20 Years of Reliable Service:

Revisiting a Distribution Automation Scheme After 2 Decades

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***Abstract*—Twenty years ago, the authors worked together to implement a distribution automation scheme to quickly isolate a faulted line section and restore service to the unfaulted segments by closing a normally open point. The scheme was designed after the utility identified a section of its service area where improvements were needed to provide commercial customers with a better experience and avoid outages and the loss of revenue associated with an outage. The location was also selected for its location to a major interstate running through the service territory and the number of businesses where motorists purchased fuel, food, and other services and would be inconvenienced by these services not being available due to a fault. This paper will revisit the scheme and provide some operational results over the two decades it's been in service. The paper will also review the design and look at how, with current technology and tools, the scheme might be designed differently and with different features if it were undertaken today.**

I. Coweta-Fayette EMC Over the Years

Coweta-Fayette Electric Membership Cooperative (CFEMC) is a not-for-profit, member-owned cooperative, power distribution utility in Georgia that started in 1945. It is located on the southwest side of Atlanta, outside of the I-285 interstate bypass, and within 30 minutes of the Hartsfield-Jackson International Airport. The majority of the CFEMC customer base is within two southeast metro Atlanta counties, Coweta and Fayette, and the rest is in six other surrounding counties. The area is popular among commuters because Interstate 85 runs through the middle of Coweta County and many state highways connect residents to Atlanta. The service territory terrain is considered to be wooded with gently sloping hills and is roughly 40 miles by 20 miles in area.

CFEMC's main office is located in Palmetto and there are two district offices in Newnan and Peachtree City for customer service purposes. Farmland once dominated this area 50 years ago but since the creation of Peachtree City, one of Georgia's first completely planned communities, many businesses and people have relocated within the territory. Suburban development has dominated most of the area's growth with population statistics showing over 5% growth many years through the 1970s, 80s, and 90s. When the original referenced automation paper was written in 2005, expectations were for continued growth without interruption. These expectations were hampered by a collapse in housing in 2008 and then a pandemic in 2020 which has slowed growth.

Twenty years (2004 – 2024) have passed since the original automation scheme was created, and CFEMC's total services have grown from 65,470 to 89,667. The peak demand growth over the same period is 352MW during the summer of 2004 to 450MW in both summer and winter of 2022. This is a 27% increase in the number of meters and a 22% increase in capacity. Improvements in energy efficiency within homes have played a large part in curtailing the linear increases in peak demands. One factor that has remained consistent is the proportion of commercial accounts which still maintains 6 – 8% of the customer base and 27 – 30% of total energy sales.

CFEMC operates a dual voltage power distribution system of 12.47kV and 25kV from 29 substations. The transmission system that serves the substations is either 46kV, 115kV, or 230kV and is owned by Georgia Power, Georgia Transmission, or MEAG. Georgia Transmission is owned by the EMCs of Georgia, and it works on behalf of the EMCs in operation of the transmission grid. From the substations, CFEMC currently has 6,764 miles of power lines, 4,008 miles of which are underground. Twenty years ago, the distribution system was 5,656 miles but evenly split between overhead and underground. The system size has increased by 17% overall, but the number of underground power lines has increased by 29% and now makes up most of the distribution system at 60% of the total. The largest customers of the cooperative consist of a hospital, a large movie studio, and a handful of light industrial plants, which operate between 3MW to 5MW normally. Also, another significant development as of 2020, is the addition of a 2MW community solar array and a 2MWh battery located in the service territory. The solar and battery system adds to the large renewable portfolio of CFEMC as it supports the growth of green technology on its grid system.

II. The Distribution Automation Scheme Over the Years

In 2004, the cooperative utility identified an area of their system where they sought to improve their service. The area is near a busy interstate near the Atlanta Metro area where there are lots of motorists' convenience businesses such as gas stations and restaurants along with larger commercial customers such as grocery and "big box" stores and a rock quarry. The businesses and the customers they served were inconvenienced and the businesses suffered lost revenue when an outage was experienced even for a short time. CFMC had planned the area with two sources with a tie point on the two feeders so that some load could be transferred manually for certain fault locations, but the time involved in responding to the outage and switching by hand meant that outages associated with a permanent fault were many minutes to hours in duration. **Error! Reference source not found.** depicts the relay communications diagram of the identified circuits where the source substations #21 and #3 were 5 and 6 miles respectfully from the load centers. With these distances it is clear a decent amount of exposure between devices exists.

