Distribution Automation: Multiple Scheme Complexity & Benefits

An overview of the benefits in implementing schemes with multiple reclosers

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***Abstract*—Distribution Automation (DA) is a rapidly growing and quickly evolving sector of the recently emerged Smart Grid initiative. DA is being implemented by many electric companies across the United States and continues to gain momentum as utilities look to provide their customers with a more reliable and uninterrupted service. This paper focuses on the description of complex Distribution Automation schemes utilizing multiple reclosers. There are numerous benefits in the application of DA on distribution networks across the national grid. The analysis presented here aims to discuss a variety of different schemes, including autonomous Full Loop, Half Loop, and peer-to-peer communication schemes. Each example is analyzed in a step-by-step manner. A brief examination of the complications involved with the implementation of DA schemes is also presented.**

***Index Terms*—Distribution Automation, Recloser, SCADA, Loop Scheme, CAIDI, SAIFI**

I. Introduction

The primary goal of a utility is to provide maximum continuity of electric service to their customers in an economical manner. It is important for us to be aware that the procurement of electric power through short or long term contracts between utilities and power providers is an important factor to ensure lower electricity rates for customers. This makes the maintenance and improvement of operation efficiency in the deregulatory environment important to provide power to customers at acceptable reliability levels. In the current system, transmission and distribution are regulated while generation competes in the open market [2]. Therefore, the regulator's goals are focused to create a balance between the dollar paid by the consumer and the return-on-investment the shareholders of the utility are allowed to earn.

The reliability indices (CAIDI and SAIFI) are often used to track the benchmark reliability performances in terms of reducing outage duration and frequency. Since the Northeast Blackout of 2003, utilities have been investing a significant portion of their annual budget on automated grid monitoring. The term Distribution Automation (DA) refers to a set of technologies that enables remote operation in real time [1]. Distribution automation and system monitoring can meet quality of service improvement while cost justification can be aligned with the corporate objectives of the system performance improvement.

DA offers a self-healing capability to the electric grid that allows issues such as faults to be resolved even before customers become aware of them. Some of the profound benefits are an increasingly observable network (especially at lower voltage levels), bi-directional power flows to avoid congestion, and demand-side management measures that allow for a controllable load.

Some of the power reliability applications that come with distribution automation are line voltage monitoring, industrial and commercial load management, automated line switches, capacitor bank controllers, sectionalizers, and reclosers [3]. A recloser is essentially a self-contained device to interrupt fault current by sensing overcurrent. With a time delay, it re-energizes the line by closing automatically. When it is necessary to isolate the faulted section from the main part of the system due to a permanent fault, the recloser locks open after a preset number of reclosing operations (typically 3 or 4) [5].

In order to make a positive impact on reliability of supply, distribution automation schemes must be able to operate when needed. Identifying incipient failures, scheme performance issues, or problems with equipment health before they result in failure of the scheme to operate when needed is an important task: it ensures that schemes perform in such a way that justifies the investment in the first place [4]. This includes the health and performance of the communication systems on which they may rely. Often, such information is implicit in the power systems data that engineers use to make assessments.

There is no one ideal DA scheme that would be suitable for every distribution system. However, there are a few schemes that have been successfully implemented in the United States, and those are the focus in this discussion.

II. Loop Schemes

DA recloser schemes on a distribution feeder can be as simple as a single recloser or can consist of multiple ties and reclosers. The DA recloser schemes aim to segment a feeder such that the reliability indices of that feeder, mainly the System Average Interruption Frequency Index (SAIFI) and the

Customer Average Interruption Duration Index (CAIDI), improve greatly. One such autonomous way of setting up a DA scheme is called a “Loop Scheme” (LS). The LS is useful for applications where the emergency tie line has the available amperage capacity all year long and analysis has been previously performed to ensure the emergency tie line will not be overloaded by picking up sections of an adjacent faulted line. The advantage of LS is that it does not require peer-to-peer communication between each device but still provides data to the Supervisory Control and Data Acquisition (SCADA) system. The two essential building blocks of complex loop schemes (Half Loop and Full Loop) are presented here.

