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Single-Phase Medium-Voltage Lateral Recloser Application Considerations

M. MEISINGER
S&C Electric Company
USA

SUMMARY

A medium-voltage lateral circuit recloser's numerous time-current characteristics (TCCs) makes achieving time-current coordination much easier. This flexibility is frequently overlooked because many users prefer to simply apply the same TCC and rating as the fuse the lateral circuit recloser replaces. Choosing to simply replicate the fuse rating and characteristic can be extremely effective provided the fuse was previously coordinated with upstream fault-interrupting devices. And coordination with downstream fuses will also generally improve because they can be permitted to clear higher fault currents before the lateral circuit recloser begins responding. However, if the previous lateral fuse coordination wasn't ideal, the various features of one lateral circuit recloser provide a virtually infinite number of coordination-improvement options. This means protective relay and recloser TCCs, selectable minimum trip current and time-multipliers, definite-time overcurrent responses, and magnetizing inrush current restraint offer greater coordination flexibility. Consequently, this paper will identify some important lateral circuit overcurrent protection and coordination issues, and then suggest how they might be overcome. Additionally, the ability to further segment a lateral circuit using two series reclosers will also be demonstrated.

KEYWORDS

Lateral, recloser, magnetizing inrush, inrush restraint, fuse, secondary lateral, cold-load pickup

Mike.Meisinger@sandc.com

Introduction

Selecting proper protection for medium-voltage transformers involves numerous considerations [1]. Consequently, this paper will cover some of these concerns as they relate to lateral circuit recloser applications and illustrate how one lateral recloser's features improve time-current characteristic (TCC) coordination.

The topics covered in this paper are:

- Transformer Magnetizing Inrush Current Considerations
- Transformer Magnetizing Inrush Restraint
- Accommodating Cold-Load Pickup
- Relay and Recloser TCCs
- Definite-Time Overcurrent Responses
- Applying Reclosers on Secondary Laterals

Transformer Magnetizing Inrush Current Considerations

Transformer magnetizing inrush current restraint makes the following application considerations substantially less significant. But to appreciate why this is true, transformer fuse-protection principles will be briefly reviewed as they also apply to lateral circuit protection.

Why transformer magnetizing inrush currents occur is explained in [1], and software coordination programs translate this into default transformer full-load current multipliers or factors at 0.01- and 0.1-seconds:

- 0.01-seconds – 25 x transformer full-load current
- 0.1-seconds – 12 x transformer full-load current

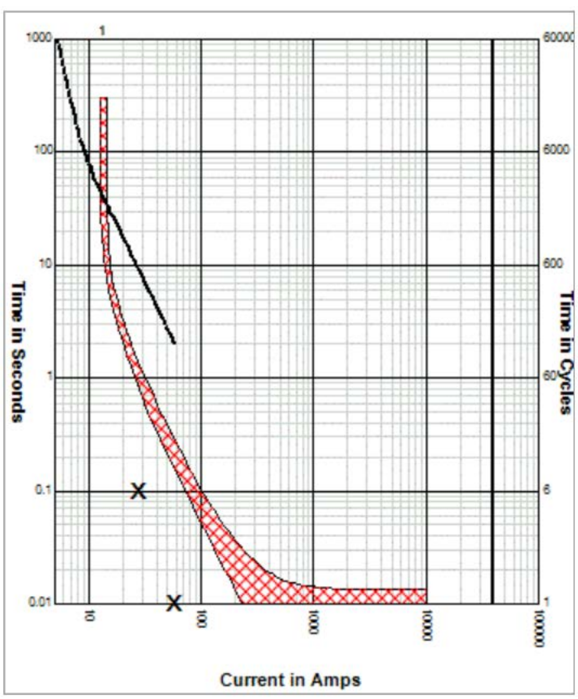

Figure 1. Avoiding 50-kVA magnetizing inrush currents with a 6A K-speed fuse. Note: The solid line is a 50-kVA (3-phase) transformer damage curve.

