A NEW FUSE-SAVING PHILOSOPHY

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Abstract Utilities generally apply one of two fuse coordination philosophies on a given distribution feeder – fuse-blowing or fuse-saving. When fuse-saving works, it benefits both the utility company and its customers. Service is automatically restored to all customers and a utility line crew does not have to travel to the fuse location to replace a blown fuse.

However, fuse-saving practices have coordination limitations at higher current levels – it is common for the upline device to trip and the fuse to operate at the same time. The result is frequent momentary outages for many customers and blown fuses, even for temporary faults. These challenges have led some utilities to abandon the practice of fuse-saving and instead migrate to a fuse-blowing philosophy.

The conventional fuse-saving practice has an inherent tradeoff of sustained outage improvement at the expense of increased momentary activity. Ratings under the reliability indices SAIFI and SAIDI are improved, but the gains are offset by an increase in momentary events, reported as $MAIFI_E$. When the fuse blowing practice is employed, the tradeoff is reversed – reduced momentary activity comes at the expense of more frequent sustained outages.

The new fuse-saving philosophy described in this paper offers several improvements over conventional practices by extending the range of coordination, minimizing miscoordination with downline devices, and eliminating unnecessary tripping. An optimized composite phase and ground fuse-saving TCC curve is developed for the smallest downline fuse that is to be saved. Tripping on this curve only occurs when it can actually clear the fault before the fuse begins to melt. If the fuse cannot be saved, the initial tripping operation of the upline device shifts to a more delayed curve to allows the fuse to operate.

While most utilities use a mix of fuse-blowing and fuse-saving on different feeders, this new fuse saving philosophy achieves an intelligent mix of both practices on the same device. The full SAIFI and SAIDI benefits of fuse-saving are achieved while avoiding excessive momentary operations similar to a fuse-blowing philosophy.

Keywords- **Fuse-Saving, Intelligent Fuse-Saving, $MAIFI_E$, Overcurrent Protection, Pulseclosing, Reclosers**

I. FUSE COORDINATION PHILOSOPHIES

Utilities generally apply one of two approaches for coordinating breakers and reclosers with downline fuses. Some use a "fuse-blowing" philosophy: The substation feeder breaker or recloser is coordinated with downline lateral fuses so that the fuses will clear any downline faults within their ratings. The breaker or recloser does not trip for faults beyond a fuse. But customers located downline of a fuse experience a sustained interruption for every fault, even faults that would have been temporary had they been given a chance to be cleared. And the utility must deal with the high cost of service calls to replace blown fuses.

Others use a "fuse saving" philosophy: The first one or two trips of a substation feeder breaker or recloser is intentionally coordinated so that the breaker or recloser operates faster than the downline fuse to attempt to clear temporary faults that occur beyond the fuse. The subsequent trips of the breaker or recloser are slower so that if the fault is still present, the downline fuse will operate to clear it. The downside of this scheme is that all customers downline of the breaker or recloser experience a momentary interruption for every fault.

Fuse-saving improves SAIFI and SAIDI. However, these gains are offset by an increase in $MAIFI_E$. This increased number of momentary outages can be very large since there are typically a large number of customers served by a breaker or recloser. Fuse-saving also has coordination limitations at higher current levels; fault currents above a certain level will result in the breaker or recloser tripping coincidentally with the operation of the fuse. This results in a blown fuse *and* a momentary outage for all customers downline of the breaker or recloser, which is undesirable.

A 1996 survey on the usage of fuse saving reported a mix of coordination practices. 40% of the surveyed utilities used fuse-saving, 27% used fuse-blowing, and 33% reported using a mixture on a case-by-case basis because fuse-saving had often resulted in too many customer complaints for momentary interruptions. A separate survey reported a steady decline of fuse-saving usage from 91% in 1988 to 71% in 1994 and finally to 66% in 2000. [1]

This paper introduces a new fuse-saving philosophy called "Intelligent Fuse-Saving." This innovative approach extends the range of coordination, eliminates unnecessary tripping, and minimizes interference with downline devices. A custom time-current characteristic (TCC) curve is constructed to optimize coordination with the downline fuse. It allows fuse-saving to be applied in situations that have proven troublesome in the past.