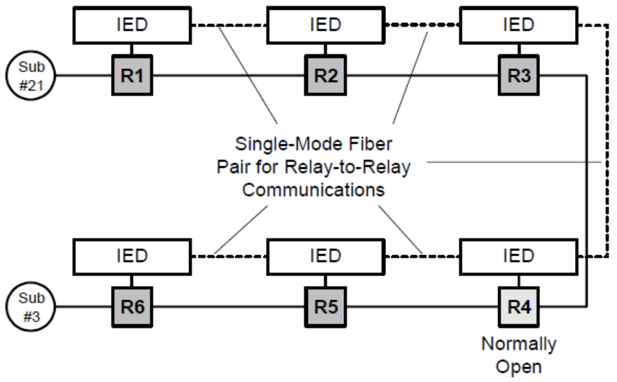

Fig. 1 Relay Communications Diagram

The cooperative discovered an arrangement that gave them the use of fiber optic cable that was installed in the area. With the options fiber offered in speed and peer to peer communications, the two original authors collaborated to develop a scheme that operated at high speed and allowed for more protective devices to be installed on the feeders to reduce the customer count and exposure in each of the sections of the feeders in the new design.

Today, the original distribution automation scheme is still operational, and the surrounding area has grown up around it. A new substation (#27) now serves the southern portion of the DA scheme, but it does not change the functionality or the original design. The load growth warranted the additional substation and it was planned to be a better source option for the largest load centers on the scheme. The load center with two grocery stores now has double the number of commercial loads. The industrial park load center near the interstate has lured more warehouses and small industrial manufacturing. The total load protected by the DA scheme is near 10 MW at the summer peak in 2023. The residential growth in Coweta County has increased by nearly 50% over 20 years, from 100k to over 150k residents. Much of the growth has occurred between Newnan and Peachtree City which is in the area served by the DA scheme.

The original paper [1] describes the implementation in great detail and can be reviewed for specifics but essentially, the scheme allows for a high-speed isolation of the faulted line section and restoration of load outside that line section by closing a normally open point. The scheme is limited to two sources and one normally open point. The number of protective devices that can be installed is limited to the number that can be coordinated adequately. The scheme as designed operates after a device has tripped to lockout and then sectionalizing and restoration is done based on a device locking out. The scheme in the implemented sense is a control scheme and not a protection scheme as each of the protective devices operates independently from the communications between the devices.

The impact of the scheme effectively reduced sustained outages for a permanent fault down to those customers inside the line section where the permanent fault occurred. With relatively fast reclosing open intervals, and the very fast isolation and restoration scheme, customers would experience the same number of momentary interruptions but the fewest possible would experience a sustained outage no matter of the location of the fault. At the time, distribution automation was just being implemented in locations of opportunity like this but in general wasn't available widespread due to the limited communications available to downline distribution protection and control devices. With today's availability of fast and secure communications to downline devices and with most utilities employing SCADA, there are several improvements and enhancements that could be implemented by taking a fresh look at it with technology available now.

The DA scheme is a two-source, six-device scheme with a normally open point in the middle. Combining trip, lockout, and switch status with customized logic, the scheme is designed so that the proper devices trip and then reconfigure accordingly. This can happen as long as all devices are in a radial configuration. The scheme is a point-to-point communication scheme, meaning each device communicates with each other for indication of tripped, lockout, and open or closed status. Then, through a single point cell modem connection at one of the reclosers, the switches communicate all data back to a SCADA system. The SCADA system does have the ability to put any device of the scheme into an abnormal state (open, close, HLT, ground block), and can disable the scheme, but does not control the automated switching. When the DA scheme was originally designed, a centralized automation SCADA system was not an option for switching and restoration. Today, through Coweta-Fayette EMC's SCADA vendor, a FLISR (Fault Location Isolation Sectionalizing and Restoration) scheme has been implemented and all other restoration automation outside of the DA scheme and some local source transfer switch schemes is performed by the FLISR software package. With this system, the individual devices operate to clear faults independently. Once a fault has been cleared, the FLISR system will perform the steps to restore all load that can be restored. The FLISR software system is constantly monitoring the loading and status of each field device. FLISR is programmed to account for loading on the system at the time of the operation in order to not overload any source or device. It is considered a centralized system because it monitors the entire utility network to ensure continuity and many programmed conditions at met before any switching is allowed to happen.

