Loss-of-Communications Backup Logic for Distribution Automation Schemes

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Presented at the
12th Annual Western Power Delivery Automation Conference
Spokane, Washington
April 13–15, 2010

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***Abstract*—Utilities are installing distribution automation (DA) schemes today to improve the reliability of service to their customers. Many are seeking federal stimulus dollars to help fund these projects. These DA schemes typically employ some sort of intelligence to determine how to reconfigure the distribution system after an outage in order to restore service to as many customers as possible. A communications infrastructure is required to communicate with devices out on the poles. This system collects information on the state of the distribution system and also provides control functions to open and close remote switches and reclosers. The communications infrastructure is the backbone of the DA scheme. Communications failure shuts down the DA scheme.**

This paper presents a method of using advanced digital logic in a microprocessor-based recloser control to provide backup automatic network reconfiguration logic when communication to a centralized distribution automation controller (DAC) is lost. The scheme automatically reverts to backup mode when communication to any one remote device is lost. The scheme automatically changes back to centralized DAC mode as soon as communication is restored. This functionality increases the dependability of the DA scheme and improves the reliability of service to customers.

I. Introduction

Distribution automation (DA) systems have been around for over a decade. A few DA systems employ very sophisticated communications systems that also provide high-speed pilot protection [1]. Interest in DA increased dramatically in 2009 because of the United States government providing stimulus dollars for DA projects in conjunction with state utility commissions providing rate relief. This infusion of capital has driven utilities and cities to initiate DA projects at a pace never seen before.

DA systems have always had some form of communications infrastructure associated with them. In most cases, electric utilities use radio systems to reach end devices. Fiber-optic systems that reach to the end devices are in place at some utilities [2]. In most applications, though, fiber-optic media for communication are utilized only on the backbone path that requires high-speed data flow. Cities, on the other hand, have a high density of customers and offer multiple services, such as broadband Internet and digital television. These data-intensive service packages along, with customer density, provide the means for cities to justify a fiber-optic-based communications system that encompasses the end devices.

This paper focuses on backup systems that can come into play when problems with the communications system arise and take the DA system offline. Communications systems associated with DA applications in electric utilities typically utilize unlicensed spread-spectrum radios. The geographical area these communications systems cover is often quite large, particularly if the setting is rural. Radio communications systems are the least expensive type of communications system to apply in these cases. Although a fiber-optic system is preferred, the installation of a fiber-optic system that includes the end devices is cost-prohibitive in most cases. Typical communications systems might utilize some fiber-optic-based communication on the backbone path of a communications system with radio links to the end devices. Many radio systems operate at relatively low data rates and can suffer short outages while moving data. In these low-speed systems, the performance of the DA systems is greatly dependent on the performance of the communications system. If data communication is delayed, it is very likely that system reconfiguration will also be delayed if an outage occurs on the distribution system at that time.

Many of the short-duration outages that can occur in a radio communications system are of little to no consequence to the overall operation of the DA system. A retry of the master controller will likely capture the data on the next poll. However, outages of the communications system that have time spans of minutes are of concern to distribution, power quality, and asset planning engineers because an outage could occur at the time the communications system is down. DA systems are dependent on communication to operate properly when an outage occurs. Loss of communication to a single device is significant enough to take the DA system offline for that particular area, because the status of that device is no longer available to the distribution automation controller (DAC).

II. Communications System Outages

We analyzed one system to determine how the communications system performed over an 81-day period. We found that the communications system was down eight times for a total outage time of approximately 56 minutes. The longest outage time was 10 minutes and 45 seconds. Extrapolating these data to a period of a year indicates this same communications system could be down for as long as 252 minutes a year. It is this type of communications system outage information that raises concern about the reliable operation of the DA system. It also causes us to ask what can be done to allow a reconfiguration of the distribution system during an outage if, at the same time, the communications system is not fully functional. This scenario motivated DA engineers to develop a backup system that could come into play if a power outage occurred when a link in the communications system was down. The idea is to keep the DA system as functional as possible, even with multiple communications links down. This concept allows the installed DA system assets to be better utilized and provide additional benefits to customers by reconfiguring the power system and restoring power.

Ideally, the backup system needs to monitor the communications link in some way to detect when the link is lost. After a time delay, the backup system needs to automatically place itself in service when the communications system goes down and disable itself when the communications system returns to normal. No intervention from the distribution control center is needed. An alarm point indicates the DA system is offline in a particular area of the distribution system, as a result of communications link failure somewhere on the DA system.

