Microgrids (Islanding)

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MICROGRID KNOWLEDGE

What is a microgrid?

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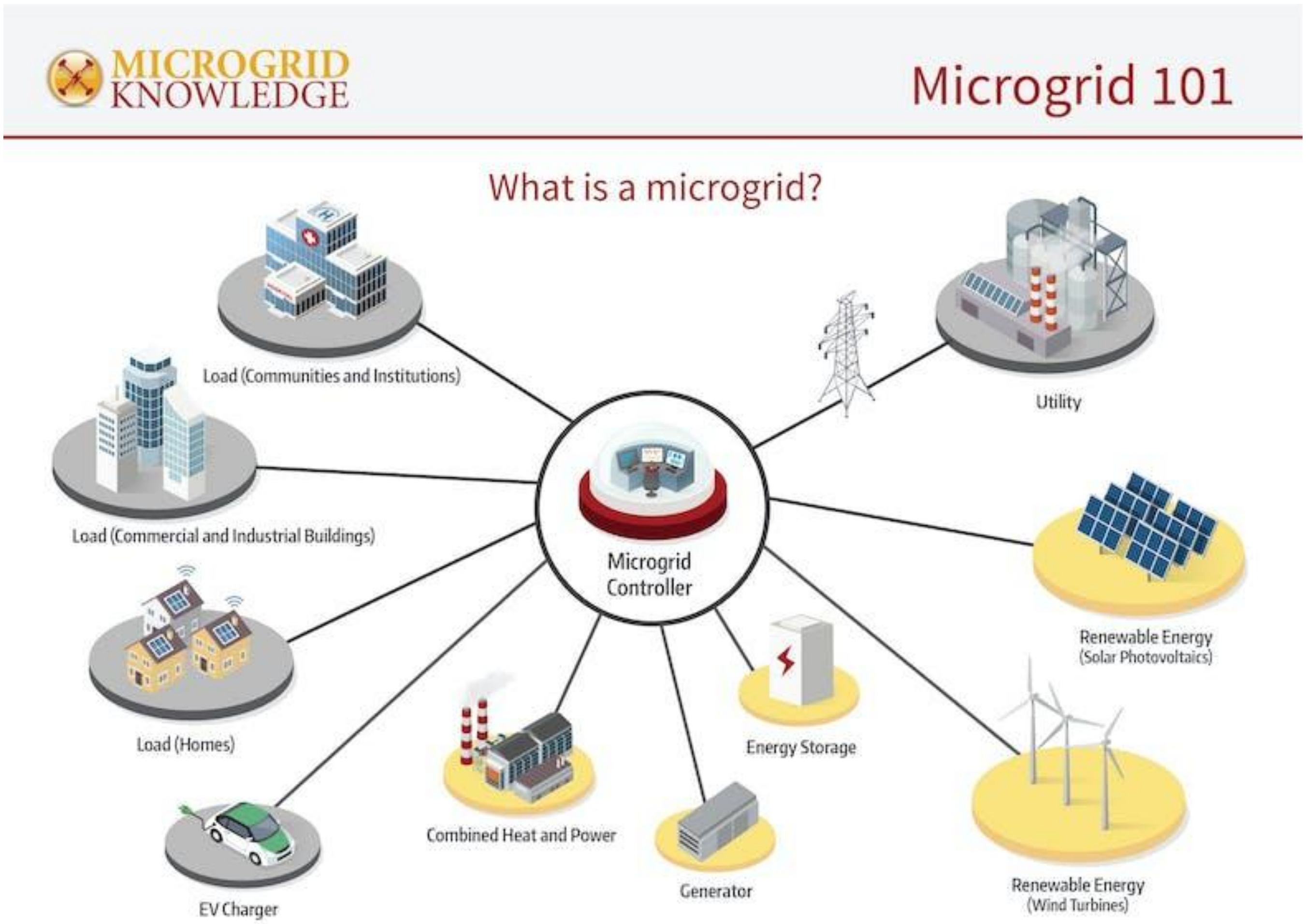
Elisa Wood



Courtesy of Microgrid Knowledge

How is a microgrid defined? A few different definitions exist. Here we set out to explain what we mean by "microgrid" at Microgrid Knowledge.

A microgrid is a self-sufficient energy system that serves a discrete geographic footprint, such as a college campus, hospital complex, business center or neighborhood.