III. Operational History

Due to changes in software systems and personnel who maintain operational records, Coweta-Fayette EMC only has data since 2011 on the operation of the DA scheme. Since 2011, the scheme has operated 46 times. Most operations were successful in isolating a faulted section of the line and restoring as many customers as possible. Half of the operations (23) were attributed to a loss of source for one side of the DA scheme. This would either be a loss of transmission to either substation or a lockout of the substation breaker which serves between the substation and the first (i.e., R1 or R6). Eight occurrences resulted in either R5 or R3 locking out due to a fault and would not have resulted in a transfer of load due to R4 being in the open position prior to the faults. Twelve operations resulted in the lockout of R1, R2, or R6 and the DA scheme isolated the faulted section and transferred load to the alternate source. Three operations did not restore as expected due to equipment failures or natural conflicts such as a squirrel chewing through a control cable or lightning striking a switch directly.

TABLE I. Causes of Outages

Causes of Outages	
Cause	***Quantity***
Animals	4
Tree on Line	13
Storms / Lightning	9
Equipment Failure	8
Transmission Outage	7
Public	5

The causes of outages were fairly distributed with no one cause being a majority. Trees were the leading cause of outages for the DA scheme, which were falling into lines mostly during times of high winds. Equipment failures were the result of faulty control cables, switches, insulators, or lightning arrestors that may have weakened over time. Public outages consisted of vehicles hitting poles, or trees being cut down into the power lines.

With regard to the outage times for the two circuits that make up the DA scheme, automation has successfully reduced outage times since implementation. The total System Average Interruption Duration Index (SAIDI) calculated time for the two circuits for the 46 outages recorded has resulted in an additional 22.42 minutes for the Coweta-Fayette EMC system. If automation restoration was not programmed into the devices but the sectionalizing devices were present and only coordinated to clear faults, the SAIDI outage time would be 39.34 minutes. If all sectionalizing SCADA switches were removed from the lines and every fault resulted in the substation breaker locking out, then the SAIDI time would be 65.23 minutes. This means that adding SCADA sectionalizing devices outside the substations has the greatest reduction in SAIDI times by eliminating 25.89 minutes and adding automation restoration to the SCADA devices reduced SAIDI further by an additional 16.92 mins. In all, the DA scheme has reduced system SAIDI time by 42.81 minutes total over the last 12 years of record keeping. If records were kept for the time before 2011, this number would be much higher.

The reduction in outage times is made further impressive by knowing that the DA scheme serves only 4% of the Coweta-Fayette EMC customer base. If these results could be spread across the entire system over the same period it would have resulted in a reduction of 1049.58 minutes over 12 years or 87.47 minutes per year which could reduce the entire system’s yearly SAIDI to under 30 minutes, considering an average of 110 SAIDI minutes yearly total for the Coweta-Fayette EMC system.

IV. What Now?

Since the implementation of the DA scheme, Coweta-Fayette EMC has installed over 125 pole-mount SCADA reclosing devices. These devices have been constructed around key accounts and public schools to ensure a higher level of reliability. Before using the current SCADA vendor’s FLISR software, Coweta-Fayette EMC used other smaller point-to-point automation schemes that operated on a loss of voltage (or source) and then transferred the load to an alternate source. These were often two-device schemes using 900MHz radios for communication. The smaller schemes were used around grocery stores, industrial areas, schools, and a movie studio.

