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Achieving SAIFI Improvement Objectives by Increasing Medium-Voltage Looped-Feeder Segmentation

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SUMMARY

Two factors directly influence medium-voltage looped-feeder SAIFI – customers (load) per feeder segment and support feeder capacity for recovering unfaulted feeder segments. Improving looped-feeder SAIFI by increasing feeder segmentation is well recognized but is often discounted beyond some number of segments because there is a diminishing SAIFI improvement return on investment (ROI). ROI diminishes at some point because further increases in feeder segmentation levels produce marginal SAIFI benefits for a given base case reference [1]. The base case reference used is often the SAIFI of an unsegmented radial feeder even though some feeder segmentation may already exist. Prior to and after looping feeders, support feeders are also frequently presumed capable of recovering 100% of their tied feeder's peak-load. However, a feeder's present segmentation level and its support feeder's capacity for recovering unfaulted feeder segments establish the base case SAIFI reference when determining the ROI of subsequent SAIFI reduction plans. When these two factors are disregarded, the ROI evaluation of SAIFI enhancements produced by further increases in feeder segmentation is flawed. Therefore, this paper will discuss the importance of these two variables and the base case SAIFI reference when evaluating the ROI of increasing looped-feeder segmentation to improve SAIFI.

Note: Because changes in SAIFI are represented in percent, feeder segment load current and support feeder spare capacity amperage will be used for convenience to represent customers throughout this paper.

KEYWORDS

Faults, feeder, loop, medium-voltage, permanent, persistent, reliability improvement, SAIFI, segmentation, support capacity, transformer, ROI

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BACKGROUND

Looped feeders traditionally have had two segments that are tied together via a normally open switching device. When a persistent fault occurs in the first half of the feeder, it is isolated by automatically opening the mid-point device after the substation breaker progresses to lockout. The unfaulted load in the second half of the feeder is then recovered by automatically closing the normally open tie device.

Referring to Figure 1, a feeder with 300 amperes of load has been equally divided into two segments and tied to an adjacent feeder with 150 amperes of spare support capacity. Presuming persistent (permanent) faults occur with the same frequency in either segment, this means Segment #2's load is recovered via the support feeder when persistent faults occur in Segment #1. Because 100% of the support feeder's spare capacity is used to recover Segment #2, no support capacity is unused or stranded.

The return on investment (ROI) of Figure 1 produces a 50% SAIFI improvement when compared to the SAIFI of an unsegmented radial feeder with 300 amperes of load [1]. Once Figure 1 is operational, the ROI of subsequent SAIFI improvements must be determined using this feeder's load-segmentation level and support feeder spare capacity as the base case reference. This is necessary because the ROI of future SAIFI reduction plans that alter these two variables will be compared to the present SAIFI produced by these two factors.

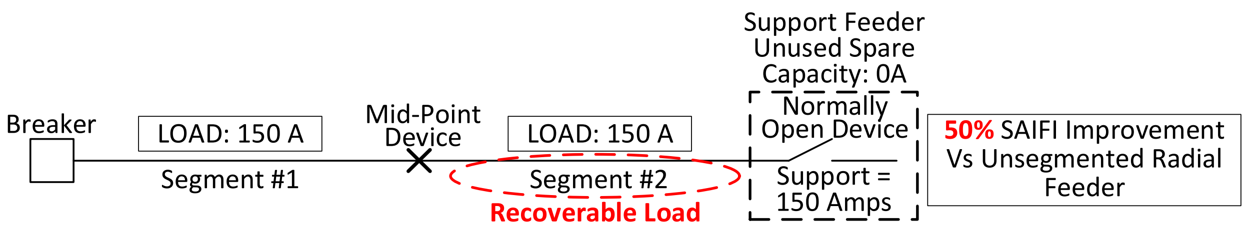

Figure 1. Conventional looped-feeder SAIFI benefits vs an unsegmented radial feeder.

RELIABILITY IMPROVEMENT BASE CASE IMPORTANCE

To demonstrate the importance of the base case reference, Figure 2's load-segmentation level and support feeder spare capacity produces a 68.75% SAIFI improvement when its base case SAIFI reference is an unsegmented radial feeder with 300 amperes of load.