Within microgrids are one or more kinds of distributed energy (solar panels, wind turbines, combined heat and power, generators) that produce its power. In addition, many newer microgrids contain energy storage, typically from batteries. Some also now have electric vehicle charging stations.

Interconnected to nearby buildings, the microgrid provides electricity and possibly heat and cooling for its customers, delivered via sophisticated software and control systems.

Microgrid defined by three key characteristics

1. A microgrid is local

First, this is a form of local energy, meaning it creates energy for nearby customers. This distinguishes microgrids from the kind of large centralized grids that have provided most of our electricity for the last century. Central grids push electricity from power plants over long distances via transmission and distribution lines. Delivering power from afar is inefficient because some of the electricity – as much as 8% to 15% – dissipates in transit. A microgrid overcomes this inefficiency by generating power close to those it serves; the generators are near or within the building, or in the case of solar panels, on the roof.

2. A microgrid is independent

Second, a microgrid can disconnect from the central grid and operate independently. This islanding capability allows it to supply power to its customers when a storm or other calamity causes an outage on the power grid. In the US, the central grid is especially prone to outages because of its sheer size and interconnectedness – more than 5.7 million miles of transmission and distribution lines. As we learned painfully during what's known as the Northeast Blackout of 2003, a single tree falling on a power line can knock out power in several states, even across international boundaries into Canada. By islanding, a microgrid escapes such cascading grid failures.

While microgrids can run independently, most of the time they do not (unless they are located in a remote area where there is no central grid or an unreliable one). Instead, microgrids typically remain connected to the central grid. As long as the central grid is operating normally, the two function in a kind of symbiotic relationship, as explained below.

3. A microgrid is intelligent

Third, a microgrid – especially advanced systems – is intelligent. This intelligence emanates from what's known as the microgrid controller, the central brain of the system, which manages the generators, batteries and nearby building energy systems with a high degree of sophistication. The controller orchestrates multiple resources to meet the energy goals established by the microgrid's customers. They may be trying to achieve lowest prices, cleanest energy, greatest electric reliability or some other outcome. The controller achieves these goals by increasing or decreasing use of any of the microgrid's resources – or combinations of those resources – much as a conductor would call upon various musicians to heighten, lower or stop playing their instruments for maximum effect.

A software-based system, the controller can manage energy supply in many different ways. But here's one example. An advanced controller can track real-time changes in the power prices on the central grid. (Wholesale electricity prices fluctuate constantly based on electricity supply and demand.) If energy prices are inexpensive at any point, it may choose to buy power from the central grid to serve its customers, rather than use energy from, say, its own solar panels. The microgrid's solar panels could instead charge its battery systems. Later in the day, when grid power becomes expensive, the microgrid may discharge its batteries rather than use grid power.

Microgrids may contain other energy resources – combined heat and power, wind power, reciprocating engine generators, fuel cells – that add even greater complexity and nuance to these permutations.

Working together via complex algorithms, the microgrid's resources create a whole that is greater than the sum of its parts. They drive system performance to a level of efficiency none could do alone. All of this orchestration is managed in a near instantaneous fashion – autonomously. There is no need for human intervention.

What a microgrid is not

It's important to note here what a microgrid is not. Some people use the term to describe a simple distributed energy system, such as rooftop solar panels. A key difference is that a microgrid will keep the power flowing when the central grid fails; a solar panel alone will not. Many homeowners with solar panels are unaware of this fact and are surprised that they lose power during a grid outage.

Simple backup generators also are not microgrids. Such systems are only employed in emergencies; microgrids operate 24/7/365 managing and supplying energy to their customers.

Side Note: The Department of Energy offers a more formal definition for a microgrid, describing it as a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. Microgrids can connect and disconnect from the grid to enable them to operate in both grid-connected or island mode.

How many microgrids and where?

Microgrids have been around for decades, but until recently were used largely by college campuses and the military. So the total number of microgrids is relatively small but growing. Guidehouse (previously Navigant) forecasts that the market will near $39.4 billion by 2028.

But the pace of installation has picked up and is expected to grow dramatically as distributed energy prices drop and worries heighten about electric reliability because of severe storms, cyberattacks and other threats.

Guidehouse expects global microgrid capacity to reach 19,888.8 MW by 2028, up from 3,480.5 MW in 2019. The research firm sees North America and Asia Pacific as the centers of growth.

Want to learn more about microgrids? See other articles in About Microgrids.

