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Advanced Fuse-Saving Techniques

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SUMMARY

Ameren Illinois was one of the early adopters of IntelliRupter® PulseCloser™ Fault Interrupters, which feature technology that significantly reduces wear and tear on distribution systems. Ameren installed its first fault interrupter in 2008, and it has since installed several hundred across its territories in Illinois and Missouri. With hundreds of fault interrupters in service, Ameren took the opportunity to review fault events over a one-year period to evaluate its protection and coordination philosophies, with a particular focus on fuse-saving coordination. Intelligent Fuse Savings is a philosophy that achieves an intelligent mix of fuse-blowing and fuse-saving practices, minimizes miscoordination with down-line devices, and eliminates unnecessary tripping. Through descriptions and analyses of fault events, this paper explains the operations of Intelligent Fuse Savings and offers a look at a practical, simple, and adoptable fault interrupter coordination-settings strategy. Descriptions and explanations are supported by voltage and current waveform captures, SCADA information, and outage data.

KEYWORDS

Ameren Illinois, S&C Electric, IntelliRupter PulseCloser Fault Interrupter, Intelligent Fuse-Saving

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I. Ameren's Service Area and Smart Grid Strategy

Ameren Illinois serves approximately 1.2 million electricity customers and 800,000 natural gas customers across 43,000 square miles. Ameren Illinois is focused on building a next generation energy-delivery system for Central and Southern Illinois, embarking on an ambitious five-year, $3.5 billion plan to improve the efficiency and reliability of its natural gas and electric energy delivery system.

Focused on improving reliability and reducing outages, Ameren Illinois developed a strategy based on the installation of SCADA-capable, three-phase backbone, and substation-protective devices on distribution circuits.

Ameren Illinois standardized on the S&C Electric Company's IntelliRupter PulseCloser Fault Interrupter as the fault-interrupting device for the 12-kV system. These fault interrupters are devices that feature technology that reduces the wear and tear on distribution systems. Ameren uses many of the fault interrupter's advanced features, including Intelligent Fuse Savings, the IntelliTeam® SG Automatic Restoration System, single-phase tripping, and simultaneous bi-directional overcurrent protection.

II. Ameren's Protection and Coordination Settings Philosophies

Ameren Illinois' philosophy is to fundamentally use the fault interrupter as a feeder mid-point protection device for fault isolation, coupled with a fault interrupter at a tie point to allow for quick and automatic system restoration. Figure 1 below shows a feeder mid-tie-mid application. Ameren Illinois uses this application on the majority of its automated distribution circuits today.

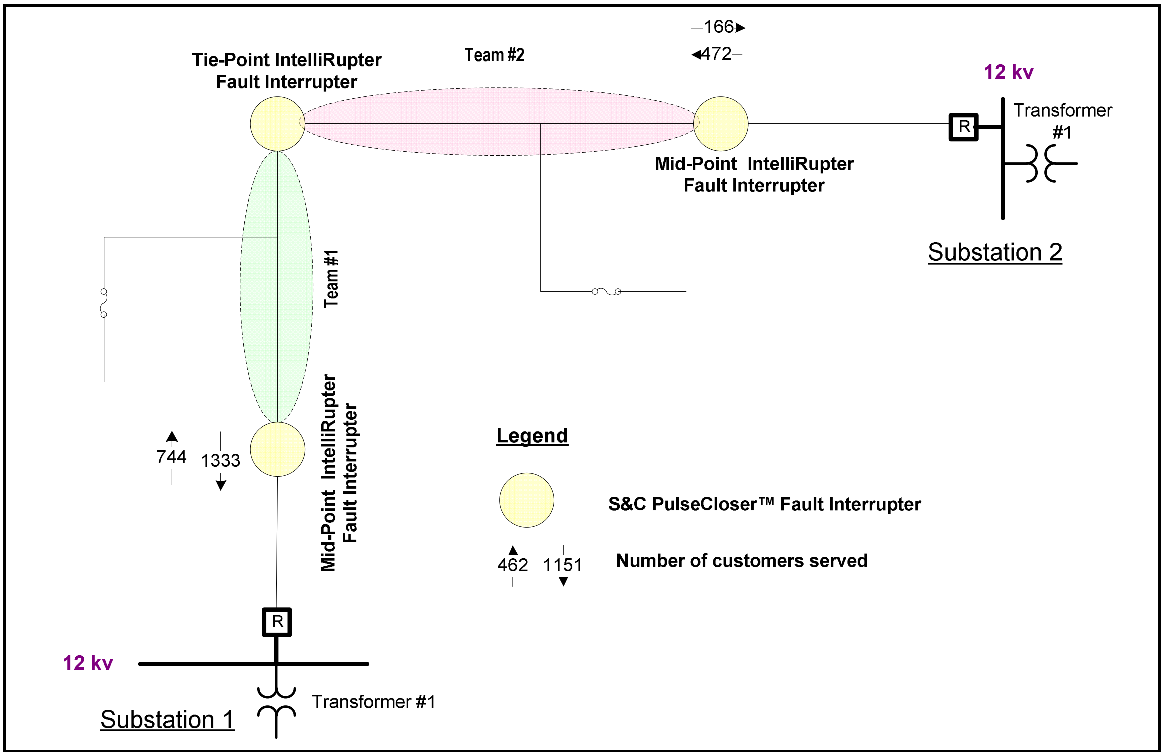


Figure 1. Feeder mid-tie-mid application scheme.