II. The Importance of Proper Overcurrent Coordination

Properly coordinated protective devices are essential to a reliable distribution system. Without proper coordination, other commonly implemented reliability enhancements such as feeder automation or fault prevention methods will have a lesser impact on SAIFI, SAIDI, $MAIFI_E$, and other reliability indices. Improper coordination results in the wrong device tripping and/or locking out for a fault event, which always increases the number of customers that experience an outage. Feeder automation automatically reconfigures the system after a fault has been cleared to restore as much of the feeder as possible, but the automation system typically depends on properly coordinated devices to determine the location of the fault.

The most common equipment pair that needs to be coordinated on a typical distribution feeder is a substation or mid-line recloser and a downline lateral fuse. Optimizing recloser-fuse coordination is very important because miscoordination results in excessive recloser tripping, causing outages for the large number of downline customers. The new fuse coordination approach described in this paper results in the best possible recloser-fuse coordination.

III. A New Philosophy - Four Improvements over Conventional Fuse-Saving

Four changes to the conventional fuse-saving method are proposed:

1. Develop optimized fuse-saving TCC curve

A unique fuse-saving TCC curve is developed specifically for each of the downline fuse sizes and types that are commonly used on distribution systems, such as Type T, K, QR, KSR, Coordinating Speed, and others. This custom TCC curve is placed just below the fuse's minimum-melting curve, with appropriate allowances for such items as the control response and mechanical interrupting time with tolerances, fuse pre-loading, ambient temperature, and fault current asymmetry.

The shape of the fuse-saving curve is designed to conform to the specified fuse curve as closely as possible, thus minimizing interference with smaller downline transformer fuses. Conventional recloser fast curves are typically much faster than necessary at lower currents, as shown in Figure 1. This miscoordination leads to recloser tripping even when it is not possible, nor desirable, to save transformer fuses.

In Figure 2, the first step of developing an optimized fuse-saving curve is plotted as a band consisting of the minimum response and maximum clear curves with all tolerances accounted for. Since the the fuse-saving curve is created based on the fuse minimum-melting characteristic of the fuse with which it is intended to coordinate, the same curve shape applies for both ground and phase applications.

Another benefit of pre-engineered optimized fuse-saving curves is that configuring an upline protective device control for fuse-saving applications is simplified. Enabling the fuse-saving element and selecting the downline fuse size and type is all that is required.

