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Improving Reliability on Mixed Overhead and Underground Distribution Feeders

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SUMMARY

Many utility companies are converting overhead (OH) main line feeder sections to underground (UG) to improve reliability, system resiliency, or other local customer demands. A Hybrid distribution feeder is one with a mixture of OH and UG main line sections. Conventional protection philosophies for hybrid feeders normally result in lower overall feeder reliability. This paper will examine an example feeder to demonstrate the impact of protection and isolation system improvements on predicted reliability for Hybrid distribution feeders.

KEYWORDS

FLISR, SAIFI, SAIDI, MAIFI, Distribution Feeder Reliability Improvement

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INTRODUCTION

Distribution system overcurrent devices have been applied by electric company distribution engineers to detect and clear system faults to minimize the probability of damage to equipment due to sustained faults. Inspection and maintenance of lines is performed to minimize the number of faults that are experienced on the feeder. Despite these efforts, the exposure to weather, animals, vegetation, vehicles and other hazards results in the expectation that some number of system faults will still be experienced. To mitigate the extent of outages, equipment is placed on the feeder to identify fault conditions and quickly isolate faulted sections of the distribution feeder.

In addition to recognizing and clearing overcurrent conditions caused by fault events, the same equipment elements are used in an overall system that performs Fault Location, Isolation, and Service Restoration (FLISR). These systems apply greater levels of system automation and integration designed to reduce outage times for customers that are somewhat remote from the actual faulted section of the feeder. The demand for these types of systems increases with customer expectations for high reliability.

Many electric utilities focus reliability improvement initiatives around maintenance activities, such as tree trimming, aimed at reducing the number of fault events. These activities should result in a lower fault rate for the feeder section as measured by faults per mile per year. It can be shown that investments in sectionalizing and automation systems, such as the design of overcurrent protection systems to better sectionalize the system after a fault, also have major reliability improvement potential for any given fault rate. If fault records indicate that many events were tree related, then increased vegetation management expense may be justified. However, in many utility situations where fault records exist, "unknown" may be the largest category of fault causes listed.

In areas where high fault rates have been experienced, or areas where customer demands for various reasons warrant the investment, utilities are converting sections of the distribution feeder from overhead (OH) to underground (UG) construction. The reduced exposure to weather, animals, and other physical hazards normally results in a lower fault incidence rate for UG construction. Since cost is higher for UG construction, the application along the feeder may only be in limited areas, resulting in a mix of OH and UG main line feeder miles. This presents challenges to conventional overcurrent protection philosophies that can result in lower overall feeder reliability. This paper will examine the application using an example feeder and demonstrate that new protection equipment technology can achieve the improvement needed to capture the intended reliability improvement

FEEDER OVERCURRENT PROTECTION STRATEGIES

Distribution system overcurrent conditions are detected and interrupted when needed using a variety of devices that include fuses, reclosing devices (single phase or three-phase), and circuit breakers in substations. The devices are designed to operate in a coordinated fashion to isolate the smallest part of the system possible for each fault event. Coordination studies are completed by system protection engineers for specific feeders with knowledge of system short circuit currents at points on the feeder. Protection philosophies are followed according to individual company developed standards, but the overall final design includes engineering judgements on the part of the distribution protection engineer. The application of the protection systems also impacts the sectionalizing of the feeder that results in accumulated outage numbers used in calculating reliability indices for the feeder and overall system.

Electric distribution companies utilize strategies to recover from the fault events experienced on the distribution feeders, since faults may be transient or persistent. A transient fault is one where fast interruption of the fault current prevents any damage to line conductors or equipment that would require a repair crew and the circuit can be automatically reclosed after a few seconds to restore service. A persistent fault cannot be re-energized without a service crew performing some equipment or line repair or replacement. The mix of transient and persistent faults on the feeder impacts the selection of overcurrent protection system philosophy regarding equipment interaction as a system.