The Ameren Illinois Distribution Automation (DA) engineering group has standardized its protection and coordination settings philosophy for the mid-tie-mid application. The group elected to configure the fault interrupters with single-phase trip and three-phase lockout. The standard applications emulate 280V4L, 200V4L and 140V4L reclosers, which were used previously. DA engineering uses the settings noted in Table 1 to coordinate the distribution system fault interrupters with the substation devices.

Table 1. Ameren Illinois' standard recloser emulations for IntelliRupter PulseCloser Fault Interrupters.

Recloser Emulation	280V4L	200V4L	140V4L
TCC Curve	SEL U2	SEL U4	SEL U4
Pickup	560 Amps	400 Amps	280 Amps
Time Multiplier	0.65 Sec	1.5 Sec	1.5 Sec

When designing the mid-tie-mid application, DA engineering runs load flow models and collects fault-duty values at all proposed fault-interrupter locations. Example data are shown in Table 2.

Table 2. Example of information collected to use for protection and coordination.

Device Location:	Substation Terminal	Upstream Backbone Device	Mid-Point Device	Downstream Backbone Device	Downstream Branch Device
Device Type	Recloser Viper	Cooper 200V4L	IntelliRupter Fault Interrupter	None	65A Type T
Fault Duty	6575 Amps	5936 Amps	5253 Amps	None	1987 Amps

The first calculation the group uses in coordination is the Coordination Timing Interval (CTI) calculation. The CTI looks at the timing difference between the protective devices installed and the proposed mid-point fault interrupters at their fault duties on the Time Current Characteristic (TCC) curves. For any given location, the largest emulation is selected.

Once the emulation is selected, Ameren engineering looks at any devices installed upstream (between the mid-point location and the substation terminal) and downstream (between the mid-point location and the tie point) of the mid-point fault interrupter. For upstream devices, removal of any backbone devices installed smaller than 280V4L is recommended. For downstream devices, removal of any backbone devices installed larger than 140V4L is recommended. In the majority of these installations, the mid-point fault interrupter replaces an existing protective device.

The example coordination plot in Figure 2 is based on the devices in Table 2. Once the mid-point fault interrupter is selected, the standard is to configure the tie point fault interrupter with the same protection settings. To maintain the coordination of series devices that have the same protection settings, an advanced feature called the PulseFinding™ Fault Location Technique is enabled. This feature uses PulseClosing™ Technology to quickly and automatically recover from intentional miscoordination. The end result is the proper sectionalization of faults, even though they have the same protection settings. This is useful in the normal feeder configuration, but it is even more effective when the tie point has closed and is providing service from the opposite direction.

The test sequence for mid-point fault interrupters is configured with single-phase initial trip, single-phase pulse close, single-phase close, and finally another single-phase pulse close. The PulseClosing Technology tests the line to determine whether the fault is still present using only 5-ms pulses of current. The regular close is used to allow fuses to operate when necessary. The tie-point fault interrupter's trips are only configured for pulse closes.

We also elected to use Intelligent Fuse Savings on the fault interrupters. The fuse-saving TCC curve is placed just below the fuse's minimum melting curve and is truncated at the maximum coordination current. Configuration is simplified because only enabling the fuse-saving element and selecting the down-line fuse size and type required.

Intelligent Fuse Savings automatically determines whether a fuse-saving "fast" trip should be used based on the fault-current magnitude. At high fault currents, a mechanical device cannot trip faster than a fuse will operate, so Intelligent Fuse Savings will avoid using the fast trip, thereby reducing momentary outages. Ameren engineering recommends enabling Intelligent Fuse Savings using a fuse-savings curve that matches the largest fuse size desirable to save downstream of the mid-point fault interrupter. Choosing the largest fuse to save should be based on the fuse size used most downstream of the fault interrupter and that serves the largest number of customers.

