EGM Eyes on The grid

Accurate Fault Location Detection (AFLD)

Prelude

Meta-Alert™ is end-to-end disruptive grids monitoring and analytics solution, developed by EGM (www.egm.net) as a tool for operation and management of T&D grid.

A study carried out by NREL[1] demonstrated over 50% reduction in the duration of sustain power fault, by using Accurate Fault Location Detection (AFLD)[2] mechanism, which is one of the major capabilities of the EGM solution.

This significant performance capability is achieved due to the ability of AFLD mechanism to identify the exact location of the fault within less than a minute from its occurrence.

Prior to the introduction of AFLD solution by EGM, utilities employed FCI and reclosers to find fault location.

To assess the benefits of EGM's solution, in finding the accurate location of the faults over the currently used FCI and recluse methodologies we have conducted internal study, conducted by Dr. Kobi Yahav and Dr. Nurit Gal.

The study depicts incremental improvement of 10% in shortening SAIDI, by addition of AFLD mechanism to the existing grid.

Thus, SAIDI reduction is demonstrated in addition to many other benefits that the utility will derive from adaptation of Meta-Alert system.

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[1] Paper summarizing this study "Advanced Sensor Deployment for Distribution System State Estimation and Fault Identification" was published by NREL in April 2022 at the IEEE PES/T&D conference https://www.nrel.gov/docs/fy22osti/80844.pdf

[2] AFLD is a cutting-edge mechanism for accurately fault location detection in electricity power lines, developed by EGM Ltd. (www.egm.net)

The Effect of Accurate Fault Location Detection (AFLD) on Grid Reliability

Kobi Yahav, Ph.D.[3] Nurit Gal, Ph.D.[4]

Abstract

The reliability of the US distribution grid is deteriorating due to aging infrastructure, extreme weather events, and transmission congestions which affect overall reliability. We have studied the contribution of technology that provides an accurate fault location detection (AFLD) to a reduction in System Average Interruption Duration Index (SAIDI). Our study finds a potential of 6-14% improvement per each disruption event compared to the commonly used Fault Circuit Indicator (FCI) technology. This improvement has an NPV of $85-$173 per consumer per one annual event. Furthermore, the combined use of AFLD with auto-reclosures can reduce SAIDI by ~70% and provide a cost-effective solution for the grid reliability concern.

(*) The study was sponsored by EGM Ltd.

Background

Grid reliability is one of today's primary concerns of utilities worldwide as fault frequency increases due to aging infrastructure and extreme weather events (Sullivan et al., 2018). Despite growing awareness, the System Average Interruption Duration Index (SAIDI) in the US, calculated without significant weather events, deteriorated from 106 min in 2013 to 119 minutes in 2020. Moreover, US SAIDI with considerable weather events, has nearly doubled from 180 minutes in 2013 to 342 minutes in 2020 [(EIA, 2020a) and (EIA 2020b)].

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[3] Dr. Kobi Yahav is a senior solution director at EGM with more than 30 years of experience in the energy sector. His former position was V.P and head of the South District at Israel Electric Corporation (IEC). He led various units and programs within IEC for more than two decades, such as the national grid unit, the Smart Grid program, DMS technical team. Dr. Yahav was also an electrical engineering lecturer at Ben-Gurion University.

[4] Dr. Nurit Gal as energy expert was deputy to the chairman of the Israeli Electricity Authority and Director of the regulation division. In this capacity, she led the implementation of Israel renewable targets and the long-term planning of the electricity sector. Gal holds a B.Sc. in Physics and Math, Master of Public Administration from Harvard University, Master in Energy Policy from Johns Hopkins University, M.Sc. in Operations Research from Tel Aviv University and a Ph.D. in Business Administration from Tel Aviv University.

Efforts to improve grid reliability indices end to focus on a faster response to a fault event rather than grid reinforcement and maintenance that would decrease fault frequency. This strategy results from the vast investments needed to prevent grid faults.

