NEW TECHNOLOGY YIELDS THREE WAYS TO OVERCOME COORDINATION CONSTRAINTS ON THE DISTRIBUTION SYSTEM

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ABSTRACT

Distribution system overcurrent protection is based upon the gradation of Time-Current Characteristic (TCC) curves to ensure that the proper device operates to isolate a fault on the line. These devices include relayed circuit breakers, reclosers, pulseclosers, and fuses. In the absence of full and proper coordination, protection is not optimized and this results in additional and unnecessary customer outages. This paper discusses how new technologies are expanding the tools that distribution engineers can use to both simplify and improve overcurrent coordination.

CONVENTIONAL TECHNOLOGY

Coordination of overcurrent protection devices is a requirement for any electrical distribution system. The focus of this paper is the medium voltage electrical distribution network, so the protection devices in scope include relayed circuit breakers in substations, substation and mid-line reclosers and pulseclosers, and fuses. Other sectionalizing devices such as manual or automated switches may be present on the feeders but do not have a direct impact on the coordination of protection device TCC curves.

It is important to use the manufacturers' published time and current tolerances when performing coordination studies. The curves plotted in Figure 1 use ±8% current tolerance and ±4% time tolerance for the substation relay, and ±10% in current and time for reclosers. For full and proper coordination, the curves for adjacent devices, plotted with tolerances included, will not overlap. Utility practices may also include a coordination time interval to ensure further time separation between devices.

The two reclosers have lockout coordination up to 3000A. Above that current, the upline recloser may lockout first due to the tolerances of the reclosers. Further adjustments downward in the minimum trip setting for Recloser 2 could be made to improve coordination at higher currents, but this needs to be balanced versus a compromise of coordination with downline fuses.

A common approach to improving feeder reliability is to add more sectionalizing points along the feeders. In this example, it is not possible to add a third recloser between the relay and the fuse without sacrificing coordination.

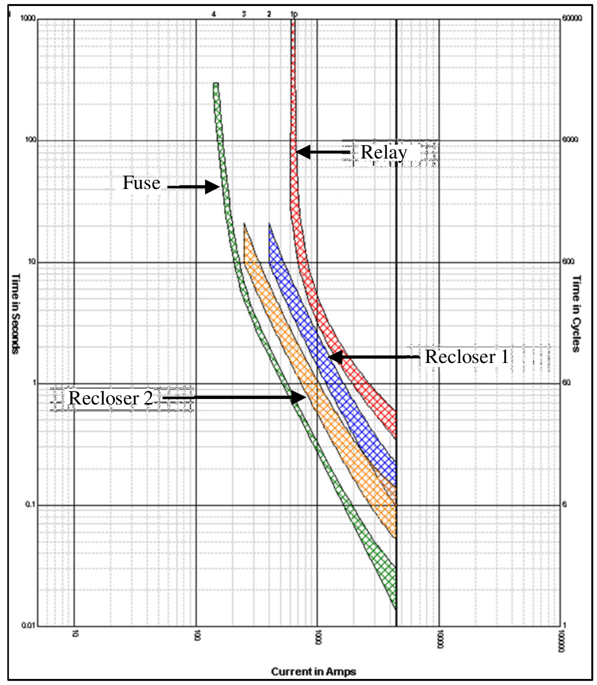

Figure 1. Coordination of relay, two reclosers, and a fuse

PULSECLOSER TECHNOLOGY

Conventional reclosing technology is based upon interrupting the fault current, waiting for a short period of time, and then reclosing to determine if the fault is still there. Each reclose re-ignites the fault, which causes thermal and mechanical stress on important components of the electric system, such as cables, splices, connectors, and perhaps most importantly substation transformers. The operating sequence is not readily apparent from the TCC chart, but it is an important part of the overall coordination effort.

A new distribution system fault interrupter called a pulsecloser has technology to both improve the ability to achieve proper coordination and sectionalization, while also reducing the stress and voltage sags that are caused by short circuits.

Pulseclosing is a very fast closing and opening of distribution switchgear contacts to determine if the feeder is faulted without allowing full fault current to flow. There is no TCC curve associated with a pulseclose operation, since it is such a short duration.

A key part of the technology is closing at the proper point on the voltage waveform to achieve only a minor loop of fault current. Just enough current is generated to be measured and analysed while still keeping the energy let-through into the fault as low as possible. The timing of the chosen point-on-wave closing angle for pulseclosing is such only a single minor loop of asymmetrical fault current is generated. The pulseclosing technique acquires the same key information in 5-7ms of reduced magnitude current as conventional reclosing does in many cycles of full asymmetrical fault current – determining whether the system is faulted or not – but it does so while minimizing harmful side effects. Figure 2 is a waveform capture from a permanent fault from a pulsecloser deployed on a 12kV line that shows the short pulses that result instead of a full reclosing.

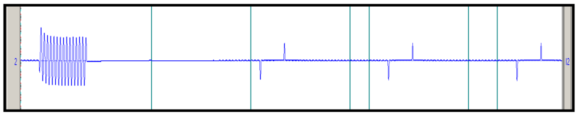

Figure 2. Permanent fault. Waveform shows initial fault plus several pulses to test the line.