Consequently, the minimum-melt response of a transformer fuse should never infringe upon these full-load current factors. This application principle also applies when these full-load current factors are de-rated based on transformer full-load-to-available-fault-current ratios as described in [1].

Magnetizing inrush currents are also known to last well beyond the 0.1-second threshold. This means a fuse's minimum-melt TCC should always plot above and/or to the right of these full-load current points represented by "Xs" in the coordination plot shown in Figure 1.

However, what is frequently overlooked is the 25x full-load current factor at 0.01-seconds is more appropriate for small single-phase transformers in the region of 25- to 200-kVA. In contrast, larger three-phase transformers will produce magnetizing inrush currents on the order of 12x full-load current at 0.01-seconds.

Likewise, lateral protection devices experience the aggregate effect of individual transformer magnetizing inrush currents. Therefore, lateral-protection practices must follow the same application principles as those for individual transformer fuses, except in aggregate.

Consequently, knowing the percentage of a lateral's small and large transformers will help determine appropriate 0.01-second full-load current factors. On the other hand, a lateral's 0.1-second 12x full-load current factor will be consistent regardless of the mix of transformer sizes.

<u>Transformer Magnetizing Inrush Restraint</u>

Should magnetizing inrush current considerations produce miscoordination concerns, one lateral circuit recloser offers an extremely effective solution – Magnetizing Inrush Current Restraint. This feature virtually ignores magnetizing inrush current influences, meaning this type of lateral recloser can infringe upon the 0.01- and 0.1-second full-load current factors. And this feature maintains its trip-avoidance behavior well beyond the 0.1-second threshold.

How this works is identical to what sophisticated and expensive substation transformer differential protection relays use to distinguish initial transformer energization (magnetizing inrush currents) from actual transformer faults or through-faults. As a reminder, through-faults are faults occurring on the transformer secondary circuit, meaning fault current has passed "through" the transformer.

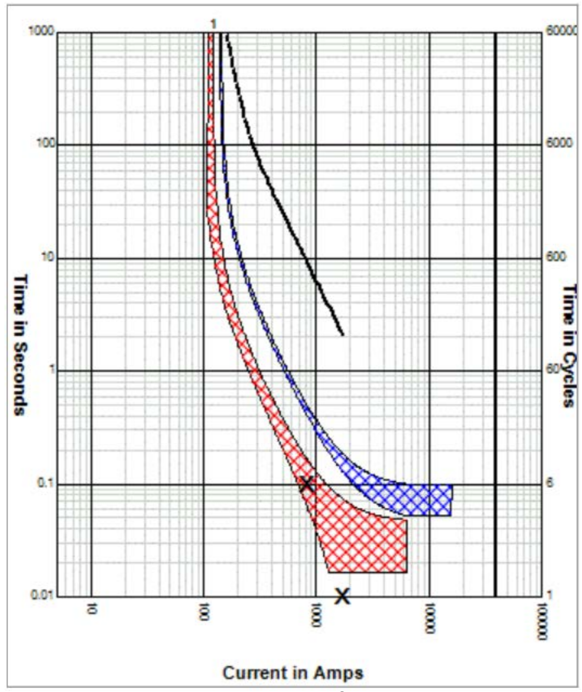

Figure 2. Magnetizing Inrush Restraint ignores magnetizing inrush currents. Note: The solid line is a 3,000-kVA transformer damage curve.

So just like the substation differential protection relay, one brand of lateral recloser will not operate for magnetizing inrush currents, but it will trip for faults at these current levels. To be clear, if a fault occurs while lateral transformers are reenergizing, the concurrence of magnetizing inrush currents won't prevent this lateral recloser from operating.

This is illustrated using the following example shown in Figure 2. A 25-kV fault interrupter is upstream of a lateral circuit recloser that protects an aggregate 3,000-kVA (three-phase) load comprised of 25-kVA and 50-kVA transformers.