Given most of the observed increase in SAIDI is related to extreme weather events, preventive maintenance may not contribute to reducing the SAIDI index, while a faster response increases reliability indices and decreases minutes of lost supply regardless of the fault's cause.

A detailed look at the fault response process reveals that most of the response duration is spent on identifying the fault location while the service to consumers along the line is interrupted. As the fault location is identified, the interruption is narrowed to a smaller community near the fault location. Therefore, faster detection of the fault location is expected to reduce the SAIDI significantly.

To date, efforts to shorten the identification of the actual fault location have been mainly based largely on the use of fault circuit indicators (FCI) located along the distribution grid or more costly remote switches/auto-reclosures. The use of older, mechanical FCIs required a physical check and, therefore, the contribution of these FCIs was limited. Today, communicating FCIs (cFCI) gives the grid control center the ability to view the indicators online, thereby, identifying the point where all downstream segments should be patrolled. This approach may still result in large sections of the grid that require time-consuming manual patrolling and may not be much better than the predicted fault location resulting from AMI or customer calls. In addition, most FCI and cFCI technology is limited to systems with high fault current and are not applicable in compensated systems that uses arc suppression coil (Petersen coil).

This paper studies the potential contribution of accurate fault location detection (AFLD) on grid reliability. We analyze the effect of AFLD on the response time and the number of consumers exposed to the interruption. We then calculate the expected impact on SAIDI reduction. The first part of the paper studies the effect of AFLD compared to regular FCIs. The second part of the paper studies the combined contribution of AFLD and auto-reclosures.

The effect of AFLD in comparison to FCI

Methodology

A simulation of fault response in a typical distribution grid was developed to study the effect of AFLD on SAIDI. The study is based on a simulator developed by the Department of Energy (DoE) in collaboration with Berkeley University[5] and on research conducted by NREL in 2021 (Paudyal et al., 2021)

Following Parikh et al. (2013), we assume a four-phase response process: fault occurrence alert, dispatch of crews, arrival at the nearest sub-station, patrolling to find the exact fault location (Figure 1).

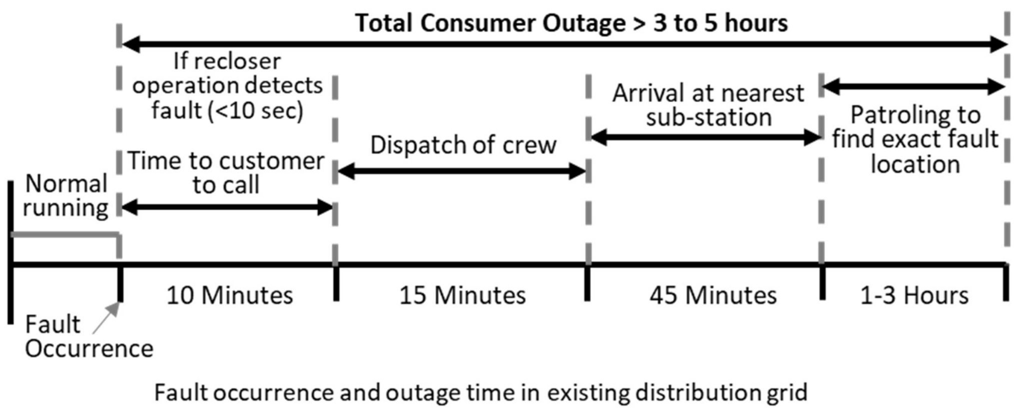


Figure 1 – Fault Response Process

AFLD enables immediate detection of the fault event and eliminates the patrol time required for locating the fault when arriving at the area (Figure 2). However, the dispatch of the crew and the arrival time of the crew remain constant.