When applying interrupting devices that can be reclosed along the main line and fuses at lateral connections to the main line, a choice is made between two overcurrent protection methodologies called “fuse saving” and “fuse sacrifice”. Fuse saving utilizes a fast-trip-and-reclose scheme to clear transient faults on the laterals before the fuse has operated. This causes a momentary outage to all customers located downstream of the reclosing device but overall reduces sustained outages. This scheme is often used in rural areas or when repair time is longer due to the time for crews to get to the fuse location. A fuse sacrifice philosophy can reduce momentary outages by eliminating fast tripping on relayed circuit breakers and downstream overcurrent devices. The elimination of fuse saving may reduce momentary operations, but it increases the overall sustained outage minutes, since transient faults on fused laterals result in a fuse operation and sustained outage. This scheme is often used in urban areas where crews can quickly arrive to the scene and make repairs and/or replace the fuse link. Intelligent fuse saving systems technologies can now be applied that blend the best of both techniques to further enhance reliability. Intelligent fuse saving prevents a fuse saving attempt when a fault interrupter’s fault clearing time for a measured fault current cannot prevent fuse operation. This is in contrast to conventional fuse saving schemes that often result in the fuse and the fault interrupter both operating.

Reliability rates can also be improved by employing automation to minimize outages resulting from either transient or persistent faults. It can be shown that sectionalizing of a radial feeder has an improvement limit and diminishing returns may not produce the desired reliability level from sectionalizing alone. Once this point is reached further improvement can be realized by sectionalizing to minimize the faulted portion of the system with feeder ties to alternate sources, such as neighboring feeders.

The general approach used to design higher reliability distribution service on radial feeders includes the following initiatives:

1. Use automatic reclosing to eliminate outages caused by transient faults on OH sections. General industry practice avoids reclosing on UG systems since cable faults are normally persistent. Therefore, hybrid main line distribution feeders present a protection challenge with the mix of UG and OH construction. However, a low-energy fault testing fault interrupter can be used to avoid reclosing into faults and further stress system components for all forms of feeder construction.
2. Use automatic reclosing on lateral circuits to eliminate momentary operations of main line devices for faults on the lateral circuits. UG and hybrid circuits essentially preclude the fuse saving philosophy. The steps taken in this example feeder will show the benefits of re-introducing reclosing and fuse-saving using a cutout-mounted recloser at the lateral level.
3. Sectionalize the system to limit the number of customers affected by a persistent fault and reduce the time necessary to locate a fault. Smart switches can accomplish this, but fault interrupting devices can further limit the affected area.
4. Build for improved reliability by including bridging points to alternate sources that are managed by a distributed intelligence automation system that reconfigures the system following an outage based on monitored system conditions.
5. Reduce device hazard rates. This can be driven by a root cause analysis to determine maintenance levels required to drive feeder fault rate to target levels.

The subsequent sections examine a typical radial utility distribution feeder with the objective being improvement of reliability indices through selection and application of appropriate fault interrupting equipment. Calculations are performed for each equipment addition to demonstrate the improvement that each step provides in the reliability indices.

EXAMPLE FEEDER EXAMINATION FOR RELIABILITY IMPROVEMENT

Figure 1 shows a simplified one-line diagram of a distribution feeder served by a substation bus located at the left side of the figure. The main line is 5.9 miles in length and provides radial service to customers that are served on laterals at the end of the feeder. There is a short section of main line UG construction shown in red (270 feet). The remainder of the main line is OH. Total circuit miles for all 3-phase, 2-phase, and 1-phase lines is 20.18 miles of OH and 1.81 miles of UG construction.