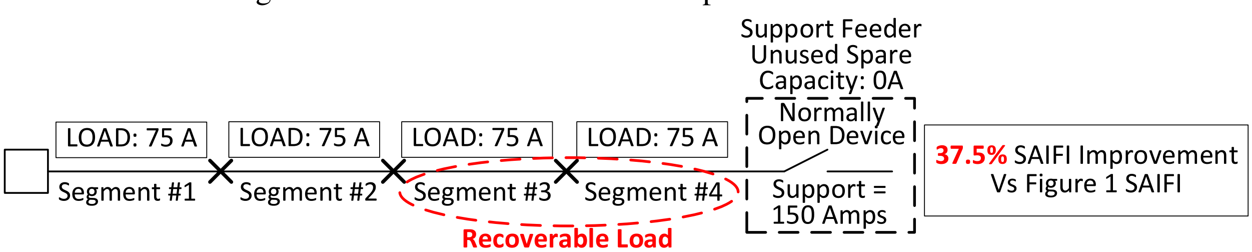

Figure 2. Further sectionalizing the Figure 1 300-ampere feeder into four equally loaded segments produces a 37.5% SAIFI improvement when compared to the SAIFI of Figure 1.

Because the base case reference used to determine this 68.75% improvement and the 50% improvement of Figure 1 is the same, you might conclude the ROI of Figure 2 only produces an 18.75% SAIFI benefit. However, an 18.75% SAIFI improvement only results when comparing the SAIFI of Figure 2 versus Figure 1 to an unsegmented radial feeder with 300 amperes of load [1].

If Figure 1 is the base case SAIFI (the present feeder condition), the ROI of Figure 2 yields a 37.5% SAIFI benefit. Therefore, when projecting the ROI of reliability improvements produced by increasing feeder customer segmentation levels and/or varying a support feeder's spare capacity, the base case reference becomes the feeder's present reliability index.

And when planning incremental reliability improvements over time, the reliability index of each step becomes the new base case reference when evaluating the ROI of the next step's enhancement.

SUPPORT FEEDER SPARE CAPACITY CONSIDERATIONS

When considering what level of feeder segmentation will produce the desired SAIFI improvement, a common oversight is presuming 100% of a feeder's peak-load can be recovered by its support feeder's spare capacity. If the feeder is already looped, the support feeder's spare capacity may remain the same, or more likely decrease in the future.

Beyond ensuring a support feeder's components will withstand increased loading during instances of load-transfer, its load-recovery capacity is generally governed by its substation transformer reserves. When looped feeders are fed from the same transformer, a persistent feeder fault reduces transformer loading or increases its reserve capacity. But when feeders from different substations are looped, a persistent feeder fault increases support feeder transformer loading or reduces its reserve capacity.

As transformer loads increase and feeders from different substations are looped, support feeder spare capacity may decrease. This happens because producing spare support capacity by routinely overloading transformers above acceptable limits is avoided to preserve transformer service life. When this occurs, and after reallocating regional transformer reserves has been exhausted, a larger transformer is installed to supply sufficient support feeder spare capacity for attaining SAIFI goals.

Replacing existing transformers with larger ones is certainly one means of achieving SAIFI objectives. However, it's an extremely expensive proposition when compared to the ROI of simply increasing feeder segmentation levels to realize comparable SAIFI targets.

INCREASING SEGMENTATION AND CONSISTENT SUPPORT FEEDER CAPACITY

After feeders have initially been looped and segmented as in Figure 1, improving reliability invariably becomes a subsequent strategy. Presuming the support feeder's spare capacity remains the same, the ROI produced by increasing segmentation and uniformly dividing the load can produce suboptimal results when a portion of the support feeder's spare capacity is stranded.

For example, imagine the Figure 1 feeder's reliability is to be improved by dividing it into three equally loaded segments as shown in Figure 3. Each feeder segment now has 100 amperes of load and the support feeder's spare capacity of 150 amperes remains the same.