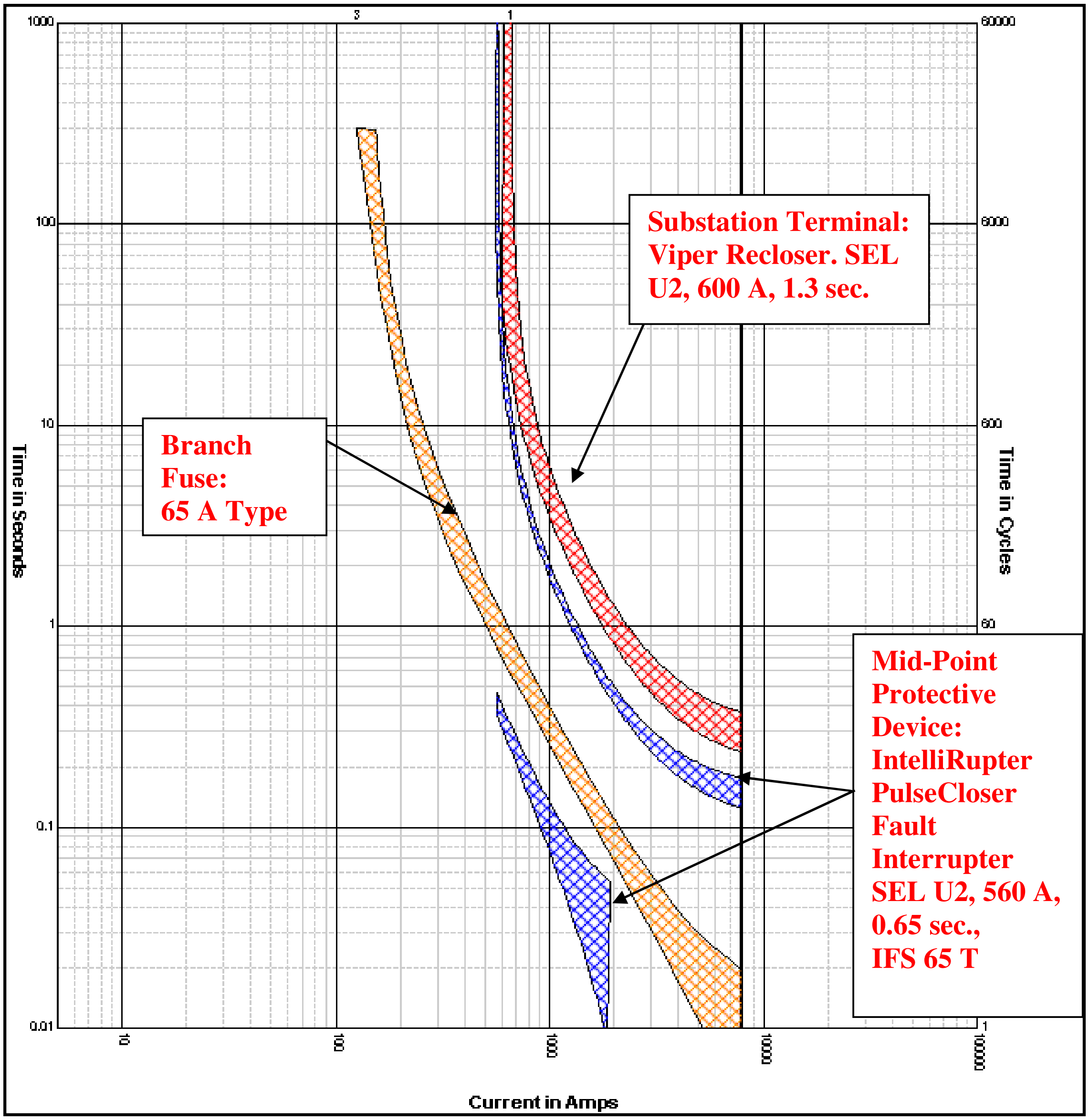
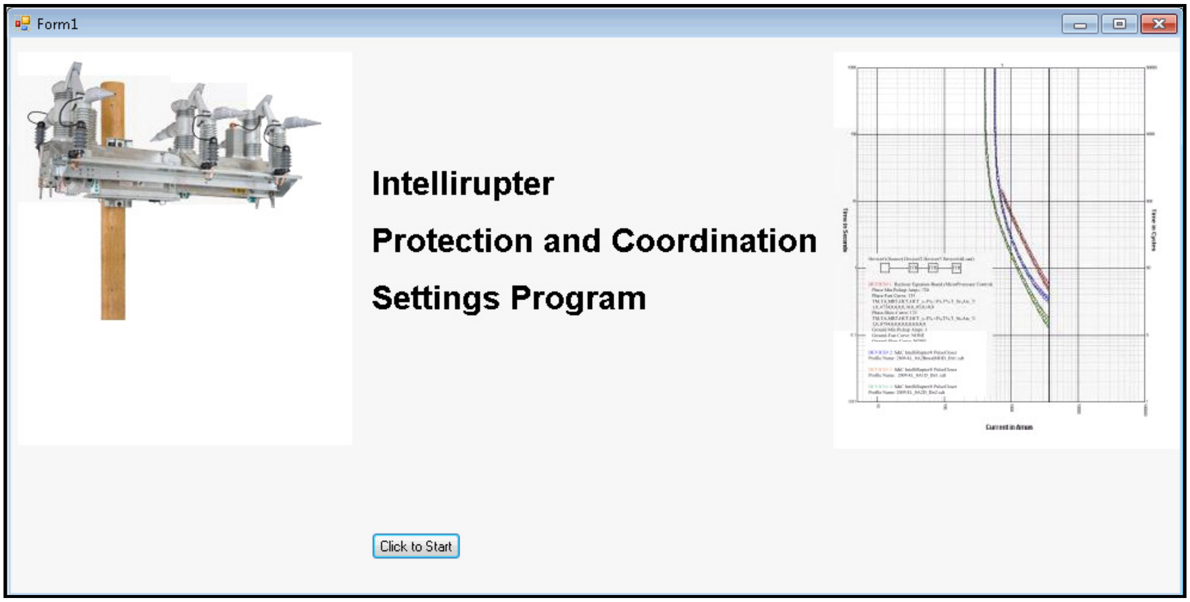