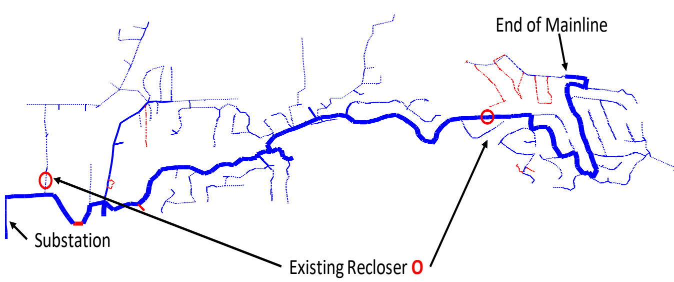

Figure 1. One-line diagram of example distribution feeder used for analysis.

The 12.47 kV feeder being analyzed is a problem feeder that is primarily OH construction with a customer count of approximately 1300 and reliability that is not near company targets. Outage data was broken into a variety of categories with the largest numbers due to lightning and vegetation. The main line feeder is radial as shown in Figure 1 with many laterals connected to the main line. Total feeder load is approximately 9 MVA.

The base case reliability calculations used fuse saving on the main line feeder recloser and three-phase lateral recloser near the substation. Fuse saving was disabled on the substation circuit breaker to help reduce momentary interruptions for all customers on the feeder. Most laterals are fused at the connection to the main line and there are several long laterals that have additional fuses placed downline in series. The following are the base case reliability indices for the feeder:

SAIFI:	11.97 Sustained Outages / Customer-year
SAIDI:	20.44 Outage Hours / Customer-year
MAIFIe:	22.83 Momentary Outages / Customer-year

CIRCUIT CHANGES IMPLEMENTED TO IMPROVE RELIABILITY

Next, improvements to the feeder construction and the protection system design will be applied and the resulting changes in the reliability indices calculated. The following sections summarize the changes to the circuit.

Convert selected sections of the Main line from OH to UG and add selected lateral circuit devices

The existing sections of the main line are predominantly OH. There are many utility companies that are converting sections of OH to UG, either to meet local demands for aesthetic improvements or to improve the overall feeder reliability. In this feeder example three sections of the main line have been converted to UG cable. They are shown in Figure 2 as sections shown in red. The end of line UG section is 5500 ft, the midline UG section is 2600 ft. and the section near the substation is 2200 ft. The underground part of the main line is 38% of the feeder.

A protection system upgrade to this feeder shown in Figure 2 includes the replacement of fuses at 5 feeder lateral locations using cutout-mounted reclosers (TS2). This type of device can sense overcurrent conditions, trip and then reclose to clear transient faults. It can also be configured to provide the fuse saving strategy for sections of the lateral that have fusing which further sectionalizes the lateral for persistent faults. The five lateral locations selected were the longer lateral circuits that would be expected to experience one or more faults per year.

The number of faults expected in the new UG sections of the main line is lower than for the OH line sections. After the conversion of the OH to UG of 38% of the main feeder length the reliability experienced by the customer population served by the feeder should improve. Applying a lower fault rate to the new underground feeder sections results in the following expected reliability indices:

SAIFI:	7.63 Sustained Outages / Customer-year
SAIDI:	13.85 Outage Hours / Customer-year
MAIFIe:	18.84 Momentary Outages / Customer-year

As expected, all the reliability indices have improved and this is a direct result of the lower number of fault events expected along the main line with 38% of it now UG.

However, with a significant part of the main line now UG construction, the use of standard reclosing philosophies becomes questionable due to the higher probability that a fault might be in the UG line sections. Faults in UG cable are a result of punctures of the solid insulation system in the cable and removing the applied voltage does not result in the insulation system restoring to full capability as would be the case with OH construction. Reclosing will result in a second (or third or fourth) fault current event until the protection device locks out. This re-application of fault current results in additional equipment stress. As a result of the UG main line conversion the reclosing on the feeder overcurrent devices will need to be blocked, but the trade-off is that any main line fault event becomes a single operation to lockout of the main line recloser or the substation circuit breaker.