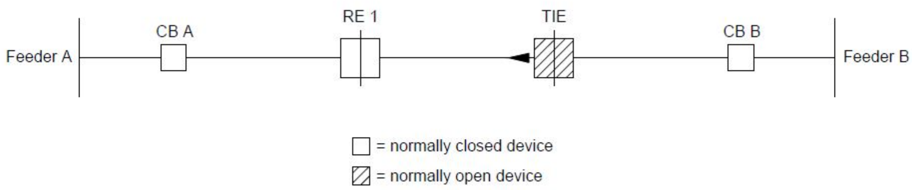

Fig. 1. Half LS with no peer-to-peer communication

Figure 1 shows an example of a simple Half LS in which the tie recloser is programmed to pick up faults in one direction, thus called a “Half Loop Scheme”. A Half LS is implemented in Figure 1 because the emergency allowable amperage rating on Feeder A is not sufficient to pick up any more load from Feeder B. The arrow on the TIE device signals that Feeder B will pick up (on loss of voltage) the customers between RE 1 (recloser 1) and TIE. Feeder B will always have the appropriate amperage reserved to pick up the aforementioned section based on previously performed load studies.

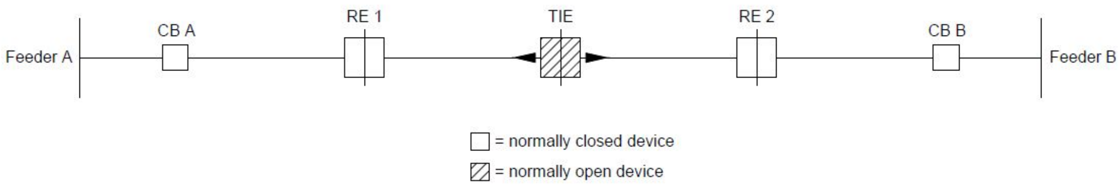

Fig. 2. Full LS with no peer-to-peer communication

Figure 2 shows an example of another simple LS in which the tie recloser is programmed to pick up line sections in either direction. The arrow on the TIE device signals that both Feeder A and B will pick up (on loss of voltage) the segment between the TIE and RE 1 or RE 2. Both Feeder A and B will always have the appropriate amperage reserved to acquire the aforementioned sections based on previous studies performed. A Full LS is advantageous because it benefits both feeders with their respective SAIFI and CAIDI indices. However, studies performed on the feeders may show that they do not have year-long allowable emergency amperage available, and since the devices work autonomously, they will not be useful for LS. In such cases, peer-to-peer communication, discussed in Section V, would be a great option.

III. Feeder Topology

The type of scheme used is dependent on the topography of the feeder and the allowable amperage for its emergency rating. To explain the topography of a feeder, consider the following case, with a 3000 customer count. The feeder has multiple ties, both close to the starting point (station) and near the ending point where most of the load is. If a simple DA scheme were to be used with 1 recloser and 1 tie recloser then the simplest design would be to split the customer count in half, or 1500, customer count segments. However, based on the topology of the feeder and where the ties are located this is not achievable. Figure 3 shows multiple customer count sections. Section faults, 1 through 4, have also been shown with an X symbol, to analyze which type of scheme may be set up. The analysis would be performed for Feeder A and the greatest advantage for SAIFI and CAIDI indices would be to set up a DA Full LS with all three ties available. The difficulty of setting up such autonomous schemes is that the recloser coordination is difficult to achieve through multiple devices with no peer-to-peer communication ability. This is due to the recloser’s minimum trip rating and time delays. Since it is economically advantageous to be standardized when installing reclosers, (devices from the same manufacturer) the reclosers cannot achieve coordination and thus another scheme needs to be implemented [6].