The fault interrupter ground minimum trip setting of 140-amperes prevents using a lateral recloser 65-ampere K-speed fuse TCC. Therefore, a 50-ampere K-speed fuse TCC is chosen instead, recognizing it will accommodate the lateral's actual maximum peak load.

Figure 2 indicates the 50-ampere K-speed fuse TCC is infringing on the 25x and 12x magnetizing inrush current plane, indicated by "Xs" at 0.01- and 0.1-seconds. Consequently, by relying on the lateral recloser's magnetizing inrush restrain feature, further manipulation of the coordination is unnecessary. This is true because the lateral circuit recloser will not trip should these magnetizing inrush currents occur.

Accommodating Cold-Load Pickup

After considering the consequences of magnetizing inrush currents, the next step when applying a lateral circuit recloser is assessing the influences of cold-load pickup. And one lateral recloser's ability to change TCCs before the last reclose attempt becomes yet another feature that makes this process easier. However, to appreciate why changing TCCs before the last reclose is a tremendous advantage, cold-load pickup concerns will be covered briefly.

Invaluable insight on this subject is offered in [1], but it is addressing three-phase substation power transformer primary fuses, and not single-phase laterals. Therefore, coordination program default cold-load pickup full-load current multipliers of 6x (1-second), 3x (10-seconds), and 2x (1,000-seconds) should be questioned when considering a lateral circuit recloser application.

For instance, presume a 12.47-kV single-phase lateral has an actual peak load of 1,200-kVA (three-phase) supplied by transformers with an aggregate nameplate rating of 2,000-kVA (three-phase). A 65-ampere K-speed lateral fuse was installed because it reasonably addressed the 1,200-kVA default cold-load pickup factors represented by "Xs" at 1, 10 and 1,000 seconds shown in Figure 3. However, further load growth will require replacing the 65-ampere K-speed fuse to accommodate higher cold-load pickup currents. Additionally, this plot indicates the 2,000-kVA magnetizing inrush current 25x and 12x factors at 0.01- and 0.1-seconds may have caused this fuse to misoperate occasionally.

Alternatively, Figure 4 shows one lateral circuit recloser's 65-ampere K-speed TCC with default 2,000-kVA magnetizing inrush and 2,000-kVA (three-phase) cold-load pickup factors plotted. This demonstrates this lateral recloser would better accommodate future load growth because it won't respond to load currents that would damage or could operate less noble fuses – it won't respond to load currents less than 130A.

Moreover, the magnetizing inrush currents would be ignored, and it would reclose after tripping if the 2,000-kVA cold-load pickup currents in Figure 4

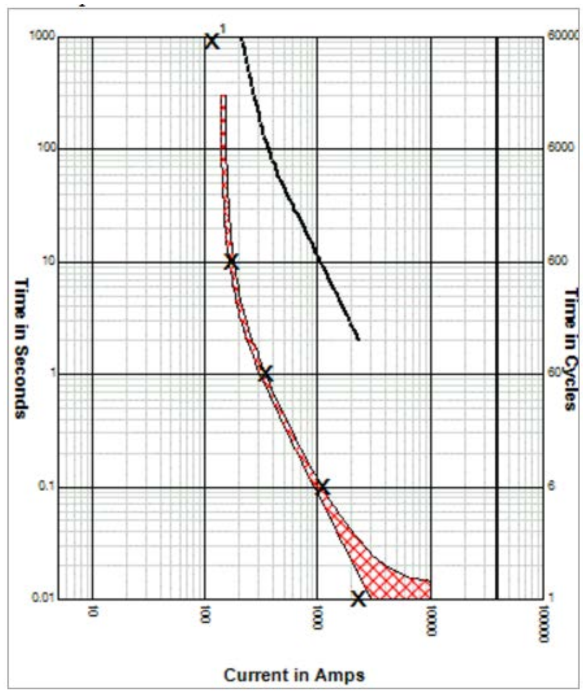

Figure 3. 12.47-kV, 65A K-speed fuse, 2,000-kVA default magnetizing inrush currents and transformer damage curve, and 1,200-kVA cold-load pickup currents. Note: Magnetizing inrush currents can cause fuse misoperation.

