is maximized [4].

I-ZSI feature is available between all circuit breaker fitted with the EntelliGuard TU trip unit, such as between;

1. EntelliGuard G and WavePro circuit breakers as either, main and feeder circuit breakers.
2. EntelliGuard G and WavePro circuit breakers as main circuit breakers and PB2 and microEntelliGuard Spectra G & K MCCBs as feeder circuit breakers.

The PB2 and Spectra G & K MCCBs will generate a zone selective signal ($I\text{-}ZSI_{OUT}$) in response to a fault in the short time, ground and instantaneous region but will react only in the short time and ground fault region on receiving a zone selective signal ($I\text{-}ZSI_{IN}$) from a downstream device. They do not respond to the signal in the instantaneous region of the fault (Figure 3).

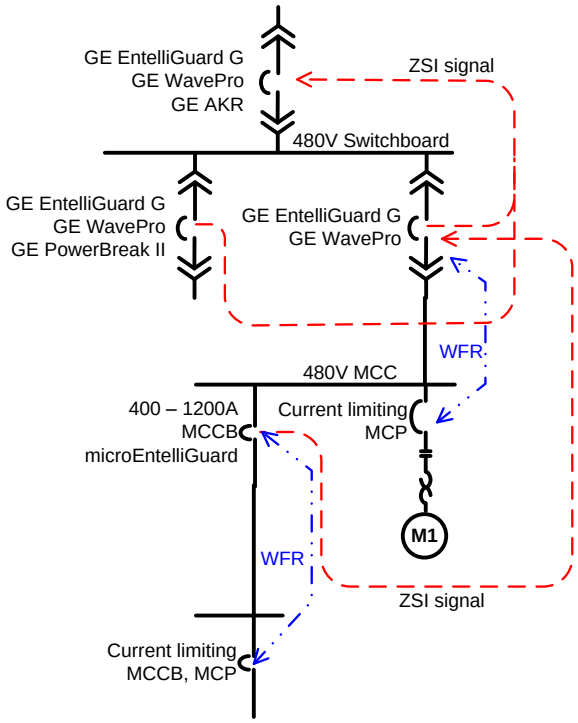

Figure 3: Typical distribution system showing I-ZSI & Waveform Recognition application

Waveform Recognition (WFR)

As indicated above, zone selective interlocking requires the connection of trip units by twisted pair copper conductors. This is easily achieved on trip units on larger circuit breakers (≥ 400A) and when the main and feeder circuit breakers are within the same enclosure or within a reasonable distance of 300 meters (1000ft) apart. Smaller circuit breaker (<400A) normally have thermal magnetic or solid state trip units to make them economical. They do not have the ability to generate a zone selective interlocking signal. However, they are most often current limiting by design and this feature has been very innovatively used by GE to enhance protection of equipment connected downstream of the EntelliGuard TU trip unit [5]. The feature is called 'Waveform Recognition' (WFR) and works between the trip unit of the circuit breaker feeding the LV MCC, panelboard or other equipment that contain current limiting MCCBs or MCPs. This feature has no relationship to waveform capture – a recording of a few cycles of the waveform - that is available in many trip units and relays.

Most trip units operate as 'Peak-Sensing' trip units. The instantaneous pick-up is set and when the current flowing through the trip unit crosses that threshold, the trip unit will pick-up and commit to trip. This is the commit time and is the bottom of the instantaneous band on the TCC and is shown touching the x-axis (current). Add to this the signal processing time, operation of

the flux shifter, opening of the main contacts and the extinguishing of the arc to give a total clearing time – the top of the instantaneous band on the TCC. This time for most low voltage power circuit breaker is around 50ms.

EntelliGuard TU trip units operate as 'Peak-To-Peak Sensing' trip unit. The instantaneous pick-up is set and when the current flowing through the trip unit crosses that threshold, the peak is measured and stored. It then waits for 8ms and measures the peak again. It adds the two measured peak values and if the resultant value is double the threshold, it will pick-up and commit to trip. In effect the trip unit is measuring the peak-to peak value of the first cycle of the fault current. This is the commit time and is the bottom of the instantaneous band on the TCC. For the EntelliGuard TU trip unit, this does not touch the x-axis (current) but is horizontal at 13ms. Add to this the signal processing time, operation of the flux shifter, opening of the main contacts and the extinguishing of the arc to give a total clearing time – the top of the instantaneous band on the TCC. This time for EntelliGuard G circuit breaker is also 50ms. Although the trip unit commits later than other trip units, it clears the fault in the same time as other circuit breakers. In the WavePro circuit breaker this time is 58ms.