Figure 2. Example of a coordination plot for mid-tie-mid application scheme.

III. Ameren Illinois' IntelliRupter Fault Interrupter Protection and Coordination Settings Program.

To drive consistency, DA engineering built a program that takes in data similar to the information in Table 2, and the group automatically runs through the rules of calculating CTI. It then selects the standard recloser emulation, the optimal PulseFinding setting, and the Intelligent Fuse Savings curve. The program runs the above tasks for coordination in both directions, draws a circuit diagram with the settings printed on it, and plots the TCC coordination curves. Figures 3 through 6 show screen shots of the program that the DA engineering group built and uses for everyday coordination work.



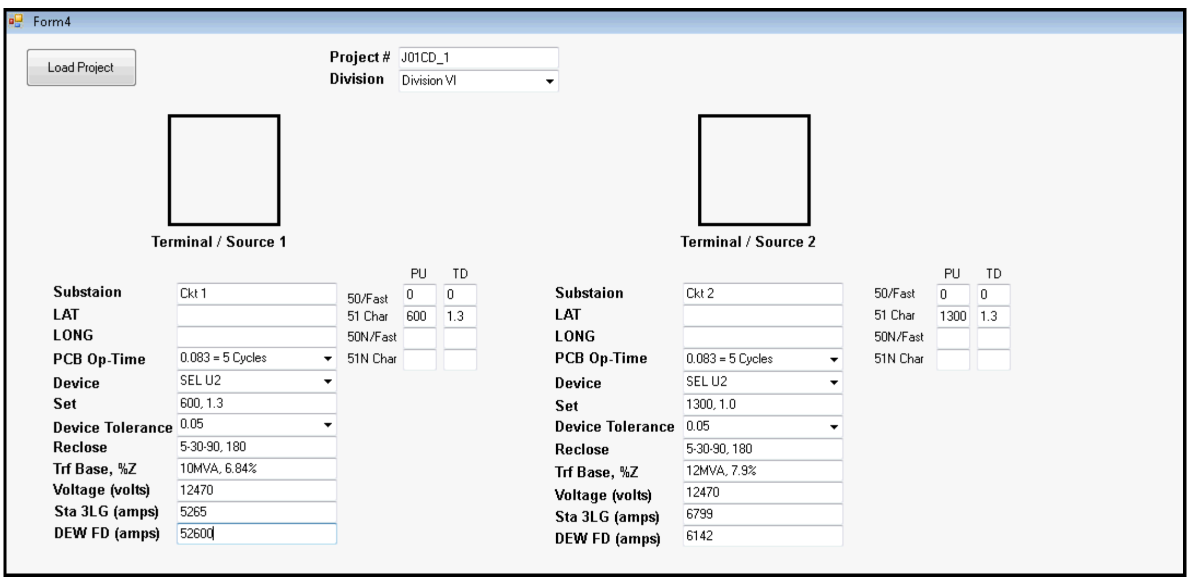


Figure 3. Ameren Illinois' IntelliRupter Fault Interrupter Protection and Coordination Settings Program.

