DISTRIBUTION RELIABILITY USING RECLOSERS AND SECTIONALISERS

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I. Introduction

This paper presents a comparative analysis of distribution reliability improvements that can be achieved by using various outdoor distribution devices. There are two objectives for this paper: First, it is to discuss the application of the most common types of devices, including line reclosers, automatic sectionalisers and manual switches. Second, an analysis to quantify the reliability improvements that can be achieved by using each (or a combination) of these devices, as well as a combination of these devices.

As background on distribution reliability and the need for its improvement, one explanation is as follows. De-regulation has resulted in a major cost cutting at many utilities. These cost cuts in equipment, crew size, maintenance, etc., could mean major reductions in reliability. State utility commissions, hearing these concerns, have reacted by requiring the reporting of reliability indices and in some states setting performance standards. In some cases, mandates, penalties and awards have been enacted or are being considered. The question to the utility is, quite frankly, how do I increase reliability at the lowest possible cost? Add to this concern the fact that power quality for sensitive loads has created many new areas of concern (momentaries and sags might be just as bad as sustained feeder interruptions) and you have the dilemma virtually every utility in the world is facing. Reclosers, sectionalisers and switches address these concerns.

In the application section of this paper, mechanical and electrical aspects of each type of switching device will be discussed. For reclosers, by example, the common configurations (i.e., single phase, three phase, loop systems) and ratings will be covered. Advantages and disadvantages of each type of apparatus will be discussed relative to the other types of switching devices. In the reliability section, typical System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), and Momentary Average Interruption Frequency Index (MAIFI) values for several radial and loop configurations utilizing reclosers, sectionalisers and switches will be presented. The Customer Average Interruption Duration Index (CAIDI) will not be covered since there is no significant difference between device selection as it applies to the restoration of permanent faults. I.e., it takes approximately as long to close reclosers after a permanent fault as it does for sectionalisers and switches.

In the comparison section of this paper, three-phase reclosers with single phase tripping capability and single phase switches will be compared to three phase gang operated devices in the same applications. Three phase reclosers with single phase capability devices have become more commonplace with the development of

magnetic actuation, and brought into the market as a tool specifically to improve distribution reliability.

There are a number of papers written on improving reliability directed towards one type of device (i.e., reclosers, sectionalisers or switches) in various configurations. This paper is geared toward comparing and utilizing a combination of these equipment types to gain the highest possible reliability improvements. This includes conventional configurations, as well as some non-conventional configurations worthy of exploration.

II. Distribution Reclosers

Reclosers have been around for a long time and have always been considered one of the "workhorses" of distribution system overcurrent protection. A distribution recloser is designed to interrupt both load and fault current. Also, per its term, it is designed to "reclose" on the fault repeatedly in a predefined sequence in an attempt to clear the fault. Reclosers are predominantly located on the distribution feeder, though as the continuous and interrupting current ratings increase, they are more likely now to be seen in substations, where traditionally a circuit breaker would be located.

Reclosers have two basic functions on the system, reliability and overcurrent protection. While one of the philosophies for the use of reclosers is to increase reliability, in the past their use for many utilities was determined primarily because the feeder breaker did not have protective reach to the end of the feeder.   This was due to the fact that high load currents forced the minimum trip setting to a higher value than the fault level at the end of the feeder. Nowadays, reclosers are more frequently applied for reliability reasons, mainly due to three of their benefits: Reclosing capability, single phase reclosing, and automated loop capabilities.

Reclosing: Reclosing, for over 30 years, was normal for virtually all utilities since most lines were overhead and most temporary faults could be cleared by the recloser before the fuse operated (feeder selective relaying). Modern reclosers have open times as low as 100 milliseconds, allowing consumer power quality devices such as microwaves and clocks to not be affected by momentaries.

Single-phase Reclosing: Single phase reclosers for main line feeders are more readily available. Traditionally, single phase reclosers operated as standalone devices with no electrical or mechanical connection between phases, and had lower interrupting ratings. Modern reclosers, however, reclosers with three phase tanks and higher interrupting ratings have been introduced which have 1 phase reclosing capability.   Single phase tripping yields significant improvements in reliability, as demonstrated later in this paper.