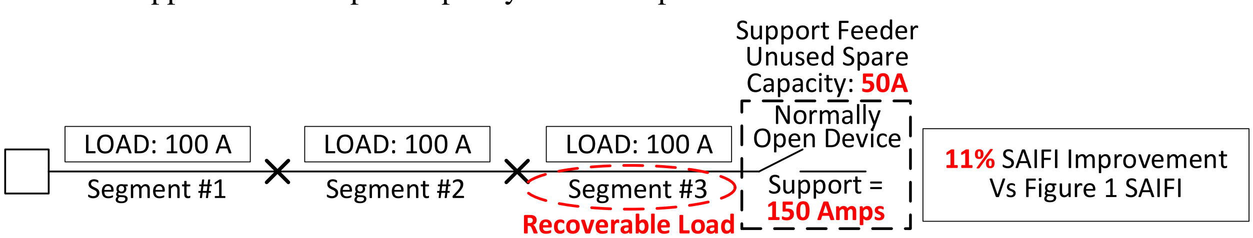

Figure 3. A support feeder's spare capacity directly impacts reliability improvement goals.

Presume again that persistent faults occur with the same frequency in each of the three segments. Because there are only 150 amperes of support feeder spare capacity, this means only Segment #3's load can be recovered via the support feeder when persistent faults occur in either Segments #1 or #2. And instead of using 100% of the support feeder's spare capacity, 33% (50 A) is stranded.

Because Figure 1 is the base case SAIFI reference, the ROI of adding the third segment in Figure 3 only results in an 11% SAIFI improvement. This occurs because only one 100-ampere segment can be recovered using the support feeder's spare capacity.

However, if the Figure 3 feeder load was unequally divided as illustrated in Figure 4, the ROI of adding the third segment yields a 33.3% SAIFI improvement versus Figure 1's SAIFI. This results by apportioning the loads in Segments #2 and #3 so 100% of the support feeder's spare capacity can recover two segments in Figure 4 versus the one segment in Figure 3.

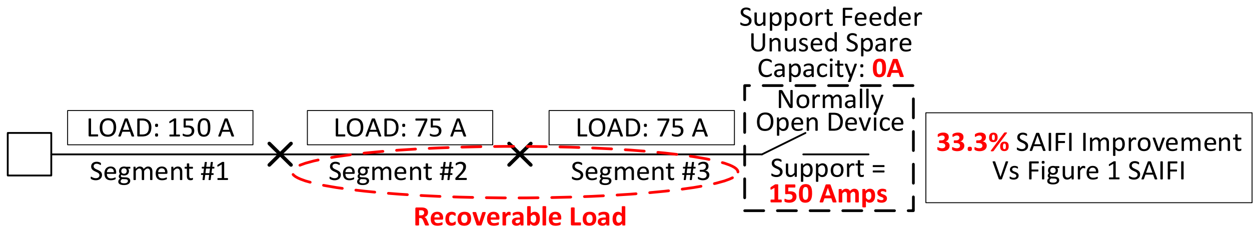

Figure 4. Unequal segment loading helps improve reliability by maximizing the use of the support feeder's spare capacity.

INCREASING SEGMENTATION AND REDUCED SUPPORT FEEDER CAPACITY

As previously explained, support feeder spare capacity can decrease at some point because acceptable substation transformer overload limits are being routinely exceeded.

As an example, presume Figure 4's support feeder spare capacity reduces 50 amperes as shown in Figure 5 – the Figure 4 support feeder spare capacity of 150 amperes is now 100 amperes.