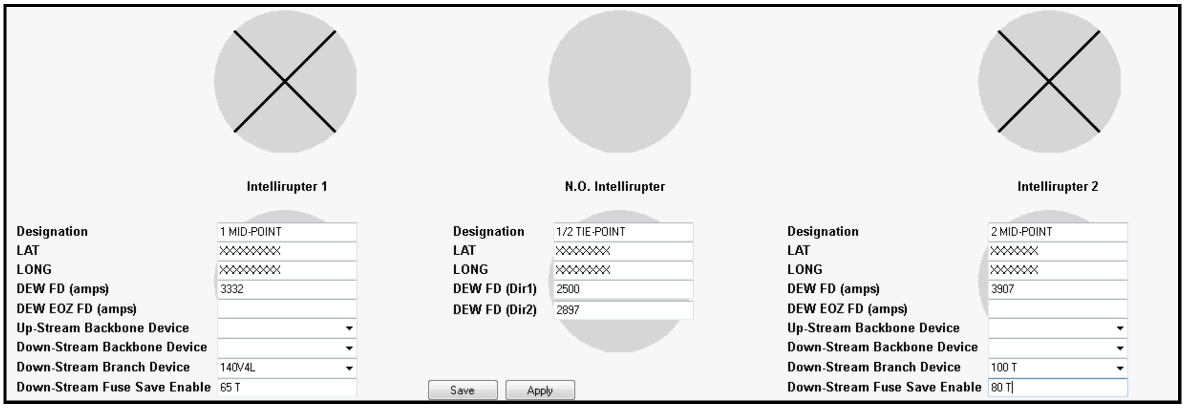


Figure 4. Program screen used to enter information for mid-tie-mid applications.

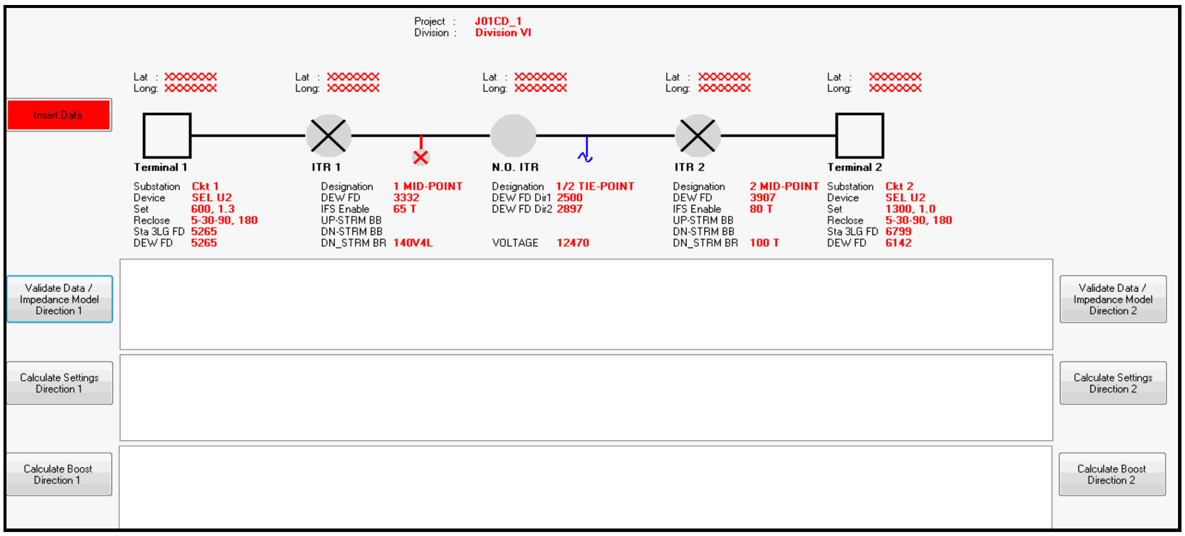


Figure 5. Program screen used to generate IntelliRupter Fault Interrupter settings.

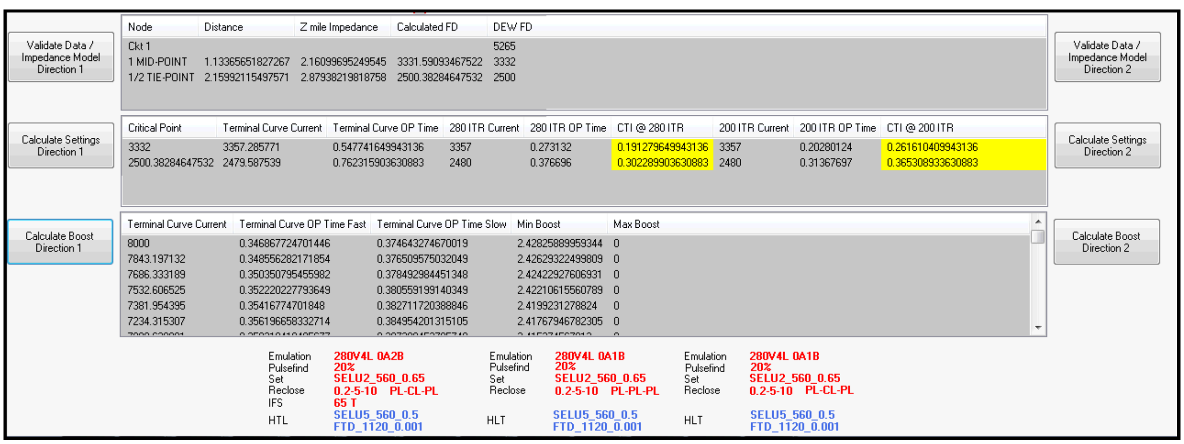


Figure 6. Program screen that displays coordination calculations and final IntelliRupter Fault Interrupter settings.