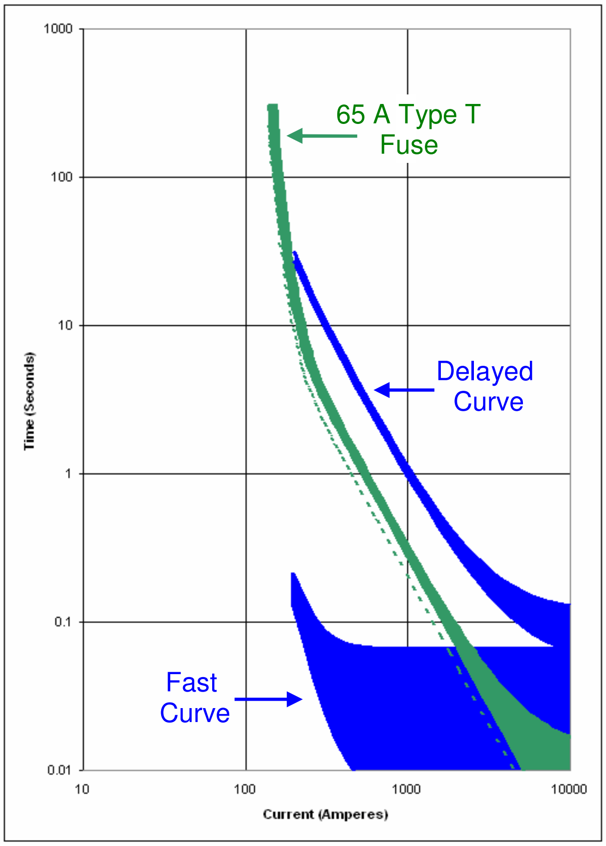

FIGURE 1. CONVENTIONAL FUSE-SAVING USING A COMMON FAST TCC CURVE

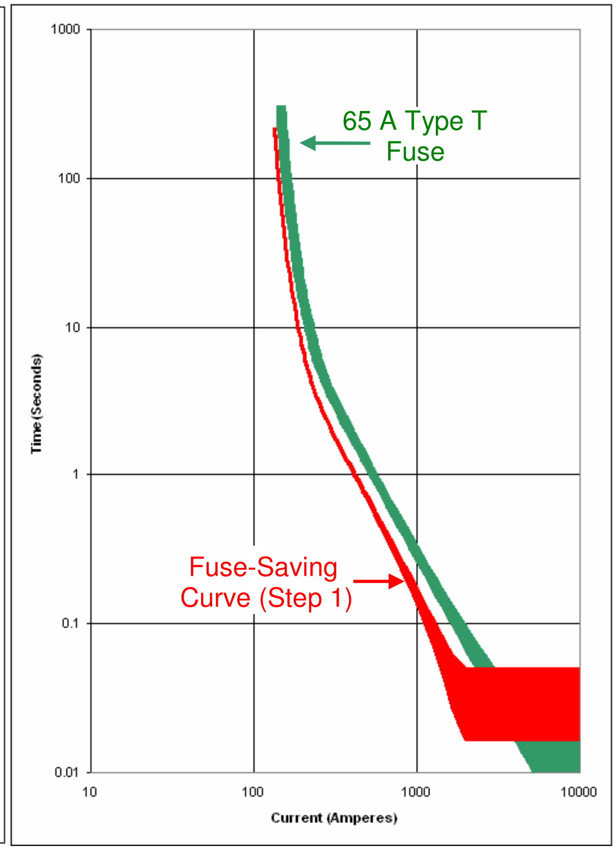

FIGURE 2. THE FIRST STEP IN CREATING A CUSTOM FUSE-SAVING TCC CURVE

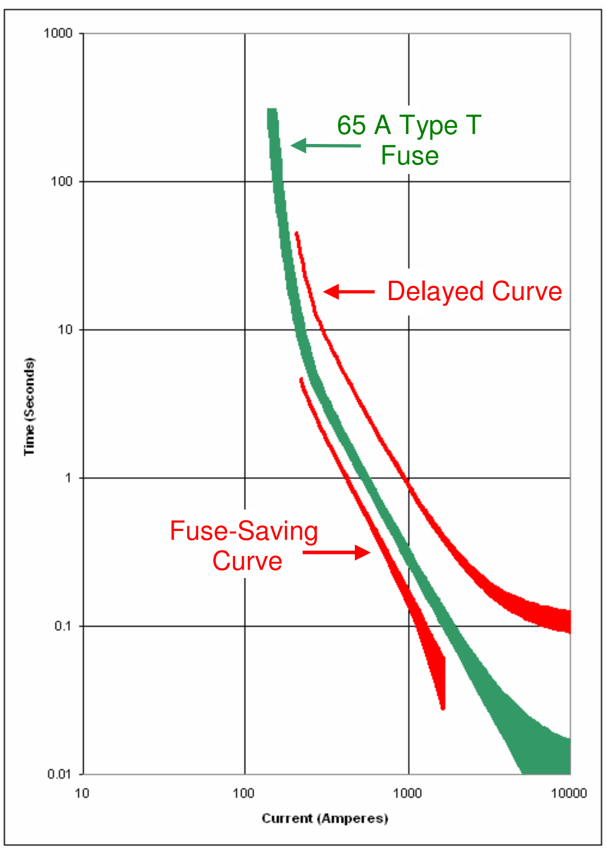

FIGURE 3. PARTIAL RANGE FUSE-SAVING CURVE IS IMPLEMENTED FROM THE DELAYED CURVE MINIMUM TRIP THROUGH THE MAXIMUM COORDINATING CURRENT