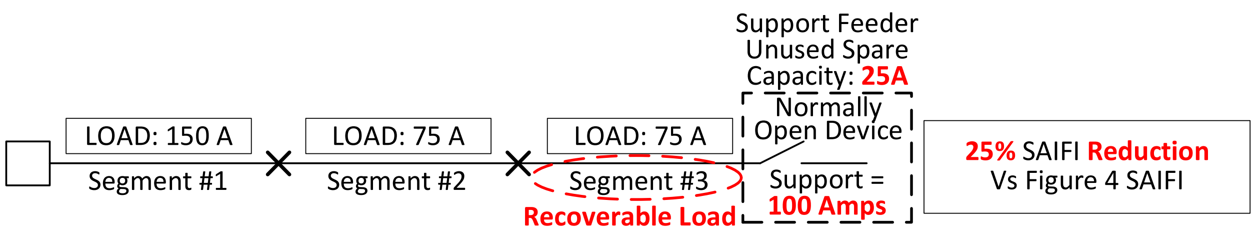

Figure 5. Reduced support feeder spare capacity can adversely affect SAIFI improvement objectives.

When Figure 5's SAIFI is calculated using Figure 4 as the base case, SAIFI reduces 25%. This 25% reduction also occurs whenever the support feeder's spare capacity falls below 150 amperes.

As in Figure 3, this SAIFI reduction results because the support feeder's spare capacity of 100 amperes can only recover one 75-ampere segment versus recovering two 75-ampere segments when it was 150 amperes.

Adding a fourth segment in Figure 6 and reapportioning the load so Segments #2, #3 and #4 each have 50 amperes overcomes Figure 5's SAIFI decrease. The ROI of this approach reverses Figure 5's SAIFI and improves Figure 4's SAIFI 12.5%.

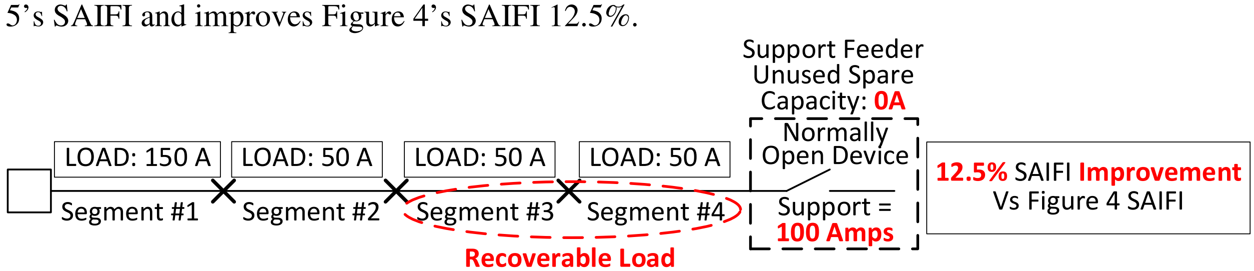

Figure 6. Increasing segmentation and reapportioning load to maximize the use of reduced support feeder spare capacity recovers SAIFI improvement objectives.

INCREASING SUPPORT FEEDER CAPACITY VS INCREASING SEGMENTATION

Marginalizing feeder segmentation to improve or maintain SAIFI can mean increasing a support feeder's spare capacity to achieve reasonable results. However, unless this increase is achieved by reallocating local or regional substation transformer reserves, replacing even one transformer to increase support feeder capacity becomes a very expensive proposition.

For example, Figure 7 divides the previous Figure 1, 300-ampere, two-segment feeder into three 100-ampere segments. The Figure 1 support feeder spare capacity of 150 amperes is also increased to 200 amperes.

Equally dividing the 300-ampere feeder into three segments and increasing the support feeder's spare capacity 50 amperes produces a 33.3% SAIFI improvement when Figure 1 is the base case SAIFI reference.

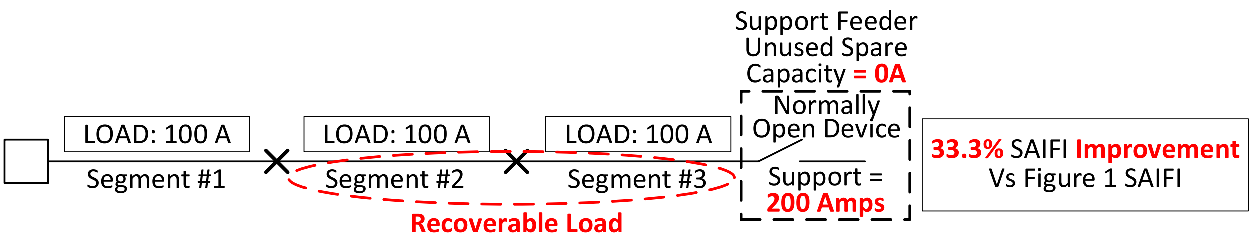

Figure 7. Uniformly increasing load segmentation sometimes means increasing support feeder spare capacity to achieve SAIFI improvement objectives.