About the Author

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Elisa Wood is an award-winning writer and editor who specializes in the energy industry. She is chief editor and co-founder of Microgrid Knowledge and serves as co-host of the publication’s popular conference series. She also co-founded RealEnergyWriters.com, where she continues to lead a team of energy writers who produce content for energy companies and advocacy organizations.

She has been writing about energy for more than two decades and is published widely. Her work can be found in prominent energy business journals as well as mainstream publications. She has been quoted by NPR, the Wall Street Journal and other notable media outlets.

“For an especially readable voice in the industry, the most consistent interpreter across these years has been the energy journalist Elisa Wood, whose Microgrid Knowledge (and conference) has aggregated more stories better than any other feed of its time,” wrote Malcolm McCullough, in the book, Downtime on the Microgrid, published by MIT Press in 2020.

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Microgrids: Smart or Dumb?

Peter Asmus — October 22, 2010

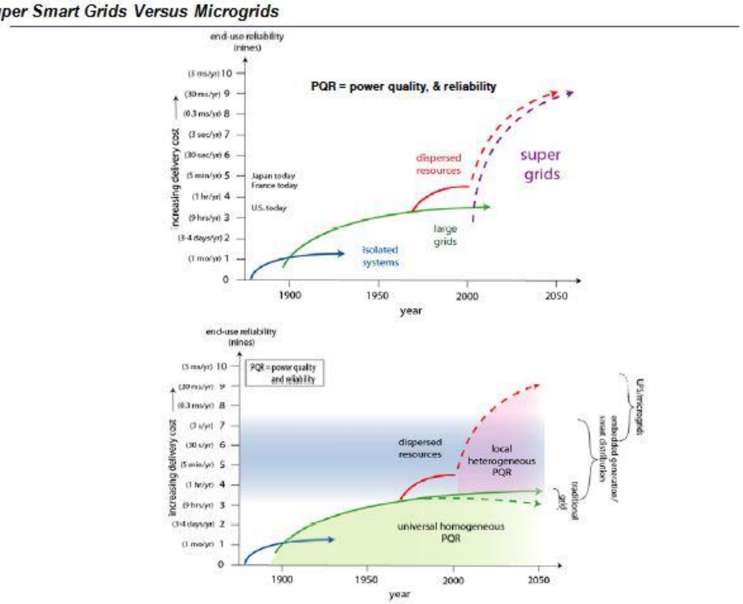
Microgrids may be a hot topic among those forecasting key future trends shaping the world's energy infrastructure, but few significant state-of-the-art commercial microgrids are actually up and running in North America, the world's leading market for microgrids. One leading domestic developer claims that not a single microgrid is providing energy services today in the U.S., but that firm uses a very narrow definition of what a microgrid is, excluding remote, off-grid microgrids within its qualifications, for example.

At present, regulations governing energy have not kept pace with emerging microgrid islanding technology, frustrating immediate progress. Most of the public and private investment dollars pouring into modernization of the globe's electric grid have been soaked up by utility smart grid deployments, with very little funding filtering down to the microgrid level of design and deployment.

Academics from the University of Wisconsin-Madison – an institution often credited with the birthing of the microgrid concept (at least in engineering terms) – predict it could take 30 years for the microgrid to become ubiquitous. Yet current trends appear to make microgrids an inevitable augmentation of today's centralized grid infrastructure. Aggregation platforms similar to microgrids will be absolutely necessary if our energy infrastructure follows in the footsteps of telecomm and the evolution of today's Internet. No doubt the existing radial transmission grid will still provide the majority of power supplies to the industrialized world. But renewable distributed energy generation (RDEG) will also play a larger role in providing energy supply, reliability, security and emergency care services.

Given consumer pushback on smart meters — the very underpinning of the utility-dominated "smart grid" — in California, Texas, Colorado and elsewhere, the microgrid represents an alternative business model for boosting the quality of grid services. It is becoming self-evident that the hype behind the Obama Administration's stimulus spending on smart grid upgrades raised expectations to unrealistic heights. Furthermore, utilities focused too much on the benefits meter data might bring to their own operations – and forgot to connect the dots with consumers, many of which only saw higher bills, and no coordinated programs and tools to respond to real-time price signals with more efficient consumption patterns and protocols. And then there were the concerns about data security.

Super Smart Grids Versus Microgrids



(Source: LBNL)

The goals of both the smart grid and the microgrid are the same: to maximize generation assets through embedded intelligence while dramatically boosting efficiencies, thereby minimizing costs. However, they appear to offer two potentially different paths forward.