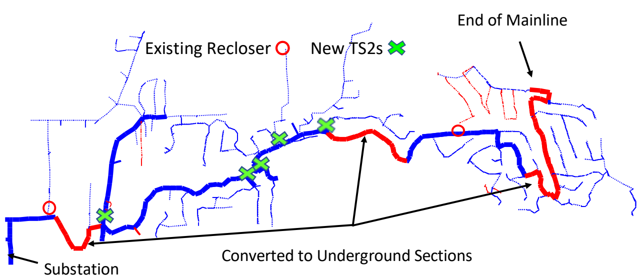

Figure 2. One-line diagram with the addition of 5 cutout-mounted reclosers (TS2), sections changed to underground construction and existing devices.

Likewise, any faults on all fused laterals will result in a sustained outage because a fuse saving strategy requires reclosing to implement. Therefore, transient faults downline of all lateral reclosers are the only faults that will be automatically cleared and service restored.

A simulation of the feeder reliability with the reclosing at the substation breaker turned off on the feeder results in the following reliability indices:

SAIFI:	18.27 Sustained Outages / Customer-year
SAIDI:	23.31 Outage Hours / Customer-year
MAIFIe:	1.32 Momentary Outages / Customer-year

The change to the feeder construction and the protection system has resulted in dramatic changes to the reliability indices for the feeder. Despite the reduction in the expected number of faults by converting 38% of the feeder to UG, the overall sustained reliability has not improved when compared to the expected performance of the original OH feeder design. The momentary events have been reduced by a large amount since there is no longer any main line device reclosing. This is due to the fact that any main line fault event, whether transient or persistent, results in a sustained outage since a protection device opens and does not reclose. Any fused lateral fault also results in a sustained outage, even for transient faults because fuse saving can no longer be practiced. The result is higher sustained outage numbers, with SAIFI increasing by over 50% relative to the base case circuit configuration. This is a direct result of the inability to use traditional reclosing on main line devices without any ability to test the circuit for sustained faults in the UG line sections.

The continued industry innovation in distribution line protection equipment has resulted in the development of low-energy fault-testing technology that can be effectively applied in situations such as this example feeder. In circuits that have UG sections of the line, low-energy fault-testing technology can identify if a fault on the circuit is persistent and prevent a reclosing operation when there is a cable fault. If the fault is present in an overhead line section and is transient, this new technology will determine that the fault has cleared after the circuit has been de-energized and the circuit can be re-energized. The application of circuit protection devices with the low-energy fault-testing feature allow the system to take advantage of the presence of transient faults on the OH sections of the line and block reclosing for persistent faults in either the OH or UG sections of the feeder.

Add main line fault interrupters with low-energy fault-testing capability and additional lateral cutout-mounted reclosers

The circuit with the new UG main line sections can be sectionalized to provide improved reliability for the customers connected to the feeder using three fault interrupter devices with low-energy fault-testing technology. These devices would be placed upstream of each UG main line section where the main line circuit is OH construction. Options exist for pad-mounted low-energy fault testing fault interrupters if there is a desire to place these devices in the UG portion of the OH/UG transition. The result is each section has a mix of UG and OH main line construction and the low-energy fault-testing feature of the fault interrupter will be applied to allow reclosing after successful interruption of transient faults in the OH line sections and prevent reclosing for persistent faults in either the OH or UG feeder sections. The device locations are shown on the one-line diagram in Figure 3.

