Abstract  In August 2008, Ameren installed its first pulseclosers, devices that feature a technology that significantly reduces the wear-and-tear on distribution systems, and has since installed more than 100 in a variety of schemes. Ameren’s installation and protection philosophy has been to ‘keep it simple.’ Engineering limits the number of protection settings available for use when designing circuit protection, and operations personnel prefer simple and automatic switching schemes to enable quick understanding and response to outages. Pulseclosing technology presents new ways to solve protection and reliability problems that would have previously been considered challenging, and also limits the exposure of transformers and line hardware to faults. Through descriptions of practical pulsecloser applications, this paper outlines the benefits of pulseclosing technology.

This paper explains the application of the following installed schemes:

- Pulseclosers installed as a feeder midpoint protective device, with and without instantaneous trip enabled at the substation feeder breaker
- Automatic fault-finding, which uses three pulseclosers installed in series with identical protection settings
- Pulseclosers installed in a main-tie-main application, utilizing loop automation at the tie switch. This non-communicating application provides reliability improvements without the potential of exposing a second feeder to a fault
- Pulseclosers installed in a multi-source automatic restoration scheme
- Pulseclosers installed in a Smart Grid pilot program in St. Louis, Missouri to demonstrate the pulseclosers combined with automation and high-speed communications infrastructure.

Explanations of these applications are supported by voltage and current waveform captures, Scada information, and line crew assessment of fault events. Ameren has been an early adopter of this new pulseclosing technology and perceives a number of benefits that will translate well to other utilities.

Keywords: Pulseclosing, Pulsecloser, Loops, Reclosers

I. AMEREN’S SERVICE AREA AND SMART GRID STRATEGY

Ameren serves approximately 2.4 million electric customers and 900,000 natural gas customers across 64,000 square miles in Illinois and Missouri. Ameren Missouri serves half of those 2.4 million customers.

Ameren has a robust transmission system aimed at delivering safe, reliable energy to our customers across 64,000 square miles in Illinois and Missouri. We own and operate more than 7,400 circuit miles of high-voltage transmission lines and more than 78,000 miles of distribution lines. Since 2000, we’ve invested more than $468 million in transmission system improvements.

Ameren Missouri and Ameren Illinois developed a joint Smart Grid Distribution Automation strategy. One element of this strategy was the recommendation that any three-phase backbone protective devices be SCADA capable. The SmartGrid DA strategy also recommends installation of DA on
a substation-by-substation basis. The chosen applications will provide empirical data demonstrating the effectiveness of SmartGrid concepts, equipment, and methods that can establish a beachhead for further expansion throughout the service territory.

In 2006 Ameren Missouri was introduced to the concept of pulseclosing vs. reclosing. Operating personnel saw the potential benefits that could be achieved by reducing exposure of line equipment and hardware to additional fault currents when 'reclosing' on a circuit to see if a fault had cleared. In 2008 S&C Electric Company began shipping the IntelliRupter® PulseCloser and Ameren Missouri was among the first customers.

In 2008 when Ameren Missouri began installing pulseclosers, many were installed at midpoint or tie point locations with SCADA indication and control. Although we have many more midpoint sectionalizer points than tie points, we have generally installed IntelliRupters at tie points when one or more midpoint switches are installed on a circuit, to provide restoration options to the tail end of feeders.

Several of our first installations of DA on distribution feeders focused on quick restoration of sensitive loads. For example, many larger hospitals have associated medical buildings, nursing homes, and extended care facilities which don’t require standby generation, but are nonetheless sensitive to extended outages.

II. PULSECLOSER FEATURES

Ameren Missouri has standardized on the IntelliRupter with pulseclosing technology as the fault-interrupting device on the 12 kV system. One reason is that it includes many standard items that simplify installation:

- **Completely integrated construction**... installation is accomplished with a single lift.
- The integrated disconnect switch gives a clear visual indication of an open gap in the circuit. It is mechanically interlocked with the vacuum interrupters to prevent inadvertant operation when the interrupters are closed.
- Two integrated power modules provide power to the unit for open, close, and pulseclose operations, as well as WiFi and Scada communications. It is essentially a self-powered device, as long as AC is available one either side of the switch. A battery provides backup power for several hours in the case of a completely dead line.
- Integrated control and communications modules protect the electronics from vandalism, inclement weather, and electrical surges. WiFi connectivity from work vehicles enhances worker safety and comfort.
- Three built-in Rogowski coil current sensors and six voltage sensors eliminate the clutter and complexity of adding separate high-accuracy sensors in the field.
The integrated design makes for greatly simplified construction work in the field. There is no control cabinet to hang, no control cables to run down the pole, no control power to run or power transformer to hang. Ameren’s units even come with arresters installed, so the only field work required is to hang it on the pole and make the jumper connections. An example installation is shown in Figure 1.