Both "supergrid" and "microgrid" will need to get smarter, though it is the distribution system that is currently the prime source of outages and unreliability. Today’s distribution grid network is clearly inadequate to support the type of innovation now occurring with distributed resources, including devices such as plug-in hybrid electric vehicles (PHEV) serving as distributed storage batteries. The question is: Do we need bottom-up or top-down innovation?

Microgrids installed in developing nations or rural regions of the United States may be quite simple, even “dumb” if compared to the hyperbole often attached to descriptions of the smart grid. The Consortium for Electric Reliability Solutions’ (CERTS) demonstration projects show that microgrids do not necessarily need to rely on all of the sensors and fast, real-time communication protocols that are hallmarks of the smart grid.

Among the current microgrid control options are centralized management systems requiring high-bandwidth links between the inverters and central controller. Other prototype microgrids rely upon distributed on-board control that reduces the bandwidth needed — but at the cost of synchronization difficulties. More recent work has investigated a hybrid control scheme where proximate inverters operate in a master-slave arrangement. Still others are focused on remote or smaller microgrids are sticking with common frequency droop method, commercialized through the CERTS work, which greatly reduces the need for any high-bandwidth communications over large distances.

Control systems fall into two major camps. The purists – epitomized by the CERTS software – believe that microgrids should operate without any central command and control system, with generators and loads harmonizing autonomously based on local information. This is the view espoused by leading academics and localization advocates and the rationale is compelling. This system will work for the majority of smaller microgrids with a single owner and whose top priority is reliability and sustainability during emergencies. These are the “dumb” microgrids, if you will.

In the other camp are what you might call the pragmatists. They lean toward systems that can be described as “master/slave,” (whereas the CERTS approach has been described as being “like a commune.”) These operating systems are much more focused on optimization of services outside the microgrid. The benefits of reliability may come second to generating new revenue streams from excess generation (or even demand reductions.)

There are also those systems that can straddle these two views. There are few clear cut direct competitors in the space since no standards exist and microgrids are so modular, diverse and optimize such a broad array of energy-related services. It is these control systems – still literally being defined – where the fiercest competition may reign within the microgrid space. This is the guts of the microgrid, if you will, and the focus of current software innovation.

How a Microgrid Works

by Robert Lamb

Joe Sohm/Digital Vision/Getty Images
Installing your own nuclear power plant in your backyard isn't an option, but imagine if even a portion of your electrical needs could be met locally.

Once upon a time, there was a kingdom ruled by an all-powerful king. Each day, the King would visit the villages in his domain, bringing every household the wonders of daily life: cold meats and cheeses, artificial lighting, air conditioning and the complete filmography of Vin Diesel on a high definition plasma screen.

So the people watched "Chronicles of Riddick," snacked on fruit pops and reveled long into the night. However, with each passing month, the King demanded a timely -- and costly -- tribute from his people, often raising the prices of this monetary token for seemingly no reason. Then one day when the King came by, he brought none of the glorious gifts they'd grown to depend on -- not even a bag of frozen peas or a screening of "The Pacifier."

When the people asked the king what had happened, he told them that a tree had fallen over on a power line in a village on the far side of the kingdom. While the people didn't think this was exactly fair, what could they do? Who would bring them such fine electric gifts if not the King? It wasn't as if they could make these things themselves.

This scenario resembles what has long been the relationship between the average U.S. resident and the power grid that supplies his or her electricity. For decades, we've depended on an outdated, centralized system that wastes power and occasionally fails to meet everyone's needs. In 1996, for example, a damaged power line in Oregon left 12 million customers in eight states without power. Yet, as is typical under tyrannical rule, there hasn't been a lot of choice in the matter. Electricity has remained the exclusive domain of wholesale power companies with virtually no retail competition for the customers' money.

The idea of the microgrid is changing all this, however. The villagers in our example have concocted a scheme to produce their own power and build their own local seat of electrical clout. Maybe the King will be a little more reasonable about how he divvies the fruit pops now.

The Independence of Localized Power Grids

AP Photo/Serge Ligtenberg
This environmentally friendly housing community in the Dutch town Amersfoort demonstrates some of the solar technology that could power a microgrid.

Fortunately for the American public, the move toward a more dependable and efficient power grid isn't a mere grassroots movement. The U.S. Department of Energy is currently pursuing a strategy to create a **smart grid**, an automated, cleaner and less-centralized means of meeting the nation's energy demands. For more information on this undertaking, read "How the Smart Grid Will Work."