The pulsecloser has at least three new technologies that help utilities overcome the constraints of distribution coordination. These new technologies and their benefits are detailed in the following sections.

BENEFITS OF ACCURATE SENSING

The first advancement in protection is to use highly accurate sensors in the fault interrupter that do not saturate, and are accurate within a fraction of percent for the entire operating and temperature ranges. This results in TCC curves with as little as ±2% time and current tolerances compared to a more common ±6% or ±10%.

Figure 3 shows the effect of replacing reclosers with pulseclosers, with no changes to the Min Trip, Time Multiplier, or any other settings. Notice the thinner curves versus the recloser curves in Figure 1, all of which are plotted with current and time tolerances. If settings were adjusted, it is possible to get up to five pulseclosers in series to fit between the relay and fuse curves, while maintaining TCC coordination.

PULSEFINDING

The second advancement in distribution system protection builds upon the pulseclosing feature when multiple pulseclosers are deployed in series.

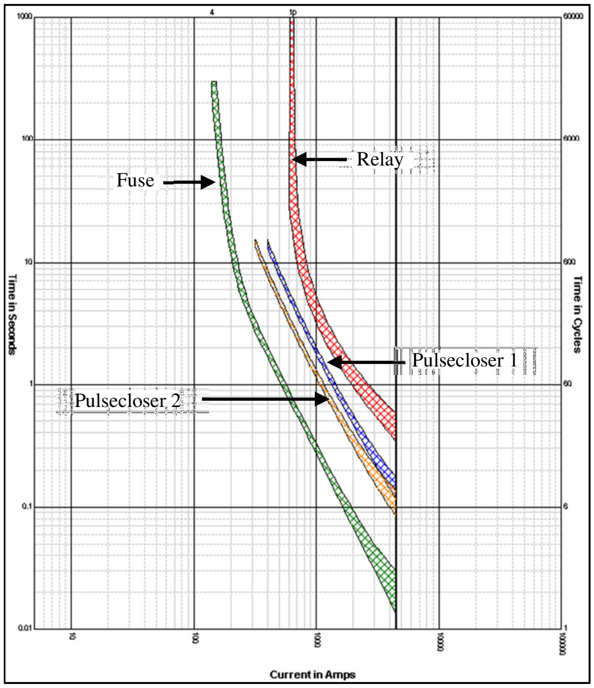

Figure 3. Reclosers replaced with pulseclosers

Building on the coordination example shown in Figure 3, it is possible to achieve lockout coordination for a virtually unlimited number of pulseclosers in series. First, conventional TCC curve coordination techniques are employed to coordinate as many series devices as possible. Then, for fault currents where the TCCs for two or more pulseclosers overlap partially or fully, the pulsefinding technique will automatically restore service to the unfaulted sections. This is accomplished without the need for communication between pulseclosers.

Even if distribution feeders have two or three devices each, the number of devices can easily grow to five or six or more when the feeders are reconfigured to provide an alternate source of supply. These advanced protection features are especially helpful on looped distribution systems. [1]

Even in a worst case scenario where several devices in series have the exact same overcurrent protection setup, pulseclosing helps recover the unfaulted sections within seconds. In this scenario, all the pulseclosers will trip in response to the initial fault. Pulseclosing will determine which sections are not faulted and restore service so that only a section of line that is afflicted with a permanent fault will experience the outage.

Figure 4 is an example of a radial system with five devices in series. Assume that, due to coordination constraints, perhaps as a result of a circuit reconfiguration, devices A2 through A5 all share the same overcurrent protection settings, including TCC curves and minimum trip settings. The following steps demonstrate how pulsefinding properly sectionalizes the system in spite of the lack of coordination:

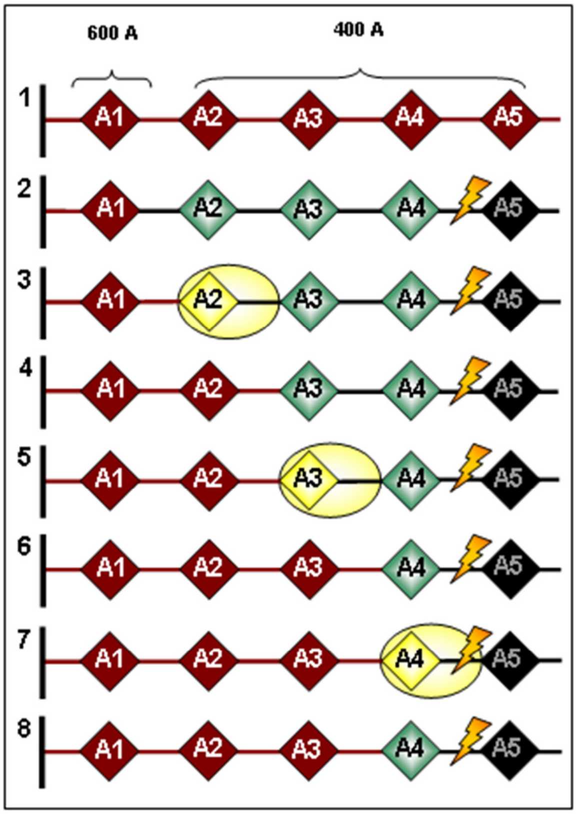

Figure 4. Steps in Pulsefinding Automatic Recovery

1. Normal unfaulted conditions, all devices closed.
2. A permanent fault occurs between A4 and A5. Since A2, A3, and A4 have the same overcurrent protection settings, all three trip. A5 does not trip, but its only source is unavailable.
3. A2 advances to the second operation in its sequence which is a pulseclose to test the line. A3 and A4 do not advance to the next step in their sequences since their sources are de-energized.
4. A2's pulseclose detects only load current since the fault is isolated by the open devices A3 and A4. Therefore, A2 closes, energizing the source of A3.
5. A3 advances to the second operation in its sequence and pulsecloses to test the line.
6. A3 detects only load current and closes, energizing the source to A4.
7. A4 advances to the second step in its sequence and pulsecloses to test the line.
8. A4's pulseclose detects the fault. A4 continues through the rest of the pulsecloses in its sequence, but since the fault is permanent in this example, it eventually locks out. Customers upline of A4 do not see voltage sags during the pulseclosing sequence.

Maximum system restoration is achieved within seconds of the initial fault detection. Pulsefinding simplifies applications where coordination is tight or cannot be achieved – it is even possible to add devices without the need to consider time-overcurrent coordination. Pulsefinding is an inherent feature in the pulsecloser, and it does not rely on communications in any way.

COMMUNICATION-ENHANCED COORDINATION

The third overcurrent protection advancement is communication-enhanced coordination between any number of pairs of pulseclosers in series. In this configuration, series devices may have the same or different TCC curves enabled. Upon initiation of the fault, all pulseclosers that detect the fault will quickly send a high priority communication message to the next upline pulsecloser to implement a slight delay in the protection. These protection changes occur during the time the fault is actually on the line, but do not in any way cause a delay in the removal of the fault.

Let's revisit the scenario described in the pulsefinding section, with the pulseclosers now equipped with fast peer-to-peer communications using Figure 5.

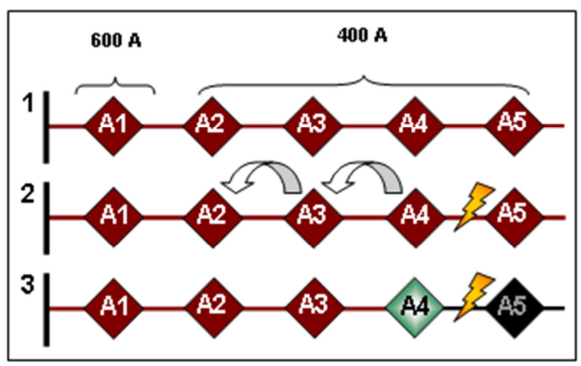

Figure 5. Communication-Enhanced Coordination

1. Normal unfaulted conditions, all devices closed.
2. A permanent fault occurs between A4 and A5. A3 and A4 sense the overcurrent and send messages to the next upline pulsecloser to add a slight delay to the protection curves, perhaps matching the protection of device A1.
3. A4 now has the fastest protection settings, so it is the only device to trip.

If the fault is permanent, A4 will progress through the test sequence until lockout. At the end of the test sequence, whether A4 has locked out or it has restored service after a temporary fault, additional communication messages instruct A2 and A3 to return to their normal protection settings.

The final state of the feeder is the same in Figure 4 and Figure 5. In both cases, proper sectionalization was achieved even though multiple devices in series were configured with the same exact protection settings. Pulsefinding restores the unfaulted sections within a matter of seconds without the need for communication, and communication-enhanced coordination eliminates the momentary outages for those customers altogether.

To be highly effective, this technology depends on high-speed peer-to-peer communications, which has been accomplished both with fiber-optics and certain over-the-air radio systems. The target time frame is less than 100ms total elapsed time for the downline pulsecloser to detect the fault, generate a priority message and transmit it to the upline pulsecloser, which then processes the message and delays the overcurrent trip. The latency and bandwidth of the communication system has a major impact on this technology.

CONCLUSION

New technologies give distribution protection engineers increased flexibilty and functionality to design protection systems that improve reliability where it is needed most. Pulseclosing technology is an innovative method to test overhead power distribution circuits for the presence or absence of a fault. It also eliminates voltage sags that result from conventional reclosing.

Pulseclosing has merits on its own, but it is also an enabling technology that allows for new and better ways to perform distribution system automation and overcurrent protection. Pulseclosing, pulsefinding, and communication-enhanced coordination overcome many coordination constraints and allow for an unlimited number of fault interrupting devices to be used in series.

REFERENCES

[1] M. Meisinger and C. McCarthy, 2013, "Improving Open-Loop Medium-Voltage Feeder Self-Healing," CIRED paper 0693, Stockholm, Sweden.