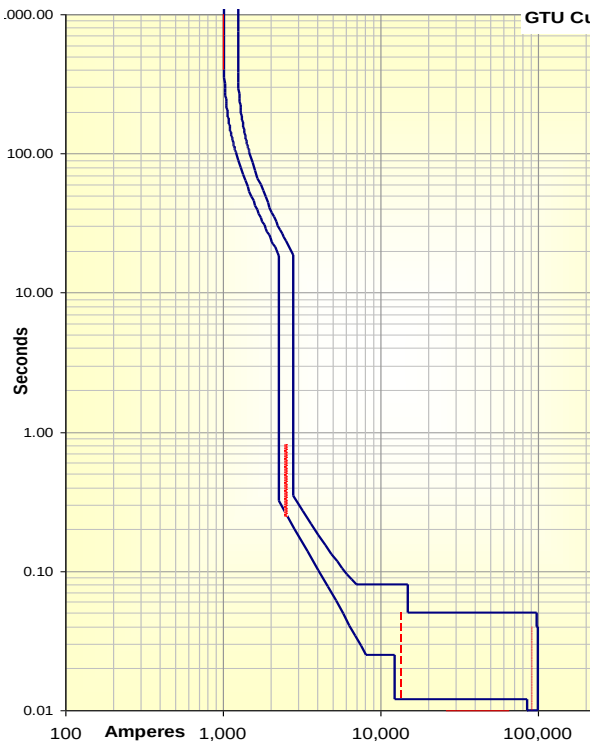

Figure 4: TCC of 'Peak-To-Peak' sensing trip unit

What is the purpose for this elaborate signal processing? Most circuit breakers rated less than 400A in LV MCCs or panelboards are by design current limiting devices. Like current limiting fuses, these devices will cut-off the prospective fault current to a much lower value called the peak-let thru' current. It will either clear the fault within the first half cycle and therefore not exhibit a second peak, or if it does let through a second half cycle current, the peak of that second half will be much smaller than the first peak. In either case, the sum of the two peaks will be much less than double the threshold and therefore the trip unit will not commit to trip. The fault was cleared by the downstream current limiting device and the rest of the circuit continues to be energized. This is the meaning of complete selectivity.

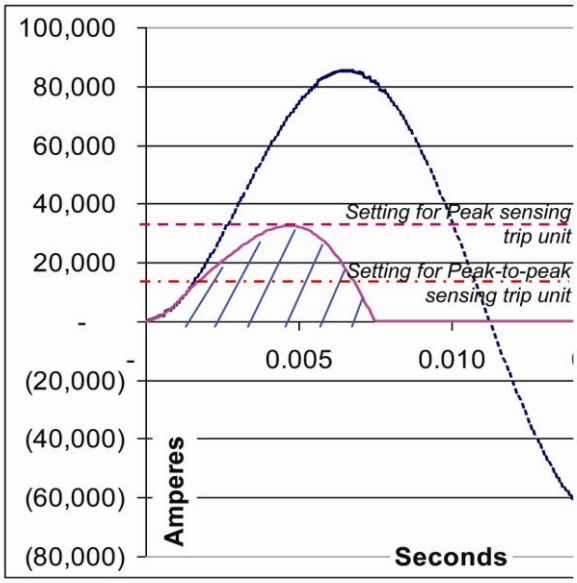

Figure 5: Setting thresholds comparison for 'Peak-to-Peak' and 'Peak' sensing trip units

Trip units that do 'peak sensing' can be set to have their threshold just above the peak let-

thru' current, knowing that the threshold will not be crossed under high fault currents. Trip units that do 'peak-to-peak sensing' can be set to have their threshold below the peak let-thru' current, knowing that the second peak might not occur or if it does occur, the magnitude would be much lower than the first peak and the trip unit will not commit to trip. The biggest advantage to being able to set the instantaneous pick-up of the trip unit to such a low value is low arc flash energy and complete selectivity. Arcing currents in low voltage circuits are normally about 50% or less than the bolted fault current. If the instantaneous pick-up of the trip unit can be set below 85% of the arcing current (<42% of bolted fault current), then all arcing faults on the incoming lines of MCCs, panelboards and other equipment can be protected by the trip unit, thus lowering the arc flash energy of these equipment without compromising on selectivity.

Case Study

The following case study will quantify the benefits of zone selective interlocking with instantaneous protection enabled and the waveform recognition features of the EntelliGuard TU trip unit. Figure 6 is a simplified one line diagram of the system that was analyzed.

- Circuit breakers CB-M, CB-F1 and CB-F2 are in a LV switchgear and are connected to provide zone selective interlocking on short time and instantaneous protection.