Another factor in selecting the IntelliRupter as the standard equipment is that a single device can be used for many different types of applications. Additional features can be enabled as needed for the application:

- **Single-phase tripping** is useful in reducing momentary outages by approximately two-thirds.
- **Intelligent Fuse Savings** automatically determines if 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.
- Multiple pulse closers can be installed in series with identical protection settings, if proper Time Current Characteristic coordination becomes difficult. By simply checking the PulseFinding option for each pulse closer, the devices will properly sectionalize the faulted section. Communications is not needed for this feature.
- **Loop Restoration** is another non-communicating feature that allows for multiple pulse closers to operate as an automatic restoration system for fault events or loss-of-source events.
- **IntelliTEAM** capability is built into each IntelliRupter and can be enabled for more advanced automatic restoration capability, including use of multiple sources, multiple tie points, and accounting for real-time loading information to avoid overloads.
- **IntelliRupter** allows for simultaneous bi-directional overcurrent protection, and has multiple protection profiles to allow for quickly switching between applications.
- A long list of DNP control and status points are available to increase SCADA capabilities. Important features for Ameren include the ability to report fault currents and voltage sensing on all six terminals.

The following sections describe several of Ameren Missouri’s various pulse closer deployments.

### III. APPLICATION: FEEDER MID-POINT PROTECTIVE DEVICES

The fundamental application of the pulse closer is as a feeder mid-point protective device. Other applications described below build on this basic functionality.

Figure 2 shows a typical sequence when the fault is permanent. The current traces for all three poles are shown. After the initial trip, multiple pulse closing attempts can be made instead of a reclose, and if the fault is still present the pulse closer will not close. (Note that the timeline is not to scale – the vertical lines represent different waveform captures that were captured in succession. Some times of no activity may not be shown.)

![Figure 2 Example of a Permanent Fault on Pole 2 – Waveform Shows Initial Fault Plus Several Pulses to Test the Line](image)

On the other hand, Figure 3 is an example of a temporary fault. Three pole currents and six voltage waveforms are shown. The pulse closer interrupts a 2800A fault on poles 2 and 3. After 5 seconds, an automatic pulse close is initiated to test the line. Pole 2 had the highest current for the initial trip (2870A) so it pulses first. No fault is detected so pole 2 closes. Pole 3 had the second highest fault current (2462A) so it pulses next, sees no fault, and closes. Then pole 1, which only had 168A of load current during the fault event, pulses and closes. The temporary fault is cleared and service is restored.
Several installations of the pulsecloser at Ameren Missouri are midpoint locations on feeder circuits with heavy tree cover, many fused taps, and no downstream ties to other feeders. The pulsecloser with Intelligent Fuse Savings works well here. Figure 4 is an example of a typical deployment.
**Fuse Savings**

Most of our distribution substations that are equipped with SCADA control also have capability to enable and disable feeder instantaneous overcurrent elements. This allows us to enable the instantaneous element during storm conditions. The instantaneous element allows us to save fuses in a storm when temporary faults would blow a fuse and cause an extended outage on a tap. On a normal day, the instantaneous element is disabled, allowing a downstream fuse to blow... with the idea being that on those days the fuse is likely operating for a permanent fault rather than a temporary one.

With this “feeder-level” fuse saving method, we have typically been disabling the pulsecloser Intelligent Fuse Savings feature, especially in normal conditions to avoid exposing more customers to momentary outages. On some heavily tree covered circuits we are leaving Intelligent Fuse Saving enabled to try and avoid extended outages on fused taps.

When the instantaneous overcurrent is enabled at the substation feeder, it doesn’t matter if Intelligent Fuse Saving is enabled or not on the midline pulseclosers, since the instantaneous is set to respond faster than anything else. So, we only enable Intelligent Fuse Saving in select situations.

