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Interruption Costs for Different Lateral Protection Strategies

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SUMMARY

Many overhead-distribution systems are comprised of single-phase laterals which experience frequent transient faults from vegetation, animals and lightning. These transient faults represent about 70% to 80% of total faults. Some utilities use a "Fuse-Blowing" protection strategy, however resulting in an unnecessary sustained interruption; other utilities use a "Fuse-Saving" protection strategy to save downstream fuse but causing a momentary service discontinuity on the entire feeder.

The need to reduce O&M costs and also the recent imposition of outage penalties due to unsatisfactory reliability indices have provided an incentive for utilities to investigate solutions for improving service continuity on overhead systems, particularly single-phase laterals. One such solution involves moving the reclosing activity from the head of the feeder to the tap point of a lateral in lieu of a fuse cutout. It eliminates the sustained interruption which results when a cutout operates in response to a transient downstream fault and prevents customers on the main feeder from experiencing momentary interruptions.

While such technology has been available in the market for several years, many utilities have not employed it on their networks because they have not realized the cost benefits from using it. This paper will demonstrate the interruption costs for different lateral protection strategies using a method we developed to show that the lateral protection strategy results in the lowest interruption costs.

KEYWORDS

Cutout-Mounted Recloser, Persistent Fault, Transient Fault, Sustained Interruption, Fuse Blowing, Fuse Saving, Momentary Interruption, Laterals, SAIFI, $MAIFI_E$

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Many overhead-distribution systems are comprised of single-phase laterals which experience frequent transient faults from vegetation, wildlife and lightning. These transient faults represent about 70% to 80% of total faults. The two commonly used strategies for lateral protection are: Fuse-Blowing and Fuse-Saving. We will discuss these two strategies first, then introduce a third protection strategy that involves the application of a reclosing device on laterals. As will be demonstrated later, the Lateral Reclosing protection strategy results in the lowest interruption costs -- both those associated with electric utilities and those associated with electricity users -- a nice financial payback to stakeholders, as well as improved reliability indices. The Lateral Reclosing protection strategy really shines as systems move from urban to suburban to rural where feeders and laterals tend to be longer, where the fault rates are higher, where the cost of a truck roll to replace a blown fuse is substantial, and where customers can experience three times the customer-hour interruptions seen by urban households.

Protection Strategies

Fuse-Blowing Protection Strategy

For the "Fuse-Blowing" strategy, the feeder recloser or circuit breaker is properly coordinated with the largest lateral fuse, so that lateral fuse will clear any fault within its rating on the lateral. This is easy to implement and beneficial in that the main feeder is not affected by faults that occur on each individual lateral. The big disadvantage of this strategy, however, is that users on the affected laterals experience sustained interruptions -- even for transient faults. Additionally, the utility must deal with the high cost of field services to replace blown lateral fuses every time a lateral fuse blows; these can range from hundreds to thousands of dollars for each truck roll.

Fuse-Saving Protection Strategy

For the "Fuse-Saving" strategy, the first trip of the recloser or circuit-breaker with a reclosing relay at the head of the feeder is set to operate before the lateral fuse to clear a transient fault downstream of the fuse. The second trip of the recloser or breaker is set slower so that if the fault is still present, the lateral fuse will operate to clear the fault before the recloser or breaker locks open. One benefit of this strategy is that for many transient faults, the lateral fuse is saved and the lateral is put back in service, avoiding a sustained outage for electricity users on the lateral. This strategy also eliminates the need for the utility to dispatch a line truck to replace a lateral fuse that would have blown had the Fuse-Blowing strategy been in place.

However, one major disadvantage of the Fuse-Saving strategy is that all customers on the feeder, and all customers on all the other laterals, will experience a momentary service discontinuity, or "blink", for every lateral fault. In addition, this strategy can be difficult to implement, and its success is not always assured, especially near the substation where the fault current is high. For faults between 600 amperes (the minimum pickup current of the recloser or circuit breaker) and around 2000 amperes, the Fuse-Saving strategy works as advertised; for faults above about 2000 amperes the outcome is not always a good one . . . the lateral fuse blows and the recloser or circuit breaker trips, thereby blinking the main feeder and all of the un-faulted laterals, while creating a sustained interruption for electricity users on the faulted lateral -- the worst of all circumstances.