To eliminate the need for any user intervention, some mechanism is needed to detect a problem with the communications system and cause the system to transfer from full DA to a backup system. Similar logic is needed to detect when communication returns to normal to allow a transfer from the backup system to full DA. Both the DAC and the remote device need to know the status of the communications link between them to allow them to transfer to the backup system when the link goes down.

To keep track of the link between the DAC and the remote devices, the DAC sends a keep-alive bit at a periodic rate to those devices. The remote devices look for this bit to arrive at a periodic rate. When the bit is no longer detected after a reasonable time period, the remote device or devices conclude that the communications link to the DAC has been lost. Logic in the remote device then switches the device from control by the DAC to backup local control logic resident in the device.

The DAC also has backup logic to allow it to recognize that data from the current poll of the remote device are no longer refreshing the data from the previous poll of the remote device. Using this technique, the DAC determines when a communications link has gone down. With this information and the configuration of the distribution system, the DAC then relinquishes control of the other devices in the area where the communications link was lost and commands those devices to begin running on local control.

By both the DAC and the remote devices detecting a problem with the communications link between them, they both take action to go into a backup scheme mode. This not only allows the device that lost the communications link to run on its own local logic but also allows devices surrounding it to begin operating on their local control logic. Even though the communications links to these other devices are functional, the DAC no longer controls them, because it does not have enough information about the power system to make intelligent decisions to automatically reconfigure it. The devices that the DAC must relinquish control over from a DA perspective are now permitted to operate from their local control logic. This technique of switching over the local devices in a particular area to run on their local control logic allows them to operate to reconfigure the power system if an outage occurs.

If loop scheme logic is added to the remote devices, they can function to reconfigure the distribution system when an outage occurs and communication is down. They do not reconfigure the system as intelligently as the DAC, because the DAC has information about the distribution system that the remote devices do not have when an outage occurs.

This scheme provides distribution engineers with backup logic that they can enable to automatically allow a reconfiguration of the power system when a communications link is down in the DA system. Without a backup system, the DAC only reports the failure of the communications link. It does not take any action to reconfigure the distribution system, because it does not have enough information to make good decisions about how best to reconfigure. Adding communications monitoring logic and backup logic in the local devices and the DAC provides a means to utilize most of the components that were installed for the DA system, even though the system might not be fully functional. The backup logic scheme provides better utilization of the dollars spent on the DA system by providing a means to reconfigure the distribution system during an outage, even if the communications system is not completely functional.

III. Backup Logic Schemes

A number of utilities use loop scheme logic on their distribution systems. Loop scheme logic does not require communication between the remote devices or to a DAC. The logic simply senses the voltage at the device and starts timing from the point in time when voltage is lost on the distribution system. A typical loop scheme is shown in Fig. 1.

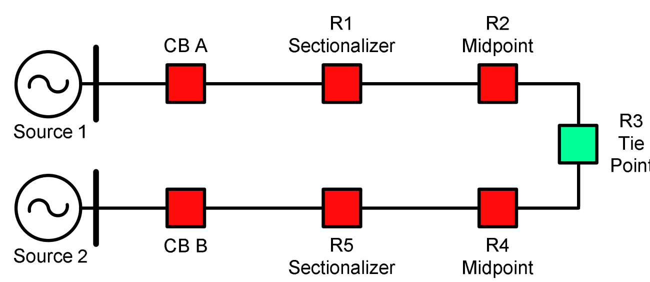

Fig. 1. Typical loop scheme configuration

As shown on the two feeders in Fig. 1, the reclosers are programmed with sectionalizer, midpoint, and tie point logic.

Sectionalizer logic detects a loss of voltage on the source side of the recloser. After a predetermined time, the recloser control opens the recloser to isolate the source-side line section. Closing the recloser with voltage on the source side resets the logic.

Midpoint logic detects a loss of voltage on the source side of the recloser. After a predetermined time, the recloser control, as an option, can change settings groups to maintain coordination on the loop if necessary. The recloser control has settable window of time to lock out if a trip occurs (one-shot mode). For a permanent fault on the source side of the recloser, the control trips and locks out when the tie point recloser closes to re-energize the line.