**Fault Location**

An added benefit not directly derived from pulseclosing, but from having a midpoint DA device, is capturing the fault amperes. We are taking the fault currents and applying them to our distribution system model to narrow down the fault location. This aids in troubleshooting not so much on permanent faults, but more on repeat temporary faults that are difficult to locate. At this point in time it’s essentially a manual effort for an engineer to apply the fault amps to a model and come up with a distance and range of circuit nodes to patrol. With Advanced Distribution Management System (ADMS) applications that Ameren is seeking to purchase, this should end up being an automated process with possible fault locations displayed on a System Operator’s map.

**Fast and Flexible Protection**

Ameren Missouri has been utilizing the Hot Line Tag feature on the PulseCloser. The Hot Line Tag protection profile is set up to trip on instantaneous overcurrent and lock out. The waveform below is from an IntelliRupter that successfully interrupted a fault that occurred while a crew was stringing a new circuit over the top of an existing circuit that had an IntelliRupter installed and in hot line tag mode. Prior to working this job the crew had reservations about counting on this device for one shot to lockout and was requesting fuses be installed for protection. After some discussion and training, the crew accepted use of the IntelliRupter for protection. After this event occurred, the crew working the conducting operation stated that they saw a brief flash when the fault occurred but didn’t realize they had locked out the circuit. They were amazed at how fast the device operated once they understood what happened.

Figure 5 shows the waveform captures from this event. The line-to-line fault that peaked at 927A was cleared in just over two cycles. Twelve minutes later a close command was given – the IntelliRupter pulseclosed, determined the line was no longer faulted, and closed to restore service.
IV. APPLICATION: FEEDER MID-POINT AND TIE-POINT PROTECTIVE DEVICES

Figure 6 shows one of our installations in a mixed use area near a hospital. The midpoint devices are installed on the feeder in locations that allow sensitive loads and heavily commercial loads to be restored quickly. The six pulse closers used in this project are set up for remote control over SCADA. The pulse closers operate independently to interrupt and isolate faults, and then the operators send DNP commands to open and close devices to pick up loads in unfaulted sections. Several events have already occurred since these units were installed in late 2008.

- **Medical Buildings**
- **Skilled Care**
- **Fire Station**

![Figure 6 Midpoint and Tie Point Applications](image)

V. APPLICATION: SINGLE-PHASE TRIP

Our outstate areas are mostly rural and have only single-phase loads. In these applications, the pulse closers can be configured in either single-phase trip going to three-phase lockout, or more commonly, single-phase trip going to single-phase lockout. Presently, all units are configured for three-phase trip and three-phase lockout. Units in locations that serve heavy commercial loads will remain in this configuration. The settings will be changed on some of the units in metro areas to enable single-phase trip and three-phase lockout. Since the outstate areas are tolerant of prolonged single-phase conditions, the settings on those pulse closers will be updated to enable single-phase trip and single-phase lockout.

VI. APPLICATION: FAULT FINDING

Most DA-capable electronic reclosers are fully configurable. Ameren Missouri decided early on in its DA program to limit available configurations to only a select few. This was based on a number of factors including limited resources available to analyze each feeder and protective device location. This same rationale was applied to non-DA protective devices; limit the available selection to keep deployment and troubleshooting easy.

Achieving coordination for multiple protective devices in series on a feeder backbone can be difficult enough with the full complement of settings flexibility available for use, but it is even more difficult when using a limited number of pre-configured options. Pulsefinding allows a good compromise. With pulsefinding, multiple pulse closers in series can have the same protection settings. If two pulse closers are installed in series with the same settings and a permanent fault occurs downstream of the second pulse closer, both will trip initially. The upstream pulse closer then pulse closes and holds up to the second pulse closer. The second pulse closer pulses, and if it sees the fault is still present it will lock out. Since pulse closing only let's 2% or less of the fault energy through, the upstream pulse closers or breaker do not "see" the fault, so they stay closed. More customers
experience a momentary outage than when the series device are fully coordinated, but quite often that coordination cannot be achieved where the sectionalizing is desired.

Also, no communications are required for pulsefinding. The devices simply react to system voltages and currents, and the whole operation for a string of devices takes only a few seconds. The waveform captures in Figures 7 and 8 were obtained from the two pulse closers in series with identical protection settings.

