21, rue d'Artois, F-75008 PARIS
http: //www.cigre.org

CIGRE US National Committee
2023 Grid of the Future Symposium

Recloser & FLISR Applications for More Resilient Microgrids

Fares ATWAN
Schweitzer Engineering Laboratories Inc. (SEL)
USA

SUMMARY

Presently, increased demand for electric power is prompting utilities to expand into distributed generation (DG) that are based on renewable energy to meet Renewable Portfolio Standards set by states in which the utilities operate. The integration of DG into the grid causes concern for coordination and synchronization of the localized grid or in some cases microgrids. Modern society is heavily contingent on electricity and increasingly it relies on a constant yet dynamic supply that meets peak and off-peak demand. A common phenomenon that occurs throughout the modern interconnected system of transmission and distribution lines, also known as the grid, are faults. They disturb and disrupt the flow of electricity to the consumers that utilize this electricity to further fuel economic, societal, and environmental prosperity for the communities that use it. Recloser's network applications improve voltage continuity metrics along with other positive impacts on the system.[1] These impacts are highlighted via comparisons of classical faults on distribution systems before and after the installation of reclosers throughout the microgrid. An overview of the history of reclosers and the innovation that has taken place over the years is covered as a foundation for the modelling of simulation cases where recloser applications are favorably implemented. Common recloser applications that can easily fill gaps in compromised grids to become more resilient and robust are highlighted. Moreover, added benefits stemming from utilizing robust communication systems are mentioned. The performance of recloser operation and response time comparing automated switching and remote switching is investigated based on Smart Grid Investment Grant Program by DOE. The philosophy behind why reclosing intervals were chosen is also stated to give context on the development of reclosing standards. Ideally, there is sufficient margin between the recloser and any upstream protective devices such as circuit breakers but more importantly transformers and fuses. The importance stems from minimizing the effects of faults on localized areas of the grid. A healthy protection coordination margin ensures longer lifetimes for grid devices allowing for utilities to not only recuperate the cost of the grid but also reap the economic benefit allowing for future grid optimization strategies and investments that will be beneficial to the customers. The approach analyzed for such recloser applications heavily relies on overhead networks where faults are often temporary and, in some cases, self-clearing. Various causes of outages are outlined but more importantly the quick yet automated response time that is provided to the control station with fault isolation and service restoration is evaluated. A cost-benefit analysis is conducted to depict the added benefit of having reclosers deployed throughout the microgrid. As far as existing networks are concerned, the optimal configuration for installing new circuit components, namely reclosers, that are strategically located with normally open and closed configurations is briefly explored to allow for improved reliability indices under typical operating conditions. The adaptive and dynamic nature of a

f.a.atwan@gmail.com

microgrid with integrated reclosers along with the element of resiliency that is added is explained and summarized.

KEYWORDS

Reclosers, Distribution Networks, Automation & Management, SCADA, Infrastructure Resilience, Proactive Reconfiguration, and Distributed Generations.

Introduction and History

In the early 1940s, the Kyle Corporation in the United States pioneered the development of early reclosers. These devices, which relied on hydraulic technology, had basic capabilities, and focused on mechanical-protection relaying. [1] Since then, advancements in technology, particularly the introduction of modern microprocessor-based protective relays, have greatly enhanced the operation of automatic reclosers in power distribution networks. These relays, which emerged in the early 1970s with electronic-based processing technology developed by Westinghouse and commissioned by PG&E, allowed for more sophisticated and dynamic responses to various faults and fault scenarios. [2]

However, it wasn't until the early 1980s that the first commercially viable microprocessor-based digital relay was invented by Edmund O. Schweitzer III. This breakthrough led to the establishment of Schweitzer Engineering Laboratories (SEL), which played a significant role in advancing the technology and widespread adoption of digital protective relays. [3]

Overall, the evolution of reclosers and protective relays from their early hydraulic-based designs to modern microprocessor-based systems has significantly improved their capabilities, enabling more efficient and reliable operation in power distribution networks.