Lateral Reclosing Protection Strategy

A third strategy involves moving the reclosing activity from the head of the feeder to the laterals by replacing lateral fuses with a single-phase cutout-mounted recloser that is applied at the tap point of a lateral in lieu of a fuse cutout. For those using the Fuse-Blowing strategy, the Lateral Reclosing strategy eliminates the sustained interruption which results when the lateral fuse operates in response to a transient fault, thereby saving money for the utility and electricity users. Utilities will also see an improvement in SAIFI (System Average Interruption Frequency Index) with a slight increase in $MAIFI_E$ (Momentary Average Interruption Event Frequency Index). For those using the Fuse-Saving strategy, this Lateral Reclosing strategy eliminates the momentary interruptions on the feeder and all other laterals in instances where the recloser or circuit breaker is tripped to save the lateral fuse during a transient fault. Utilities will also see a slight improvement in SAIFI and a significant improvement in $MAIFI_E$.

Interruptions Costs

The need to reduce O&M costs and also the recent imposition of outage penalties due to unsatisfactory reliability indices have provided an incentive for utilities to investigate solutions for improving service continuity on overhead systems, particularly single-phase laterals. The aforementioned Lateral Reclosing strategy by using a single-phase cutout-mounted recloser is one such solution. While such technology has been available in the market for several years, many utilities have not employed it on their networks because they have not realized the cost benefits. We will now take a closer look at the interruption costs for different lateral protection strategies using our methodology.

Calculating Utility Interruption Costs

Utility interruption costs – the costs per feeder spent on dealing with permanent outages – are made up of two components; the cost of a line truck dispatched to replace a blown lateral fuse, and the number of truck rolls needed over a given period of time, typically a year. To identify the cost of a truck roll, consider that the line crew has to drive to the blown lateral fuse, patrol the line to locate the fault, repair the damaged apparatus or conductor (if the fault was persistent) and, finally, replace the lateral fuse. The time it takes to accomplish these tasks will vary based on the topology of the system, that is, the length of the feeder, the number of laterals and the average length of laterals. The number of truck rolls in a year is determined by the fault rate on the laterals, the protection strategy employed, the percentage of faults that are transient versus persistent, and, for the Fuse-Saving protection strategy, how well that strategy works. In our methodology, we use the general formula below with different input parameters to calculate the annual utility interruption costs per feeder for various protection strategies.

Utility Interruption Costs = number of overhead lines * average length of the overhead lines * fault rate per unit distance per year * percent of permanent faults * truck roll cost

For each strategy, the costs due to sustained interruptions on laterals and on feeders are calculated separately because of the different input values used for the lateral lines and feeder lines. In the case of Fuse Saving Strategy, the additional cost due to unsuccessful lateral fuse save attempts is to be calculated using the formula below and included in the final cost sum.

Utility Interruption Costs due to unsuccessful lateral fuse saving attempt = number of overhead lines * average length of the overhead lines * fault rate per unit distance per year * percent of temporary faults * fuse save failure factor in percent * truck roll cost

The following topologies are representative in our work: Urban, Suburban, Exurban (collar counties around a big city), and Rural. The values in Table I are typical of the parameters used in the utility interruption costs calculation that might apply to each of the topologies.

Table I. Typical Inputs to the Interruption Costs Calculation

Topology	Feeder		Laterals			Other			
	Length, Miles	Faults Per Mile Per Year	Number of Laterals	Average Length, Miles	Faults Per Mile Per Year	Transient Faults %	Fuse-Saving Success Factor	Truck Roll Cost	Installed Cost of Lateral Recloser
Urban	3	0.3	30	0.5	1.0	80%	25%	$500	$2,500
Suburban	5	0.3	25	1.0	1.0	80%	25%	$500	$2,500
Exurban	10	0.4	20	2.5	1.0	80%	50%	$750	$2,500
Rural	20	0.5	20	5.0	1.0	80%	50%	$1000	$2,500

Calculating Electricity User Interruption Costs

In our method, the user interruption costs for each protection strategy are calculated by summing up the costs due to both sustained interruptions and momentary interruptions. For each type of these interruptions, the costs attributed to interruptions on laterals and on feeders are again calculated separately because of the different input values used for the lateral lines and feeder lines. We further segment user base into three sectors – Medium and Large C&I, small C&I, and Residential due to the differences in the number of electricity users in each of these sectors and the sector's location on the main feeder. The assumptions we made on the user composition and their locations are shown in Table II below. Within each sector the interruption costs are calculated by the total number of user interruption events that sector experiences multiplying the cost per event type which is obtained from the US Department of Energy's database [1]. The cost per event type for each user sector is also shown in Table II.