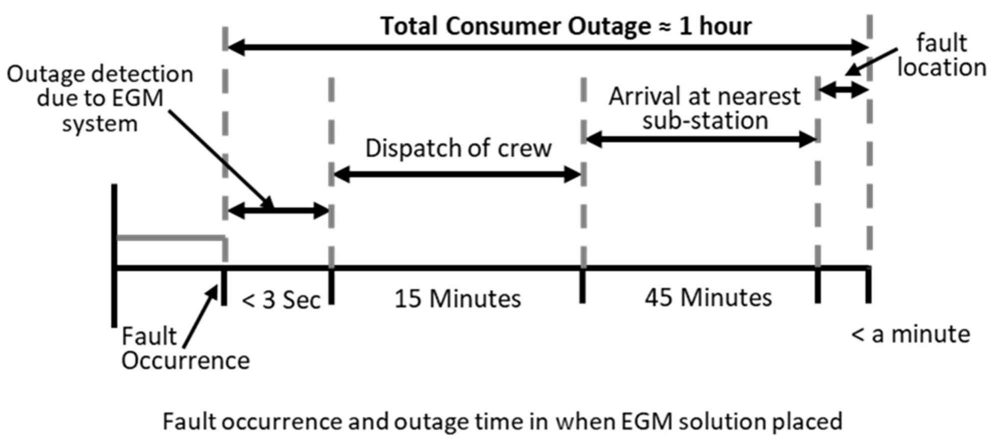


Figure 2 – Fault Response Process with AFLD

[5] https://icecalculator.com/home

The simulation assumes a feeder composed of 14 miles of distribution line with seven segments, serving 2500 total customers (2300 residential, 166 small C&I, and 34 medium-large C&I) distributed along the circuit.

Faults are randomly generated along the feeder, assuming a unit probability. The simulation calculates the number of interrupted consumers at each phase of the response process, multiplied by the duration of the stage. The sum of interruptions is divided by the overall number of consumers to calculate SAIDI.

The calculation was repeated for three possible scenarios: 1) base case (no detection means); 2) use of FCI/cFCI technology; 3) ability to determine accurate fault location. The base case and the FCI scenarios were tested for two possible durations of the Fault Response Process, 4^{th} phase – patrol time to find the exact fault location: 120 min and 60 min. AFLD enables an immediate fault location, therefore, the duration of the fourth phase with AFLD is zero.

Results

Table 1 depicts a SAIDI comparison, in minutes, for three scenarios: without alerting means along the circuit, with FCI, and with AFLD.

Table 1 – SAIDI by Fault Detection Scenario [Min]

	No fault alert means	FCI	AFLD
Base scenario SAIDI [min](Exact fault location time - 120 min)	138	78	60
Sensitivity Analysis SAIDI [min] (Exact fault location time - 60 min)	129	69	60
Base Scenario Improvement (%)	0	43%	57%
Sensitivity Analysis Improvement (%)	0	47%	53%

As seen, FCI's enable a 43% to 47% reduction of SAIDI vs. the base case (no alerting means). Note that the improvement of the patrolling time to find the exact fault location has a minor effect on the SAIDI because, at this phase of the response process, a limited number of consumers are interrupted.

Table 1 also shows that AFLD provides an additional 9-to-18-minute reduction of SAIDI per each annual event at this use case. The contribution of AFLD over FCI is two-part: i) the immediate detection of a fault saves the expected time needed to initiate dealing with the outage, affecting all the consumers along the feeder; ii) the immediate and accurate identification of the fault location eliminates a much longer time needed for manually identifying the fault location, affecting a smaller number of consumers located along the segment.

Discussion

Accurate fault location detection (AFLD) shortens the time needed (~10 min) for initial action to start dealing with the fault event and the time required for the exact fault location (1-3 hours). Therefore, the response duration is reduced significantly, and the interruption can be limited only to the consumers connected to the faulted segment.

Though fault circuit indicators (FCI) provide a substantial SAIDI reduction, the simulation shows that AFLD enables a significant additional reduction by eliminating the allocation period.

We used the Interruption Cost Estimation (ICE) calculator prepared by the Berkeley National Laboratory for the DOE (Sullivan et al., 2018) to monetize the AFL's SAIDI reduction vs. FCI. The calculator estimates the value of the SAIDI reduction per consumer-type based on a meta-analysis of various surveys that estimated the value of lost load (VOLL).

