Improving Medium-Voltage Main-Feeder Reliability by Increasing Fault-Sectionalizing

Introduction

Optimizing medium-voltage main-feeder reliability essentially means minimizing the number of customers inconvenienced by transient and persistent faults. Historically, this has equated to utilities sequentially implementing the following fault-mitigation strategies and objectives using cost-justified solutions:

1. Increase main-feeder fault-sectionalizing to reduce SAIFI, SAIDI and MAIFI
2. Loop feeders to further reduce SAIFI and SAIDI:
    a. Manually transfer unfaulted load to adjacent feeders initially
    b. Automate load-transfer without using communication devices
3. Intelligently restore load quickly using communication to further extend SAIFI and SAIDI reductions:
    a. Without overloading support feeders
    b. Using multiple feeder interties

Unfortunately, utilities often overlook choosing the best product that will satisfy all these objectives from the outset because they do not foresee the costs associated with the increasing challenges and complexities of subsequent goals.

So, rather than select a highly flexible product that incrementally and effortlessly achieves the first objective and ultimate goal, utilities frequently instead choose familiar low-cost products that they expect will accomplish the easier initial strategies.

Eventually, utilities discover the significant hidden costs involved in making low-cost products more sophisticated and adaptive. And if they can't augment the product with ancillary local and remote components that make it more intelligent, but subsequently add costs, utilities will end up replacing it as the reliability program progresses.

While the IntelliRupter® PulseCloser® Fault Interrupter is such a highly flexible product, this publication will only focus on its features when tackling the first strategy – increasing main-feeder fault-sectionalizing. Although utilities might consider this to be a fairly simple objective, this publication will demonstrate reclosers can limit a feeder-segmentation goal.

Consequently, the following example will compare the capabilities of a 21st-century IntelliRupter fault interrupter with 20th-century recloser technology. ***Note: S&C publication 766-576 "Tolerance-Based Time-Current Coordination" is an excellent reference for understanding the time-current coordination method used in this publication.***

Increasing Main-Feeder Fault-Sectionalizing

Using the IntelliRupter fault interrupter or reclosers, a utility intends to divide a 14.3-mile, 25-kV, overhead feeder into equal segments so each segment has an equal number of customers. The available fault current at the existing substation circuit-breaker is 12,000 amperes and its phase-overcurrent pickup is 900 amperes, or twice the 450-ampere load capacity of the feeder.

Additionally, the feeder's peak load is 300 amperes, which leaves 150 amperes of spare capacity for occasional (manual) restoration of unfaulted load in adjacent feeders. Soon, the utility will use this spare capacity to support automated load-restoration once this feeder is tied to an adjacent feeder via a normally open fault interrupter.

Because reliability improvement is the primary reason for segmenting the feeder, the user wants the final build-out to maximize the number of feeder sections. This means eventually installing as many series reclosers or IntelliRupter fault interrupters as possible.

Ideally, the user prefers feeder-sectionalizing devices initially not require communication for protection coordination between or among these normally closed devices. This also means batteries should not be required initially.

The Optimum Solution

Figure 1 suggests this feeder can be segmented six times using five IntelliRupter fault interrupters, or IRs, (a future normally open IntelliRupter fault interrupter is not shown). The distance between feeder devices varies, indicating how the utility would divide the feeder to achieve equal customer distribution.

The minimum trip levels of all IntelliRupter fault interrupters provide for much more than the 50 amperes of peak load per feeder segment (300 A ÷ 6 = 50 A). And IntelliRupter fault interrupter #5 will easily accommodate the future automated normally open device and its 150 amperes of adjacent feeder load-recovery current.

Figure 1 also illustrates the time-current characteristics (TCCs) and conventional time-current coordination of the breaker and IntelliRupter fault interrupters. Because the IntelliRupter fault interrupter uses the sensing precision of Rogowski coils and its control has extremely tight protection tolerances, they are easily coordinated with each other and the substation breaker.