IV. Field Results of Intelligent Fuse Saving

All of the waveform captures in this section were retrieved from fault interrupters applied on the Ameren Illinois system. They demonstrate the different behavior of the IntelliRupter Fault Interrupter protection responses for transient and sustained faults of various magnitudes.

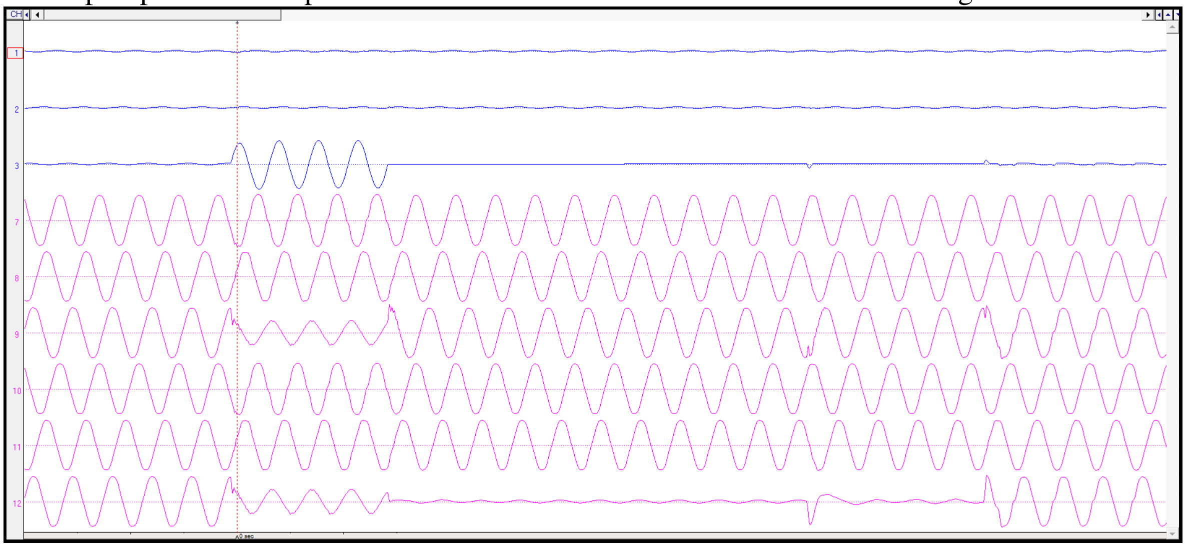


Figure 7. Example of a fuse saved on a transient fault–B163 6/14/2014.

The waveform in Figure 7 shows three current signals on top, followed by six voltage signals representing both the source and load side of the IntelliRupter Fault Interrupter. Based on the TCC plots, effective fuse-saving ranges from 560 A through 1900 A. Faults greater than 1900 A exceed the maximum coordinating current of the fuse-saving curve, so timing only occurs on the delayed curve.

Steps involved in this fault sequence include:

- A lateral experiences a low-magnitude phase-ground transient fault on pole 3 (~1900 A RMS).
- A fast Intelligent Fuse Savings trip clears the fault after several cycles (66 ms) before the down-line fuse begins to melt.
- The IntelliRupter Fault Interrupter checks whether the fault is still present using PulseClosing Technology, which is a very fast close-open of the switchgear contacts that results in a minor loop of asymmetrical fault current lasting approximately 5 ms. The pulses are observable in the trace for pole 3 current toward the end of the event.
- Since the fault has disappeared, service is restored after first pulse close (~200 ms).
- Single-phase tripping reduces momentary outages by approximately two-thirds because the customers served by poles 1 and 2 remained in service throughout this event.