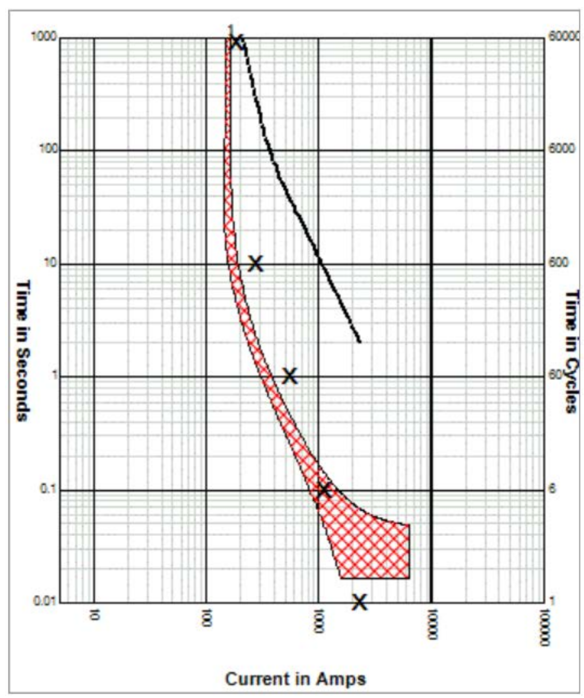

Figure 4. 12.47-kV, lateral circuit recloser 65A K-speed TCC, 2,000-kVA default magnetizing inrush and 2,000-kVA cold-load pickup currents and transformer damage curve.

were to occur. And, if its last reclose was a 100-ampere K-speed fuse TCC shown in Figure 5, the higher cold-load pickup issues would be resolved.

Admittedly, if this lateral recloser was responding to faults instead of cold-load pickup, it might miscoordinate with an upstream device after switching from the 65-ampere to the 100-ampere K-speed TCC. But if its last reclose operation resulted in both the upstream device and the lateral recloser tripping, the recloser would lock out, and the upstream device would reclose and hold.

Relay and Recloser TCCs

One make of lateral recloser is equipped with numerous relay and recloser TCCs. These TCCs offer more coordination flexibility because they can be shifted laterally and vertically using low cutoff current and time-multiplier settings. However, unlike fuses and recloser TCCs that typically begin responding at twice their load rating, relay TCCs begin responding at their minimum trip setting.

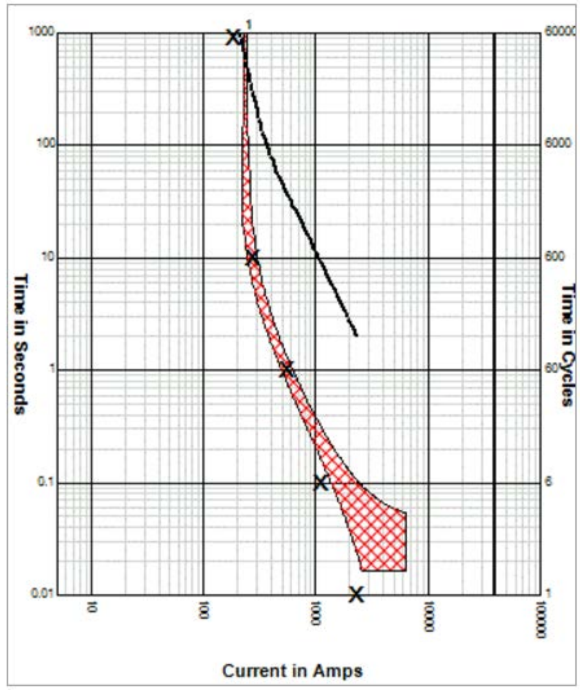

Figure 5. Lateral recloser 100A K-speed fuse TCC and default 2,000-kVA magnetizing inrush and cold-load pickup factors and transformer damage curve.