Tie point logic detects loss of voltage on either side of the recloser. After a predetermined time, the recloser control, as an option, changes settings groups. The recloser control has a settable window of time to lock out if a trip occurs (one-shot mode). After a predetermined period of time, the recloser closes. Closing into a fault results in a trip and lockout of the control.

Consider the following fault scenarios to understand how these modes operate to reconfigure the feeders. In Fig. 2, a permanent fault occurs between Circuit Breaker (CB) H and Recloser R1. CB H goes through its reclosing cycle and locks out. The sectionalizer logic in the R1 control recognizes the loss of voltage on the source side and opens after a time delay.

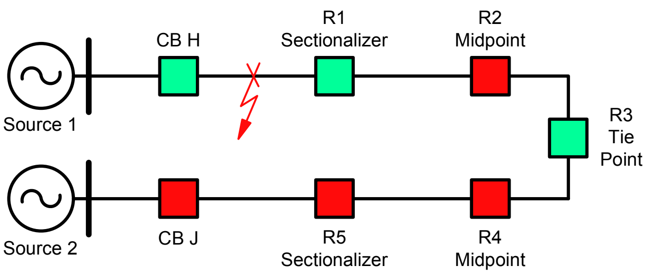

Fig. 2. Sectionalizer logic opens R1 after a loss of voltage

The tie point logic in the R3 control also senses the loss of voltage on the Source 1 side. The logic checks the voltage on the Source 2 side and, after a time delay, initiates a close command to close the recloser. This restores the load on the line sections from R1 to R2 and R2 to R3, as shown in Fig. 3. Note that loop scheme logic in the controls for R2 and R3 can also be set to provide a settings group change before the control on R3 issues a close command to close R3. A settings group change could be needed to maintain coordination of the time-overcurrent curves in the controls on these reclosers.

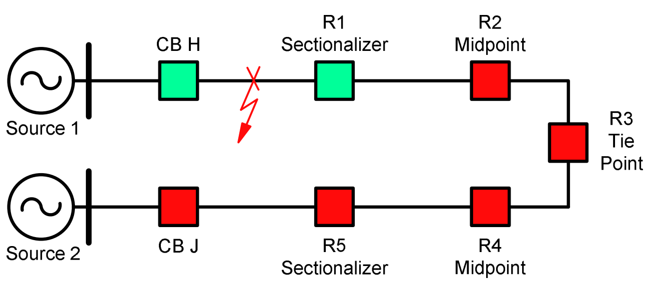

Fig. 3. Tie point logic closes R3 after a loss of voltage

Fig. 4 shows a permanent fault between R1 and R2. R1 goes through its reclosing cycle and locks out. The midpoint logic in the control for R2 recognizes the loss of voltage on the source side and goes into one-shot mode after a time delay. This sets up the means to isolate the fault when R3 closes after a time delay that is coordinated with the time delay for the one-shot mode at the midpoint recloser.

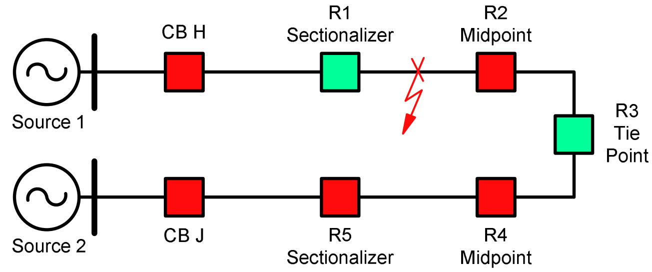

Fig. 4. Midpoint logic allows fault isolation when R3 closes

The tie point logic in R3 senses the loss of voltage on the Source 1 side. The same logic checks that voltage is present on the Source 2 side and initiates a close command to R3. R2 trips and locks out when R3 closes into the permanent fault. This restores the load on the line section from R2 to R3, as shown in Fig. 5.

