MICROGRIDS: A RELAYING PERSPECTIVE

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1 INTRODUCTION

1.1 WHAT IS A MICROGRID?

A microgrid is a cluster of utility customers, power generation, and switchgear that can electrically isolate itself from the rest of the grid, all while maintaining a local supply of power to its load. This is done by way of communication channels between a microgrid's power sources, its protective devices, and tie-in distribution equipment such as reclosers or circuit breakers. These devices determine when a fault has occurred, dispatch local power generation, and open the point of common coupling (PCC) with the rest of the grid. In this case, customers without a microgrid would lose power, costing the utility potential income. With the right battery storage or generation system, microgrids can seamlessly island from the rest of a distribution system during fault conditions.

Microgrids can provide substantial benefit not only to utility equipment, but also to rate-paying customers. From a utility perspective, fault durations are to be minimized in any way possible. While reclosers often

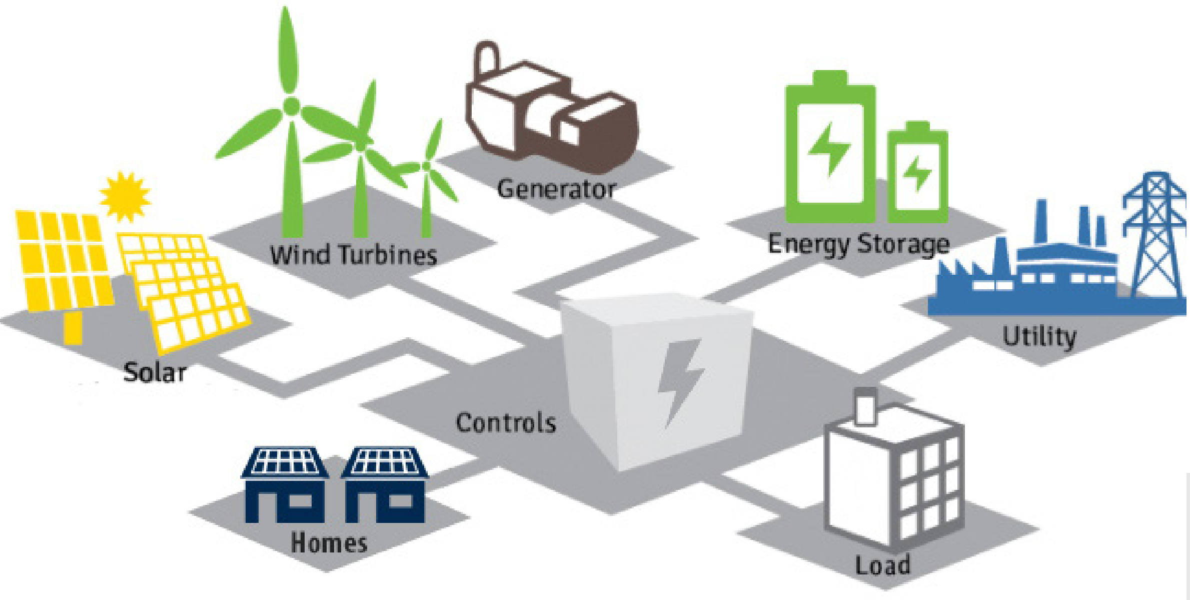

Figure 1: Typical Microgrid Configuration

serve to isolate fault conditions on line segments, this comes at the cost of supplying power to downstream network branches and radial feeders. The impact of such faults has historically been mitigated by adding network feeders, reducing the length of any given distribution line. Microgrids, however, only need to tie into existing lines. This simplifies the process of improving distribution reliability.

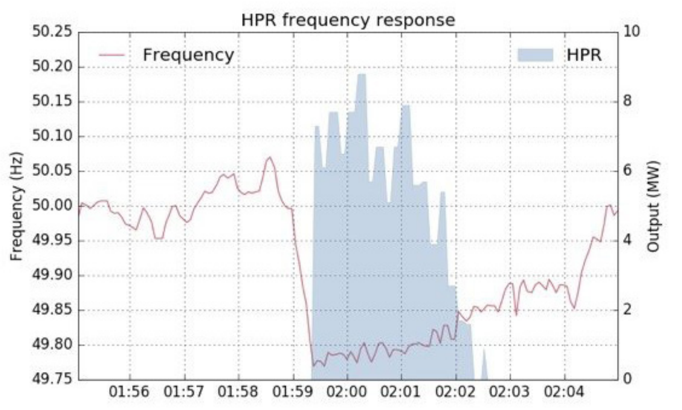

Figure 2: Grid Frequency response to HPR frequency stabilization

1.2 WHY NOW?

Like many developments in electrical engineering today, one can attribute the rise of microgrids, from research and development to mainstream, to the developments in computer and communication technology. Over the past several decades, utilities have been replacing electromechanical relays with microprocessor-based ones. Pilot wires have been replaced with fiber rings and microwave communication. Infrastructure has been created to allow more devices to communicate with one another. For a microgrid to island, it must be able to communicate with distribution automation equipment to prevent erroneous operation.