Some relay TCCs can be used to emulate fuses with great success. For example, Figure 6 shows a 65-ampere T-speed fuse versus one recloser's IEC-EI TCC with a 130-ampere minimum trip and a

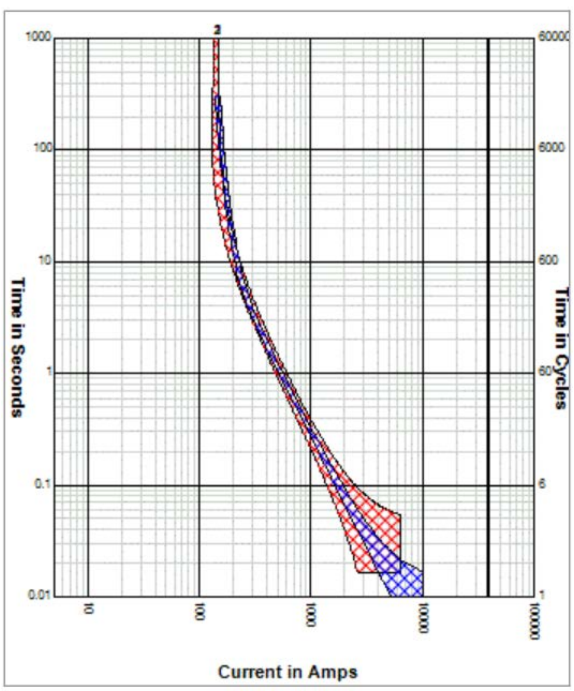

Figure 6. 65A T-speed fuse vs a recloser IEC-EI TCC with 130A minimum trip and 0.2 time-multiplier.

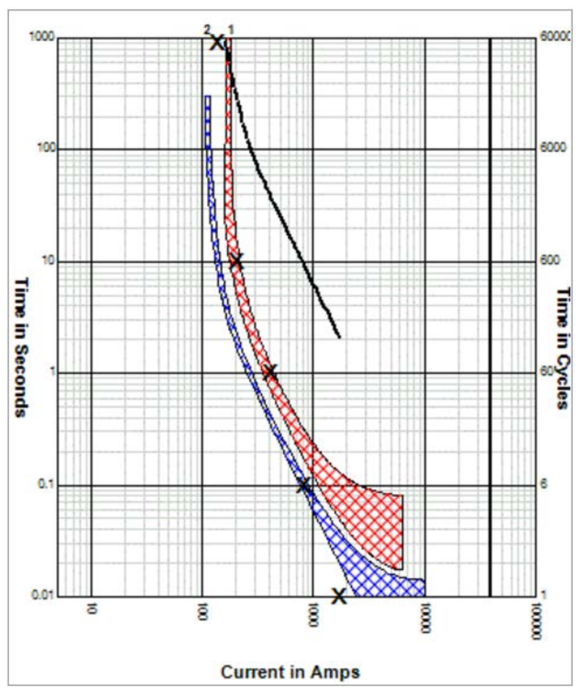

Figure 7. One 25-kV lateral recloser's SEL-U4 TCC accommodates 3,000-kVA of aggregate load and a 50A K-speed fuse. Note: The solid line is a 3,000-kVA transformer damage curve.

