THE EFFECT OF REDUCING MOMENTARY OUTAGES ON DISTRIBUTION RELIABILITY INDICES

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ABSTRACT

Momentary outages are one of the major causes of power quality complaints. One method of reducing momentary outages is to eliminate the instantaneous trips on the feeder breaker, thereby making all lateral faults permanent. While this practice does indeed reduce the number of momentary outages, it can adversely impact reliability indices that may be reported to regulatory commissions. The purpose of this paper is to study the effect of converting momentary outages to permanent outages on distribution feeders, as well as to study the relationship of momentary outages to good power quality. It will also discuss the effect on reliability of adding reclosers to distribution feeders.

KEYWORDS: Power Quality, Distribution Reliability, Reclosers, Overcurrent Protection.

INTRODUCTION

In the modern era, consumers have become very sensitive to fluctuations in electric service because many of the devices they own are disrupted by short disturbances in electrical service. The typical residential consumer owns sensitive loads such as VCR's, digital clocks, and microwave ovens. Many Industrial/Commercial customers have computer driven processes which are sensitive to short disturbances in power. In the future, the number of sensitive loads will only increase and hence, utilities need to understand how momentary outages affect their systems.

The major causes of momentary outages on power systems are trees, lightning, and animals. There are ways to mitigate the effects of these problems, although many of the reduction techniques depend on the circuit configuration (including protective devices), the failure rate of the circuits, and the crew procedures. Hence, the reduction of momentary outages is utility dependent.

Since the sensitivity of today's loads is increasing, utilities are being forced to find ways to reduce the number of momentary outages that occur on their systems. In the process, difficult decisions about their present operating practices are being made. One practice that is currently the topic of much debate is Feeder Selective Relaying (FSR). Feeder selective relaying is the practice of allowing the breaker or recloser to clear momentary faults that occur on taps or in other words, allowing the fuses to operate only for permanent faults. Using FSR has two effects. First, it has the potential of saving fuses from blowing due to momentary faults. Secondly, it increases the number of momentary outages experienced by the whole feeder.

Simulations were performed to analyze the reliability of systems by varying parameters such as the circuit configuration, crew practices, weather conditions, customer types, loading practices, line lengths, failure rates, repair times and/or protective devices. The simulations were performed via a PC based computer program which is unique in respect to its ability to evaluate the effect of momentary outages on reliability indices.

SAMPLE SYSTEM

A sample study was performed on two feeders. There are two basic feeders, an urban feeder (Feeder A) and a rural feeder (Feeder B). Both feeders are assumed to have uniform load, although calculations could be performed assuming diversified load. Both feeders have been classified residential. Specific characteristics of these feeders can be found in the appendix.

The customer makeup is important when calculating reliability indices. If a feeder is primarily residential, then customer based indices must be calculated, but if a feeder is mainly industrial or commercial, then load based indices should be calculated. Feeders that are comprised of residential, industrial, and commercial customers should have both load and customer based indices calculated. Since these feeders are both residential, only customer based indices will be calculated. Figure 1 shows the simplified feeder configurations. Figures in the appendix give the exact layout of each of the feeders studied.

INDICES

One way to track the reliability of a system is through the use of indices that quantify the frequency and duration of outages. A survey of 100 US utilities was conducted to obtain information about distribution reliability practices. Some results of the survey are given here. Of the 100 companies surveyed, 48 responded. The survey concluded that the most commonly used indices in the US are SAIFI, SAIDI, CAIDI and ASAI, as shown in the bar graph below.

The formal definitions of the indices are given in Reference 1. It may be more useful, however, to define the indices in layman terms. SAIDI is the average customer minutes outage (CMO), CAIDI is the average duration of an outage and SAIFI is the average frequency of outages. In this paper SAIDI will be referred to as CMO.

The survey revealed the nationwide average, high and low values of the most commonly used indices, SAIFI, SAIDI, and CAIDI. Figures 3 and 4 show some of the results of the survey.

The graph in Figure 3 shows that the typical customer in the United States experiences approximately 1.4 outages per year. According to the survey, some customers on an average experience as much as 3.3 outages per year, while others experience as few as an average of 0.554 outages per year.