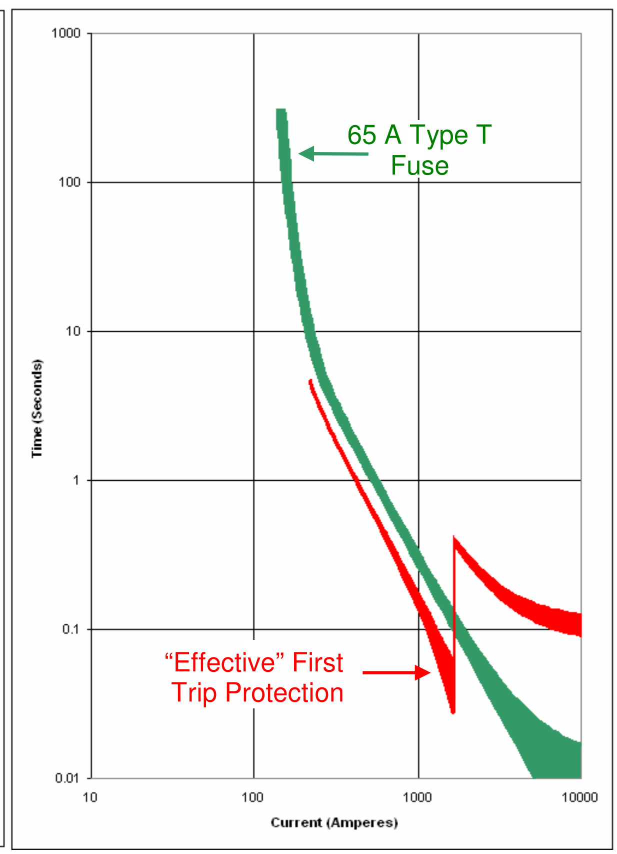

FIGURE 4. EFFECTIVE FIRST TRIP PROTECTION COMBINING THE FUSE-SAVING CURVE AND PART OF THE DELAYED CURVE

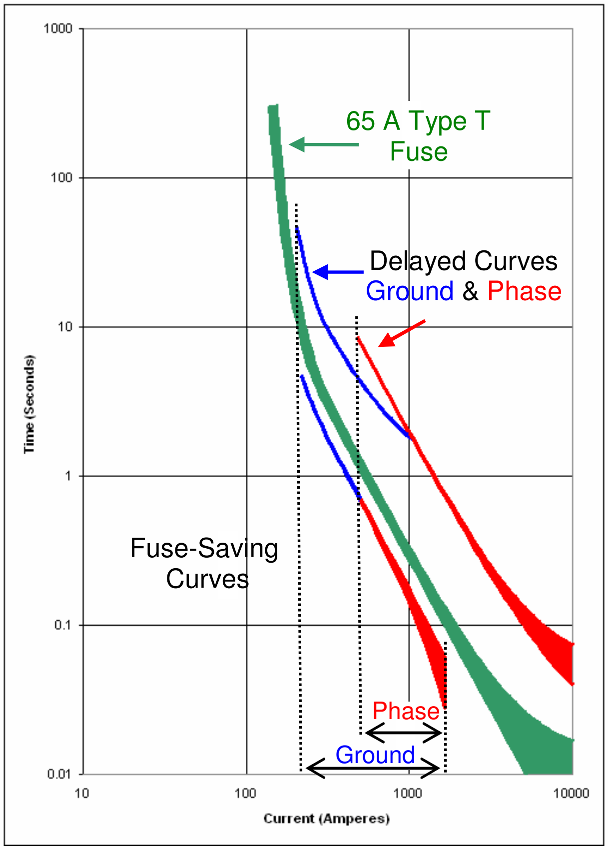

FIGURE 5. FULL IMPLEMENTATION OF PHASE AND GROUND ELEMENTS WITH FUSE-SAVING AND DELAYED CURVES

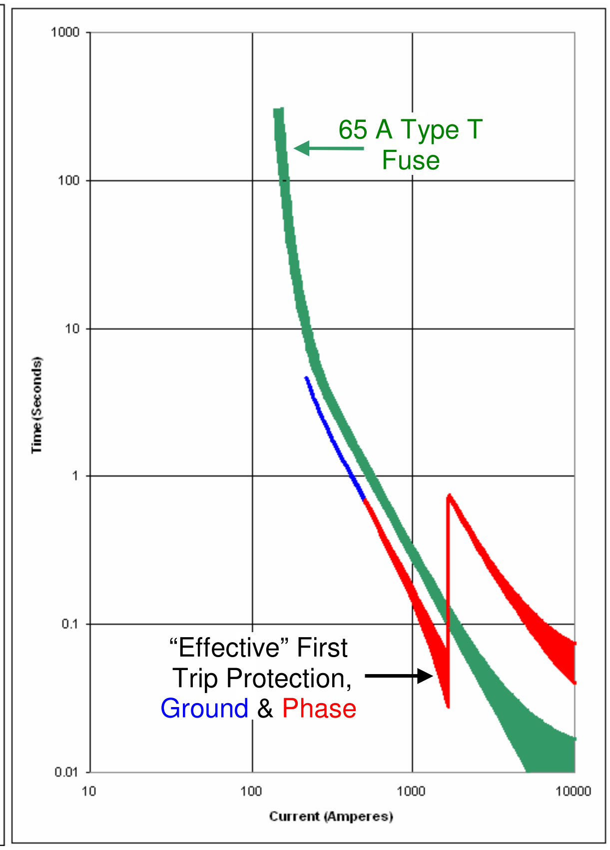

FIGURE 6. EFFECTIVE FIRST TRIP PROTECTION OF BOTH PHASE AND GROUND ELEMENTS

2. Partial range fuse-saving curve

Ideally, a “fast” fuse-saving trip should only occur when the fault can actually be cleared before the downline fuse begins to melt. If the fuse cannot be saved, fast tripping should be skipped and timing should occur using a delayed curve that allows the fuse to operate before the recloser trips. This technique garners all the benefits of successful fuse-saving without the nuisance trips resulting from miscoordination at higher fault currents.

As shown in Figure 3, the fuse-saving curve starts at the lowest phase or ground minimum trip current setting specified for the “delayed” curves. The custom curve is also truncated at the maximum coordination current, which is defined as the current where it can no longer be guaranteed that the breaker or recloser will interrupt and clear the fault before the fuse begins to melt. Therefore, low current faults will cause a trip on the fuse-saving curve and high current faults may only result in a trip on the delayed curve. The effective first trip protection curve is shown in Figure 4. This maximizes the range of possible fuse-saving coordination currents and prevents the fuse-saving element from tripping for fault currents that will result in a blown fuse anyway.

If both phase and ground delayed curves have been specified, the ground fuse-saving curve will be implemented over the range of currents from the minimum trip value of the delayed ground curve through the maximum coordinating current. This is shown in Figure 5. The phase fuse-saving curve, which has the same exact shape as the ground fuse-saving curve, will be implemented over the range of currents from the minimum trip value of the delayed phase curve through the maximum coordinating current. The ground fuse-saving curve and the phase fuse-saving curve are driven by the residual ground current and the phase current, respectively.