Historically, increased generation for power generation has incorporated building conventional power generation facilities that utilizes natural resources or the burning of these fossil fuels. In recent years this trend has changed. Modern trends have shown that this is not the case anymore. Climate change being the driving factor for this shift. Moreover, modern technologies coupled with economic market forces have made distributed generation a main focus on increasing power demand over the next decade to while also progressing towards power generation stemming from renewables. A more sustainable form of power generation at the distribution level is a viable and attractive avenue for modern microgrids. A significant number of investments have already been made in the transmission domain to protect the transmission of electricity mainly because that is where the most impactful losses can be and have been incurred.[5] Nowadays that is not the case. For the end user, one of the most impactful metrics for quality power service provided would be continuous supply of good quality electricity that is always available and relatively cheap and not prone to fluctuations in prices or availability.

So how do you safely integrate reclosers into an already existing infrastructure safely without maximizing the capital costs and initial investments of the overhauling the existing distribution system. Coordination between fuses is needed as we will show in the example of a fault on a microgrid and what the adaptable coordination, and how the system will be able to recover given these faults occur.

Before delving into the operation of reclosers, it is essential to understand key concepts and the finite states or sequence of states reclosers are configured during system service. An accompanying image depicts these cycles.

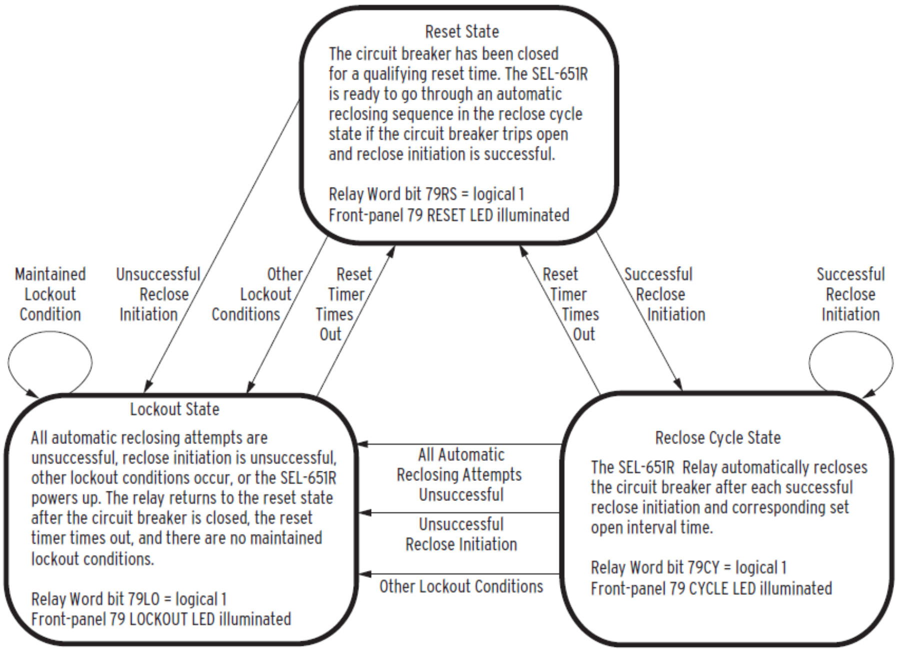

Figure 6.9 Reclosing Relay States and General Operation

Figure 1. Reclosing States and General Operation

Two significant concepts are as follows:

- Reclosing State (1 and 2): Reclosers operate in a reclosing state where they attempt to restore power after detecting a fault. This state involves a series of reclosure attempts to reestablish the power supply.
- Dead-Time: Dead-times are intervals during which reclosers remain open after detecting a fault. These deliberate pauses allow for fault clearance or isolation before initiating reclosure. Dead times provide a safety measure to ensure proper fault handling.
- Additionally, there is the concept of lockout state, which refers to the conditions that cause a recloser to remain permanently open after a specified number of reclosure attempts. This prevents continuous reclosure attempts in situations where the fault persists.