Table II. Distribution of Electricity Users Per Feeder

Sector	Location	Number of Users Per Feeder	Cost Per Sustained Interruption	Cost Per Momentary Interrution
Medium & Large C&I	Feeder	13	$6,547	$3,332
Small C&I	Feeder	83	$1,021	475
	Lateral	4	$1,021	475
Residential	Lateral	900	$6	$4

Calculating Reliability Indices

For each protection strategy, SAIFI is calculated by using the total number of sustained interruption events we obtained in the analysis divided by our assumption of the total number of customers served, which is 1,000 per feeder. $MAIFI_E$ is similarly calculated using the total number of user momentary events we obtained in the analysis divided by the total number of customers served, again 1,000 in this paper.

A. **Fuse-Blowing Versus Lateral Reclosing Protection Strategies**

Utility Interruption Costs:

Annual utility interruption costs for the Fuse-Blowing protection strategy compared to the Lateral Reclosing protection strategy are listed in Table III. Cost savings to be realized by the Lateral Reclosing protection strategy are shown in the "Lateral Reclosing Savings" column. The installed cost of a recloser on each lateral can be "netted out" against annual cost savings to show payback (in years) and internal rate of return (IRR). As you might expect, Lateral Reclosing protection strategy shows increasing economic benefits as the circuit becomes more rural.

Table III. Comparison of Annual Utility Interruption Costs -- Fuse-Blowing Versus Lateral Reclosing Protection Strategies

Topology	Utility Interruption Costs		Lateral Reclosing Savings	Payback, Years	IRR
	Fuse Blowing	Lateral Reclosing			
Urban	$7,509	$1,509	$6,000	12.5	-4%
Suburban	$12,650	$2,650	$10,000	6.3	10%
Exurban	$38,100	$8,100	$30,000	1.7	59%
Rural	$102,000	$22,000	$80,000	0.6	160%

Electricity User Interruption Costs:

Annual electricity user interruption costs for the Fuse-Blowing protection strategy compared to the Lateral Reclosing protection strategy are listed in Table IV. The cost savings to be realized by the Lateral Reclosing protection strategy are again shown in the "Lateral Reclosing Savings" column.

Table IV. Comparison of Annual Electricity User Interruption Costs -- Fuse-Blowing Versus Lateral Reclosing Protection Strategies

Topology	Electricity User Interruption Costs		Lateral Reclosing Savings
	Fuse Blowing	Lateral Reclosing	
Urban	$100,236	$98,607	$1,629
Suburban	$168,610	$165,352	$3,258
Exurban	$448,077	$439,931	$8,146
Rural	$1,108,564	$1,092,273	$16,291

Reliability Indices:

In addition to the utility and electricity user costs savings that are realized by the Lateral Reclosing protection strategy; improvements in key reliability statistics are also realized. SAIFI values for the four circuit topologies are shown in Table V for the Fuse-Blowing protection strategy compared to the Lateral Reclosing protection strategy. The substantial SAIFI reductions to be realized by the Lateral Reclosing protection strategy are listed in the "% Reduction" column.

Although customers on laterals do not see sustained interruptions for transient faults when the Lateral Reclosing protection strategy is used, they will experience additional momentary interruptions. In other words, the Lateral Reclosing protection strategy trades expensive sustained interruptions (reducing SAIFI) for much less expensive momentary interruptions. That's why SAIFI goes down and $MAIFI_E$ goes up. $MAIFI_E$ values for the Fuse-Blowing protection strategy compared to the Lateral Reclosing protection strategy are also listed in Table V. Increases in $MAIFI_E$ values are listed in the "% Increase" column.

Table V. Comparison of Reliability Statistics -- Fuse-Blowing Versus Lateral Reclosing Protection Strategies

Topology	SAIFI			$MAIFI_E$		
	Fuse Blowing	Lateral Reclosing	% Reduction	Fuse Blowing	Lateral Reclosing	% Increase
Urban	0.6	0.3	50%	0.7	1.1	57%
Suburban	1.2	0.5	58%	1.2	1.9	58%
Exurban	3.1	1.3	58%	3.2	5.0	56%
Rural	6.5	2.9	55%	8.0	11.6	45%

B. Fuse-Saving Versus Lateral Reclosing Protection Strategies

Utility Interruption Costs:

Annual utility interruption costs for the Fuse-Saving protection strategy compared to the Lateral Reclosing protection strategy are listed in Table VI. Note the cost savings to be realized by Lateral Reclosing protection strategy are shown in the "Lateral Reclosing Savings" column. As before, the installed cost of a recloser on each lateral can be "netted out" against annual cost savings to show payback (in years) and internal rate of return (IRR). Also, Lateral Reclosing protection strategy shows increasing economic benefits as the circuit becomes more rural.