During steady-state operation, both the fuse-saving curve and the delayed curve are active and will time in parallel. The effective composite curve of first trip overcurrent protection is shown in Figure 6. The fuse-saving curve is faster for a limited range of fault currents. Fuse-saving trips only occur for relatively low magnitude faults. For the 65T downline fuse shown in Figure 6 and a selected minimum trip of 200 A on the upline protective device, the effective fuse-saving range is from 200 A through 1700 A. Faults greater than 1700 A exceed the maximum coordinating current of the fuse-saving curve, so timing only occurs on the delayed curve.

A fault beyond the fuse will cause the fuse to operate without ever causing a trip on either the fuse-save curve or the delayed curve. If the high-magnitude fault is actually on the main line and not beyond a fuse, then a trip will be triggered according to the delayed TCC curve.

Note that if the maximum available fault current at the fuse location is 5200 A, the effective fuse saving range is only 30% of the total available protection range. This fact is often overlooked due to the visual nature of a log-log plot. Even disregarding the fact that most fault currents tend to be closer to the maximum available fault current rather than the minimum, it can be assumed that fuse-saving has a chance to work for approximately 30% of all faults that occur beyond the downline fuse. Therefore, the fuse-saving approach described in this paper prevents a momentary outage to a relatively large number of customers for 70% of the faults that occur beyond the fuse due to the fuse-saving TCC curve only being instantiated over a partial range of the available fault currents.