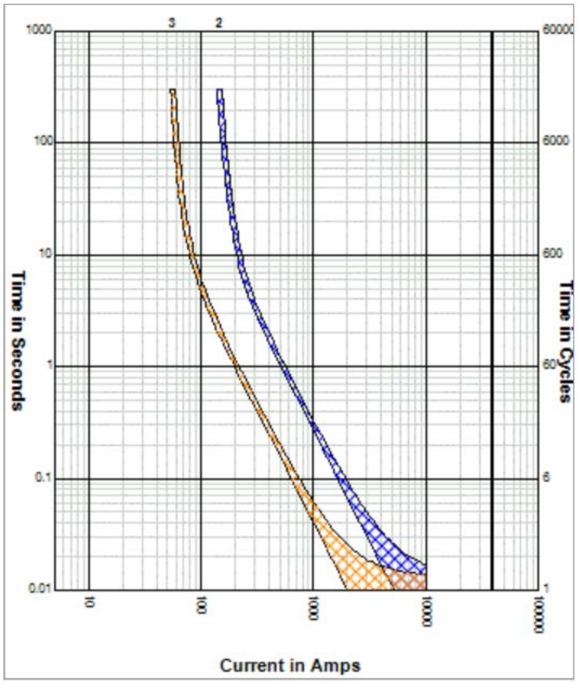

Figure 8. 25A T-speed fuse (left) and 65A T-speed fuse (right) miscoordinate at 4,000A.

time-multiplier of 0.2 – the fuse extends down to the horizontal 0.01-second line.

Another example is shown in Figure 7. Here the lateral circuit recloser is protecting an aggregate 25kV, 3,000-kVA (three-phase) load, and downstream is a 50-ampere K-speed fuse. The plot shows this recloser's SEL-U4 TCC will minimize coordination challenges with any upstream device while handily accommodating the 3,000-kVA default cold-load pickup factors.

<u>Definite-Time Overcurrent Responses</u>

Coordination with downstream fuses will improve by applying definite-time overcurrent to one lateral circuit recloser's fuse TCC. For example, Figure 8 illustrates a 25-ampere T-speed fuse (left TCC) is downstream of a 65-amperre T-speed fuse (right TCC) and they miscoordinate at about 4,000-amperes.

Simply choosing this lateral recloser's 65- ampere T-speed fuse TCC doesn't quite resolve the issue as shown in Figure 9. However, referring to Figure 10, the simple application of 50-milliseconds of definite time at 2,200-amperes now properly coordinates this recloser's 65-ampere T-speed fuse TCC with the downstream 25-ampere T-speed fuse.

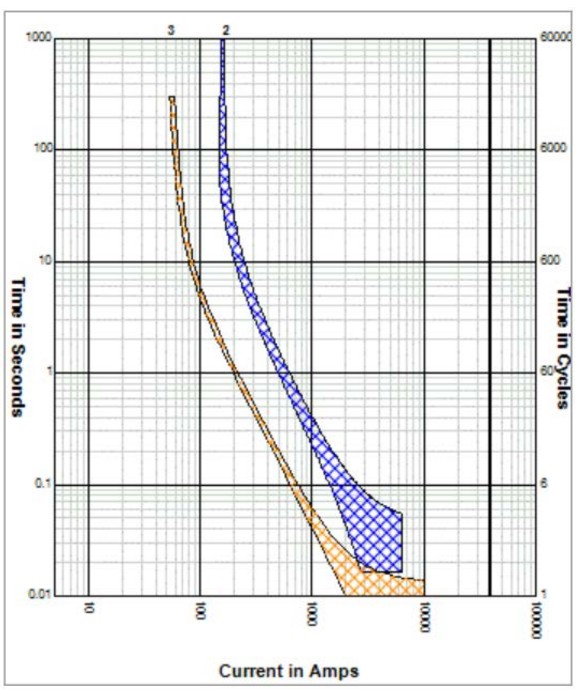

Figure 9. 25A T-speed fuse (left) and 65A T-speed lateral recloser fuse TCC (right) still miscoordinate.