Automated Recloser Loop Systems: Reclosers can be configured to work together in an automatic restoration system.   Automatic restoration provides a significant improvement in the SAIDI and SAIFI index, with common applications including 3, 4 or 5 reclosers. Protection on single phase basis can compliment loop systems to further

improve reliability. This paper is intended to compare reclosers, sectionalisers and switches, in the most common arrangements of up to three devices (2 midpoints and one tie) outside the substation. Using more than 3 units on the system further improves the reliability of a given system.

In addition to the protective and reliability benefits, reclosers with newer, more sophisticated controllers have several additional useful features for application on distribution feeders:

- **Directionality -** The increased use of distributed resources and automation may make the ability to trip in each direction with different settings a requirement.
- **Under/Over Voltage and Frequency -** The ability to monitor, alarm and control on these power quality events. Underfrequency shedding may be necessary or mandated in some regions of the country.
- **Power Quality Monitoring -** Performance based rates will force utilities to monitor their system performance at all levels.
- **Load Monitoring -** Equipment loading will become a much greater issue as higher loading of equipment to reduce costs becomes a factor. The recloser could monitor this.
- **Fault Monitoring -** Information such as coordination success, I^2t, fault levels, success of reclosing sequences, oscillographic capture, etc., provide utilities with data to improve system performance at virtually no cost.
- **Flexibility -** Since no one can predict the future, especially in the environment we find ourselves today, one of the major requirements of any intelligent device is that it must be flexible to changing system needs. Reclosers can easily be reprogrammed with settings to match existing conditions.

III. Sectionalisers

Sectionalisers can either take the form of a cutout with a CT ring around the tube and an electronic actuation module, or they may take the form of a solenoid/actuator driven devices with 6 bushings. Three phase setionalisers are devices which often look similar to reclosers, but they have different functionality.   The term "Sectionaliser" is not to be confused with the generic term "Sectionalising" device, which is sometimes referred to as the first recloser (outside the substation) in an automated loop restoration system. The functionality of this device is significantly different.

The function of a sectionaliser is not to interrupt a faulted line, but instead count the fault occurrences on the line and upon a predefined number of counts, and open up when the line is de-energized. The interrupting device, which allows the counting action, is either an upstream recloser or circuit breaker in the substation.

Sectionalisers are often used in locations where coordination with other devices is difficult due to tight coordination curves, or they can be used in place of fuses in high fault current areas (i.e. single or three phase taps near the substation) where it is difficult to coordinate with the fuse. In either case, sectionalisers perform only as a feeder selective ("save the tap") arrangement, requiring the main line device to operate in order to open.   This may be disadvantageous where there are critical loads on the main feeder, where a reduction in MAIFI is important.

Though sectionalisers are generally lower cost than reclosers, they have several features useful for the utility:

- **Discrete Timing –** Detailed coordination study is not required.
- **Independent Phase Operation –** Some models have the capability to sectionalize on a single phase basis.
- **Cold Load Override –** If the recloser has been in the open state for some time, it is possible to have the sectionaliser "count" which can cause a miscoordination event. Newer controls can make the counting dependent on voltage, which can prevent this circumstance.
- **One Shot Mode –** Some sectionalisers can be switched over to one shot mode for safety purposes or to reduce the number of main feeder interruptions.

IV. Switches

Manual and motor operated switches are the most basic type apparatus on the line. These are typically air break devices which are not typically designed for automatic operation and are for local (and occasionally remote) operation.   These devices are useful for manual temporary restoration of faulted lines, where if several are used can be useful to reconfigure a line manually to regain as much of the segments as possible after a fault. The problem with switches is mostly time. Without remote capability, a manual switch operation can take up to 1 hour, significantly impacting the overall feeder reliability.