3. Separate fuse-saving operating sequence

Fuse-saving requires both a “fast” curve and a “delayed” curve. The fast curve, or fuse-saving curve, trips the device before the downline lateral fuse begins to melt to try to clear temporary faults. But if the fault is permanent, the recloser must close and begin timing on a curve that is more delayed than the fuse in order for the fuse to melt and clear the fault.

A distinction needs to be made regarding the difference between reclosing and pulseclosing. After the initial trip, a device capable of pulseclosing can be used to determine if the line is still faulted without actually “reclosing” into the fault. Pulseclosing is a very fast close-open of the switchgear contacts that results in a minor loop of asymmetrical fault current lasting approximately 5 ms. This pulse of current provides enough information for an algorithm to determine if the line is faulted or not. [2]

A device configured for pulseclosing operations does not actually close in to the faulted line, so the dual timing characteristic is accomplished using a separate operating sequence that includes a “forced close” when the initial trip occurs on the fuse-saving curve. If the fault is higher in magnitude and the initial trip occurs on the delayed curve, then the regular overcurrent operating sequence will be followed. This may consist of only pulseclosing operations or may include one or more “forced” closes.

Consider the example in Figure 7 and Table 1. For a 1000-ampere fault, the device trips on the fuse-saving curve. The operating sequence might be configured to subsequently perform two pulseclosings, which would allow adequate time for the fault byproducts to dissipate. The third test might be configured as a close operation, which would allow the fuse to operate if there is indeed a permanent fault downline of a fuse. The final test might be configured as a pulseclose, which would test the line once more to determine if the fault is actually a permanent fault on the main line that the fuse will not clear.

One of the main goals of pulseclosing is to relieve system and equipment stresses caused by the repeated occurrence of high magnitude fault currents that result from a conventional reclosing sequence that has three or four operations. Due to the implementation of a partial range fuse-saving curve, the only faults that will result in fuse-saving attempts, including the associated forced close to initiate timing on the delayed curve, will occur only at relatively low magnitude faults. Therefore, the full benefits of pulseclosing and intelligent fuse-saving can both be achieved on the same fault interrupting device.

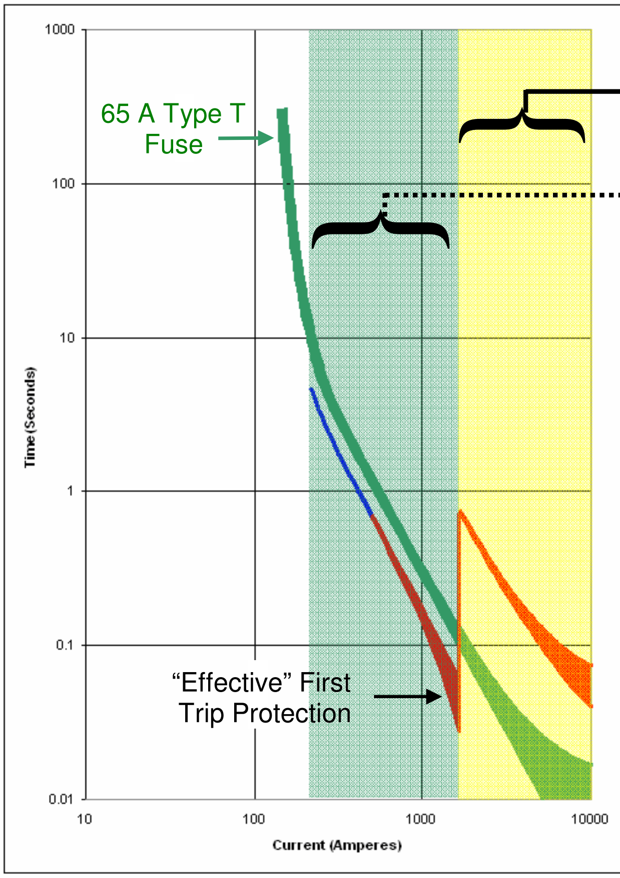

FIGURE 7. THE LEFT SHADED AREA (GREEN) REPRESENTS THE RANGE OF EFFECTIVE FUSE-SAVING

Fault Current Range	200 - 1700 A	> 1700 A
Initial Trip Operation	Fuse-Saving Curves	Delayed Curves
Test #1	Pulseclose	Pulseclose
Test #2	Pulseclose	Pulseclose
Test #3	CLOSE	Pulseclose
Test #4	Pulseclose	Pulseclose

