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**CIGRE US National Committee
2016 Grid of the Future Symposium**

**Medium-Voltage Feeder Interruptions Caused by Protection Operations:
What Causes Them and How to Mitigate Them**

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SUMMARY

The imposition of customer-interruption penalties and the increased scrutiny of reliability metrics by governmental regulators are encouraging utilities to investigate solutions for improving service continuity on overhead feeders, particularly laterals. This paper discusses the reasons fused-lateral “fuse blowing” and “fuse saving” protection philosophies cause momentary and sustained interruptions on overhead medium-voltage (MV) feeders. The paper then introduces a cost-justifiable solution – the sophisticated cutout-mounted recloser. This self-powered, electronically-controlled, single-phase, vacuum fault interrupter is applied at the tap point of a lateral in lieu of a fused cutout. It eliminates the sustained interruption caused by a fuse blowing philosophy that results in a cutout operation in response to a transient downstream fault. And it eliminates momentary interruptions on the main feeder produced by a fuse saving strategy, that has questionable operation success.

KEYWORDS

Cutout-mounted recloser, interruptions, single-phase, laterals, feeder, faults, time-current characteristics, ratings, recloser

I. Introduction

A high percentage of overhead MV feeders are laterals. Overhead laterals account for 63% of one North American utility's total overhead-feeder circuit miles. While both the main overhead feeder and its laterals are subjected to frequent faults, customers served by overhead laterals account for 82% of this utility's Customer Minutes of Interruption (CMI).

Although CMI aggregates momentary and sustained interruptions, most utilities do not track the frequency of momentary interruptions, and they do not have sufficient historical data to develop appropriate baselines. [1] However those utilities that account for momentary interruption frequency indicate 60% to 80% are attributable to transient faults on overhead laterals, and some claim this number is as high as 90%.

One cause of sustained interruptions on overhead fused laterals is the use of a "fuse blowing" philosophy when responding to lateral faults. In this instance the fuse cutout clears any downstream fault within its rating, but all customers served by this lateral experience a sustained interruption, even if the fault is only transient. When time-current coordination between the lateral fuse and an upstream recloser or substation circuit-breaker is improper, customers downstream of these main feeder devices experience a momentary interruption.

Fuse blowing philosophy is a polar opposite of fuse saving philosophy. When a fuse saving strategy is implemented, an interim feeder recloser or substation circuit-breaker is purposely miscoordinated so it ideally operates before the fused cutout. But the fuse saving concept, whether it works successfully or not, has a downside as well. All downstream customers served from the recloser or circuit-breaker are subjected to a momentary interruption for every fault on every fused lateral.

II. Fuse Coordination Philosophies

Utilities with overhead MV feeders generally apply one of two approaches for coordinating substation circuit-breakers and interim feeder reclosers with downstream fuses. Some use a fuse blowing philosophy while others use a fuse saving approach. However, fuse saving strategists typically abandon this approach in favor of fuse blowing whenever available fault currents make the probability of fuse saving success highly unlikely.

Fuse Blowing

In a fuse blowing strategy, the substation circuit breaker or interim feeder recloser is coordinated with downstream lateral fuses so that the fuses will clear any downstream faults. The breaker or recloser does not trip for faults beyond a fuse, but customers located downstream of the fuse experience a sustained interruption for every fault, including those faults that are transient. And the utility must deal with the high cost of service calls or "truck rolls" to replace blown fuses.

The costs related to a fuse blowing philosophy are often overlooked as utilities generally allocate money annually for the availability of service resources regardless of what duties are being performed. Consequently, the per-event costs of replacing blown fuses are often ignored, and seldom determined.

Further, governmental regulators occasionally penalize utilities for sustained customer interruptions and encourage utilities to reduce related reliability indices. As an example, one European regulator required utilities to improve customer interruption performance by about 5%

per year and imposed clearly-understood bonuses and penalties for success or failure to meet the targets.

For each customer interrupted (CI) there was a penalty of \$16 and for each customer hour lost (CHL) there was an additional charge of approximately \$13. Applying this to a rural 20-transformer lateral, with 4-customers per transformer, that had suffered a 3-hour interruption, we get:

- Number of Customers Affected = $20 \times 4 = 80$
- CI penalty = $80 \times \$16 = \$1,280$
- CHL penalty = $80 \times 3 \times \$13 = \$3,120$
- Total interruption penalty = $\$1,280 + \$3,120 = \$4,400$

To complete the utility's cost picture, it must add the cost of dispatching a crew and its vehicle(s) to restore supply and deal with the residual customer issues and their monetary losses in order to obtain the total cost of the interruption. Using average lateral fault-frequency statistics and today's conservative field-crew and truck-roll cost estimates, fuse-replacement costs alone can substantiate upgrading fuses to single-phase cutout-mounted reclosers.