Basic switches are typically lower in cost and provide the following features for the utility:

- **Simple device –** Undoubtedly the simplest device on the system.
- **Motor operation –** Can have motor operation to improve restoration time through SCADA.
- **Provides Visible Break –** External switch blades provide visible break for line work.
- **Often have capacitor ratings or are dedicated for capacitor switching.**

V. Reliability Comparisons

As mentioned previously, in the past feeder reclosers were primarily installed because of the need to see faults further on the line, sectionalisers in place of fuses for more defined protection, and switches were applied for reconfiguration of the feeder due to loads and manual fault restoration.

Now, these devices play a key role in meeting performance measures mandated by PUC's and demanded by customers. The question for the engineer is: Which device(s) will give the greatest reliability benefits? To assist the engineer in making decisions, including types and locations of devices on the feeder, detailed modeling programs are available. A modeling program can determine for a feeder or group of feeders the optimal location and quantity of devices that will yield the greatest reliability, taking the guesswork out of the task.

The reliability values in this paper were obtained using an analytical reliability analysis program created by ABB Consulting, which is designed to determine the best methods for improving reliability of a given feeder or system. For the purposes of this paper, an example feeder (Figure 1) is used for reliability comparisons. The specific parameters and assumptions are for a typical suburban/rural circuits and are as follows:

- 10 miles of 3-Phase 13.8 kV Main Feeder
- 8 single-phase laterals, evenly distributed on the main feeder. Each lateral 3 miles long, and connected to the main feeder through a fuse
- A total of 1800 customers (8 x 225 customers/lateral)
- Parameters doubled for tied circuits
- Manual devices require 1 hour to switch
- Recloser loop tie points take 1 minute to reconfigure
- Faults are distributed along all parts of the circuit
- The model uses 0.12 sustained faults per year per mile and 0.18 temporary faults per year per mile
- There are 0.04 sustained faults per year per mile per phase and 0.06 temporary faults per year per mile per phase
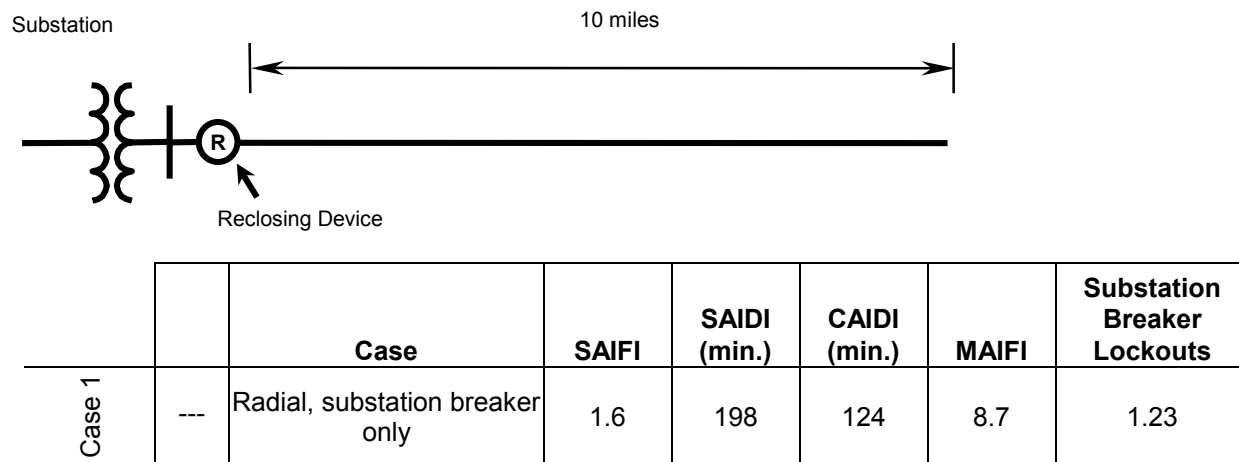
Figure 1 – Typical Distribution Feeder
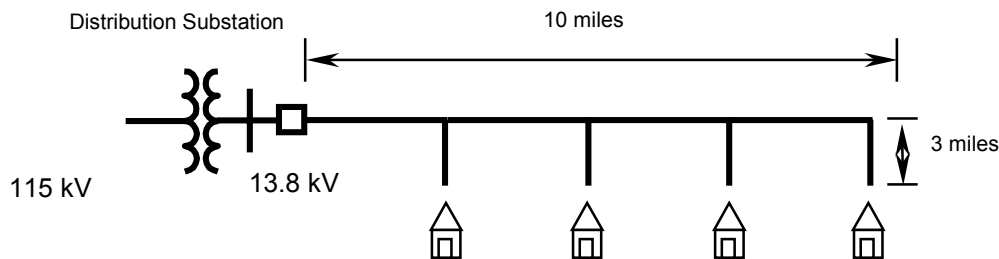
When quantifying the reliability indices for various configurations, it is important to establish a base case. The base case used in our model is given in figure 2. This