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MOMENTARY OUTAGES

A. Theory

To understand momentary outages, it is necessary to examine the three major causes of momentary outages:

- Lightning
- Trees
- Animals

In high isokeraunic areas, lightning strokes may produce the majority of momentary outages on power systems. The primary cause of a momentary outage comes from the flashover of the line due to the lightning stroke. Lightning arresters limit the overvoltage and thereby prevent the flashover which would cause a momentary outage. For other utilities, tree contact may be the number one cause of momentary outages. The best way to eliminate tree induced outages is to perform tree trimming on a regular basis. In areas where animals are a primary cause of momentary outages, devices could be installed to limit the effect of the animal. For example, in the northeast, squirrels are a large concern because they short across transformer connections. To help alleviate this problem, squirrel guards have been invented.

In addition to lightning arresters, tree trimming, and animal guards, it may be possible to minimize the effect of momentary outages by installing reclosers or modifying the protective scheme on a feeder. The installation of reclosers will protect the upstream portion of the circuit from momentary outages that occur on the downstream portion of the circuit, but may cause voltage sags which can be as harmful as momentary outages. The removal of feeder selective relaying will reduce the number of momentary outages, however, there are pros and cons to the removal of feeder selective relaying.

Some utilities are wrestling with a decision about feeder selective relaying. To better understand the role feeder selective relaying plays in the reliability of the system, simulations were performed to show the effect on reliability indices of removing feeder selective relaying. One result of removing feeder selective relaying is that momentary faults (that occur on taps) will be converted into permanent faults and hence the number of momentary outages experienced by the whole feeder will be reduced. The number of momentary faults experienced on the taps will go to zero, but the number of permanent faults will increase, possibly dramatically.

B. Results

The cases in this section were performed assuming that no manual switching was available, that the taps were protected and that an alternate supply was not available. Any of these conditions could be changed to reflect an actual system.

The effect on CMO of removing feeder selective relaying is shown in Figure 5. If feeder selective relaying is eliminated for Feeders A or B, then the CMO increases by 40-50%. Presently most regulatory commissions only require information to be reported about permanent outages. Hence, the durations that are reported to the commission will increase by 40-50%.

As noted above, reliability indices have been developed to examine frequency as well as duration of outage. Figure 6 graphically illustrates the effect of removing feeder selective relaying on the frequency index. Bear in mind, that currently most public service commissions do not require utilities to report the frequency of momentary outages. If feeder selective relaying is removed from a feeder, then the average frequency of momentary outages will decrease, BUT the average frequency of permanent outages will increase. Therefore, the indices that are reported to the commissions will increase.
SWITCHING PROCEDURES AND CIRCUIT CONFIGURATIONS

Most utilities have a number of different circuit configurations and one set of operating practices. The switching practices of a utility have a profound effect on reliability indices. Two switching practices were examined which are:

- Simultaneous Switching
- No Feeder Switching

Simultaneous switching requires a crew to divide into groups. One group locates the fault, then communicates with the other groups to immediately switch out the faulted section, then fixes the fault and communicates with the other groups to switch the section back into service. This method leaves no additional travel time for switching and hence is the fastest method of fixing a fault.

Certain feeders may have no feeder switches installed. If a fault occurs on these feeders, then the whole circuit is out of service until the fault is fixed.

Circuit configurations, as well as operating procedures, vary within and between utilities. Two ways that circuit configurations may vary are:

- Tap protection
- Availability of an alternate supply

Most US utilities protect taps off the main line (generally with fuses), however, in certain cases the taps may not be protected. Some circuits have an alternate supply available, while others are purely radial systems.

When evaluating the reliability of a system, it is important to model the system as closely as possible to the original. Varying the different parameters outlined above, will allow engineers to make educated decisions on design and operating practices.

APPLICATION OF RECLOSERS

The effectiveness of adding reclosers to increase system reliability is highly dependent on operating procedures and circuit configurations outlined above. The graphs shown in Figures 7 through 9 show the results of adding reclosers to the feeders. Note that the addition of one recloser is always at the midpoint of the feeder while the addition of two reclosers is always at the 1/3 and 2/3's points, respectively.