TABLE 1. TWO OPERATING SEQUENCES BASED ON THE FAULT CURRENT RANGES IN FIGURE 7

4. Single-phase tripping for fuse-saving

The concept of a separate fuse-saving operating sequence can be taken one step farther by implementing single-phase tripping for the fuse-saving trips. Even in locations where single-phase tripping is not acceptable for any extended duration, it may be allowable to have just the first trip occur on the faulted phase in an attempt to clear a temporary fault in fuse-saving situations. If the fault current is higher than the maximum fuse-saving possibility, the first trip would occur on the delayed curve, and this could be specified to be a three-phase trip. After the initial single-phase trip for fuse-saving, all subsequent operations can be single-phase or three-phase as desired.

The control and hardware can minimize any single-phasing concerns by accommodating a mix of single-phase and three-phase tripping. This includes the ability to turn off ground and negative sequence protection elements only for the duration of the single-phase open interval and allowing a setting range for the first open inverval to be very short.

The advantage of a single-phase trip is a further reduction of the $MAIFI_E$ index by approximately two-thirds since customers served by the non-faulted phase will not experience a momentary outage. As described for the 65T fuse above, implementing a partial range fuse-saving curve can reduce $MAIFI_E$ by approximately 70% of what it would be for conventional fuse-saving. Single-phase tripping further reduces $MAIFI_E$ by a factor of 3, resulting in momentary relibability indices that are reduced in total by a factor of 10 compared to the conventional fuse-saving technique. The expected level of $MAIFI_E$ improvement can be calculated for different fuse-saving applications using the fuse size and type, the minimum trip current setting, and the range of available fault currents.

IV. CONCLUSION

With the limited coordination that can be achieved using conventional recloser fuse-saving, customers experience frequent momentary outages for faults on other parts of the system as the breaker or recloser trips in a futile attempt to save fuses. When a fuse-blowing strategy is employed instead, any fault on a lateral - even a temporary fault due to conductor slapping or animal contact - will cause fuses to operate and results in frequent and lengthy customer outages.

The new fuse-saving technique described in this paper bridges the gap between the two conventional fuse coordination philosophies. By using custom-generated fuse-saving curves and only tripping when the fuse may actually be saved, the best combination of reliability and overcurrent protection is achieved. Using a separate operating sequence for fuse-saving trips allows the full use of pulseclosing and fuse-saving together. Additionally, tripping only the faulted phase(s) for the fuse-saving trip greatly reduces $MAIFI_E$ and can likely be used even in locations where extended single-phasing conditions are not acceptable.

V. REFERENCES

[1] "Electric Power Distribution Handbook," T.A. Short, CRC Press, 2004.

[2] "Advancing the State of Looped Distribution Feeders," Christopher McCarthy and Douglas Staszesky, S&C Electric Co., DistribuTECH 2008, January 22-24, 2008, Tampa, Florida.

VI. BIOGRAPHIES

Christopher A. McCarthy is a Senior Engineer in the Power System Services Division of S&C Electric Company in Chicago, Illinois. Chris is participating in R&D, marketing, and field application support for the IntelliRupter® PulseCloser. Prior to joining S&C in 2006, he was with Cooper Power Systems for 11 years. His experience includes performing analytical studies, software development, and presenting engineering workshops in the fields of overcurrent protection, recloser applications, and optimizing reliability of distribution systems. He received a BSEE from the University of Illinois at Champaign-Urbana, a Masters in Electric Power Engineering from Rensselaer Polytechnic Institute, in Troy, New York, and an MBA from Keller Graduate School of Management. He is a registered Professional Engineer in the state of Wisconsin.

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