The idea of a localized power grid or **microgrid** fits into this overall strategy in several key ways. First, the more power produced on a local level, the less a community will need to import from outside power plants or leech off the network. Many of the nation's energy woes are due to the electrical equivalency of a run on the bank. Temperatures suddenly skyrocket, so more people crank up the air conditioning -- which puts a huge drain on the grid. If there's not enough to go around, then not everyone gets power -- at least until sufficient energy becomes available elsewhere on the grid.

Think of a home garden: The more produce you grow in your backyard, the less you're going to need to buy from the grocery store. And if you have enough tomatoes on hand or produce prices at the store become ridiculous, you could simply quit going to the grocery store. You might even be able to sell your excess crop to a local farmer's market. Now imagine doing all of this with homespun electrical energy.

Naturally, the key enabler to all of this is technology. Fuel cell, micro tube, reciprocating engine, solar cell and wind farm development have reached the point where a small network of assorted generators can provide power to neighborhoods, retail areas and even industrial facilities. In a microgrid-enabled future, you might not have to drive to the hydroelectric dam one state away to see where your electricity comes from. Instead, you might find the source in the refrigerator-sized micro turbine behind your house and in the wind farm on the outskirts of town.

One particularly interesting concept involves driving home in the evening and plugging your electric car into an outlet. Oh, but you wouldn't be using the microgrid to charge your car; you'd be using your car to charge the microgrid. This approach is called **vehicle to grid technology**.

Micromanaging the Microgrid

David McNew/Getty Images News/Getty Images
While barely the size of a tractor-trailer, Los Angeles' John Ferraro Building Fuel Cell Power Plant provides enough energy for 250 homes. This technology plays a key role in many microgrid plans.

One of the key advantages to the microgrid approach is that it allows local users to make smarter choices regarding their use of power, turning them from cowering subjects under an all-powerful king to empowered consumers in a flexible energy economy. It's the difference, again, between growing a small plot of tomatoes for local use and running an industrialized farm. Which farmer can really claim to have a hand in the rearing of his or her crops?

As previously mentioned, microgrids don't necessarily exist apart from the larger, nationwide power grid. When it makes economic sense, a local community could purchase electricity from outside sources. If prices were to rise, it could all but completely cut itself off from the grid, only using the grid's overpriced juice in the event of local shortages.

Microgrids will not only allow for the optimization of power sources, but also power uses. For instance, a properly equipped microgrid could deal with an energy shortage not by cutting off all power, but selectively killing feeds to certain ends. For instance, the system might prioritize vital communications and healthcare-related energy expenditures, while cutting power to superfluous uses or to appliances such as refrigerators which can usually get by with occasional, short-term power outages.

Another huge advantage to local power production is the optimization of heat energy. Large power plants also tend to create a great deal of unused heat. In fact, between 60 and 80 percent of a typical power plant's energy consumption never becomes electricity. On a local level, however, that energy could be used to heat water for regional use.

Already, cities, industries and military bases around the country are in various stages of implementing microgrid technology -- just one component of a more efficient and dependable energy future.

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Microgrid protection: A comprehensive review

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Abstract

Amalgamation of distributed energy resources (DER) with power system is developing as an emerging power framework. It is ecumenically based on the paramount issues such as extensive use of technologies based on distributed energy resources, shortage of fossil fuel in future, liberalism of electrical service industries and custom vigilance on environmental impact of the conventional method of generating electrical power. These issues are transmuting the concept of conventional power generation globally and introduce incipient challenges in the generation and distribution system. The interconnection of distributed generators has initiated the concept of microgrid which is the assemblage of interconnected distributed generators, intermediate storage units and loads. The pragmatic application of microgrid faces numerous technical challenges. Scheming with a congruous protection scheme is one of the solemn challenges in a microgrid framework. The level of fault current in both the modes of operation, active distributed generation, two-way flow of power, increased value of impedance and quality of communication network are the profuse challenges in scheming an efficacious protection technique. The protection scheme must be reliable, selective, fast and susceptible in both the working modes. This paper presents the meticulous study of the architecture of AC microgrid, DC microgrid and hybrid microgrid along with the associated protection issues and solutions. It also provides the censorious assessment of available challenges in the protection of microgrid in both grid-tied & islanded mode and available protection strategies for both AC microgrid and DC microgrid. An all-inclusive review has been done in each section considering the latest developments along with the future progression in the field of microgrid protection.