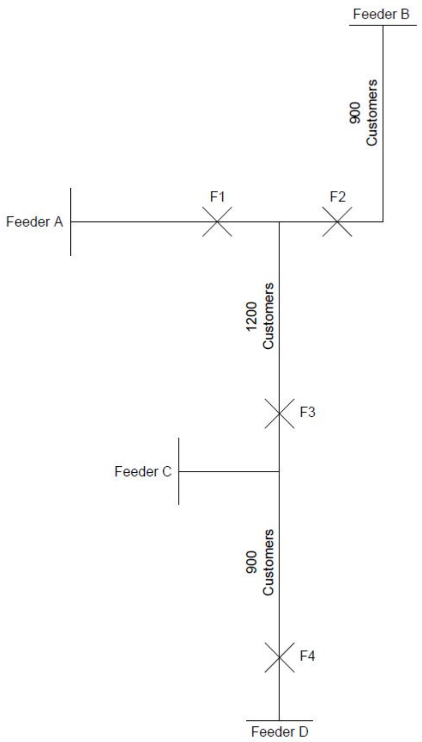

Fig. 3. Case 1 Topology

IV. COMPLEX LOOP SCHEMES

Though coordination is difficult to achieve between reclosers with no peer-to-peer communication, an option does exist where the feeder can be split up into multiple segments and still benefit from using autonomous LS's. Figure 4 shows one such example of implementing multiple autonomous schemes. From the example in Figure 4 it is important to note that Feeder A has a combination of Full LS's and Half LS's installed.

A Half LS (Scheme 2) is used on Feeder A because it will exceed its allowable emergency amperage rating if it picks up additional load from Feeder B. However, RE 2 in Scheme 2 is a Three-Phase Sectionalizer (i.e. a recloser programmed as a sectionalizer). The sectionalizer is used because of coordination issues between RE 1 and RE 2 [6]. The sectionalizer will not break fault current but will be programmed to open, on loss of voltage, typically 1 count prior to the recloser locking out. A recloser's attribute is generally adjustable according to the design need of the distribution feeder, but for this example, RE 1 is programmed as a 3-shot-to-lockout device. Consider the following fault on Feeder A between RE 2 and TIE 1:

1. RE 1 opens on fault current; CB A remains closed.
2. RE 2 sees an over-current followed by a loss of voltage when RE 1 opens and RE 2 (sectionalizer) counts to ONE.
3. TIE 1 and TIE 2 start timing to close on a loss of voltage.
4. RE 1 closes after 2 seconds.
5. Then RE 2, TIE 1, and TIE 2 timers reset when RE 1 closes.
6. RE 1 trips open due to fault still present; CB A remains closed.
7. RE 2 sees an over-current followed by a loss of voltage when RE 1 opens and counts to TWO. The RE 2 total preset count has been met. RE 2 opens and locks-out while RE 1 is open.
8. TIE 1 and TIE 2 start timing to close on a loss of voltage.
9. RE 1 closes after 30 seconds and remains closed, as the fault was isolated by the opening of RE 2.
10. TIE 2 timers reset when RE 1 closes. TIE 1 remains open.
11. Loss of voltage causes TIE 1 to close 60 seconds after RE 2 opened.
12. TIE 1 closes into the fault and trips open due to the fault current.