Although in the realm of protection many devices are used to “Protect & Control” the electrical grid and its vital equipment, the focus of this paper is on one aspect of that grid and how it can affect the operation of the grid, its’ reliability, and improve metrics that are tracked for resiliency Protection equipment and control are closely related concepts in the context of electrical power systems. While they are not synonymous, they are interconnected and often work together to ensure the safe and reliable operation of the system. Here's an explanation of their relationship:

Protection Equipment: Protection equipment refers to devices and systems designed to detect and respond to abnormal operating conditions, faults, or disturbances in the power system. The primary purpose of protection equipment is to detect faults and rapidly isolate them to minimize damage, ensure the safety of personnel, and maintain system stability. Protection equipment includes devices such as relays, circuit breakers, fuses, reclosers, and other protective devices.

Control: Control refers to the mechanisms, systems, and devices that regulate the operation of power system components to maintain desired operating conditions, system stability, and optimal performance. Control functions involve monitoring, coordination, and adjustment of various parameters such as voltage, frequency, power flow, and system configuration. Control equipment includes controllers, switches, supervisory control, and data acquisition (SCADA) systems, and other devices used to manage the power system operation. [10]

While protection equipment and control have distinct roles, they often work in conjunction to ensure the proper functioning of the power system. Reclosers can be viewed as circuit breakers with an added advantage of having the option to not only trip the circuit but also close the circuit after some time.

Most unsymmetrical faults are self-clearing faults, and the self-clearing duration is usually lasting only a few milliseconds, mainly due to the nature of the faults being caused from surrounding vegetation that occurs on the systems causing a fault yet being cleared rather quickly. Thus, it is of great benefit for utilities, industrial complexes, and microgrids to capitalize on this phenomenon. How might they do this? By installing reclosers throughout the most vulnerable grid components the speed with which the fault can be cleared, and the system be restored outpaces that of a system that has no reclosers that are set to work seamlessly into the system. [2]

Below is the occurrence of conventional faults on overhead systems compiled from leading utilities from the eastern and southern US that meet current regulatory requirements for reliability metrics.

S.No.	Type of Short-Circuit Fault	Representation	Percentage Occurrence
1.	Single phase to ground (L-G)	R Y B	70
2.	Phase to phase (L-L)	R Y B	15
3.	Two phases to ground (L-L-G)	R Y B	10
4.	Phase to phase and third phase to ground	R Y B	2 or 3
5.	All the three phases to ground (L-L-L-G)	R Y B	2 or 3
6.	All the three phases shorted	R Y B	2 or 3

Figure 2. Statistical Findings on Conventional Faults

Based on the latest IEEE reclosing standard outlined in IEEE C37.100, top experts and organizations were able to standardize reclosing interval attempts to give protection engineers at utilities and consultancies the best chance at providing reliable services to consumers. The following is outlined in the standard:

- Three-phase faults: The first reclosing attempt should be made after a time delay of 0.5 to 2 seconds.
- Single-phase-to-ground faults: The first reclosing attempt should be made after a time delay of 2 to 8 seconds.
- Phase-to-phase and phase-to-phase-to-ground faults: The first reclosing attempt should be made after a time delay of 8 to 30 seconds.

Reclosers & Microgrids

What is a microgrid? A smart microgrid refers to a microgrid that incorporates advanced technologies, communication systems, and intelligent control strategies to optimize its operation, enhance energy management, and improve overall efficiency.

Microgrids offer significant advantages over typical interconnect or conventional grids with common topologies, particularly in terms of their ability to restore power in the event of a fault. Unlike larger grids, microgrids rely on a smaller number of powers generating units and a less extensive network of interconnected circuits, limiting their ability to reroute power through unaffected lines. However, the implementation of reclosers in microgrids or islanded networks can address these challenges by isolating and locating faults, as well as restoring the system apart from the faulted section.

Reclosers can be programmed with specific time intervals to control their operation. These intervals determine the timing of reclosing attempts after a fault occurs. When a fault is detected, reclosers can promptly trip the entire system, interrupting power almost instantaneously. This action isolates the faulted section from the rest of the network. Reclosers are typically activated in a sequential manner, starting from the most downstream device or the furthest point still receiving power. Each recloser attempts to reclose its corresponding circuit segment, monitoring for the presence of a fault within its designated area.