Today, all other restoration automation outside of the DA scheme is performed by the FLISR software package. This means that each field SCADA device will coordinate and operate independently of other devices, as programmed, unaware of its location in relation to other devices. They will operate and will wait for the FLISR to tell them what to do next. The FLISR software is constantly monitoring the loading and status of each field device. It is programmed to not overload any source or device and is considered a centralized system because it monitors the entire utility network to ensure continuity. Many programmed conditions across the network must be met before any switching is allowed to happen. The FLISR software is slower for automation but provides many options for configuration and acts holistically for a grid without point-to-point communications.

In 2017, Coweta-Fayette EMC used the software which allowed for more complicated configurations to be assembled. The first scheme that was built involved 12 pole-mount triple single reclosers, four substation breakers, and three sources. It was named the "Tyrone – Fife – New Hope Scheme" after the three substation sources. The layout of the scheme resembles a "star" shape with the Tyrone circuit being able to back feed the three other circuits. The scheme serves four schools, a grocery store, many small businesses, and almost 4000 residential customers. Since becoming active it has saved 25 mins of SAIDI time. Three other schemes have emerged from this first success on the system and have had similar results. The pole-mount SCADA reclosers are programmed very basically, using time-current curves for coordination since there is no fiber available for point-to-point communications.

Each new automation scheme becomes more complicated than the previous one and involves multiple open points on a single circuit. Also, a single circuit may split at an intersection which creates a scenario where a fault at the end of a line is not seen by all devices on that circuit. Circuits that have a split or multiple open points would not be able to use the same logic or functionality as the original DA scheme. The automation philosophy has been to create sectionalizing of between 300 to 500 customers, large commercial areas, and isolate areas of known problem outages. Automation schemes today try to incorporate as many circuits as possible that can connect via large conductors with ampacities of over 500A. A goal is to have each circuit from one station tie with another station through a SCADA control open point device. This goal is not always possible because some circuits can only tie with others from the same substation. Some circuits connect twice with another circuit and in this situation, the FLISR software allows one source to be set as a priority over the another. When a source or open point is set as a priority, the software will choose this option first, if available.

When this DA scheme was developed, there was limited availability of fiber optic cables for use by distribution utilities. For transmission lines, OPGW was being installed in many areas but installing fiber optic on the distribution system was expensive and the use cases that exist today were not as prevalent, so it wasn't financially feasible to apply fiber in bulk. At the time the original DA scheme was being developed and presently, the SEL Mirrored Bits TM protocol in the relays and recloser controls available made a peer-to-peer scheme easy to implement. Spread spectrum radios were an option, and some were compatible with the SEL Mirrored Bits protocol. With the original scheme operating as a high-speed control scheme and not a protection scheme requiring high speed and high reliability data transfer, the use of spread spectrum radios was thought to be possible where distances were sufficiently short and clear paths existed although it was not attempted at this cooperative.

In today's utility world a good number of utilities have or are exploring opportunities to make a business case for installing fiber on their systems. The use cases for fiber have grown tremendously as the market for broadband internet access has increased as well as other services for customers that utilities may identify for non-traditional service offerings. The market for leased fiber has also increased and the existing right-of-way and infrastructure that electric utilities have lends itself to installing and operating or leasing the equipment to others to operate. What should not be lost in these opportunities is to consider the operational benefits that are available from having fiber for their own use.

V. Building on the Original Design

The original design left protection to traditional means with coordination of devices based on different time overcurrent settings. The scheme operates after a device has tripped and reclosed until it has gone to lockout and then the scheme takes steps to isolate the faulted line section and then close the normally open point to pick any stranded load back up. One improvement that could easily be implemented would be to move from a traditional coordination scheme to a pilot type of blocking scheme. The fiber would provide enough speed and security for the data transfer so that devices could be coordinated through this blocking scheme with only a few cycles delay needed to allow for receipt of the blocking signal(s). The scheme like that written about in [2] allows for coordination of unlimited devices so the number of line segments can be increased as desired to reduce the customer count and exposure to as small as desired. Additionally, by moving from a peer-to-peer scheme to a network protocol such as IEC-61850 GOOSE, the number of sources and open points can be increased as well.

At the time of the development and implementation of the original DA scheme, this utility and most others used three pole tripping reclosers and controls. Programmable three pole and single pole tripping recloser controls and the independent pole interrupting equipment required had been introduced but was still early in adoption by utilities. Today, the proliferation of single pole capable reclosers and controls is widespread and although not all utilities operate their systems using single pole tripping, the potential to design protection schemes to meet specific needs is available including some automation schemes.