Twisted pair of copper wires connected the feeder circuit breaker trip units to the main circuit breaker trip unit. There is a maximum length limitation of 300m (1000ft) for this connection.

- Circuit breaker MCB is in a panelboard fed from CB-F1 and because it is of a current limiting design, waveform recognition is used to obtain selectivity between it and the feeder circuit breaker in the switchgear.
- Circuit breaker CB-F2 feeds a low voltage MCC which contains current limiting motor circuit protectors - MCP. Because MCP is also current limiting in design, CB-F2 uses the waveform recognition feature to be selective with MCP.

There is no other connection between the switchgear and the panelboard and MCC except the power cables that connect the feeder circuit breakers to their respective downstream equipment. There is also no distance limitation between the panelboard and MCC, and the switchgear for the waveform recognition feature to work.

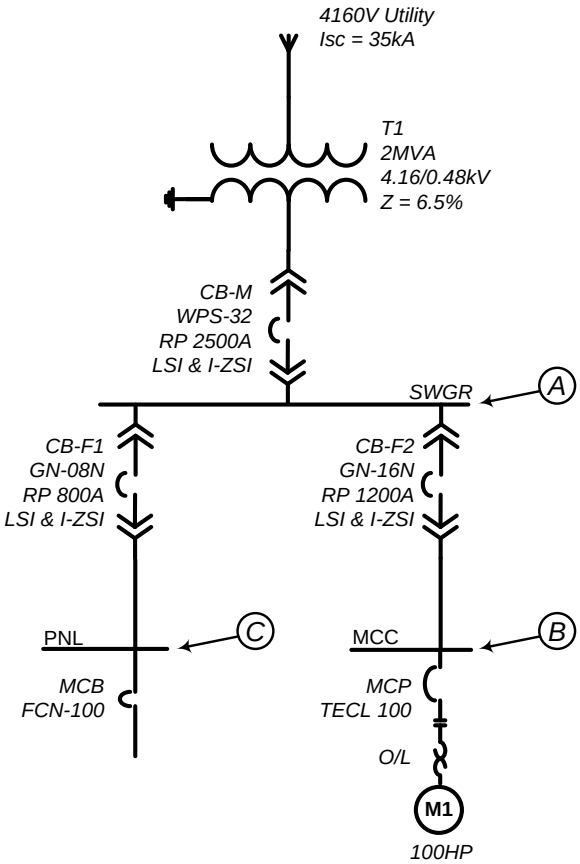

Figure 6: Simplified One Line Diagram of the case study.

The following are the results of the arc flash hazard analysis;

ARC FLASH ENERGY RESULTS OF THE CASE STUDY

Case Study Senarios	Location A	Location B	Location C
EntelliGuard TU with I-ZSI & WFR	2.1 cal/cm^2	2.9 cal/cm^2	2.8 cal/cm^2
MVT+ with traditional staggered protection	11.0 cal/cm^2	11.1 cal/cm^2	11.0 cal/cm^2

NOTE:

1. Refer to Figure 6 for locations A, B & C.
2. The senario with I-ZSI & WFR uses the EntelliGuard TU trip unit.
3. The senario with traditional staggered protection uses the MicroVersaTrip Plus/PM trip unit.
4. Working distance for Switchgear is 24" and for panelbaord and MCC is 18" according to IEEE1584.
5. The analysis was performed using SKM software.

Conclusion

The EntelliGuard TU trip unit has two innovative technologies – Zone selective interlocking on Instantaneous and Waveform recognition. Zone selective interlocking on Instantaneous requires that the trip units be connected by twisted pair copper cables and enables the arc flash energy level to be reduced to a very low value in the switchgear and switchboard. Waveform recognition will reduce the arc flash energy level in MCC and panelboards connected downstream of the trip unit and does not need any connection between the trip units. These downstream equipment can be placed at any distance from the trip unit and still realize the full benefits of waveform recognition. In addition to low arc flash energy levels, both technologies will provide complete selectivity. With this trip unit, safety does not have to be an option.

Reference

1. NFPA70E – Standard for Electrical Safety in the Workplace (2012 edition).
2. CSA Z462 – Workplace Electrical Safety (2012 edition).
3. NEC – National Electric Code (2011 edition).
4. Maurice D'Mello, Michael Noonan, Harbans Aulakh, Jorge Mirabent, "Arc Flash Energy Reduction – Case Studies", IEEE No. 2012-PCIC-116.
5. Marcelo Valdes, Tim Hansen, Dr. Peter Sutherland, "Optimizing Circuit Breaker Instantaneous Trip Settings for Selectivity and Arc Flash Performance". Simultaneously", IEEE ESW.