Fuse Saving

With a fuse saving philosophy, the first one or two trips of a substation circuit breaker or interim feeder recloser are intentionally miscoordinated, so the breaker or recloser operates faster than the downstream fuse. This strategy attempts to clear transient faults occurring beyond the fuse, but requires subsequent trips of the breaker or recloser to be slower, allowing the fuse to operate and clear the fault, if it is persistent. The downside of this scheme is that all customers downstream of the breaker or recloser experience a momentary interruption for every fused-lateral fault.

Fuse saving improves SAIFI and SAIDI. However, these gains are offset by an increase in MAIFI or MAIFe. The increased number of momentary interruptions 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 fault current levels. Fault currents above a certain level will result in the breaker or recloser tripping coincidentally with the fuse operation. This results in a blown fuse and a sustained interruption for customers downstream of the fuse, as well as a momentary interruption for all customers downstream of the breaker or recloser.

A 1996 survey on the use of fuse saving reported a mix of coordination practices. Of the utilities surveyed, 40% used fuse saving, 27% used fuse blowing, and 33% reported using a mixture on a case-by-case basis, because fuse saving often resulted in too many customer complaints of 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. [2]

Further, recent research into the customer-borne cost of interruptions indicates a momentary interruption can actually be more costly than a sustained interruption. While these higher costs for momentary interruptions are primarily relegated to three-phase commercial loads, commercial loads are typically connected to the main feeder which experiences momentary interruptions when a fuse saving strategy operates.

III. Best of Both Philosophies – Single-Phase Reclosers

The single-phase recloser, in lieu of a fuse, overcomes the disadvantages of both fuse blowing and fuse saving strategies.

Principles of Operation

Unlike a fuse, a single-phase recloser enables multiple tripping operations, but as with fuse saving, requires time-current coordination with the upstream-substation circuit breaker or interim feeder recloser to ensure tripping selectivity. This multiple-tripping capability enables loads of the protected lateral to be automatically restored after transient faults clear. And if the fault is persistent the single-phase recloser trips to lockout and remains open.

Previous Technology

The single-phase recloser concept is not new, and has traditionally been produced using hydraulic or vacuum technology.

Hydraulic Technology

Time-current characteristics (TCCs) are used to achieve coordination with upstream and downstream devices. TCCs of hydraulic reclosers are factory set, and changing the TCC is extremely laborious, so users frequently exchange one unit with another when a different TCC is required.

These devices are also quite heavy and become a permanent fixture of the network, usually involving the installation of bypass and isolating switches for maintenance and troubleshooting purposes. And if these hydraulic devices experience a tank rupture due to an internal fault or inadequate maintenance, environmental cleanup costs are substantial.

Because the hydraulic recloser's oil is used for both interrupting faults and producing time-current responses, periodic maintenance is required to ensure the oil is reasonably clean. This is a time consuming process, and the time period between maintenance intervals has grown to the point many hydraulic reclosers are simply replaced.

Vacuum Technology

Single-phase vacuum technology is gradually replacing hydraulic technology, but typically still requires the ancillary isolating and bypass switching hardware associated with hydraulic reclosers. Additionally, a battery powered electronic overcurrent control, either integrated or supplied separately, accompanies these devices.

While vacuum technology has overcome most of the drawbacks associated with hydraulic technology, their total installed cost is still appreciable, and replacement is not easy should they develop problems.

IV. IMPROVING UPON THE SINGLE-PHASE RECLOSER – THE CUTOUT-MOUNTED RECLOSER

The problems described above can be eliminated by using a self-powered, electronically-controlled, single-phase, vacuum fault interrupter that can be installed in new or existing current-production fuse-cutout mountings.

Cutout-mounted reclosers are ideally suited for protection of laterals that experience frequent transient faults. They will eliminate the persistent interruption caused by a fuse blowing strategy

when the lateral fuse operates in response to a downstream transient fault. Consequently, utilities using a fuse blowing scheme will see an improvement in SAIFI without sacrificing MAIFI or MAIFIE. Utilities using a fuse saving scheme will eliminate main-feeder momentary interruptions as the breaker will no longer trip to save the lateral fuse for a downstream transient fault. Therefore, utilities presently using a fuse saving scheme will see an improvement in MAIFI or MAIFIE without sacrificing SAIFI.