case consists of only one protective device, located at the substation. It assumes that this substation device is either a recloser or a circuit breaker with reclosing capabilities. The reason for this is that it has become un-common to have a substation device without reclosing in the substation for suburban/rural feeders. In each figure, calculated reliability indices for various devices in that arrangement is indicated.

Figure 2 - Substation Breaker or Recloser set to multiple operations (Case 1).

		Case	SAIFI	SAIDI (min.)	CAIDI (min.)	MAIFI	Substation Breaker Lockouts
Case 1	---	Radial, substation breaker only	1.6	198	124	8.7	1.23

For Case 2, a midpoint device is added to the feeder. Figure 3 identifies all the considered configurations. Note that device type "D" represents several considered devices. This (radial) feeder configuration is most common in rural areas, where tie-points are not typically feasible.

Figure 3 – Addition of Midpoint Devices (Case 2a – 2e).
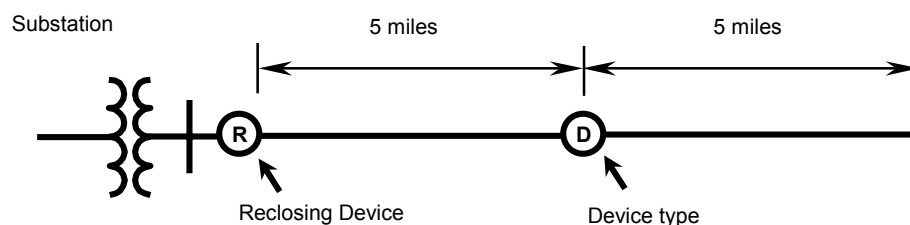
Where Device type "D" is Case:
2a. Midpoint switch
2b. Midpoint sectionaliser
2c. Midpoint recloser
2d. Midpoint 1 phase switches
2e. Midpoint recloser with single phase tripping and lockout

		Case	SAIFI	SAIDI (min.)	CAIDI (min.)	MAIFI	Substation Breaker Lockouts
Case 2	a.	Radial, midpoint switch (ganged)	1.6	178	105	8.7	1.23
	b.	Radial, midpoint sectionaliser (3φ)	1.3	160	124	9.0	0.62
	c.	Radial, midpoint recloser	1.3	160	124	6.4	0.62
	d.	Radial, midpoint switches (1φ)	1.6	170	105	8.7	1.24
	e.	Radial, midpoint recloser w/1φ reclosing	1.1	139	126	5.0	0.63

For case 3, a tie point device is added to the feeder. Figure 4 identifies all the considered configurations. When considering this type of feeder, all the physical characteristics are doubled, i.e., two times the size feeder considered in Case 1 and 2.