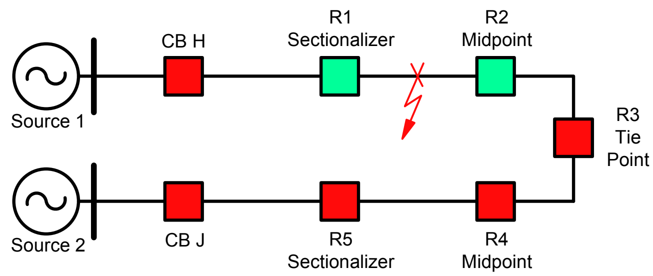

Fig. 5. R2 trips and locks out when R3 closes

A fault can occur on the line section from R2 to R3 as well. The control for R2 goes through its reclosing cycle and locks out. As before, the tie point logic in R3 senses the loss of voltage on the Source 1 side. After a time delay, the logic checks for voltage on the Source 2 side and issues a close command to R3. Because a tie point recloser is operated normally open, the reclose logic in the control is initially in the lockout state. The tie point logic has a settable time window for the control to remain in a one-shot mode. Upon closing into the permanently faulted line section from R2 to R3, the recloser trips. The recloser remains open, as shown in Fig. 6, and the control remains in lockout.

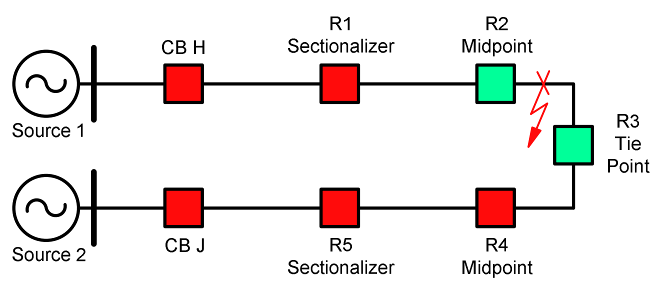

Fig. 6. R3 closes into a fault, trips, and locks out

Now that we have seen how the loop scheme logic functions for faults on the loop, we can overlay the two distribution feeders with a DA system, as shown in Fig. 7. The DAC has communications links to the five reclosers. As long as the communications links are functional, the DAC can reconfigure the distribution system intelligently if an outage occurs [3].

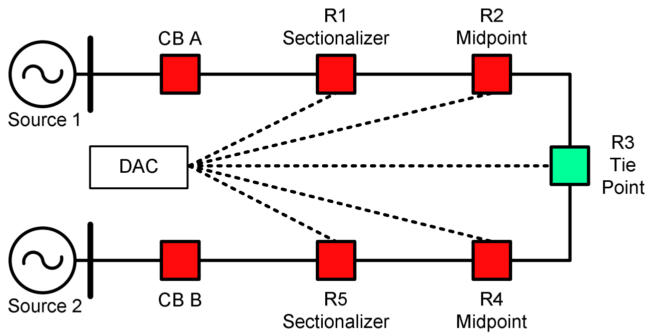

Fig. 7. DAC uses communications links to control the reclosers on the loop

In Fig. 8, assume the communications link between R2 and the DAC has failed. After a time delay, both the DAC and the R2 control recognize that the communications link between them is down. The control for R2 changes settings groups to go out of DA mode and into loop scheme mode using midpoint logic.

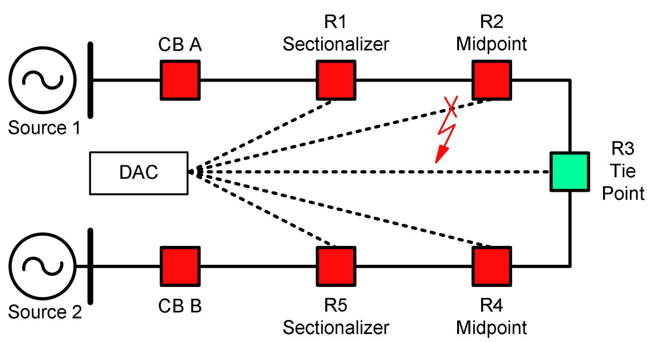

Fig. 8. Communications link failure to R2

The DAC also sends commands to the other four recloser controls to change their settings groups from DA to loop scheme settings. This puts the entire loop into loop scheme mode. With the loop recloser controls using backup loop scheme logic, the loop can reconfigure if a permanent fault occurs.

One common question about these schemes has to do with the behavior of the scheme if a fault occurs at the time the scheme is transitioning from full DA to the backup loop scheme logic because of a communications link failure. At this time, the control that lost communication with the DAC is timing to go into backup mode. Also, the DAC is attempting to reestablish the communications link that was lost. When the DAC fails to reconnect with the communications link, it begins putting the controls on the loop in backup mode. This does not usually happen at the same time that the control that lost its communications link goes into backup mode. If the power system is quiescent, this does not matter. However, if the power system faults during the time of this transition, the coordination of the timers in the controls on the loop could become unsynchronized. To keep this from happening, the controls on the loop locally sense the loss of voltage on the line and start their timers at that point in time. As long as the dead-line timers are set long enough to allow the controls on the loop to go into their backup modes before they time out, the timers in the controls around the loop remain coordinated to isolate the faulted line section using backup logic.