This intelligent reclosing following a test of the circuit using low-energy fault-testing is applied to regain the reliability improvement expected by converting OH main line sections to UG. A simulation of the feeder reliability with the low-energy fault-testing technology applied on the feeder results in the following reliability indices:

SAIFI:	7.16 Sustained Outages / Customer-year
SAIDI:	11.82 Outage Hours / Customer-year
MAIFIe:	4.29 Momentary Outages / Customer-year

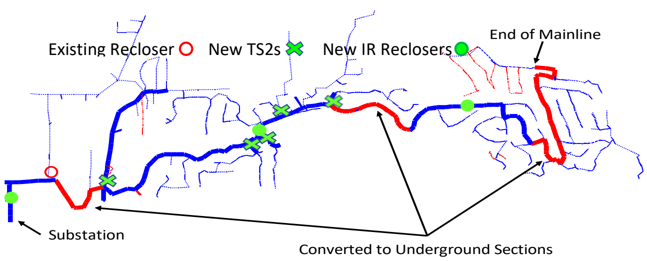

Figure 3. One-line diagram with two additional low-energy fault-testing fault interrupters (IR), 5 additional cutout-mounted recloser (TS2) devices, underground conversions and existing device locations shown.

The use of low-energy fault-testing technology results in a significant reduction in the reliability indices for the feeder compared to the original feeder design. The sustained outage rate experienced by the average customer on the feeder has been reduced by approximately 40% (11.96 to 7.16). The momentary outage rate experienced by the average customer on the feeder has been reduced by approximately 81% (22.82 to 4.29). The dramatic reduction in the momentary outage rate is because there is a lower main line transient fault rate due to the UG conversion plus the protection system operating in a fuse sacrifice mode.

Add cutout-mounted reclosers in the heavy customer concentration at the far end of the feeder

Laterals connected to the feeder are predominantly OH construction that typically would have a large number of transient fault events. The lateral exposure is approximately 70% of the total feeder construction. The main line devices are not configured in a fuse saving protection mode, so these transient faults result in a sustained outage for the lateral customers when the fuse operates. This will add to the sustained outages experienced by customers connected to the feeder.

The design of the fault detection system for a distribution feeder requires that decisions must be made that impact operations as well as overall outage rates. Cutout-mounted reclosers placed at lateral connection points can help reduce the number of sustained outages by tripping and reclosing when transient faults are experienced. In the case of a fuse operation a service crew would need to be dispatched to replace the fuse to restore service. Overhead laterals that have sufficient length to experience frequent faults can quickly justify the cost of a cutout-mounted recloser. Payback is typically achieved after a cutout-mounted recloser clears four transient outages, saving four field visits by a line crew.

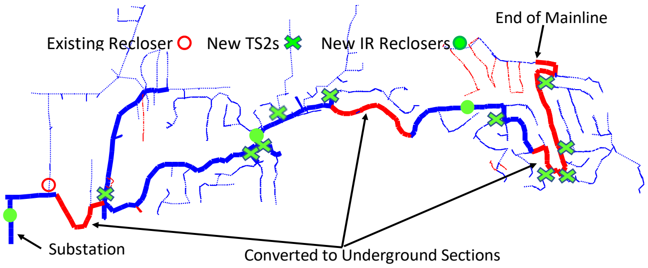

Figure 4. One-line diagram with 5 additional cutout-mounted recloser (TS2) devices, previous improvements and existing device locations shown.

The following reliability improvement strategy examined the impact of adding five additional cutout-mounted recloser locationss. Lateral locations near the end of the feeder were selected for applications of these devices. This results in the ten longest laterals on the feeder being equipped with cutout-mounted recloser devices that only trip and reclose the faulted lateral circuit. The five additional (TS2) locations are shown in Figure 4.

The addition of the five cutout-mounted recloser locations on the longest laterals connected to the circuit in the downline location and coordinated to work with the upstream low-energy fault-testing fault interrupter is expected to further reduce the number of sustained outages. The following are the resulting reliability improvement indices for the feeder:

SAIFI:	6.86 Sustained Outages / Customer-year
SAIDI:	11.61 Outage Hours / Customer-year
MAIFIe:	4.64 Momentary Outages / Customer-year

Momentary interruptions have increased slightly (≈8%) with the application of the additional five cutout-mounted recloser locationss. This occurs because any lateral reclosing device causes downline customers to experience brief interruptions instead of sustained outages as transient faults are sensed and cleared. However, the sustained outages experienced for the average customer served by the feeder has decreased as a result of the clearing of these transient fault events.