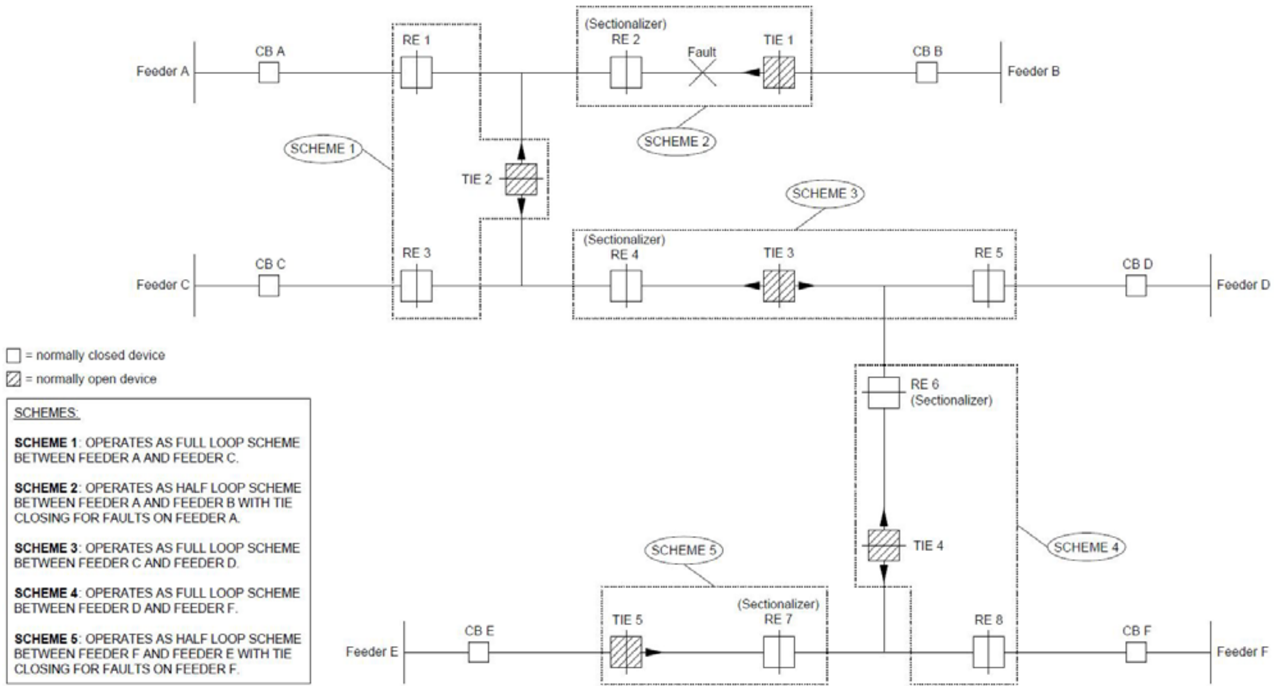

Fig. 4. Complex Loop Scheme Example

The fault has been isolated to the segment between RE 2 and TIE 1 autonomously. Feeder A's sections for Scheme 1 have been picked up with the normal feeder by the locking-out of RE 2. Feeder A's Scheme 1 section saw two momentary interruptions but not a sustained outage. This combination of Full LS and Half LS is beneficial because it allows the feeders to take advantage of the multiple ties located throughout the feeder topology. The LS system can only operate properly if adequate loading analysis was performed for the distribution feeders prior to the development of the DA scheme. From Figure 4, it is clear that the distribution network can get complex with multiple ties. These tie feeders can have their own multiple ties to other distant feeders. Thus, the planning for DA schemes can be very involved.

V. Schemes with Peer-To-Peer Communication

Although autonomous recloser schemes, such as Full LS and Half LS, are very effective in improving SAIFI and CAIDI indices for a distribution feeder, the feeder topology and tie locations may not allow perfectly split sections with low customer counts. Consider a distribution feeder with just a single tie location and 1500 customers as shown in Figure 5.

The topology of the line does allow multiple 500 customer segments. However, as stated earlier, an autonomous recloser scheme would not be achievable due to time-delay coordination issues [6]. Also, a scheme with a recloser and a three-phase sectionalizer would only allow the feeder to be split in half. Thus, the most advantageous scheme would be to have three 500-customer segments as shown in Figure 5.

A DA scheme with peer-to-peer communication would benefit from the ability to test an upstream line segment before fully closing, to prevent unnecessary $I^2 \cdot t$ damages to the distribution feeder's equipment. Devices such as S&C's IntelliRupter® PulseCloser possess this capability to test line segments [9]. A scheme with reclosers having relays for peer-to-peer communication will achieve the quickest isolation and restoration of power to other segments of the distribution feeder. Decreased restoration time depends on the type of high-speed communication available. Generally, optical fiber is used but other high-speed communication devices, such as S&C SpeedNet™ Radios, can also be used where fiber is not available [7] [8]. Figure 5 shows the breakdown of a 1500 customer count distribution feeder with 1 tie.