When the fault initially occurs downstream of both units, both devices trip since IR1 and IR2 have the same protection settings. Then IR1 pulses and does not see the fault since downstream pulse closer IR2 is also open. IR1 closes to pick up load between pulse closers, then IR2 begins its test sequence. The pulses in both waveforms are due to the IR2 test sequence. Note that load before the fault is 66.7, 65.8, and 62.6 A for the three phases. After IR1 is closed it restores service up to IR2, and load current is 22.3, 24.0, and 22.4 A. Service is restored to these customers, automatically, and within seconds. When IR1 closes to return source-side voltage to IR2, then IR2 begins its test sequence. Since the line is faulted, IR2 locks out, isolating the fault.
Non-communicating loop automation involves the use of a recloser or pulsecloser at a normal-open point. Reclosers are equipped with PTs to sense loss of voltage. The IntelliRupter has six integral voltage sensors.

The idea of loop automation is that the protective device installed at the normal-open point senses loss of voltage and then starts a timer. After a predetermined time delay that allows for all other normally-closed protective devices to complete their functions, the tie device closes in one time to see if a fault is present or not. If not, the device has now picked up load.

Ameren Missouri decided not to implement loop automation in the past because we didn’t want to expose a previously unfaulted feeder to a fault, and expose those previously unaffected customers to a voltage sag.

With pulseclosing, loop automation is now an option. With no communications between devices or to/from SCADA, we can test the outaged section of circuit from a tie point without exposing the unaffected feeder to fault currents or voltage sags. Ameren Missouri has now installed this at a number of tie points. Loop automation settings are only installed on the normally-open tie switch. Normally-closed mid-point devices installed on either feeder are configured with standard protection settings.

Figure 9 shows a circuit having long overhead exposure to reach a hospital complex, more than 1.75 miles on each feeder. There is also extensive overhead exposure after the hospital complex. Devices S2 and S5 were installed to clear off most exposure after the hospital taps. Devices S1, S4, and S5 work with S3 to transfer hospital load if there is loss of source.

All five pulse closers are installed with the same coordination settings. Pulsefinding is used to help isolate the fault to the smallest possible section.

Loop automation was used on this scheme. Only S3 was set up with loop automation and time-coordinated such that the normally-closed positions would have had opportunity to isolate faults or switches prior to S3 closing. This is a clean and simple way to provide automatic source transfer by only enabling loop logic in a single stand-alone device.

There was a fault event on July 21, 2010 that put the system to the test. The event happened during stormy conditions, so the instantaneous trip was enabled at the substation feeders. In this case, what occurred was a fault downstream of S2. F1, S1 and S2 all tripped. Then F1 reclosed and held, restoring service up to S1. When S1 saw return of source, it pulseclosed, saw no fault, and closed to pick up load up to S2. When S2 saw return of source, it pulseclosed, saw the fault, and after a few more pulse closes to check the line, went to lockout. The system worked as expected.
Figure 10 shows another installation around a medical complex near a hospital. Pulseclosers were installed at locations that split loads based on sensitivity and tie capacity. The pulsecloser on F2 is installed at the head of the feeder with the intention of avoiding stress on the substation transformer from repeated fault events. Since pulseclosing only lets reduced magnitude 5ms pulses of current flow through the system instead of full asymmetrical fault current, the thermal and mechanical stresses on the substation transformer are two orders of magnitude less compared to a conventional reclose into a fault.

**Figure 10 Multi-source Automatic Restoration**

IX: APPLICATION: SMART GRID PILOT PROGRAM

In 2010 Ameren Missouri initiated a Smart Grid pilot that fully built out two entire substations and most of a third substation, all of which were adjacent to each other, totaling 15 feeders with multiple mid-point and tie-point pulseclosers. Figure 11 shows the first phase of the project which completed eight feeders at a substation with ties to five adjacent substations. This phase of the project installed 32 pulseclosers and two padmount switchgear. The project tied into some existing pulsecloser installations so more than 32 are shown in the drawing. The pulseclosers were all set up with the same protection settings, so we are taking advantage of the simple setup and the fault finding capabilities, with as many as three pulseclosers in series. The pulsecloser locations were selected based on a variety of parameters such as isolating commercial circuit sections from tree covered residential sections, and sectionalizing loads such that they can be picked up in pieces from adjacent feeders or substations.

This is a complex scheme with a lot of information coming in for a system operator to analyze if an event occurs. This is a heavily loaded substation with limited tie capacity depending on time of year or temperatures. We purchased a distribution automation controller to collect and analyze information to make appropriate decisions for fault isolation and restoration.

Phase two of this project expanded this system into adjacent substations, and will use S&C’s IntelliTEAM SG Automatic Restoration System to provide for fast fault isolation to the smallest possible section, and automatic restoration to customers outside the affected area in a matter of seconds.
X. REFERENCES


XI. BIOGRAPHIES

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