Weather can seriously affect reliability indices. As a result, some simulations were run to model storm conditions. Storm conditions can be simulated by varying either the feeder failure rate, the repair time, or both. The appendix gives the feeder failure rates and repair times for both normal and storm conditions.

A very interesting point is immediately visible on Figures 7 and 8. Figure 7 displays the results that occur when two reclosers are added to Feeder A under normal weather conditions and Figure 8 shows the same results under stormy weather conditions.
reclosers is not particularly effective in reducing the number of customer minutes outage.

Comparing the number of customer minutes outage experienced in normal weather conditions with the number of CMO experiences in adverse weather conditions, it is clear that the CMO increases dramatically with stormy conditions. The CMO increases because the repair time increases. During storm conditions, many customers are out of service at one time, therefore, it takes longer to fix all of the problems and a higher CMO is the result.

Figure 9 shows the results of calculating the average customer minutes outage for a feeder which has no feeder switching available, but may have an alternate supply. Notice that for this case, the addition of one recloser yields a 25% decrease in CMO. The addition of a second recloser decreases the CMO but not nearly as significantly as the addition of the first recloser. Also notice that for a feeder with no feeder switching, the CMO is greatly increased from the case where the crew simultaneously switched the fault. This would indicate that a utility with feeders that have no feeder switching and a high CMO, it would be advantageous to place a recloser at the midpoint of the feeder.

![Figure 9. Switching Procedures - Normal Weather Conditions](image)

During storm conditions, the repair times and the feeder failure rates may be significantly higher than under normal weather conditions. The study of power system quality and system reliability is highly dependent on operating procedures, circuit configurations, repair times, failure rates, weather condition, etc. It is crucial that each utility decide on operating philosophies and then protect accordingly. Many factors must be taken into account when deciding on operating procedures. Once philosophies have been established, decisions can be made about the application of feeder selective relaying and the addition of reclosers for the improvement of reliability indices.

In summary,

- Reducing the number of momentary outages by methods (lightning arresters, tree trimming) other than the removal of feeder selective relaying may be more advantageous.

- The removal of feeder selective relaying may indeed reduce the number of momentary outages seen by the whole feeder, but it will increase the frequency and duration of permanent outages on a feeder. Only permanent outages are presently reported to the commission.

- Calculating indices is customer base dependent. If a circuit has a mix of residential and industrial and commercial customers, then both customer and load based indices should be calculated. If a feeder is comprised solely of residential customers, then only customer based indices need be calculated. If the customers on the feeder are solely Industrial or Commercial, then load based indices should be calculated. Necessarily, if there is a mix of residential and Industrial/Commercial, then both load and customer based indices should be calculated.

- Switching procedures directly affect the average customer minutes outage.

- Adding one recloser does not necessarily equate to a 25% reduction in customer minutes outage.

- The law of diminishing returns is prevalent when applying reclosers. Adding one recloser may have significant advantages in terms of reliability indices; however, the addition of two or more does not decrease the average duration or the average frequency of outage by the same amount as the addition of the first recloser.

- During storm conditions, the repair times and the feeder failure rates may be significantly higher than under normal weather.
conditions. The effectiveness of reclosers diminishes under storm conditions.

APPENDIX 1 - Feeder Configurations

Both of the sample feeders consist solely of residential customers. Feeder A has characteristics similar to an urban feeder while Feeder B represents a rural feeder. Figure A1, below, shows the configuration of Feeder A.

![Uniform Feeder A](image)

Figure A1.1. Circuit Configuration of Feeder A

Figure A1.2 shows the configuration of Feeder B.

![Uniform Feeder B](image)

Figure A1.2. Circuit Configuration for Feeder B

APPENDIX 2 - Operational Information

Two specific operating cases were examined in this paper, normal weather conditions and storm weather conditions. Table A2 gives the values associated with each of these weather conditions.