Add a low-energy fault-testing fault interrupter tie point device located near the end of the feeder using non-communicating or communication-based automation to restore service

Serving a distribution feeder in radial fashion results in limits to the resulting reliability experienced by the average customer on the feeder. Sectionalizing the feeder into smaller segments helps to drive down the outage frequency and outage time but customers at the end of the feeder are still impacted by fault events between the substation and customer location. The ability to serve the customers with an alternative source during an outage can further drive down the outage time experienced. With a second source of supply at a strategic location on the feeder, smaller sections can be isolated for persistent faults, while quickly restoring other customers on the feeder.

In this example a tie point is added near the end of the feeder with an alternate source that has sufficient capacity to recover the unfaulted load when a fault occurs on the feeder. The restoration process in this example can be accomplished through a loop scheme type of application that does not require communications between devices or it can also be completed using an automation system that uses the feeder loading data prior to restoring service. In either case the service can be restored in times that are faster than the threshold for sustained outage recording. The fault event does result in a momentary outage to some customers while the automatic fault

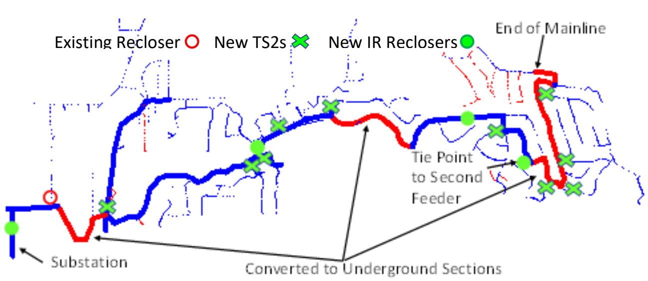

Figure 5. One-line diagram showing previous improvements, the addition of a tie-point low-energy fault-testing fault interrupter (IR) and existing device locations.

clearing, and restoration action is completed. Figure 5 shows the feeder with the devices added and the location of the tie point to an alternative feeder that recovers unfaulted feeder load when needed.

The addition of the feeder tie and capability to restore service to customer loads when a main line persistent fault is experienced is expected to improve the sustained outage reliability numbers. For example, a sustained fault in the mid-line UG section would normally result in a long outage for customers connected to the end of the feeder. With the feeder tie, there is a brief outage to customers as sectionalizing devices open on the main line to isolate the cable fault and the tie device closes restoring service. This does result in a momentary outage to these customers, but the sustained customer outage event (SAIFI) and the outage event time (SAIDI) are avoided. The following are the resulting reliability indices for the feeder:

SAIFI:	4.45 Sustained Outages / Customer-year
SAIDI:	3.00 Outage Hours / Customer-year
MAIFIe:	7.05 Momentary Outages / Customer-year

Momentary interruptions increase with the application of the tie device and automatic service restoration for main line persistent faults. The sustained outages experienced for the average customer served by the feeder has decreased as a result of the ability to quickly provide service from another source for these events.

PROTECTION SYSTEM COORDINATION STUDIES

The addition of the main line and lateral protection devices resulting in the higher reliability experience for the average customer on the feeder require devices that can be coordinated to function as an overall system. The philosophy examined earlier when calculating the performance of the system assumed that the main line devices would not apply a fuse saving strategy but would be configured to reclose following a low-energy test of the feeder sections prior to reclosing. Fuse saving will be applied on the lateral interconnection point to the main line using cutout-mounted recloser devices to prevent outages for temporary faults downstream of fuses on the laterals.

Settings applied consider the full load current expected at the protection device location as well as the fault currents that are experienced by the device at the installation location and at the remote end of the feeder where that device would be called upon to sense and clear any fault. A fault analysis for the feeder was completed to obtain the fault currents described to compare against the protective device curves. One will note that the fault currents increase with the feeder changes due to the lower overall main line feeder impedance of the underground cable sections compared to the equivalent length of overhead construction.