Additionally, developments in power electronics have permitted faster responses of high-energy systems. In December 2017, the Hornsdale Power Reserve (HPR) transmission-interconnected battery storage system responded to a coal power plant unit failure by dispatching energy to stabilize grid frequency. Whereas a fossil fuel plant would have taken several minutes to start up, HPR was able to dispatch power in fractions of a second [1]. In the context of microgrids, batteries can provide nearly instantaneous power in the event of an outage. This is only possible because inverters, which convert battery DC power into AC, are now able to dynamically adjust to load and dispatch conditions.

Figure 3: Microgrid Equipment

2 COMPONENTS

Microgrids can contain a variety of generators, from wind and solar to batteries and rotating generators. Each generation source comes with its own challenges and integration schemes. For a microgrid to operate effectively, each generator must be equipped with its own discrete protection scheme, controllable by a central controller. In this way, microgrids are capable of economic dispatch based on weather and loading characteristics.

2.1 GENERATORS

Fossil fuel and natural gas rotating generators can play a key role in microgrid design. Through conventional generator control schemes, they can synchronize with grid frequency with minimal droop. This makes them optimal for black start and initial interconnection after islanding.

2.2 INVERTERS

The IEEE (Institute of Electrical and Electronics Engineers) standard for smart inverters was recently updated to 1547-2018. Between the 2003 and 2018 iterations of the standard, the role inverters play in utility planning has fundamentally changed.

Inverters are used in microgrids to convert DC power from solar photovoltaic or battery sources to grid-connected AC. Since inverters are power-electronics controlled, they will respond to a logical "trip" command by ceasing semiconductor switching and electrically isolating the DC source from the AC grid. Historically, inverters were required to trip not only by external command but also during any abnormal conditions. This includes over/under frequency, over/under voltage, and overcurrent.

Since the IEEE1547-2018 standard was rolled out, inverters are now required to ride through abnormal frequency and voltage characteristics. This is part of a broader attempt to utilize inverter-based DERs to help with grid stability and VAR contributions. Instead of contributing only real power in accordance with the 2003 standard, the 2018 standard requires inverters to be capable of contributing VARs to stabilize abnormal voltage and frequency conditions. The mechanism through which VARs are controlled (volt/var, volt/watt) is up to the utility [2]. In the context of microgrids, this provides crucial stability for a system without the need for capacitor banks or static VAR compensators.

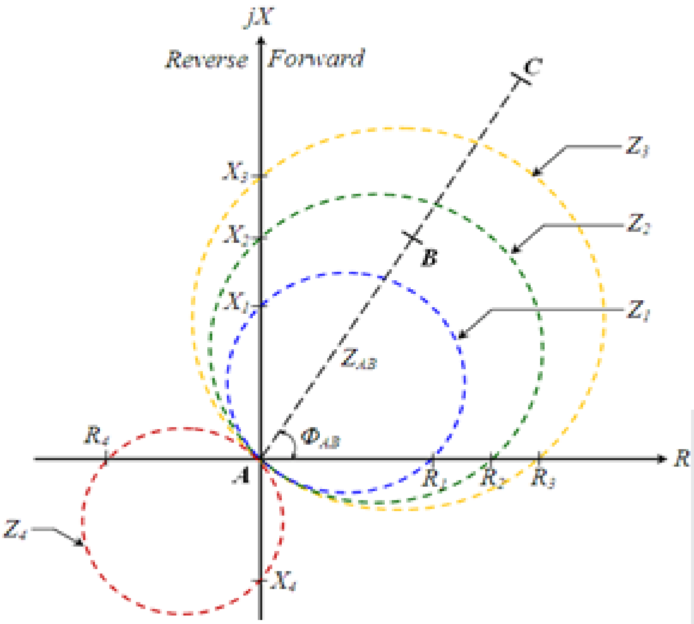

Figure 4: Typical bi-directional mho distance relay zones

2.3 RELAYS & COMMUNICATIONS

A major hurdle in implementing microgrids outside of research and development has been dynamic relay protection systems. G.D. Rockefeller first hypothesized in 1969 that computer programming dynamics could shape distance protection zones arbitrarily, rather than relay tripping characteristics [3]. Since then, the new frontier for protective relays has been creating dynamic relay settings. Since microgrids can still operate while islanded, their relay settings must adapt to changes in power flow. This includes adjusting current sensitivity, since inverter-based power sources and small rotating generators have substantially lower maximum fault contribution than conventional distribution systems [4].