<table>
<thead>
<tr>
<th></th>
<th>Normal Weather</th>
<th>Storm Conditions</th>
</tr>
</thead>
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<tr>
<td>Main Line Feeder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failure Rate</td>
<td>0.1 fail/mi/yr</td>
<td>0.1 fail/mi/yr</td>
</tr>
<tr>
<td>Tap Feeder Failure Rate</td>
<td>0.25 fail/mi/yr</td>
<td>0.25 fail/mi/yr</td>
</tr>
<tr>
<td>Main Line Repair Time</td>
<td>1.5 hours</td>
<td>3 hours</td>
</tr>
<tr>
<td>Tap Line Repair Time</td>
<td>3 hours</td>
<td>7 hours</td>
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<tr>
<td>Feeder Switching Time</td>
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<td>0.5 hours</td>
</tr>
<tr>
<td>Alt Supply Switch Time</td>
<td>1 hour</td>
<td>1 hour</td>
</tr>
</tbody>
</table>

APPENDIX 3 - Definition of Indices

SAIFI - System Average Interruption Frequency Index

\[
SAIFI = \frac{\text{Total No. Customers Interrupted}}{\text{Total No. Customers}}
\]

\[
= \frac{(\text{No. Customers Interrupted}) \times (\text{No. of Interruptions})}{\text{Total No. Customers}}
\]

SAIDI - System Average Interruption Duration Index

\[
SAIDI = \frac{\sum \text{Customer Interruption Durations}}{\text{Total No. Customers}}
\]

\[
= \frac{(\text{Duration of Outage}) \times (\text{No. Customers Affected})}{\text{Total No. Customers}}
\]

CAIFI - Customer Average Interruption Frequency Index

\[
CAIFI = \frac{\text{Total No. Customer Interruptions}}{\text{No. of Customers Affected}}
\]

CAIDI - Customer Average Interruption Duration Index

\[
CAIDI = \frac{\sum \text{Customer Interruption Durations}}{\text{Total Number of Customer Interruptions}}
\]

ASAI - Average Service Availability Index

\[
ASAI = \frac{\text{Customer Hours Service Availability}}{\text{Customer Hours Service Demand}}
\]

ATPII - Average Time per Interruption Index

\[
ATPII = \frac{\sum \text{Interruption Duration}}{\text{No. of Interruptions}}
\]

CMPII - Customer Minutes per Interruption Index

\[
CMPII = \frac{\sum \text{Customer Interruption Duration}}{\text{No. of Interruptions}}
\]

ASIDI - Average System Interruption Duration Index

\[
ASIDI = \frac{\text{KVA Minutes Interrupted}}{\text{Total Connected KVA Served}}
\]

ASIFI - Average System Interruption Frequency Index

\[
ASIFI = \frac{\text{KVA Interrupted}}{\text{Total Connected KVA Served}}
\]

APPENDIX 4 - Rural Figures for the Application of Reclosers

The following figures show the results of adding reclosers to the rural feeder. They correspond to Figures 7 - 9 in the main text. These figures were generated exactly as the figures in the main text except that they give the results for the rural feeder instead of the urban feeder. These figures have been added for completeness.

As can be seen in the figures above, this rural feeder is less reliable than the urban feeder. The decrease in reliability is mainly due to the exposure of the rural feeder. The longer the feeder, the more likely it is to have outages as well as to have outages that are of a longer duration.
The Effect on CMO of adding Reclosers to an Rural Feeder

Figure A4.1. Rural Feeder - Comparison of Switching Procedures - Normal Weather Conditions

The Effect on CMO of adding Reclosers to an Rural Feeder - Storm Conditions

Figure A4.2. Rural Feeder - Comparison of Switching Procedures - Storm Conditions

The Effect on CMO of adding Reclosers to a Rural Feeder - No switching

Figure A4.3. Rural Feeder - Comparison of Switching Procedures - Normal Weather Conditions

REFERENCE


Ms. Warren received her BSIE (1987) and MSEE (1990) from Union College. She worked at Central Hudson Gas & Electric for two years in the Electric System Protection Section where she specialized in distribution protection. She joined PTI in 1990. She is a member of IEEE, the PES, the Distribution Subcommittee and the Task Group on Distribution Reliability.