Principles of Operation

The cutout-mounted recloser described in this paper can support up to three reclosing operations (four tripping operations in total) before it drops open. A wide variety of user-configurable time-current characteristic (TCC) curves are available. The open interval between tripping operations is user configurable and has a maximum value of five seconds. The vacuum interrupter resets two seconds after the cutout-mounted recloser drops open. The field crew can then close the recloser into the mounting using a switching stick.

In instances where a transient fault is cleared before the cutout-mounted recloser reaches the end of its operating sequence, it will revert to its first TCC curve and reset after a short period of time following the last reclosing operation. Reset time is user configurable and has a maximum value of 15 seconds.

Consider a transient fault downstream of the cutout-mounted recloser, as shown in Figure 1.

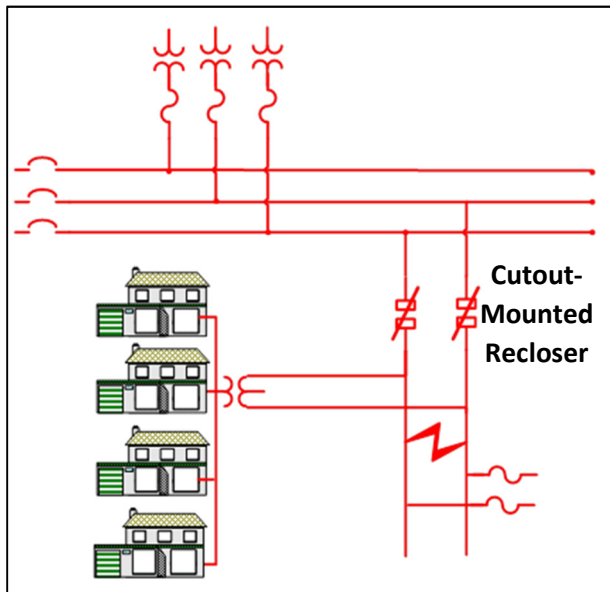


Figure 1. Transient fault.

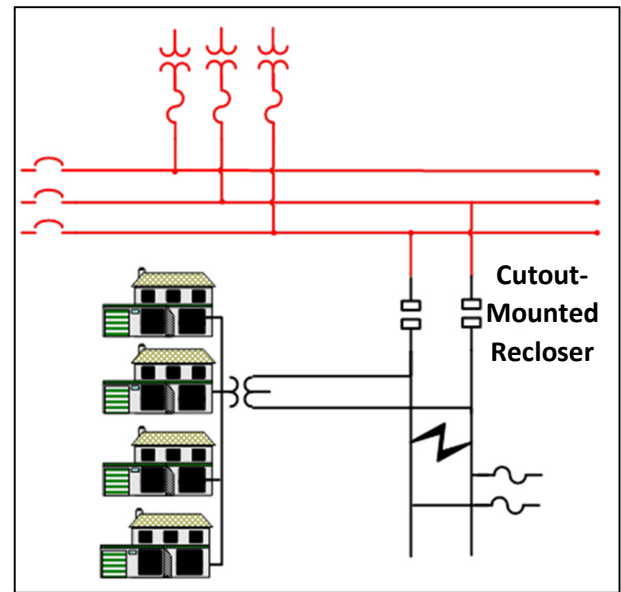


Figure 2. The cutout-mounted recloser operates.

Utilizing its fast TCC curve, the cutout-mounted recloser opens, as shown in Figure 2. Only customers served from the lateral downstream of the cutout-mounted recloser experience a momentary interruption.

After the user-selected reclose interval expires, the cutout-mounted recloser recloses to restore power to downstream customers served from the lateral, as shown in Figure 3. Since the fault was transient and has been cleared, further tripping operations are suspended. The cutout-mounted recloser then reverts to its first TCC based on the reset time selected by the user.