Figure 4 – Addition of Tie Point Devices (Case 3a – 3e).
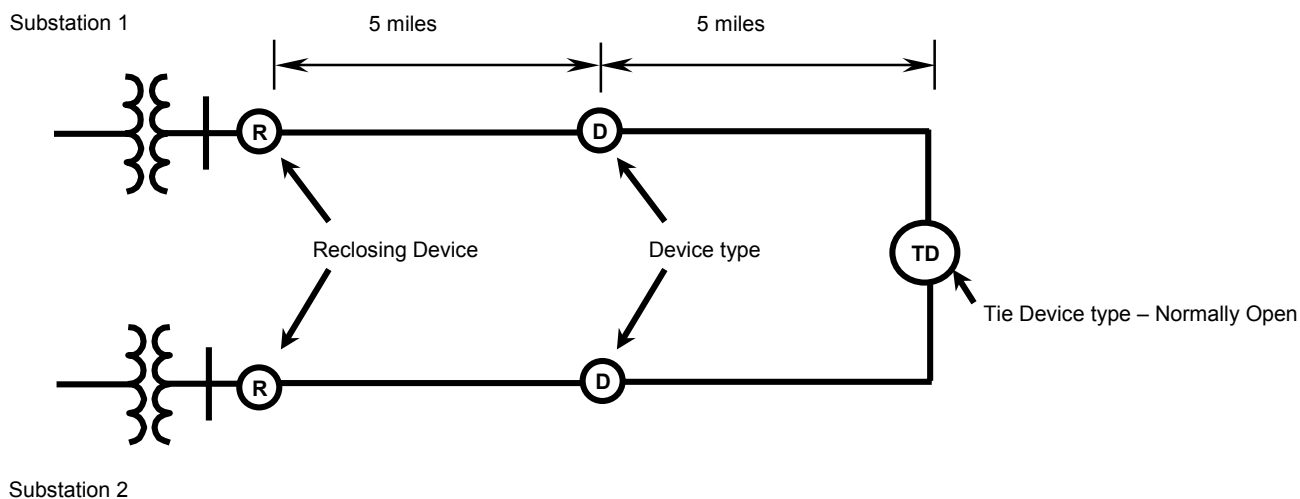
Where Device type "D" is Case:
3a. Midpoint switch and tie switch
3b. Midpoint sectionaliser and tie switch.
3c. Midpoint recloser and tie switch.
3d. Midpoint 1 phase switches and tie switch.
3e. Midpoint recloser with single phase tripping and tie switch.

		Case	SAIFI	SAIDI (min.)	CAIDI (min.)	MAIFI	Substation Breaker Lockouts
Case 3	a.	Looped, midpoint switch (ganged), w/ tie switch	1.6	177	111	8.7	1.23
	b.	Looped, midpoint sectionaliser (3φ) w/tie switch	1.3	139	126	9.2	0.63
	c.	Looped, midpoint recloser with tie switch	1.3	140	109	6.4	0.62
	d.	Looped, midpoint switches (1φ)	1.6	167	104	8.7	1.25
	e.	Looped, midpoint recloser w/1φ reclosing with tie switch	1.1	118	107	5.0	0.63

For Case 4, automated reconfiguration systems using reclosers are considered. The system shown in Figure 5 is the same size as that given in Case 3. The type of system being considered performs reconfiguration based on voltage, ad the only devices that include the automated reconfiguration logic are the three devices outside the substation. Four and five unit loop schemes are also used, which yield improved reliability results, though these are not considered in this paper.

Figure 5 – Automatic reconfiguration systems using reclosers (Case 4a & 4b).
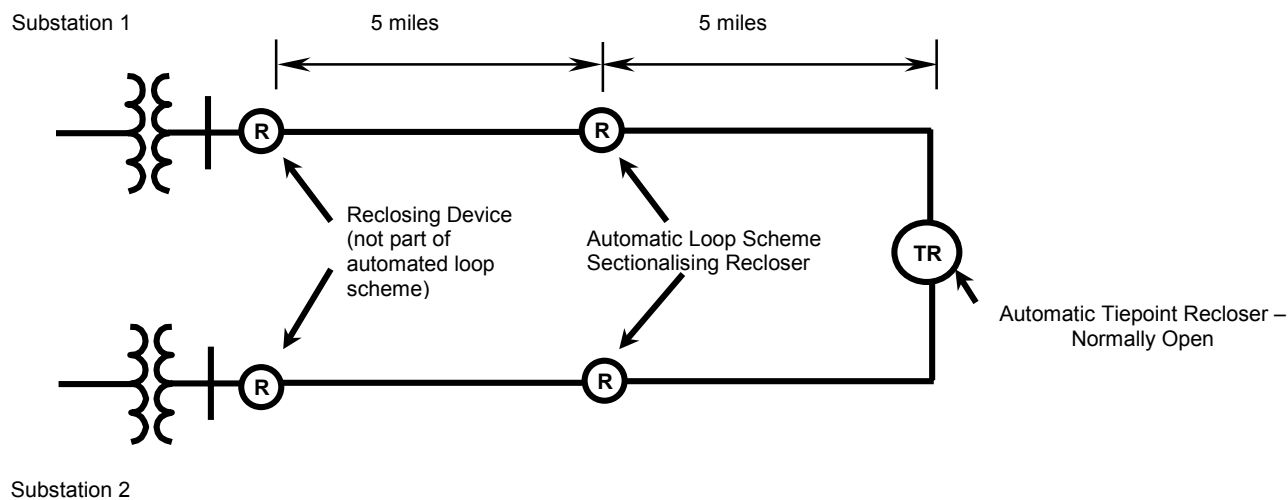
Where all reclosers outside substation (3 total) are set up in Case:
4a. Three recloser automatic loop scheme
4b. Three recloser automatic loop scheme with 1 phase tripping