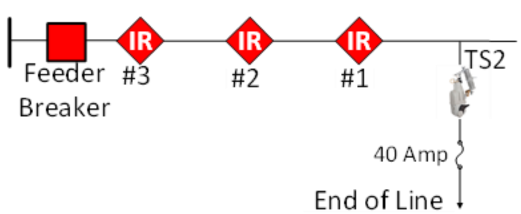

Figure 6. One-line diagram with coordinated series low-energy fault-testing fault interrupters.

Main line low-energy fault-testing fault interrupter time-current characteristic curves (TCCs) were selected as an example to demonstrate the ability to coordinate multiple devices along the feeder. The tighter overcurrent protection response tolerances of the low-energy fault-testing fault interrupters are desirable when considering placement of multiple series devices when all the tolerances of a device's performance are considered.[3] In this example, a fault that is experienced at the more remote parts of the feeder on a single-phase lateral will result in fault current flowing through as many as six overcurrent devices – the substation relayed circuit breaker, three main line low-energy fault-testing fault interrupters (IR#1, IR#2 & IR#3), one cutout-mounted recloser (TS2), and one 40 Amp fuse that is closest to the fault. Figure 6 shows a simplified one-line diagram with the protection devices. Table 1 shows the details of the load current and fault current at the location of each of the six devices.

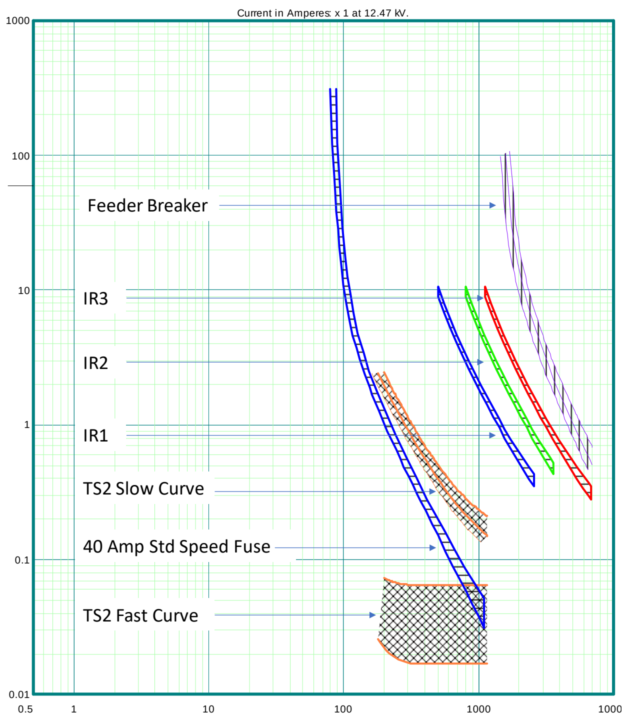

Figure 7. TCC curves selected for example feeder devices. Note: TCC curves are truncated at the maximum available fault current for their respective devices

The operating current and tolerance-based TCC curve [4] selected for achieving the desired coordinated fault sectionalizing of each example feeder device results in the curves shown in Figure 7. As a general starting point, the minimum operating current was selected based on approximately 2.5 times the maximum load current expected at each device location. The maximum fault current at each device location was also examined using the values shown in Table 1. The final device is a 40-ampere fuse that is down line of cutout-mounted recloser on a lateral. The cutout-mounted recloser fast (fuse saving) and delayed (fuse sacrifice) curves selected are also shown. A final consideration in a TCC selection and setting might also include its minimum fault sensing capability where a line to ground fault is considered with an impedance. For this example, a minimum fault current of 180 amperes for a single-line-to-ground fault on a lateral was applied. This value is within the operating range of the fuse and cutout-mounted recloser devices placed on the feeder achieving the minimum fault sensing requirement.