The breaker and IntelliRupter fault interrupter TCCs have been truncated at their maximum available fault current. For example, the breaker TCC stops at 12,000 amperes, while the IntelliRupter fault interrupter #1 TCC stops at 6,000 amperes.

The reason the TCCs stop at their respective current levels is because fault current reduces as the distance from the source (or substation breaker) increases. Consequently, they will never sense more than the indicated current. So, to be properly coordinated, the maximum response (upper line) of their TCCs must not touch the minimum response (lower line) of upstream TCCs at or below this current level.

Ultimately, this coordination plot provides a roadmap for deploying IntelliRupter fault interrupters. This means the user can incrementally improve reliability by initially installing IR #2 and IR #4 in **Figure 1**, dividing the feeder into three equal 100-ampere customer segments. Then, when the budget allows, the utility can add the remaining IntelliRupter fault interrupters one by one or together to achieve the maximum segmentation of 50 amperes per feeder section.

The Recloser Option

The utility then considers using a very popular three-phase recloser and control to achieve the same feeder segmentation shown in **Figure 1**. However, **Figure 2** on page 3 illustrates why this recloser (RC) cannot achieve the time-current coordination accomplished using the IntelliRupter fault interrupter.

As in **Figure 1**, the load and distances between devices are the same, and so is the available fault current at each device. However, the higher primary-to-secondary current-ratio error of the recloser's iron-core current transformers, and the less precise protection tolerances of the recloser control, prohibit the resulting TCCs from being adequately separated.

Consequently, the minimum (lower or left lines) and maximum (upper or right lines) response tolerances of most TCCs overlap. This means fault levels between about 1,400 to 4,400 amperes will always result in two or more reclosers tripping. Additionally, the wider TCC tolerance bands of the recloser control prevent them from accommodating the total fault current when load contribution is considered.

For instance, recloser #1 could be sensing 250 amperes of load just before a fault occurs. This is true because its feeder segment and the four downstream feeder sections each would be serving 50 amperes of load (5 x 50 A = 250 A).

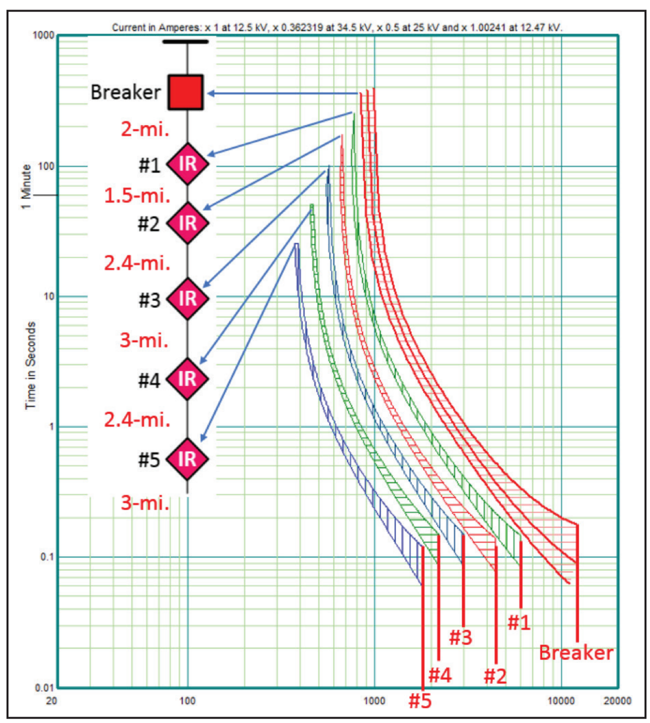

Figure 1. A 14.3-mile, 25-kV feeder is successfully segmented six times using five IntelliRupter fault interrupters.

Consequently, when a fault occurs,this load current initially adds to the fault current. So, if the fault was 1,000 amperes, the total fault current sensed by recloser #1 becomes 1,250 amperes.