The detection process involves checking if the fault persists and if it lies within the segment of the circuit being assessed. This helps identify the fault location and determine if it has been cleared. If no fault detections occur, the recloser can repeat the reclosing process, moving to the next segment that now has power supplied to it, while adhering to the programmed time intervals. In some cases, a subsequent attempt may be made after a designated time to determine if the fault has self-cleared. This is often done to avoid unnecessary recloser operations and allow temporary faults to clear on their own. If the fault persists or reoccurs after multiple reclosing attempts, the reclosing relay can enter a lockout state. In this state, manual intervention from maintenance and operational personnel is required to resolve the issue before further reclosing attempts can be made.

An advantage of this approach is that a single set of reclosing intervals can be applied to all the relays corresponding to the reclosers. Additionally, certain sections of the recloser can act as segments or sectionalizers, allowing for the restoration of power through the creation of new circuits. The sectionalizer plays a role in this process by changing its state to accommodate the new circuit, assuming the fault does not occur in its vicinity.

In conclusion, microgrids benefit extensively from the implementation of reclosers due to their fault isolation, fault location identification, and system restoration capabilities. By utilizing a systematic reclosing process and incorporating sectionalizing features, power can be restored to unaffected sections while enabling controlled fault resolution.

Some claims can be made about replacing existing pole mounted switches or remotely operated pole switches. When we convert such equipment to include reclosers and their integrated protection and control smart devices using robust communication infrastructure, then we are using state of the art technology that not only reduce continuity indices (SAIDI and SAIFI/MAIFI) but also allow operation and maintenance teams to act with specialized information regarding system disturbances.

Of course, it is not practical, economically speaking, to install multiple reclosers on existing MV microgrids that already utilize some sort of protection philosophy such as fuses, switches, and circuit breakers or GIS (gas insulated switchgears) that already protect the system from equipment damage for extending the operational lifetime of such critical infrastructure. It is interesting to note that only certain reclosers are selected at strategic locations based heavily on the topology of the microgrid system. That is where some technical analysis of the system takes place and key grid locations are identified as being critical since companies go belly up. It just be stated that using one recloser in the microgrid serves the customer not a lot of great feedback since it is the only device with such capabilities. So, a few of these reclosers at once might be more beneficial to the microgrid. Moreover, the slow and fast curves need to be faster than the fuses minimum melt curves. [9]

The location of reclosers within the circuit topology has a huge impact on the operational nature of having reclosers within the system Distributed Network. However, it could be very time consuming to find the ideal location for incorporating reclosers at specific locations. The number of reclosers also has an impact on the effects of including reclosers for a DN that previously did not have or was not designed for such protection equipment. Overall, coordinating a circuit breaker or recloser with a fuse improves fault response, selective fault clearing, equipment protection, and system resilience. By aligning the time-current characteristics of these devices, faults can be cleared more efficiently, reducing downtime, minimizing damage, and extending the lifetime of equipment within the system. The minimum melt curve of a fuse refers to the current-time characteristic that represents the minimum melting time of the fuse element at different levels of current. It indicates the minimum time required for the fuse element to melt and interrupt the circuit under specific current conditions.

In configuring the coordination margin to achieve desired relay-to-relay or even element- to-element, modifying the TD of the recloser's fast curve based on the minimum value of is proposed to ensure recloser fuse coordination even in the presence of DG. To accomplish this, the use of a microprocessor-based recloser is recommended.

Communication Infrastructure & FLISR

Robust communication infrastructure is needed and used: IEC 61850 and how it speeds up, visibility of network operation, and controllability aspect via SCADA. The two-way communications network must have sufficient coverage and capacity to interface and interoperate with a wide variety of technologies and systems, including various field devices and DMS, OMS, and SCADA systems. The utilities found that communication networks require greater resilience than power delivery systems because they must be able to control automated switches under conditions where the grid system is damaged or not functioning properly due to downed lines, faults, or other grid disturbances. vii. Utilities with legacy communication networks should conduct evaluations and implement upgrades before deploying FLISR technologies and systems. Utilities with legacy communication networks should conduct evaluations and implement upgrades before deploying FLISR technologies and systems.