There are several things that could be considered to build on the original DA scheme to improve the operation and increase the reliability indices savings. Starting with what might be the easiest way to improve would be to adapt the settings to a blocking type scheme for coordination of more devices. This would provide an improvement to traditional time overcurrent characteristic based coordination margins in that with a blocking signal, the margins between devices only need enough time to allow for the blocking signal to arrive and so the traditional 12-18 cycles of margin that were traditional between devices can be reduced down to 2 or 3 cycles. This type of scheme also makes it such that the margins are not necessarily cumulative. The end devices (i.e., R1 and R6) that would normally have the highest tripping times based on the margins adding up along the feeder to maintain coordination between several devices. The delay now can be consistent and only long enough to allow the blocking signal to be received from an adjacent device. Depending on the load distributions and sensitivities required, it may also be possible that the same setting file could be applied on all the devices on the feeder. This type of scheme also isn't limited to the number of devices placed on a feeder so segment sizes can be as low as the expenses can be tolerated for adding devices on the feeder. Another benefit from the blocking-based coordination schemes is that it allows tripping/clearing times to be lowered to as little as a few cycles. Lowering the clearing time reduces the time a voltage sag may show up on adjacent feeders during the fault. This may reduce the number of problems caused to customers on the faulted feeder as well as adjacent feeders due to the sag.

The second improvement would be to move to single pole tripping. While at the time the original DA scheme was being developed, single pole tripping was just beginning to be considered, it is widely adopted now with a variety of manufacturers offering equipment for that mode of operation. With single pole tripping, the same scheme could have been implemented with an additional reliability improvement from the avoidance of 2 of the 3 phases experiencing blinks and the permanent fault segment being reduced by 2/3's as well for single phase faults which are by and large the most common type of faults experienced. The paper [3] describes the savings as well as some solutions for some of the inherent problems with single pole tripping.

The single pole tripping improvement could also be carried over to the blocking scheme improvement presented above as well. With smaller segments and now avoidance of tripping on two of the three phases for the most common type of fault, the reliability metrics could be enhanced to nearly as well as possible, certainly for permanent faults. Single pole operation may be applied to a fast restoration scheme as well. For this it would be important to work through the operation so that the tripping and isolation is ultimately done at the same devices. In the initial action the tripping device may trip, and lockout single phase then trigger the next device to open to isolate the same phase. Following, the normally open point would close to energize the non-faulted line sections. If all three phases of the normally open device were closed then, until either the tripping or isolating device is opened on the non-faulted phases, there would be a networked distribution system which is not desirable. If only the faulted phase is closed at the normally open point, then there could be depending on the location of the fault relative to the normally open point, a section where the restored sections of the system are fed from one source and the other two phases fed from the second source. This scenario is also not desirable. Both scenarios can easily be corrected with logic to trip at the preferred location. If the normally open point only closes the faulted phase to restore the outaged load, then there could be a situation where one phase is from one source and the two other phases from the second source. This is not ideal so logic should be included to isolate the two sources at the same three phase location. Tripping the remaining phases at the isolating device after restoration is completed would avoid this situation.