Because this load contribution to the total fault current happens for all devices from the breaker to recloser #5, upstream devices operate faster than illustrated by the coordination plot of **Figure 2**. Therefore, faults below 1,400 amperes are also likely to cause two or more reclosers to trip.

Reduced Recloser Fault-Sectionalizing

Figure 3 indicates a more prudent approach would reduce the number of series reclosers from five to three. This also means increasing the distances between devices to achieve equal customer distribution among the four feeder segments. Consequently, this changes the load per feeder segment from 50 amperes in **Figure 1** on page 2 and **Figure 2** to 75 amperes in **Figure 3**.

Because of increased distances between reclosers, the available fault current at recloser #1 has changed from 6,000 amperes in **Figure 2** to 5,000 amperes. Recloser #2 still has the same available fault current as recloser #3 in **Figure 2**, and recloser #3 in **Figure 3** has an available fault current of 2,050 amperes.

Additionally, the reclosers are now properly accommodating the 75 amperes of load in each of the four feeder segments. And recloser #3 will easily accommodate the future normally open device and its 150 amperes of automated load-transfer current.

Persistent Main-Feeder Faults

Increasing feeder fault-segmentation produces the SAIDI benefits shown in Table 1. These improvements occur because persistent faults in downstream feeder segments are always isolated, enabling load in upstream segments to be automatically restored [1]. ***Note: The Table 1 base case is an unsegmented radial feeder with uniform fault and customer distribution and fault-repair times.***

Table 1. SAIDI Benefits Attributable to Increased Radial Feeder Fault-Sectionalizing

SAIDI Benefits Attributable to Increased Radial Feeder Fault-Scetionalizing	
2 Feeder Segments	25% SAIDI improvement
3 Feeder Segments	33% SAIDI improvement
4 Feeder Segments	38% SAIDI improvement
5 Feeder Segments	40% SAIDI improvement
6 Feeder Segments	42% SAIDI improvement

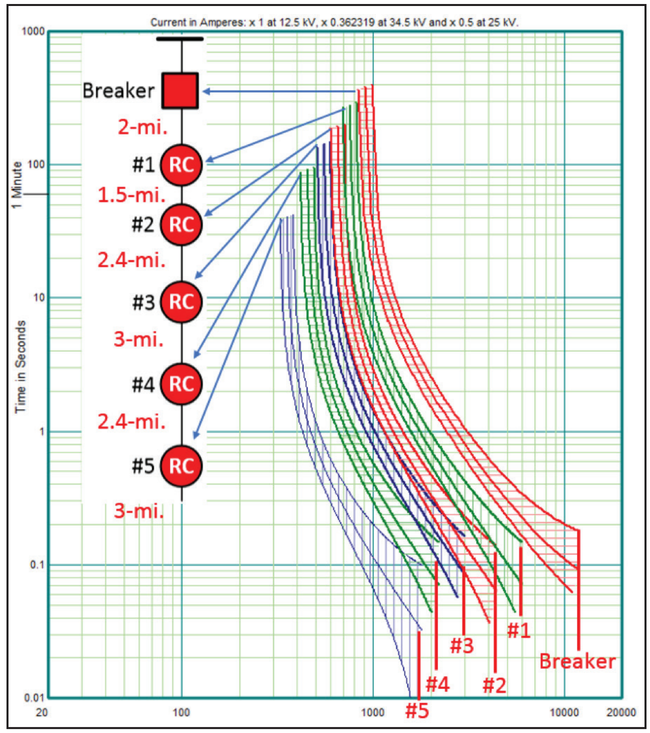

Figure 2. A 14.3-mile, 25-kV feeder is unsuccessfully segmented six times using five three-phase reclosers.