If this was a regional SAIFI improvement goal involving several two-segment Figure 1 feeders, implementing this strategy may require replacing the support feeders' substation transformer with a larger one to increase support feeder spare capacity.

Referring to Figure 8 as an example, consider Substation #1's 12.5-kV, 25-MVA transformer supplies four 300-ampere (peak-load) feeders (25-MVA = 1,155 A at 12.5-kV or 289 A per feeder). This requires overloading the 25-MVA transformer 104% during peak-load conditions.

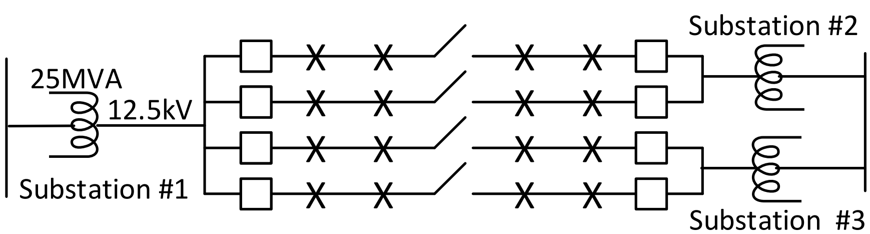

Figure 8. The 25-MVA Substation #1 transformer cannot reasonably supply its 4-300 A, 3-segment, feeders and provide 200 A of support capacity to the 4-300 A, 3-segment Substation #2 and #3 feeders to achieve regional SAIFI improvement objectives – it must be replaced.

These four Substation #1 feeders are tied (looped) to two feeders from Substation #2 and two feeders from Substation #3 whose peak-load is also 300 amperes. To further improve regional reliability, all eight feeders are to be upgraded from two-segment (Figure 1) feeders to the three-segment (Figure 7) feeders shown in Figure 8.

All eight two-segment feeders currently have 150 amperes of support feeder spare capacity. The present 150 amperes of support capacity for the two Substation #2 and two Substation #3 feeders [(300 A + 150 A) x 4 = 1,800 A)] comes from temporarily overloading the Substation #1 25-MVA transformer 156% (1,800 A ÷ 1,155 A = 1.56).

This level of transformer overloading is required to achieve regional reliability targets in the event the source supplying Substations #2 and #3 is lost – Substation #1 is fed from a different source.

Providing an additional 50 amperes of spare support capacity per feeder (4 x 50 A = 200 A) requires overloading the Substation #1 transformer 173% [(1,800 A + 200 A) ÷ 1,155 A = 1.73]. This means the Substation #1 transformer must be replaced with a larger one to satisfy the 200 amperes of support feeder spare capacity indicated in Figure 7.

A 12.5-kV, 40-MVA transformer would supply each of the four Substation #1 feeders with 462 amperes, resulting in 162 amperes of spare support capacity per feeder (462 A – 300A = 162 A). Producing the additional 18 amperes (200 A – 162 A = 18 A) of spare capacity per support feeder (4) would only require overloading the 40-MVA transformer 123% (200 A ÷ 162 A = 1.23).

Although substation transformer prices can vary widely over a 5-year period, presume the price of a 40-MVA transformer is $500,000. Also consider the existing 25-MVA transformer has a salvage value of $100,000. This results in a first cost of $400,000 to increase support feeder spare capacity for the four Substation #1 feeders.

Rather than continuing to project the installed cost of increasing support feeder spare capacity by estimating the additional costs involved in replacing the transformer, all these considerable expenses would have avoided by simply increasing feeder segmentation.

For instance, the previous 300-ampere feeder example with four uniform 75-ampere segments and 150 amperes of support feeder spare capacity is illustrated in Figure 9. The base case reference for projecting the SAIFI of Figure 9 is the SAIFI achieved by the two-segment, 300-ampere (Figure 1) feeder with 150 amperes of support feeder spare capacity.