Figures 3 and 4 depict the monetized value of the additional SAIDI reduction achieved by AFLD in addition to the reduction achieved by FCI. As seen, in the base scenario, the decrease of SAIDI from 78 to 60 minutes has a value of $173 per consumer while, in the sensitivity scenario, AFLD enables a reduction of SAIDI from 69 to 60, which is equivalent to $85 per consumer.

Sector	# Of Customers	Total Benefit $ (2022)	Benefit $ per Customer (2022)
Residential	2300	$3,555.13	$1.55
Small C&I	166	$68,002.43	$409.65
Medium and Large C&I	34	$141,073.91	$4,149.23
All	2500	$212,631.47	$85.05

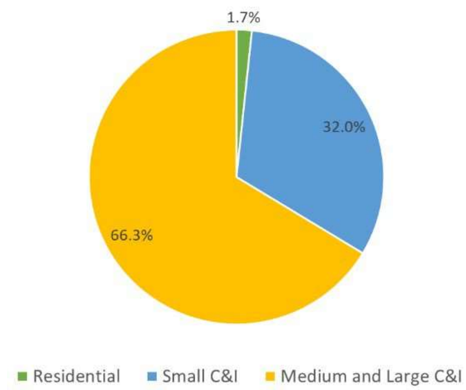


Figure 3 – SAIDI reduction cost estimation – base scenario

Sector	# Of Customers	Total Benefit $ (2022)	Benefit $ per Customer (2022)
Residential	2300	$7,174.27	$3.12
Small C&I	166	$139,088.27	$837.88
Medium and Large C&I	34	$286,641.97	$8,430.65
All	2500	$432,904.51	$173.16

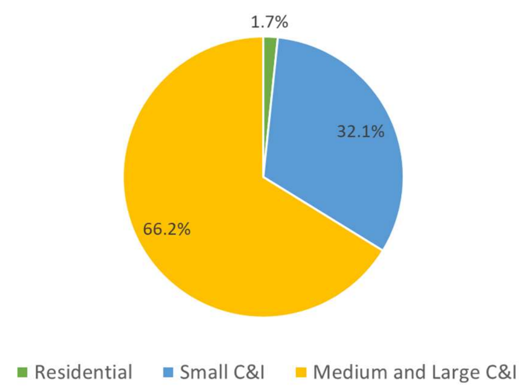


Figure 4 – SAIDI reduction cost estimation – sensitivity analysis

Contribution of AFLD to a grid with installed auto-reclosures

Auto-reclosures, or simply reclosures, are devices that designed to automatically close a breaker that had been opened by a transient grid fault [Ashour, A., 2018]. As most faults, such as tree branches touching the conductors, are transient in nature and can

self-heal", reclosures can improve grid reliability by automatically restoring power following the transient fault self-elimination [Mather et al., 2021].

In the case of sustained faults, such as broken wires, on-site repairs are required and reclosures cannot be used to restore power remotely. In these cases, reclosures improve grid reliability by isolating the faulted segment, shortening the time needed for fault allocation, and enabling the continued service in the segments upstream.

Given the potential contribution of reclosures, we quantify the combined contribution of reclosures and AFLD.

Methodology

To study the contribution of AFLD to a grid with installed reclosures, we assume the same grid configuration described above, considering two scenarios for reclosure installation: 1) one reclosure located in the middle of the distribution feeder, and 2) two reclosures dividing the circuit into three roughly equal segments.

We assume that in the case of a fault located after the reclosure, the reclosure will enable a continuous service to the consumers connected to the grid between the circuit breaker (feeder head) and the reclosure, thus reducing the number of consumers affected at the first response stage. However, in the case of faults located between the feeder head and the reclosure, all consumers will be interrupted until the arrival of the field crew and the elimination of the faulted segment.

In addition, the use of reclosures shortens the time needed for fault allocation because the allocation process can be limited to a smaller segment between the reclosures: in this simulation we assume that the use of one reclosure shortens the allocation time from 60 minutes to 30 minutes, while two reclosures can shorten this period to 15 minutes.