Many industrial facilities and military facilities see great benefits to incorporating microgrid designs for avoiding fluctuations in energy demand that are vulnerable to neighboring power consumption and network faults. Since reclosers can act as circuit breakers in some cases, then it would be highly influential and effective to incorporate reclosers to directly replace circuit breakers in existing microgrids to increase the penetration rate for more reclosers being integrated in power distribution networks. Utilities saw the most benefit from FLISR investments that modernized poorly performing or highly vulnerable substations and feeder groups, or those that serve customers that suffer significant economic or public health and safety losses during power outages.

Typically, when we consider reclosers as part of the Bulk Electric System (BES) that utilities operate, the reclosers are closer to the end point where consumers tap into the grid and provide reliability that impacts the consumers at the distribution level. However, when we consider recloser that are integrated in microgrids, they serve a more critical role as major line of defense against system outage for extended periods of time. These extended outages not only damage critical equipment but also have negative cascading effects that can be detrimental to the overall system. Consider the most common fault (Single Line-Ground Fault) that occurs at a random point throughout the topology. For the sake of this example, we stipulate that the power distribution network has no communication, monitoring, or consolidated control or visibility of the distributed network, thereby acting as a conventional microgrid. Should the single line to ground fault occur somewhere on the network and be cleared after some time on its own as do most faults play out, then the way that local operators are informed of an outage, or a fault is by communication from the customers impacted by the outage. Following that a team is dispatched to locate the fault, isolate the system, and perform maintenance to be able to restore power to the faulted system which is a time-consuming affair.

What we can do to not only serve conventional microgrids that are already existing, but we can enhance the design of our microgrid to incorporate renewable resources along with reclosers couples with state-of-the-art Intelligent electronic devices (IEDs) to serve as a modern microgrid with very low carbon footprint and very modern smart-microgrid. The need for robust communication infrastructure is to be able to handle large volumes of traffic stipulated by utilities to accommodate transfer of data and messages through secure communication channels with bidirectional capabilities for visibility on the system and increased controllability.

Modern microgrids with communication infrastructure should be able to handle heavy flow of data transfer throughout areas that cover large swaths of geographic coverage. The result would be a power system that is buttressed by a communication system that is able to monitor the status of the circuits in close to real-time and notify key operational personnel on the dynamic conditions of power flow, voltage metering, faults, and other key incites.

It is also important to highlight that reclosers solutions are increasingly using Fault Location Isolation & System Restoration (FLISR) to be able to minimize their impacts of extended outages on customers when they do occur. FLISR does not avoid outages but instead reduces economic fines associated with lengthy and frequent outages that utilities try to avoid. The regulations set by North American Electric Reliability Corporation (NERC) and Federal Energy Regulatory Commission (FERC) ensure that utilities incorporate the latest standards to increase power system reliability and resiliency.

Key Takeaways and Statistical Findings

In summary, a microgrid system using circuit breakers and electromechanical relays (Option a) may have slower operation, potentially lower reliability due to mechanical limitations, and limited self-healing capabilities. On the other hand, a system with modern reclosers and microprocessor-based protective relays (Option b) benefits from automated operation, improved reliability through advanced fault detection and coordination, and enhanced system resilience with self-healing capabilities.

It is important to note that FLISR does not avoid outages but works to minimize their impacts on customers when they do occur. Remote switching operations that are manually validated by control room operators typically suffer from time lags that do not occur with fully automated switching. In an initiative spearheaded by the Department of Energy Office of Electricity Delivery and Energy Reliability revolved around incorporating FLISR solutions in distribution networks for several utilities within the US. The results of the initiative after modern reclosers had been installed and data had been collected were as follows: [1]

- Reduced number of customers interrupted: About 270,000 fewer customers suffered interruptions (of >5 minutes) compared to estimated outcomes without FLISR.
- Reduced outage impact: Customers experienced about 38 million fewer minutes of interruption compared to estimated outcomes without FLISR.
- On average during this time period, FLISR reduced the number of customers interrupted (CI) by up to 45% and reduced the customer minutes of interruption (CMI) by up to 51% for an outage event.