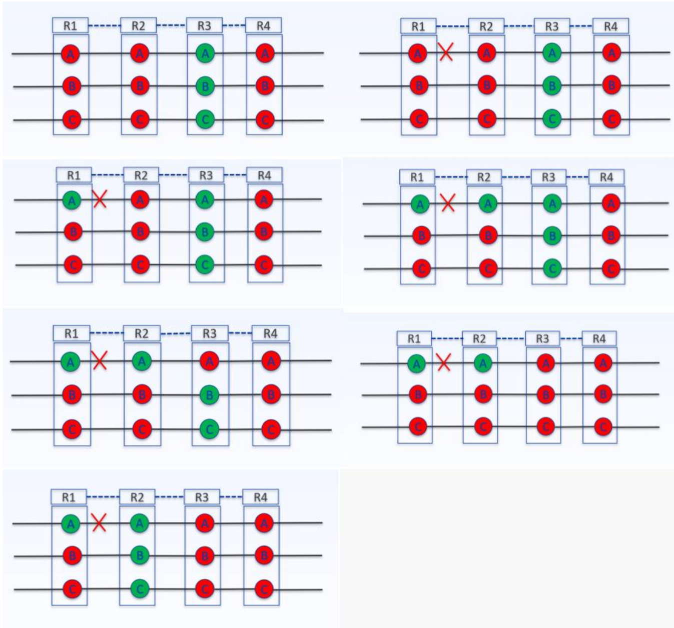

Fig. 2 Single Pole Tripping Operation for Restoration

With fiber communications between devices and high speed, secure protocols available there are many customizable options that can be built with logic in the individual protective devices or in dedicated logic processors. As the functional complexity increases though so does the logic programming required to achieve the results. Testing and commissioning complexity must also be considered but as requirements for serving critical loads as well as the call for improved customer service get stronger these schemes may become more worth the efforts required to see them implemented.

In combining modern communications with programmable relay logic, there are other approaches that could offer improvements in reliability metrics; however, some may only be reserved for premium power delivery customer/locations. In one such scheme a sensitive load might be fed from two distinct sources so that a transfer could be initiated at the onset of a voltage sag, due to a fault upstream, so that it quickly ties the load to the alternate source then isolates from the original source.

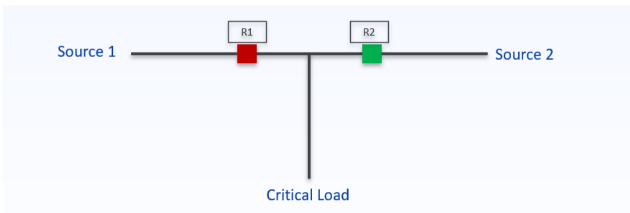

Fig. 3 Automatic Transfer Source

A simple source transfer as shown in **Error! Reference source not found.** can be easily achieved for critical load where two sources are available with a normally open point available. While this scheme is readily available in switchgear applications, it can also be easily extended to normal overhead distribution systems with reclosers. With the low cost and ease of implementation, the threshold of critical becomes perhaps less restrictive and utilities can offer premium power to more customers. The scheme typically operates with peer-to-peer communications over radio or fiber. Given the typical short distances involved either is economical for the value gained. In this simple source transfer, the scheme can be programmed to return to the normal configuration if normally there is a preferred source between the two.

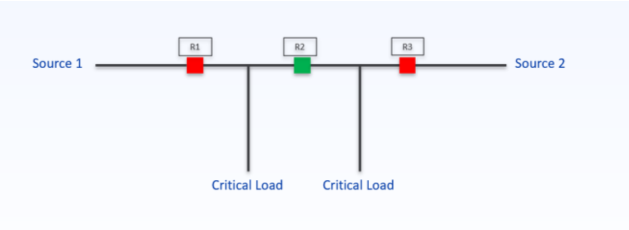

Fig. 4 Main-Tie-Main

A main-tie-main scheme is similar to the source transfer scheme described above but as shown in **Error! Reference source not found.** may be implemented where there are dual lines to the same load for highly reliable service. In the case of a main-tie-main scheme, it is typically designed to split the load when the missing source returns to normal for the redundancy the dual lines offer.

VI. The Role of Centralized FLISR in Fast Operating Schemes

The high-speed tripping and restoration DA schemes described previously offer the means to reduce tripping and outage times to the lowest values, but they don't have some of the features that a centralized FLISR scheme has. The high-speed schemes are generally limited to a defined area as the devices are programmed with logic to operate on defined parameters and it typically would not have the ability to make decisions based on system conditions to change the way it operates. A centralized FLISR system can monitor and adapt the output so it can adjust things like picking up load so that load that would be too high to pick up on one feeder could be shared among others to avoid causing more problems by overloading a circuit and causing more tripping. The tripping schemes hold value in the increased speed and potential to simplify settings and coordination but perhaps the feature that can be most impactful to reliability indices is the blocking-based coordination scheme that allows for many more devices to be coordinated on a feeder and allows the customer count and distance between devices per segment to be adjusted to a balance point with cost. While the high-speed restoration feature has value in reliability metrics and with customers that may be more sensitive to outage length, combining a high-speed tripping/coordination scheme with a FLISR scheme to perform restoration with the ability to adapt provides a well-balanced protection and control strategy. Although the restoration performed by the FLISR scheme can take as long as a few minutes it usually falls below what the utility has identified as the threshold for a sustained outage. The number of customers that are in the faulted segment and the number that cannot be restored by the FLISR scheme can be as low as the utility decides by adding protective devices on the feeder.