		Case	SAIFI	SAIDI (min.)	CAIDI (min.)	MAIFI	Substation Breaker Lockouts
Case 4	a.	3 Recloser auto restoration	1.0	122	124	6.7	0.62
	b.	3 Recloser auto restoration w/1φ reclosing	0.8	99	126	5.3	0.63

VI. Reliability Summary

What do all the numbers in Table 1 mean? It is difficult to weigh all the parameters in a cost benefit equation. It is instead useful to separate the data into categories which can be correlated to the specific needs of the utility on a feeder level or on a system level. In other words, if a particular feeder is having problems with frequent interruptions, SAIFI could be of greater importance. SAIDI may be of greater importance where continuity of power is high priority (refrigeration, industrial, etc). In any case, it is in the best interest of the utility to analyze feeder circuits which have the most critical loads and have the worst reliability. These feeders will have the greatest impact on improving the overall system and customer satisfaction.

Table 2 indicates the percentage improvements for each of the cases indicated above. The CAIDI index is not included in the comparison due to the fact that the system configuration has relatively little effect on the value. If there is a permanent fault where a line crew is dispatched, it will take approximately the same amount of time to fix it, regardless of the type devices used.

The examples utilizing reclosers are highlighted as reclosers are typically associated with the highest reliability improvement. Though this is generally the case, each Index/variable will be discussed.

Table 2. Percentage Reliability Improvement Summary and Expected Substation Breaker Lockouts for all Cases (Calculated)

		Case	SAIFI %IMP	SAIDI %IMP	MAIFI %IMP	Substation Breaker Lockouts
Case 1	---	Radial, substa. bkr only	Base	Base	Base	1.23
Case 2	a.	Radial, midpoint switch (ganged)	None	10	None	1.23
	b.	Radial, midpoint sectionaliser (3φ)	19	19	-3	0.62
	c.	Radial, midpoint recloser	19	19	26	0.62
	d.	Radial, midpoint switches (1φ)	None	14	None	1.24
	e.	Radial, midpoint recloser w/1φ reclosing	31	30	43	0.63
Case 3	a.	Looped, midpoint switch (ganged), w/ tie switch	None	11	None	1.23
	b.	Looped, midpoint sectionaliser (3φ) w/tie switch	19	30	-6	0.63
	c.	Looped, midpoint recloser with tie switch	19	29	26	0.62
	d.	Looped, midpoint switches (1φ)	None	16	None	1.25
	e.	Looped, midpoint recloser w/1φ reclosing with tie switch	31	40	43	0.63
Case 4	c.	3 Recloser auto restoration	38	38	23	0.62
	d.	3 Recloser auto restoration w/1φ reclosing	50	50	39	0.63

The following is a summary of these reliability improvement results.

A. SAIFI Improvment
Switches yield no improvment in the SAIFI simply because they do not automatically segment the distribution feeder. The application of a sectionaliser or recloser at the midpoint yields a 31% improvement in SAIFI.