Even though one of the communications links is down, the DAC continues to poll all of the controls. Also, the R2 control continues to try to send data that were requested from the DAC. Once the data make it through the communications system, the DAC recognizes the link is back up and begins changing the settings groups in the controls back to their DA settings groups so that full DA is functional again. As can be seen from the descriptions of the operations, this happens automatically, without user intervention.

IV. Complex Distribution Systems

Loop schemes tend to be located in more rural areas where there is just one tie point between the feeders. In cities, distribution loads typically have multiple sources for feeding those loads. In Fig. 9, we show distribution feeders with multiple sources. On the first look at this complex system, we would not think that any of the loop scheme backup logic could be applied. However, after studying the layout of the distribution system, we see that backup logic can be applied. The key is that not every recloser has a control with the backup logic enabled. In the system diagram shown in Fig. 9, all of the controls that could have backup logic enabled are labeled with their particular mode of operation. All of the normally closed reclosers have either sectionalizer or midpoint backup logic enabled. When it comes to the normally open reclosers, only about half of them have the tie point logic enabled. The tie point backup logic allows the control to close the recloser to pick up load on either side of it. By limiting the number of controls with the tie point logic enabled, we can minimize testing of adjacent line sections for faults after an outage via the backup logic.

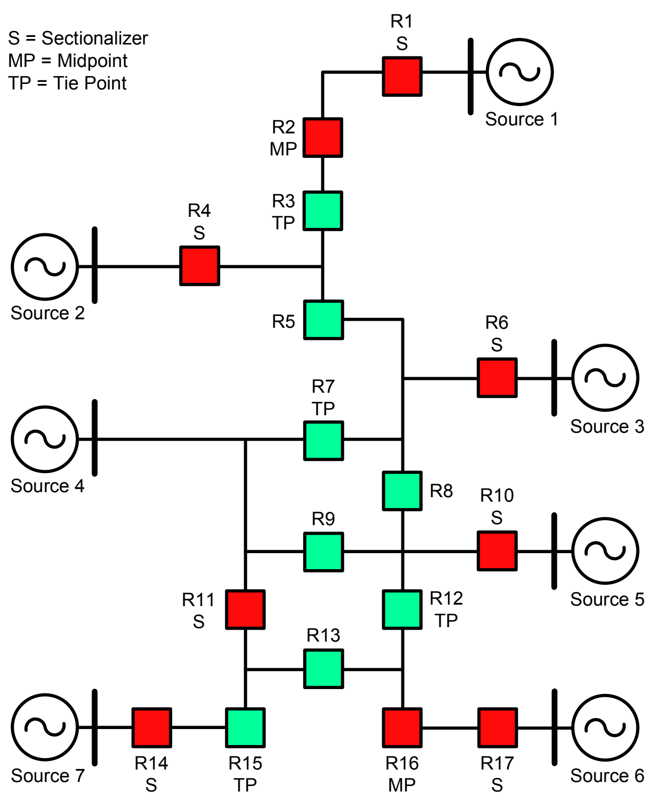

Fig. 9. Complex distribution system with multiple sources

Another control option for the tie point recloser backup control logic is to specify the preferred source side for the recloser. The logic only allows the tie point recloser to close if the preferred source side is hot. This option allows the backup logic to be enabled but is more selective when it issues a close by requiring a specific side of the recloser to be energized before a close command is issued.

As an example, assume a loss of the communications link to R10. After a time delay, the control on R10 switches settings groups to allow it to run sectionalizer logic. The DAC also recognizes that the control on R10 is no longer responding to periodic polls and declares the communications link to that control down. In addition, the DAC recognizes that it can no longer utilize R8, R9, R10, and R12 in its DA logic because the DAC no longer knows the status of R10. After a time delay, the DAC places the control for R12 in its backup logic mode by changing settings groups. The DAC also recognizes that R8 and R9 do not have any backup logic enabled and, as a result, makes no change to the settings group they are currently running. The distribution engineer preprogrammed the control at R10 to revert to sectionalizer logic if communication is lost. Also, the control at R12 was preprogrammed to revert to tie point logic when communication is lost.