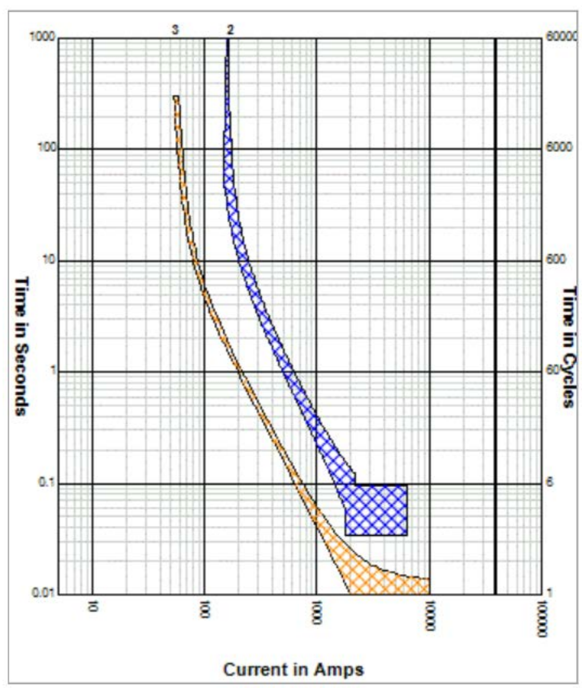

Figure 10. Adding 50ms of definite-time at 2,200A coordinates the 25A T-speed fuse (left) and 65A T-speed lateral recloser fuse TCC (right).

Applying Reclosers on Secondary Laterals

Lateral circuits are frequently segmented to improve reliability. This means locating a primary fuse at the main feeder tap, and one or more secondary fuses further downstream to split the load into two or more segments.

Consequently, the following real-world example demonstrates there are further opportunities to substantially improve lateral circuit reliability and reduce operating costs. As shown in Figure 11, lateral reclosers are installed as primary (TS2 #1) and secondary (TS2 #2) reclosers downstream of a substation breaker at 25kV.

The primary lateral TS2 #1 replaces a 100-ampere T-speed fuse and is serving an aggregate load of 1,370-kVA (single-phase). Additionally, the secondary lateral TS2 #2 replaces a 50-ampere T-speed fuse and serves an aggregate load of 400-kVA (single-phase). An 8-ampere K-speed fuse is the largest fuse and protects 75-kVA single-phase transformers in both lateral segments.

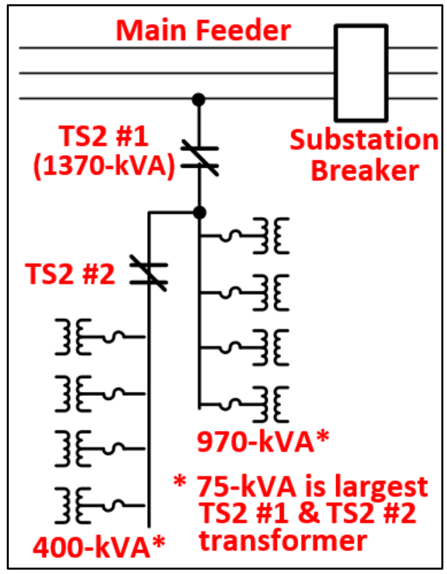

Figure 11. Cutout-mounted recloser applied as primary (TS2 #1) and secondary (TS2 #2) lateral protection.

Therefore, TS2 #2 must coordinate with the 8-ampere K-speed fuse, and TS2 #1 will be coordinated with TS2 #2 and the substation breaker. However, both lateral reclosers must also accommodate their respective aggregate transformer magnetizing inrush currents. And as the percentage of small versus large transformers is unknown, default 25x an 12x magnetizing inrush factors are used.