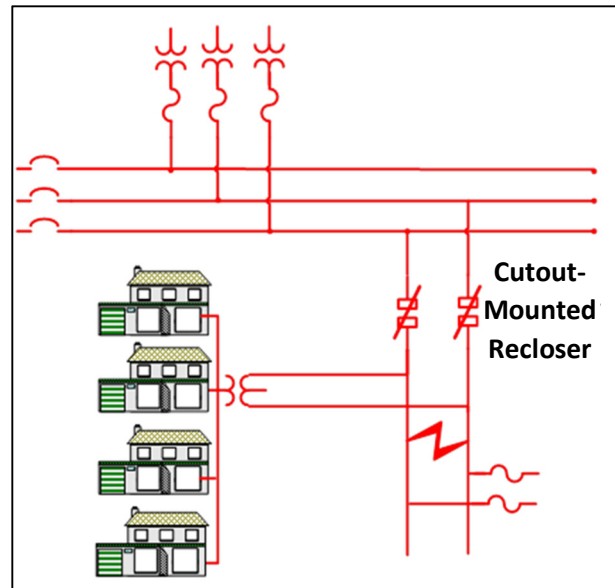
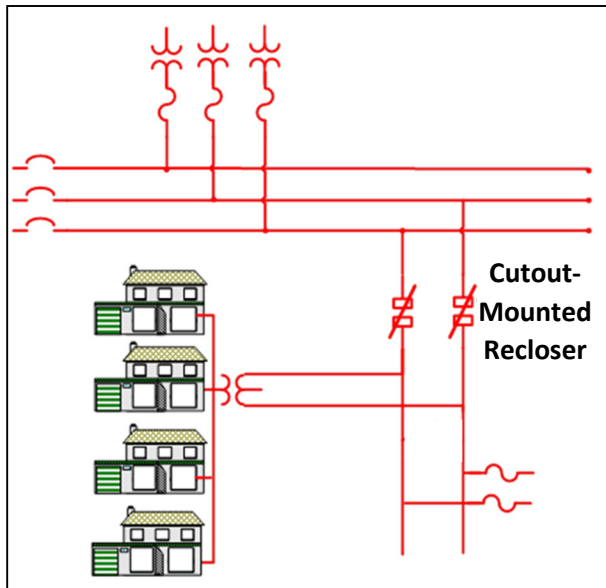


Figure 3. The cutout-mounted recloser recloses. **Figure 4.** Persistent fault.

Now consider a persistent fault downstream of the cutout-mounted recloser, as shown in Figure 4. Since the fault is persistent, the cutout-mounted recloser will perform additional user-configured tripping operations. The cutout-mounted recloser will drop open at the end of its operating sequence, in the same manner as a standard fuse cutout providing visual indication that the faulted lateral has been isolated. See Figures 5 and 6.

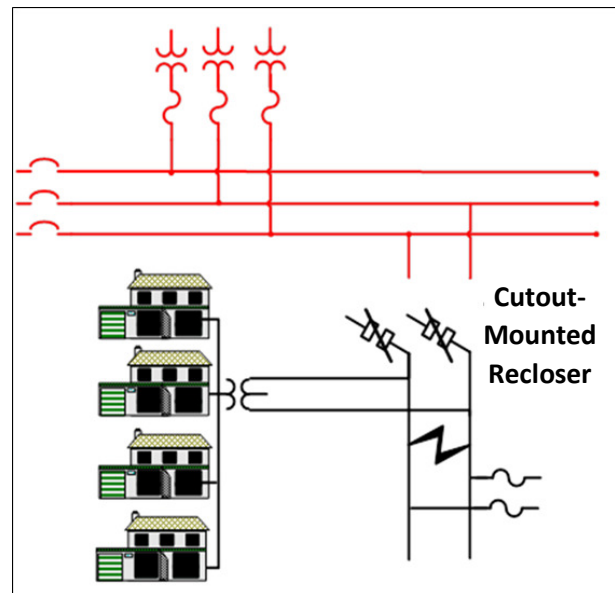
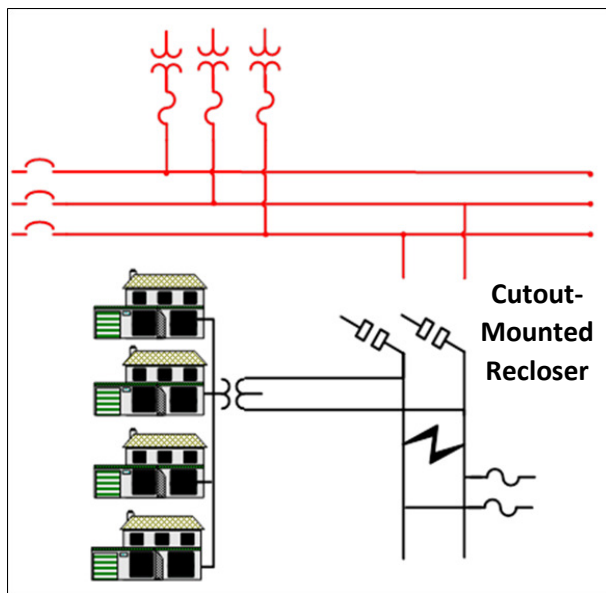


Figure 5. The cutout-mounted recloser drops open at the end of the operating sequence.