For example, one common method of protecting a distribution feeder is with mho distance relaying. In this scheme, a "Mho Circle" is set on quadrant 1 of an x-y plane, representing the real and complex power plotted during a fault. The shape and angle of the circle is determined by the intrinsic impedance of the distribution line. When a fault occurs that protection engineers want the relay scheme to trip on, the mho circle is set such that the fault falls within that circle. For a distance relay to operate effectively, it must have pre-set parameters which describe the system pre-fault. When nearby generation is dispatched or a tie-in recloser is opened, the pre-fault conditions must adapt to a smaller mho region, often in a different shape if the islanded microgrid is more capacitive. For this to be possible, the adaptive relay system must distinguish between fault conditions and changes in system parameters, like islanding. This is accomplished through a communication channel between the relay and generation systems, with generators typically using communication protocols like IEC 61850 to indicate whether they are actively generating power.

Additionally, distributed generation and battery storage systems can operate as ancillary generators that can be dispatched like any other transmission-operated generation source. Due to the updates to IEEE-1547, new inverters are better equipped than ever to assist with power generation. In addition to protecting local loads during an outage, microgrids can communicate with local generators to prevent outages from happening by supporting voltage, frequency, and reactive power flow. This presents a challenge for protection engineers because additional current contributions from ancillary generation causes the angle of mho distance relays to shift [5].

Ultimately, microgrids stand to influence the way we think about distribution systems. They will not only improve the reliability of customer loads, but also critical loads like hospitals, schools, and military bases.

This is one additional use that increases the required complexity of protective relay settings for a microgrid, which is possible through conventional substation automation controllers such as an SEL RTAC. An RTAC can act as a central hub for utilities to provide real-time updates to relay settings [4].

3 IMPLICATIONS

Ultimately, microgrids stand to influence the way we think about distribution systems. They will not only improve the reliability of customer loads, but also critical loads like hospitals, schools, and military bases. This is where the biggest demand for microgrids has come from - the Illinois Institute of Technology and Ameren Illinois were the first owners of microgrids in Illinois. Both centered their microgrids on critical infrastructure like the IIT campus and the University of Illinois Technology Innovation Center. Centering microgrid infrastructure around large institutions both provides reliable power and allows utilities to avoid the most expensive outages. However, the benefits from a utility perspective are such that microgrids could proliferate to the average home-owner's distribution feeder. From a relaying perspective, they change the fundamental ways in which protection and control engineers think about zones of protection and interconnectivity. Bi-directionality of power flow, integration of distributed generation, and adaptive relay settings and communication have come together to form the microgrid, a new frontier in power transmission and distribution. While this challenge is sizable, Primera Engineers has the expertise and ingenuity to integrate the grid of the future.

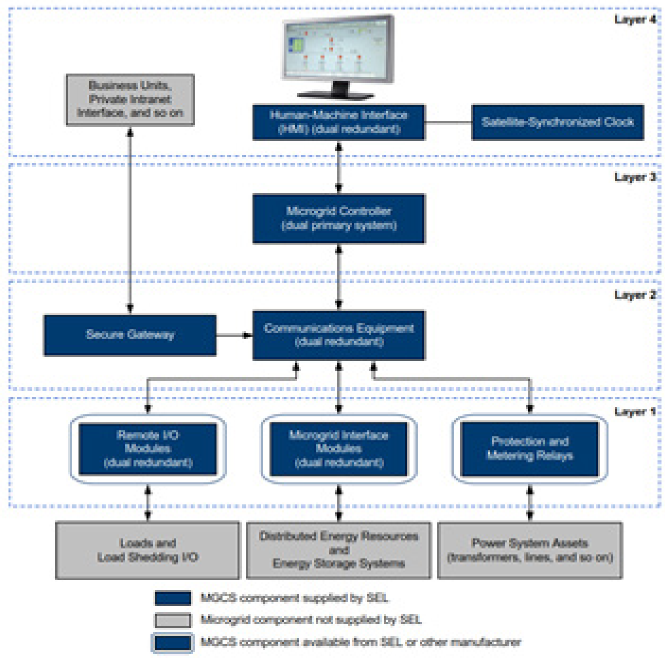

Figure 5: SEL Microgrid Control structure

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Figure 1 Typical Microgrid Configuration, courtesy of https://www.totemcontracting.com/service/microgrids/

Figure 2 Grid Frequency response to HPR frequency stabilization, courtesy of https://reneweconomy.com.au/wp-content/uploads/2017/12/HPR-frequency-fig-copy.jpg

Figure 3 Microgrid Equipment**,** courtesy of https://www.energy.gov/articles/how-microgrids-work

Figure 4 Typical bi-directional mho distance relay zones, courtesy of https://www.intechopen.com/books/an-update-on-power-quality/impact-of-series-facts-devices-gcsc-tcsc-and-tcsr-on-distance-protection-setting-zones-in-400-kv-tra

Figure 5 SEL Microgrid Control structure, courtesy of https://selinc.com/solutions/microgrid-control-systems/

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Adam is one of Primera's protection and control engineering experts. His expertise includes transmission operations, solar feasibility studies, and protection and control design. He is an active member of IEEE Power and Energy Society and has attended several seminars on distributed generation and microgrid development.

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