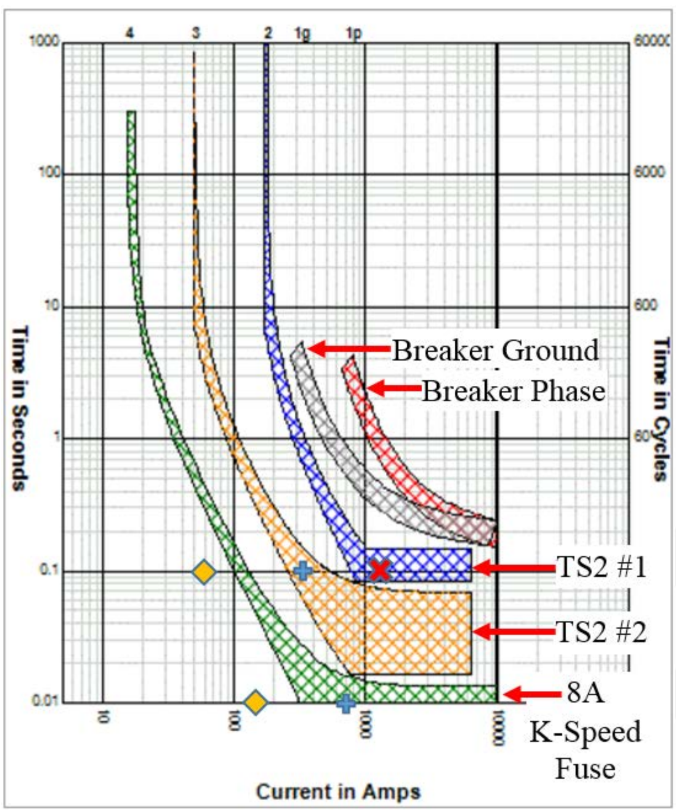

Figure 12. Coordination plot of Figure 11 breaker phase and ground protection, primary (TS2 #1) and secondary (TS2 #2) reclosers, and 8A K-speed fuse.

Figure 12 shows the coordination plot of the four devices – the substation breaker phase and ground protection, TS2 #1, TS2 #2 and the 8-amperre K-speed fuse. The single "X" at 0.1-seconds represents the 12x magnetizing inrush factor (1,139A) for the 1,370-kVA aggregate single-phase load served by TS2 #1. As definite-time overcurrent minimum trip and time delay have been applied to TS2 #1, the 25x full-load current multiplier is disregarded.

The "+s" at 0.01- and 0.1-seconds indicate the aggregate 400-kVA load 25x (693A) and 12x (333A) magnetizing inrush current factors addressed by TS2 #2. And the "◊s" at 0.01- and 0.1-seconds illustrate the 25x (130A) and 12x (62A) magnetizing inrush current factors for the 75-kVA single-phase transformers.

The 400-kVA magnetizing inrush current factors conflict with conventional fuse coordination philosophy and the 1,370-kVA, 12x full-load current factor also violates these principles. However, the lateral recloser's magnetizing inrush restraint feature overcomes these issues. This is especially true recognizing magnetizing inrush currents can continue well beyond the 0.1-second threshold.

Also, please note that while cold-load pickup factors are not shown to reduce clutter in Figure 12, the lateral reclosers' settings satisfy these requirements.

Conclusions

Lateral fault-protection coordination has been more of an art than a science. This is primarily true because lateral fuses are occasionally of inferior design and construction but, more importantly, lack the ability to record why they operated. Consequently, when a lateral fuse persistently misoperates, the easiest solution is to simply replace it with a higher rated fuse.

Fortunately, the introduction of one brand of lateral recloser makes the process of lateral fault coordination more of a science than an art. This lateral recloser not only offers the best options and solutions for optimizing lateral fault coordination, its event logs will provide further insights into previously unknown or unrecognized fault responses.

Often unheralded, this lateral recloser's magnetizing inrush restraint feature will further help improve lateral circuit protection responses. Even if this recloser uses the same TCC and rating of the fuse it replaces, the consequences of magnetizing inrush events (that are likely to be the cause of unexplained fuse misoperations) will no longer be an issue.

Ultimately, all a user need consider when deciding whether to deploy lateral circuit reclosers is the cost incurred in replacing blown fuses. These fuse-replacement costs, consisting of people and vehicles, quickly exceed the expense of installing one make of lateral recloser. And the improved reliability afforded to customers served by laterals protected by this cutout-mounted recloser is a further benefit when considering the advantages of this investment.

BIBLIOGRAPHY

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