Assume a fault occurs on the line section to Source 5, as shown in Fig. 10. Both of the controls at R10 and R12 sense the loss of voltage on the Source 5 side. After a time delay, the control on R10 opens to isolate the fault. After some preprogrammed delay coordinated with the delay set in the R10 control, the R12 control checks three-phase potential on the Source 6 side and issues a close command to R12 to pick up load encompassed by R8, R9, R10, and R12.

Even though the distribution system in Fig. 10 looks very complicated at first glance, backup logic can be utilized on this complex system with little difficulty.

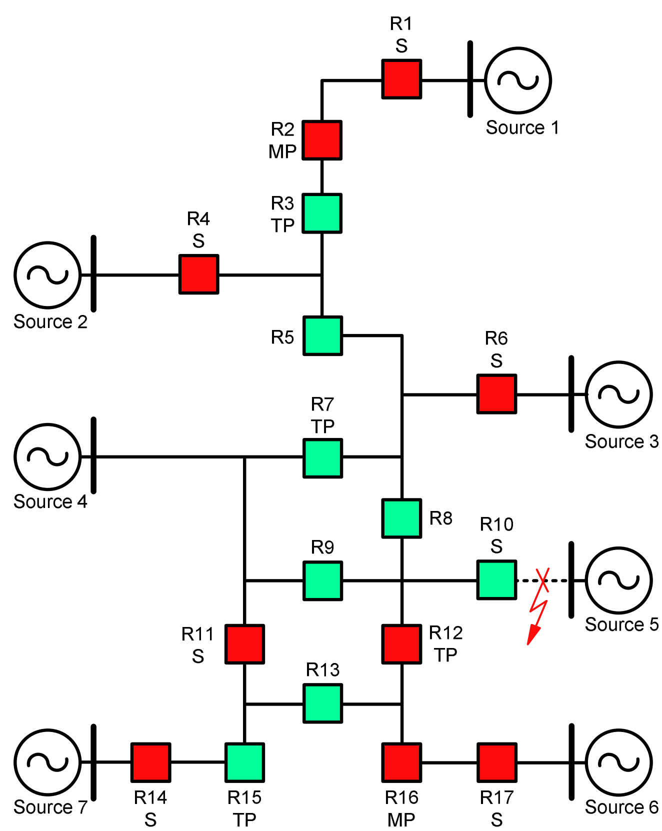

Fig. 10. R10 opens (sectionalizer) and R12 closes (tie point)

V. Conclusion

DA systems are relatively new to most users. Backup logic resident in the local controls and the DAC associated with these DA schemes enhances the performance of the DA system. When a communications link goes down, the backup logic comes into play to allow an automatic reconfiguration of the distribution power system when an outage occurs. Without this additional backup logic, the DAC only reports the failure of the communications link. It does not take any action to reconfigure the distribution system, because it does not have enough information to make good decisions about how best to accomplish this. Adding communications system monitoring logic and backup logic in the local devices and DAC provides the means to take advantage of the DAC and the communications system that were put in place for the DA system. The backup logic scheme provides the means to better utilize the dollars spent on the DA system by providing additional functionality to reconfigure the distribution system after an outage, even if the communications system is not completely functional. This increases the overall reliability of the distribution system, which can be attributed to the installation of the DA system.

VI. References

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VII. Biographies

Richard Greer received a BSEE from Virginia Polytechnic Institute and State University in 1992. In 1999, he earned an MBA from Radford University. He began his career in 1993 as a distribution engineer with Appalachian Power Company in Pulaski, VA. In 2001, he joined Siemens Power Transmission and Distribution in Wendell, NC, as a recloser application engineer specializing in the integration of reclosers into distribution automation schemes. In March 2006, he returned to American Electric Power (AEP) in Roanoke, VA, as an asset planning engineer and now serves as an application engineer in the Grid Management Deployment Department at AEP. He is a registered professional engineer in the state of Virginia.

Jim Schnegg received a BSEE from Ohio State University in 1976. He worked at Goodyear Atomic for four years as a production engineer at a uranium enrichment plant in Ohio. In May 1980, he began his career as a protection engineer with American Electric Power (AEP), where he held various positions in the protection and control of stations and transmission systems. In May 2000, he joined Schweitzer Engineering Laboratories, Inc. as an application engineer, and he now serves as a senior application engineer. He is a registered professional engineer in the state of Ohio.