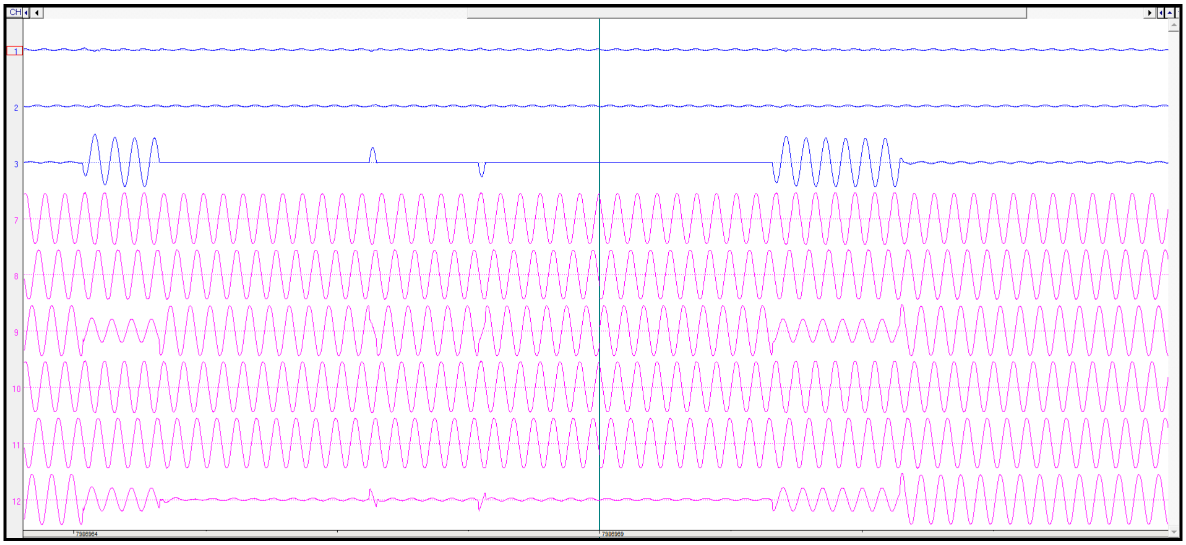


Figure 8. Example of a fuse operation for a sustained fault on lateral–B163 9/14/2014.

For the next example, as shown in Figure 8, the event starts off similar to the previous event. However, the pulse closes seen in trace 3 are larger and indicate that the fault is still present.

Steps involved in this fault sequence include:

- A lateral experiences a low-magnitude phase-ground fault (~2000 A RMS).
- After the initial trip, pulse closes in both polarities indicate that the fault is still present, so the fault interrupter remains open for several more seconds.
- A close operation on the second test allows the fuse to operate on the sustained fault down line of the fuse. It is evident that the fuse cleared the fault because the current in trace 3 goes from fault current immediately to load current.

One of the main purposes of PulseClosing Technology is to limit the damage caused by fault currents experienced by distribution and substation equipment. It significantly reduces stress on system components and improves power quality experienced by customers upstream of the fault. When "hard close" operations are configured to let fuses operate for downstream faults, the IntelliRupter Fault Interrupter still aims to minimize peak fault currents by closing at a point-on-wave that creates symmetrical fault current.

One of the key benefits to using Intelligent Fuse Saving is avoiding momentary outages on the main line for higher magnitude lateral faults that cannot be cleared by a mechanical device before the fuse operates.