Consider a permanent fault between RE3 and TIE:

1. An overcurrent through RE 1 forces it to open and relay information through peer-to-peer communication to open RE 2 and RE 3 even if they have not tripped in real time.
2. With RE 1 sensing voltage on its source side it would send a pulse current to test the first line segment.
3. With no fault detected RE 1 would close and energize the segment between RE 1 and RE 2.
4. RE 2 pulse closes to test the next line segment.
5. With no fault detected RE 2 would close and energize the segment between RE 2 and RE 3.
6. RE 3 pulse closes to test the next line segment.
7. RE 3, sensing a fault would pulse close one more time before locking out and remaining open.
8. RE 3 would relay information to the TIE notifying the relative location of the permanent fault and preventing the TIE from closing in on a fault.

VI. Cost Effectiveness And Design Complications

For most utilities, it is beneficial to standardize DA scheme installations for financial purposes (e.g. bulk ordering from a single manufacturer). With each recloser costing anywhere from $20,000-$30,000, improper installation can defeat its purpose and have a negative effect on the reliability of the distribution feeder [6] [8]. The DA planning and implementation can also vary significantly because of multiple factors as explained in the previous sections.

Some common mistakes in installing DA schemes in the field are: improper orientation/installation by field construction personnel, improper locations of installations due to mistakes made by the distribution line designer, and schemes being very close to the maximum allowable amperage ratings of lines.

If the proper installation standards of DA devices are not closely followed, complications can arise. For example, certain manufacturers require their products to be installed in a specific direction, so the construction personnel need to apply particular care when setting up the devices. With the possibility of human error in the installation process, damage to equipment, lines, and workers can occur.

In many utilities, the actual studies performed and schemes planned are usually done by a distribution engineer or planner. When the project diagram is given to a distribution line designer, they must correctly read the scheme and implement it

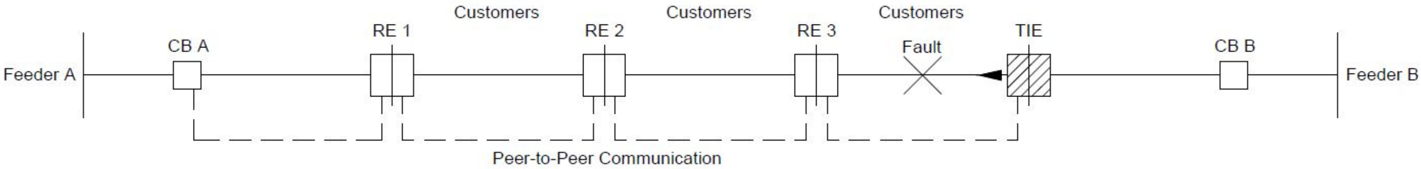

Fig. 5. DA scheme with peer-to-peer communication

into a construction drawing/design. If the reclosers are placed in the wrong areas of the feeder topology then the scheme will not work as planned by the distribution engineer/planner.

For autonomous schemes, it is undesirable to be very close to the emergency current rating of the tie feeder. Based on the maximum allowable amperage rating of the tie, when the scheme is planned, one must account for unforeseen variances in peak summer loads. In other words, the scheme must be designed to be resilient to varying changes in load on the tie feeder for LS.

VII. Conclusion

DA system installations, specifically recloser schemes, are increasing in number and complexity. The DA schemes discussed in this paper are some of the more commonly implemented schemes by utilities. The option to go with one scheme versus another typically depends on the reliability needs of the distribution feeder, the feeder topology, and the geographical location (urban versus rural). The benefits to the customer and utility outweigh the initial setup and installation costs of the DA schemes. Frequency and duration of outages are reduced so the consumer can continue to pay for electricity usage. Thus, the utility does not lose revenue for minor transient fault events. Electric consumers will see greater reliability in the future as DA schemes play a bigger role in moving into a smarter grid.

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IX. Biographies

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