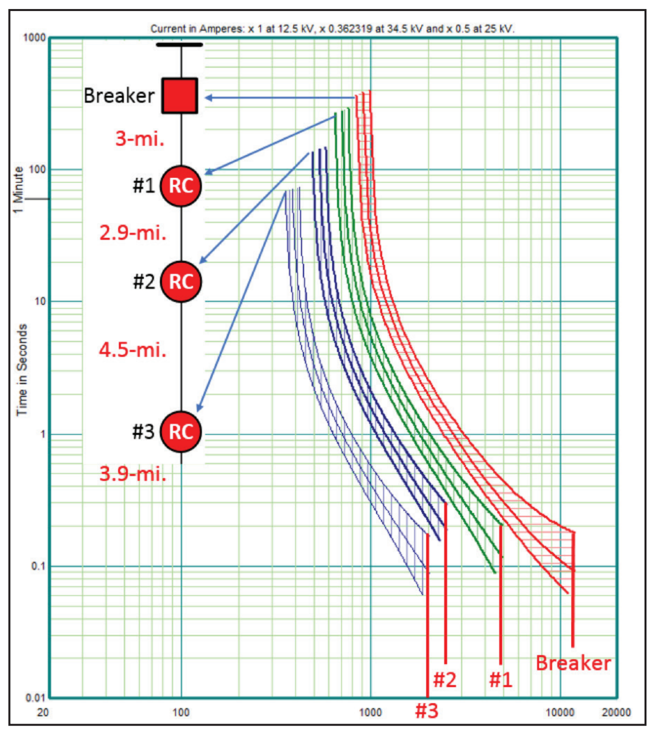

Figure 3. A 14.3-mile, 25-kV feeder is successfully segmented four times using three reclosers.

Using the previous feeder-segmentation example, **Table 1** on page 3 indicates the six feeder segments resulting from the five series IntelliRupter fault interrupters would yield in a 42% SAIDI benefit. Conversely, the three reclosers (four segments) would only produce a SAIDI benefit of 38%.

Admittedly, the SAIDI benefits of increased fault-sectionalizing for a radial feeder may limit initial segmentation plans. However, once automated load-transfer and intelligent load-restoration are implemented, the benefits of multi-segmented feeders (covered in subsequent publications) will become more obvious.

Conclusions

This feeder-segmentation example has demonstrated that the IntelliRupter fault interrupter is the best choice for maximizing feeder fault-sectionalizing. This is true because its extremely precise sensing and measurement tolerances enable more devices to be conventionally time-current coordinated than do any of today's reclosers.

It should be noted that other breaker-protection settings, feeder topology, and fault characteristics will ultimately determine how many series IntelliRupter fault interrupters can be conventionally coordinated. However, despite these influences, the IntelliRupter fault interrupter's tighter TCC responses will ensure more of the devices can be coordinated than can reclosers, regardless of manufacture.

The user preferred that the fault-interrupting devices not require batteries. However, most modern reclosers and controls won't trip without them or an uninterruptible power supply (UPS). To be clear, if the feeder supply is lost for an extended time and the recloser remains closed, it relies on batteries (or a UPS) to trip if a fault is present when the supply returns.

Conversely, the IntelliRupter fault interrupter is self-powered, meaning utilities can deploy it without batteries. But users can easily add them in the future when the communication device is installed. Additionally, six-phase voltage sensing required for future bi-directional overcurrent protection is immediately present. Also, provisions for integrated communication hardware that will eventually support the pre-installed distributed-intelligence load-restoration software have been anticipated. Consequently, the next steps in the reliability-improvement program outlined in the Introduction will be significantly easier to implement using IntelliRupter fault interrupters instead of reclosers.

So, unlike reclosers, the IntelliRupter fault interrupter has been designed to seamlessly transition from radial applications to highly sophisticated and complex intelligent load-restoration operations. And this distributed-intelligence, load-restoration process can take just tens of seconds to complete.

Bibliography

[1] M. G. Ennis, C. Williams, "Using Real-Time Outage Data to Understand How Protection and Coordination Affect Distribution Reliability Indices

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