Device Name	Load Current (Amps)	Fault Current (Amps)
Feeder Breaker	450	6863
IR #3	450	6863
IR #2	320	3600
IR #1	200	2585
TS2	17	1165
40 Amp Fuse	9	1100
End of Line	0.45	1013

Table 1. Fault currents at low-energy fault-testing fault interrupters (IR #s), cutout-mounted recloser (TS2), 40A fuse and end-of -line locations.

SUMMARY AND CONCLUSIONS

This paper has examined the impact of converting a distribution feeder from entirely OH design to a hybrid design that has multiple sections of the main line converted to UG construction. The initial change included the OH to UG conversion and addition of lateral cutout-mounted recloser devices at five locations, but no change to the main line feeder overcurrent protection devices. The application of UG feeder construction will normally result in reclosing being undesirable using conventional protection equipment since faults in the UG sections are typically persistent faults. The reliability is negatively impacted by eliminating reclosing because a significant part of the feeder remains OH construction. Reclosing can be used provided protection equipment unobtrusively tests the feeder for persistent faults using low energy prior to a reclose attempt which the low-energy fault-testing fault interrupter provides. Applying these devices upstream of the three cable sections in the example feeder allows a reclosing strategy to be applied without risking reclosing on a faulted circuit.

Cutout-mounted reclosers were used to replace fuses at 10 lateral locations on the feeder to offset the loss of fuse saving for transient faults on the lateral circuits – a fuse saving strategy was abandoned because of UG feeder section additions. This equipment provides improvements to overall feeder reliability as reflected in the summary of the predictive reliability analysis shown in Table 2. In addition to the reliability benefits, the cutout-mounted recloser devices also offer reduced O&M costs by eliminating the time required to replace fuses for transient fault events.

Long laterals were selected to produce an estimated payback on this example feeder in less than 2-years due to the high fault rate.

The final radial feeder alternative (with no normally open tie to an adjacent feeder) examined the application of state-of-the-art protective devices using low-energy fault-testing technology along the main line and cutout mounted reclosing devices at 10 selected lateral locations. This resulted in a 43% reduction in sustained outage indices compared to the average customer experience with the original OH circuit design. The momentary outages experienced by the average customer was reduced by approximately 80%. Table 2 is a summary of the reliability values for each alternative discussed in this paper.

The addition of an automated normally open tie device further improved the sustained outage indices. This addition resulted in a 63% reduction in sustained outage indices compared to the average customer experience with the original OH circuit design. The load restoration of unfaulted feeder segments using the automated normally open tie increases the momentary outage index in order to drive down sustained outages and sustained outage times. But the momentary outages experienced by the average customer is still reduced by approximately 69% compared to the original OH circuit.

Description	SAIFI	MAIFIe	SAIDI
Base case - All OH Feeder	11.97	22.83	20.44
OH main line sections converted to UG. Added Lateral Devices at 5 locations with reclosing enabled.	7.63	18.84	13.85
OH main line sections converted to UG. Applied cutout-mounted recloser devices on 5 selected lateral locations. Main line device reclosing disabled.	18.27	1.32	23.31
OH main line sections converted to UG. Applied cutout-mounted recloser devices on 5 selected lateral locations. Main line device reclosing enabled using 3 low-energy fault-testing interrupters.	7.16	4.29	11.82
OH main line sections converted to UG. Applied cutout-mounted recloser devices on 10 selected lateral locations. Main line device reclosing enabled using 3 low-energy fault-testing interrupters.	6.86	4.64	11.61
OH main line sections converted to UG. Applied Cutout-mounted recloser II devices on 10 selected lateral locations. Main line device reclosing enabled using 3 low-energy fault-testing interrupters. Added automated feeder tie device to line end area.	4.45	7.05	3.00

Table 2. Reliability index comparison summary of example feeder alternatives.

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