Figure 6. After dropping open, the cutout-mounted recloser resets 2-seconds later.

Salient Features of a Cutout-Mounted Recloser

The ideal cutout-mounted recloser discussed here has two voltage ratings, 15.5 kV and 29 kV maximum. The interrupting rating for either voltage rating is 4 kA or 6.3 kA. Three significant features of the ideal device are the easy to operate mode-selector lever, inrush-current restraint, and the liquid-crystal display screen.

Mode Selector

The mode-selector lever is used for selecting automatic reclosing or non-reclosing operation. In the up position the cutout-mounted recloser is in AUTO mode, it will open and reclose based on the number of user configurable tripping operations. In the down position, the ideal cutout-mounted recloser is in non-reclosing (NR) mode, it will operate “one-shot-to-lockout,” suitable for use when crews are performing live-line work downstream of the device, or when initially reenergizing a lateral after addressing a fault.

Inrush-Current Restraint

A 2nd harmonic restrain element is always activate. This feature becomes very useful when attempting to reenergize a lateral after a permanent fault has been corrected. Specifically, after a lateral has been de-energized for some time, reenergizing it can introduce magnetizing-inrush conditions, rich in 2nd harmonics, which frequently would cause other reclosers to trip on inrush-current. However, this cutout-mounted recloser’s inrush-restraint feature detects this condition and prevents tripping, thus enabling more sensitive protection settings under these conditions.

LCD Viewing Screen

The LCD screen displays important information about the cutout-mounted recloser, including its status. A user might configure a default screen display. Secondary screen displays are capable of showing vacuum-interrupter contact status (open or closed), number of tripping operations, and contact wear remaining, and other data.

V. CUTOUT-MOUNTED RECLOSER SAVINGS

Based on the European energy regulator’s interruption penalty regime described earlier, savings are shown in Table 1 for the cutout mounted recloser fault events during a four month period.

Table 1. Interruption savings using a cutout-mounted recloser

No	Cutout-Mounted Recloser Location	Event	Result	Savings (+) or Losses (-) in \$
1	10kV Lateral	Temporary Phase-Phase Fault	Cutout-mounted recloser cleared	+3326
2	10kv Lateral	Temporary Phase-Phase Fault	Cutout-mounted recloser cleared	+4493
3	10kV Lateral	Temporary Phase-Phase Fault	Cutout-mounted recloser cleared	+6480
4	20kV Lateral	Temporary Ground-Fault	Cutout-mounted recloser cleared	+7733
5	20kV Lateral	8-Temporary Ground-Faults	Cutout-mounted recloser cleared	+36288

For this utility the Table 1 values indicate that one to two operations of a cutout-mounted recloser on a lateral covered the cost of the investment. Additionally, the physical handling, installation

and operating aspects of the cutout-mounted recloser conformed to normal practices in the field with minimal adjustment of work-methods and procedures.

VI. CONCLUSION

This paper has demonstrated that cutout-mounted reclosers offer the best alternative to a fuse saving or a fuse blowing operating philosophy. Further it has suggested that the investment associated with installing these devices can be recovered in very little time, even if there are no regulatory incentives or penalties.

Ultimately, all a utility needs to consider are the costs incurred in replacing blown fuses that either were not “saved” (fuse saving), or operated in response to transient faults (fuse blowing).

The fuse replacement costs, consisting of people and vehicle expenses, quickly exceed the expense of installing cutout-mounted reclosers. And the improved reliability afforded to customers served by laterals is hopefully a further benefit when considering the cost-justification of this investment.

VII. REFERENCES

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- [3] Nicholas Carlson, Haukur Asgeirsson, Raluca Lasca, James Benaglio, and Michael Ennis, p“Application of Cutout-Type Reclosers on Distribution Lateral Circuits — A Field Study.”