The adaptive and dynamic nature of a microgrid with integrated reclosers adds a high element of resiliency to the grid thereby increasing the reliability of service provided to the customer. The increased reliability of the distributed networks and microgrids depict the high impact and increased value that can be extracted from existing customers and networks by minimizing outage times and frequency of such faults. [5]

BIBLIOGRAPHY

[1] U.S. Department of Energy Office of Electricity Delivery and Energy Reliability. (2019, December 16). Fault location, isolation, and service restoration technologies reduce outage impact and duration. Document Details: | SmartGrid.gov. https://www.smartgrid.gov/document/fault_location_isolation_and_service_restoration_technologies_reduce_outage_impact_and.html

[2] Glover, J. D., Overbye, T. J., Birchfield, A. B., Sarma, M. S., & Glover, J. D. (2022). Power System Analysis & Design / J. Duncan Glover, Thomas J. Overbye, Adam B. Birchfield, Mulukutla S. Sarma (Sixth Edition). Cengage Learning.

[3] A. Arafa, M. M. Aly and S. Kamel, "Impact of Distributed Generation on Recloser-Fuse Coordination of Radial Distribution Networks," 2019 International Conference on Innovative Trends in Computer Engineering (ITCE), Aswan, Egypt, 2019, pp. 505-509, doi: 10.1109/ITCE.2019.8646557.

[4] D. Zhang, S. Li, P. Zeng and C. Zang, "Optimal Microgrid Control and Power-Flow Study With Different Bidding Policies by Using PowerWorld Simulator," in IEEE Transactions on Sustainable Energy, vol. 5, no. 1, pp. 282-292, Jan. 2014, doi: 10.1109/TSTE.2013.2281811.

[5] V. A. Freire, J. J. Márquez, C. Bordons, A. Zafra-Cabeza and L. V. R. de Arruda, "Energy Management System for Microgrid Considering Operational Faults in Power Supply," 2020 International Conference on Smart Energy Systems and Technologies (SEST), Istanbul, Turkey, 2020, pp. 1-6, doi: 10.1109/SEST48500.2020.9203115.

[6] P. K. Dodiya, B. R. Bhalja and T. P. Swecha, "Universal approach to tackle the threat of miscoordination between fuse and recloser in distribution network with distributed generations," 2015 Australasian Universities Power Engineering Conference (AUPEC), Wollongong, NSW, Australia, 2015, pp. 1-6, doi: 10.1109/AUPEC.2015.7324813.

[7] O. D. Montoya, A. Grajales, R. A. Hincapié, M. Granada and R. A. Gallego, "Methodology for optimal distribution system planning considering automatic reclosers to improve reliability indices," 2014 IEEE PES Transmission & Distribution Conference and Exposition - Latin America (PES T&D-LA), Medellin, Colombia, 2014, pp. 1-6, doi: 10.1109/TDC-LA.2014.6955232.

[8] L. G. Perez, E. Sorrentino, A. E. Hernandez, A. J. Urdaneta and J. F. Bermudez, "Application of adaptive reclosers to automatic distribution systems," Proceedings of First International Caracas Conference on Devices, Circuits and Systems, Caracas, Venezuela, 1995, pp. 159-163, doi: 10.1109/ICCDCS.1995.499136.

[9] A. Dan, B. Hartmann, J. Kiss and I. Vokony, "Recloser application possibilities and the related benefits at a Hungarian MV network," 2015 IEEE Eindhoven PowerTech, Eindhoven, Netherlands, 2015, pp. 1-6, doi: 10.1109/PTC.2015.7232680.

[10] J. Wafi, S. M. Saad, N. E. Naily, K. El-Arroudi and F. A. Mohamed, "Applicability analysis of proactive recloser-fuse scheme for wind distributed generation into modern distribution network," 2018 9th International Renewable Energy Congress (IREC), Hammamet, Tunisia, 2018, pp. 1-6, doi: 10.1109/IREC.2018.8362500.

[11] "IEEE Guide for Automatic Reclosing of Circuit Breakers for AC Distribution and Transmission Lines," in IEEE Std C37.104-2012 (Revision of IEEE Std C37.104-2002) , vol., no., pp.1-72, 6 July 2012, doi: 10.1109/IEEESTD.2012.6232415.