VII. Conclusion

The scheme the authors collaborated on 2 decades ago continues to perform in its original state and has historically performed well. Although, historical records for the entire life of the scheme are not available, data for more than a decade shows a significant savings contribution to the utility's reliability indices and improved service for the customers served from the feeders involved. For its time, the scheme was outside of the norm for utilities and displayed some opportunistic planning and foresight in taking advantage of the limited opportunity to have fiber on distribution. With communication advances, other more "packaged" schemes were available to utilities and this utility moved toward those type schemes in parallel with this original DA scheme. In current times, the tools to create more advanced schemes are prevalent. Fiber is being installed routinely on distribution feeders and protocols like IEC-61850 GOOSE offer the benefit of "mass" communication now versus the peer-to-peer protocol utilized in this original DA scheme. With more devices communicating information, more complicated feeder arrangements and multiple sources can be accommodated to increase the footprint of the automation. Coupled with a centralized FLISR system, the high-speed tripping to clear faults at the lowest times and high-speed restoration in locations where that is a priority along with the smart switching from the FLISR on the rest of the system, the two offer a very good option to maximize service to customers, commercial and residential alike.

VIII. References

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IX. Biographies

Dustin McNeely received his Bachelor of Electrical Engineering Technology from Southern Polytechnic State University (now Kennesaw University) located in Marietta, GA in 2008 and his Master's degree in Engineering Management from Vanderbilt University in 2022. He is a registered Professional Engineer in the State of Georgia and an IEEE member. Upon graduating, he worked one year as a test engineer before joining Coweta-Fayette EMC 14 years ago. He was recently promoted within the Engineering Department to the Manager of System Engineering role and oversees system protection, power quality, apparatus, metering, substations, and SCADA.

Greg Hataway, PE, received his B. S. in Electrical Engineering from the University of Alabama in 1991. He has over 33 years of broad experience in the field of power system operations and protection. Upon graduating, he worked for 12 years at Alabama Electric Cooperative where he worked in distribution, transmission, and substation protection before assuming the role of Superintendent of Technical Services at the cooperative. He joined Schweitzer Engineering Laboratories in 2002 as a Field Application Engineer in the Southeast Region working with SEL in stints from 2002-2009 and then 2012-2018. In 2018, he moved to the services industry working for EASi Engineering who later became Actalent Services. He joined Burns & McDonnell in 2023 where he holds the title of Business Line Manager for Protection Applications in the Southeast Region. He is a registered professional engineer in the states of Alabama, Georgia, Texas and Mississippi and a member of IEEE.

Bryant Grace, PE, graduated from the University of Alabama with a BSEE in 2012 and an MSEE in 2013. He has spent time working as a project engineer, application engineer for a relay manufacturer, and consulting engineer in the power systems industry. In 2023, Bryant joined Burns & McDonnell, serving as a senior project engineer in the Substation Protection Applications group. His responsibilities include developing relay settings, coordination studies, QA/QC activities, solar interconnection studies, and project management. Bryant is a registered professional engineer in the state of Alabama.

Brett Cockerham, PE, earned his BSc in electrical engineering technology, summa cum laude, in 2014 and his MSc in applied energy and electromechanical systems in 2016. Both degrees were awarded by the University of North Carolina at Charlotte. In 2014, Brett joined Schweitzer Engineering Laboratories, Inc. (SEL) as an application engineer focusing on power system protection and control. In 2023, Brett joined Burns and McDonnell as a senior electrical engineer with responsibilities in performing coordination studies, protective relays settings and logic, event analysis, relay testing, etc. Brett is a registered professional engineer in the state of North Carolina and a senior member of IEEE.