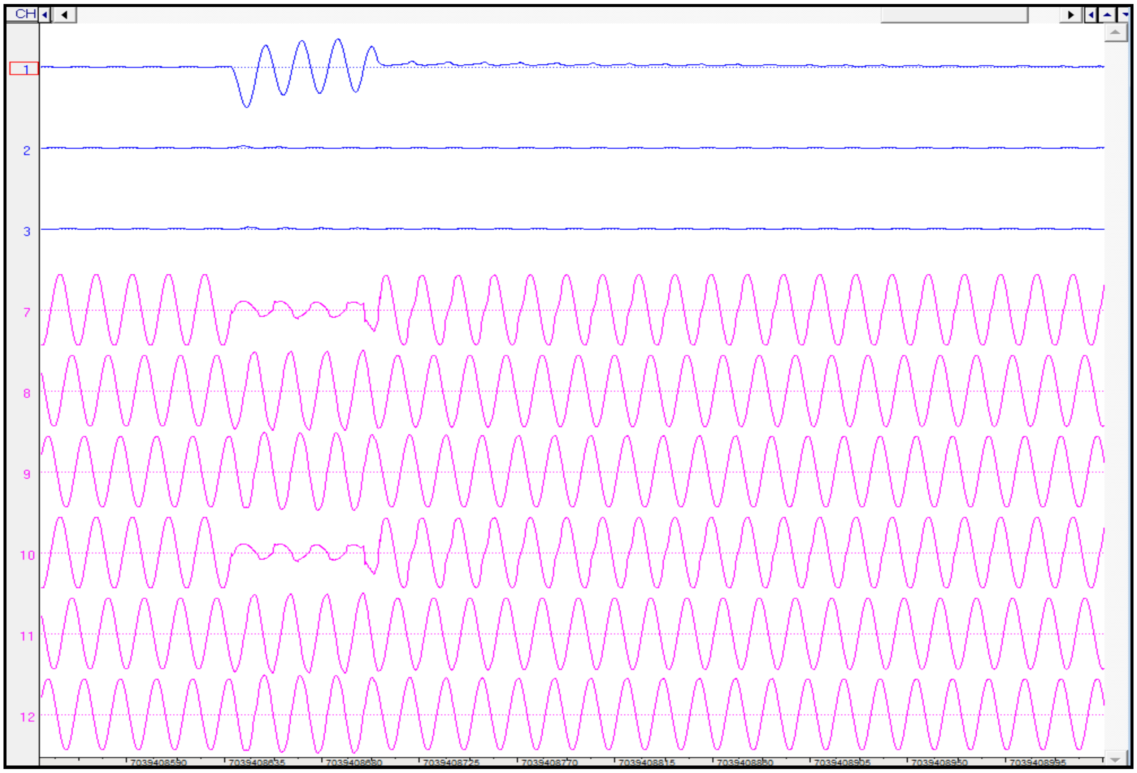


Figure 9. Example of a fuse blown on a transient fault–B176–10/2/2014.

For the example in Figure 9, the following steps occur:

- A lateral experiences a high magnitude phase-ground sustained fault on pole 1 (~3493 A RMS).
- Because of the high magnitude, the fuse cannot be saved. The Intelligent Fuse Savings feature skips the fast curve tripping, and timing occurs using a delayed curve that allows the fuse to operate before the fault interrupter trips.
- The fuse interrupts the fault in roughly 73 ms.
- Load current on pole 1 is immediately restored (except to customers downstream of the fuse). All customers downstream of this fault interrupter have been spared from a momentary outage.

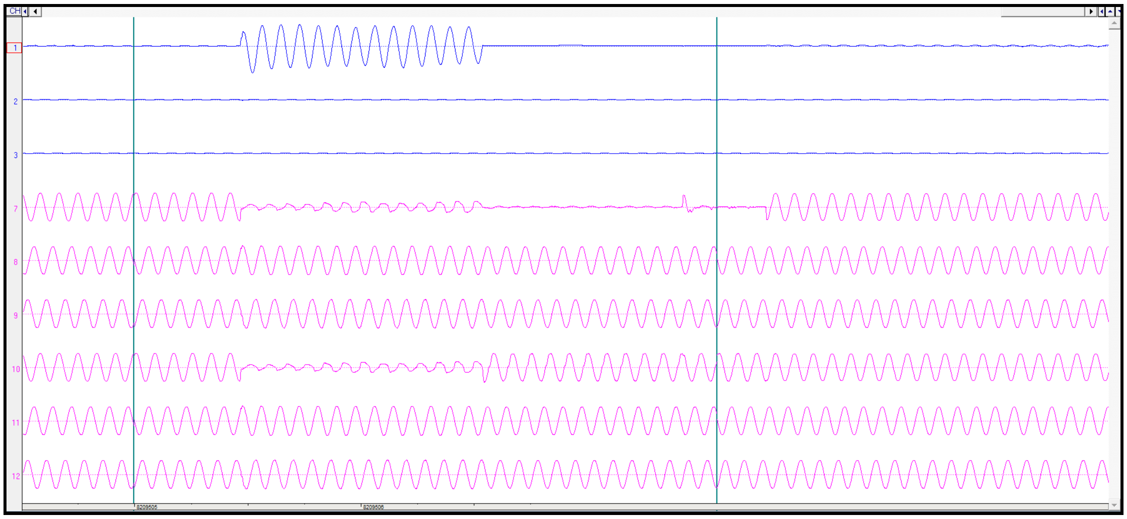


Figure 10. Example of a transient fault on the main line–MV155 8/23/2014.

For the final example in Figure 10, a fault occurs on the main line, with the following steps:

- The main line experiences a phase-ground transient fault of 3600 A on pole 1, which exceeds the fuse-saving cutoff.
- Because of the high magnitude, fast tripping is skipped and timing occurs using a delayed curve that allows the fuse to operate before the fault interrupter trips. Because the fault is on the main line, the lateral does not see the fault, and there is no fuse operation. The fault interrupter trips after 217 ms.

V. Conclusions

Ameren Illinois has standardized on the S&C IntelliRupter PulseCloser Fault Interrupter for 12-kV distribution feeder-protection applications. The objective is to simplify the coordination and configuration of the distribution-system devices by using advanced features of the fault interrupter.

The calculator tool created by the DA engineering group simplifies coordination for the typical mid-tie-mid application by automating and optimizing the protection settings. The real-life examples of faults on main lines and laterals demonstrate that single-phase tripping and Intelligent Fuse Savings features are improving customer service reliability. Ameren Illinois will continue to monitor the field events and look for opportunities to improve reliability of electricity service while simplifying and standardizing protection and coordination practices.

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