Table VI. Comparison of Annual Utility Interruption Costs -- Fuse-Saving Versus Lateral Reclosing Protection Strategies

Topology	Utility Interruption Costs		Lateral Reclosing Savings	Payback, Years	IRR
	Fuse Saving	Lateral Reclosing			
Urban	$6,090	$1,590	$4,500	16.7	-8%
Suburban	$10,150	$2,650	$7,500	8.3	3%
Exurban	$23,100	$8,100	$15,000	3.3	27%
Rural	$62,000	$22,000	$40,000	1.3	80%

Electricity User Interruption Costs:

Annual electricity user interruption costs for the Fuse-Saving protection strategy compared to the Lateral Reclosing protection strategy are listed in Table VII. Note that these costs are very significant -- electricity users really benefit when the serving utility uses the Lateral Reclosing protection strategy instead of the Fuse-Saving protection strategy. See the "Lateral Reclosing Savings" column.

Table VII. Comparison of Annual Electricity User Interruption Costs -- Fuse-Saving Versus Lateral Reclosing Protection Strategies

Topology	Electricity User Interruption Costs		Lateral Reclosing Savings
	Fuse Saving	Lateral Reclosing	
Urban	$1,107,934	$98,607	$1,009,328
Suburban	$1,847,798	$165,352	$1,682,446
Exurban	$3,853,170	$439,931	$3,413,239
Rural	$7,918,750	$1,092,273	$6,826,478

Reliability Indices:

In addition to the utility and electricity user costs savings that are realized by the Lateral Reclosing protection strategy; improvements in key reliability statistics are also realized. SAIFI values are shown in Table VIII for the Fuse-Saving protection strategy compared to the Lateral Reclosing protection strategy. The substantial SAIFI reductions to be realized by the Lateral Reclosing protection strategy are listed in the "% Reduction" column.

The Lateral Reclosing protection strategy results in a significant reduction in $MAIFI_E$ compared to the Fuse-Saving protection strategy because it eliminates the repeated reclosing operations affecting the main feeder and all laterals for any fault on any lateral. $MAIFI_E$ values for the four circuit topologies are also shown in Table VIII for the Fuse-Saving protection strategy compared to the Lateral Reclosing protection strategy. Significantly reductions in $MAIFI_E$ values are listed in the "% Reduction" column.

Table VIII. Comparison of Reliability Statistics -- Fuse-Saving Versus Lateral Reclosing Protection Strategies

Topology	SAIFI			$MAIFI_E$		
	Fuse Saving	Lateral Reclosing	% Reduction	Fuse Saving	Lateral Reclosing	% Reduction
Urban	0.5	0.3	40%	4.6	1.1	76%
Suburban	1.0	0.5	50%	7.6	1.9	75%
Exurban	2.2	1.3	41%	25.1	5.0	80%
Rural	4.7	2.9	38%	51.8	11.6	78%

CONCLUSIONS

Of the three protection strategies discussed in this paper, the Lateral Reclosing protection strategy indeed offers the best overall results. It has the lowest annual interruption costs for both utilities and electricity users, and lowest SAIFI of any of the protection strategies.

The Fuse-Blowing protection strategy has relatively low annual interruption costs for electricity users. But it has the highest annual utility interruption costs because every fault on a lateral results in a fuse operation necessitating a truck roll to replace the blown fuse.

Utility interruption costs for the Fuse-Saving protection strategy are reasonably low, because some of the fuse-save attempts are successful and sustained outages on the laterals are avoided. Serving utilities will not have to dispatch line trucks to replace blown lateral fuses as frequently. But the interruption costs for electricity users are extremely high because the recloser or substation circuit breaker "blinks" the entire feeder and all of the laterals every time it operates to clear a lateral fault.

This paper concludes that the Lateral Reclosing protection strategy does provide cost benefits to both utilities and electricity users. Although the serving utilities do not directly bear the electricity user interruption costs, there are strong societal and regulatory reasons to take immediate actions to minimize both momentary and sustained outages. Lastly, note that the interruption costs presented in this paper are per feeder. The improvements can be really significant when multiplying by the number of feeders an electric utility has.

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