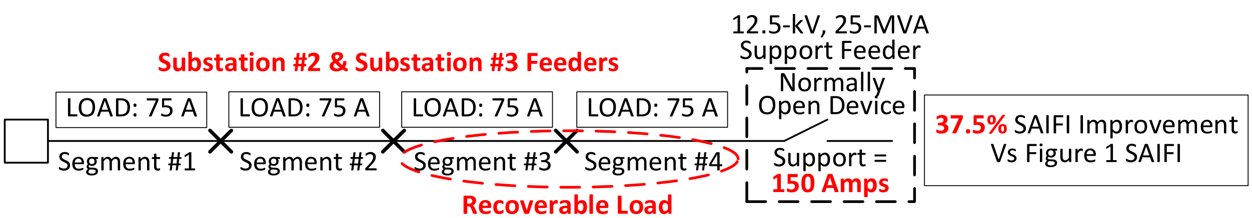

Figure 9. Adding more feeder segments can avoid increasing substation transformer reserve capacity and exceed SAIFI improvement objectives.

Without increasing support feeder spare capacity, i.e., upgrading the Substation #1 25-MVA transformer, adding a third sectionalizing device and uniformly dividing the load into four 75-ampere segments improves SAIFI 37.5% when compared to Figure 1's SAIFI.

Comparing the ROI of installing one more sectionalizing device per Substation #2 and #3 feeder (4-devices) to the expense of replacing the Substation #1 25-MVA transformer, the conclusion is glaringly obvious – add more feeder devices.

And the bonus for this increased segmentation results in a slightly higher (4%) SAIFI benefit.

CONCLUSIONS

Evaluating the ROI of SAIFI improvements starts with recognizing the importance of the base case SAIFI reference – it's not typically an unsegmented radial feeder. The base case reference is generally a looped feeder's present SAIFI which is primarily influenced by its customer (load) segmentation level and its support feeder's spare capacity.

As was demonstrated, there is an interdependent relationship between looped-feeder customer segmentation levels and support feeder spare capacity. Because both influence the ROI of reliability improvement plans, projecting SAIFI enhancements requires ensuring adequate support feeder spare capacity will be available for the foreseeable future.

If feeders from different substations are looped, a persistent feeder fault increases the support feeder's transformer loading and reduces its reserve capacity. When this transformer's loads increase and more of its feeders are looped with feeders from other substations, its capacity for recovering unfaulted load on adjacent substation feeders diminishes.

Reductions in support feeder spare capacity invariably occur even after reallocation of regional transformer reserves has been exhausted. This generally reduces looped-feeder SAIFI, however reapportioning loads and/or increasing feeder segmentation have been shown to overcome reduced support feeder spare capacity.

Increasing support feeder spare capacity to achieve SAIFI targets after regional transformer reserves have been depleted means replacing existing transformers with larger ones. Although this approach produces more support feeder spare capacity, the ROI analysis of replacing transformers versus increasing segmentation glaringly favors increasing segmentation.

The best and least complex approach to increasing looped-feeder segmentation (while mitigating MAIFI) is deploying battery-free fault interrupters with extremely precise Time-Current Characteristics (TCCs). In sharp contrast to reclosers, multiple series fault interrupters can be conventionally time-current coordinated because of this TCC precision. Alternatively, reclosers must rely on batteries and complex communication-based protection schemes that compensate for their imprecise TCCs to achieve comparable feeder segmentation levels.

These fault interrupters not only have the most precise TCCs in the industry, they also use a revolutionary fault-testing technology that is vastly superior to reclosers. Compared to reclosing, this innovative technology reduces system stresses 95% and eliminates voltage-sags when testing for continued fault presence.

BIBLIOGRAPHY

[1] M. Meisinger "Combining Fault Mitigation Strategies Substantially Improves Overhead Medium-Voltage Feeder Reliability" (CIGRE US National Committee 2017 Grid of the Future Symposium)