As in the first part of the study, faults are randomly generated along the feeder assuming a unit probability. The simulation calculates the number of interrupted consumers at each phase of the response process, multiplied by the duration of the stage. The sum of interruptions is divided by the overall number of consumers to calculate SAIDI.RESULTS

Table 2 depicts SAIDI by the configuration of reclosures and AFLD use. Each scenario is analyzed for a base scenario with 120 minutes of exact fault location identification and a sensitivity scenario with 60 minutes of exact fault location.

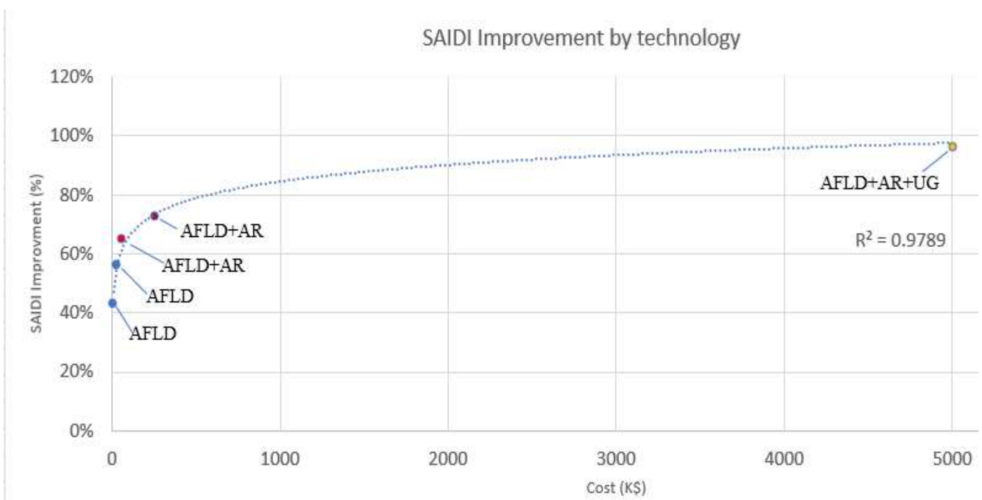
Table 2 – SAIDI [min] by use of Reclosures and AFLD

	No detection	One reclosure	Two reclosures	One reclosure + AFLD	Two reclosures + AFLD
Base scenario SAIDI [min] (Exact fault location time - 120 min)	138	90	67.8	48	40
Sensitivity Analysis SAIDI [min] (Exact fault location time - 60 min)	129	81	58.8	48	40

Base Scenario Improvement (%)	0	35%	51%	65%	71%
Sensitivity Analysis Improvement (%)	0	37%	54%	63%	69%

As seen, reclosures have a significant contribution (35%-54%) to SAIDI reduction in the case of permanent faults. However, the combined use of AFLD in a grid with installed reclosures can enable a further significant (63%-71%) SAIDI reduction. The additional contribution of AFLD is a result of the accurate allocation time affecting the consumers served at the faulted segment.

Figure 5 summarizes the cost-benefit of AFLD and reclosures, assuming a $30K cost per reclosure and a $30K cost for an overall AFLD solution. The figure also depicts the potential improvement of an underground grid at the cost of $5M ($360K per mile). As seen, the use of AFLD alone can provide a 53-57% SAIDI reduction, while the combined use of reclosures with AFLD can provide an overall 63%-71% reduction. SAIDI can be further improved by an underground grid at a prohibitive cost.



AR - Auto-reclosure   UG - Underground

Figure 5 summary of the cost-benefit of AFLD and Reclosures

Conclusion

Grid reliability is a major concern for utilities worldwide and a rapid fault identification process is one of the most cost-effective means of improving grid reliability indices. Though FCIs, alone, contribute to SAIDI reduction, an accurate fault location in additional to fault detection can contribute significant additional SAIDI improvements of ~10% per each annual disruption event, which has an estimated NPV of $85-$173 per consumer per one annual event.

The combined use of reclosures with AFLD can reduce SAIDI by 70%, thus enabling a cost-effective solution for the electricity market reliability concern.

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