The sectionaliser and recloser provide the same reliability since their functionality is effectively the same for midpoint applications.

Adding a tie switch does not have any effect on SAIFI.

Automatic loop restoration improves the SAIFI due to the fact that less customers are included in outages due to the tie restoring segments of the line. In our example case, the significant improvement is seen for customers downline of the sectionalising recloser, when the fault is between the substation and the sectionalising device. The tiepoint is able to restore that segment of feeder within one minute, avoiding a SAIFI event for those customers.

Single-phase reclosing yields an approximate 12% improvement in SAIFI over three phase reclosing and is generally independent of the system configuration, be it radial, looped or automated loop. Single-phase switches, however, do not have any effect.

B. SAIDI Improvment

SAIDI constitutes the amount of time the average customer is without power over a one year period. The assumption is that a switching operation takes 60 minutes, while an automated recloser operation takes 1 minute. Essentially anything that is placed on the line, whether it is a switch, sectionaliser or recloser will improve SAIDI. As can be seen in Table 2, The effect goes up incrementally from a basic 3 phase switch (10% improvement) to a more sophisticated 3 recloser, single-phase reclosing automated loop scheme (50% improvement). In effect, the decision on which method is best, if SAIDI is the main objective, is a cost/benefit comparison. One notable item is that Case 3, utilitzing single-phase reclosing at the midpoint with a basic tie switch (no automatic restoration) actually yields better SAIDI performance than a three-phase automated reclosing system. This suggests that if unless you plan to include single phase reclosing in an automated loop scheme, it may not be worthwile in terms of SAIDI to incorporate loop schemes.

Single-phase reclosing yields an approximate 11-12% improvement in SAIDI over a comparable system with three phase reclosing.

C. MAIFI Improvment

Momentary interruptions (any interruption in service) are most effectively reduced by using reclosers. The ability to interrupt faults closer to the location of the fault instead of interrupting the whole feeder provides one of the most dramatic improvements in any of the indeces discussed. If the feeder has sensitive loads near the substation (often the case on the typical feeder), it is advantageous to place a recloser beyond that segment, vs. a switch or sectionaliser.

Single-phase reclosing yields an approximate 16% improvement in MAIFI over a comparable system with three phase reclosing. This is due to the fact that for most faults, two-thirds of the customers will see no interruption in service.

D. Breaker Lockouts

In all of the cases studied, breaker lockouts are directly related to the number of sectionalisers or reclosers placed on the feeder, assuming equal distribution of customers and equal placement of devices. Though not a consideration in this paper, if the subsation breaker is a single-phase capable recloser, lockouts on a customer basis can be significantly improved on a feeder. This technique is applied at many utilities today, made possible by the higher interruption capabilities of today's reclosers.

VII.   Combining Devices on Systems

It is often the case that systems have more than one of the above type devices on a given system. There are instances where the system has existing equipment of a certain type that is different than new installed type. Some of these cases are covered in the above comparisons, such as the application of sectionaliser midpoints with manual switch tie points (case 3b) or recloser midpoints with switch tie points (case 3c and 3e). From the model, it is shown that the addition of a switch tie point to a feeder with either a sectionaliser or a recloser will yield a 10% SAIDI improvement. However, adding a switch to these type of systems will have no impact on SAIFI and MAIFI.

VIII.   Conclusions

The models given in this paper represent a symmetric system, 10 miles long, with evenly distributed taps. In practical application for actual systems, the model can factor in more parameters, such as including portions of the feeder where faults are more frequent (more trees, for example), and can come up with recommendations for the locations of devices which may provide reliability values even better than those outlined in this paper.

All devices discussed in this paper offer an improvement in reliability. Switches will improve SAIDI. Midpoint switches also possess significant value for tie-point applications where feeder ties are possible. Sectionalisers and reclosers perform relatively closely for the various configurations except that reclosers offer more improvement for MAIFI. The highest possible accross the board improvement is achieved by using single-phase reclosers and single-phase reclosing loop schemes.

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