Introduction

In modern present power system scenario, renewable energy sources are becoming most paramount energy sources due to the increased awareness on environmental issues. Also, the power generation capacity of DER is low. This low generation ability has incentivized the need for integration of various types of DERs and loads in the form of a microgrid. This integration provides various benefits.

These benefits are as follows:

- ✓ Intensify the power generation capacity
- ✓ Facilitate localized generation at customer ends
- ✓ Reduce the load congestion on the traditional power system [1].

In the present power system scenario, the distributed generation (DG) or distributed energy resources (DER) has following benefits:

- ✓ Better power system efficiency
- ✓ Reduced greenhouse gases emission
- ✓ Reliable operation
- ✓ Reduce the pressure of transmission and distribution on existing power system [2].
- ✓ Power system is transformed into small distributed energy systems
- ✓ Enable consumers to have flexible energy utilizations up to some extent
- ✓ Transmute the manner of transmission of energy via utility power grid
- ✓ Offers supplementary services such as demand response and voltage support

The microgrid augmented with modern power electronics predicated technology can offer better quality of power supply, better efficiency of energy & higher dependability of service [[3], [4], [5]]. Integration of various micro sources and new framework abolish the conventional control method of power flow. Research field based on microgrids have become very popular because it covers various aspects of power electronics field and power systems [6,7]. The microgrid concept is proposed mainly because of two reasons. These reasons are as follows: (i) Make traditional grids more congruous for extensive deployment of distributed generators, and (ii) To control the impact of distributed generators.

Microgrids not only maintain service quality, but also help in providing uninterrupted service. Microgrid has various distributed energy resources and can operate at a low voltage distribution. It has the ability to operate in grid mode or off grid mode [8]. Microgrid can simplify the accomplishment of various smart grid functions such as digital and two-way communication, distributed generation, self-monitoring, self-healing, adaptive and islanding mode, remote check and persaive control [9]. Microgrid is a congruous suppression for circumscribed fossil fuels and can effectively resolve various issues based on power generation [10]. Some of the most paramount of these challenges are operation in normal and island modes, plug and play operation, protection, power quality, security, voltage and frequency control, system stability and energy management. Microgrid offers many technical challenges despite of umpteen benefits. Protection is one of them which requires more attention. Protection of microgrid system is essential for reliable and economic operation. The protection scheme must be proficient in handling any type of fault without disturbing the entire framework. It should execute in minimum possible time span. It must be capable of meeting the requirements of both the modes grid-tied as well as islanded mode. The process of protection scheme includes identification of fault, disconnection of faulty area from rest of the framework and clearing the fault in minimum time duration. So, protection system must be designed carefully [[11], [12], [13]].

Section snippets

Microgrid and its various frameworks

Microgrid is a smaller version of the subsisting centralized electricity system, because microgrids too regulate and distribute the flow of electricity to consumers like the subsisting power grids. But unlike the conventional system, it is done locally. It is a single controlled unit in a power system that can be considered as a single aggregated load [14]. “A microgrid is an incipient concept, which refers to minuscule power system with a cluster of distributed generators operating together

Protection challenges in microgrid

The framework of microgrid protection system should be meticulous, reliable and must have high speed and low-cost operation. The process of microgrid protection must have following steps as shown in Fig. 4, which need to be followed starting from the occurrence of fault to the restoration of the normal operation of the system.

The various protection challenges and solutions for both AC and DC microgrid are shown in Fig. 5.

Solution for AC microgrid protection

Various strategies have been projected in literature to overcome the challenges. Table 3 shows the various strategies to overcome the challenges in AC microgrid.

Solutions for DC microgrid protection

DC microgrid system requires a protection scheme which improves the overall performance of the DC distribution system. The various protection strategies are embellished in Table 6. For addressing the issues associated with the lack of natural zero crossing and grounding the protection schemes are discussed in this section.

- (i)
  Reconfigurable

Application of industrial aspects in the protection framework of microgrid

The current scenario of microgrid process is mainly depends on smart features such as intelligent techniques-based supervision of overall operation and measurement. The distributed generation sources, surveillance of grid-status, substations, intelligent electronic devices and consumer demand are the various sections of modern microgrid framework. These sections must be interconnected through secure and efficient communication framework in order to enhance the overall performance of the system.

Future scope and challenges

The comprehensive review of this paper shows that numerous factors are responsible for scheming an efficient protection technique. In future, the following aspects of microgrid protection technique must be scrutinized while designing it for both the frameworks.

- (i)
  The interconnection of active distributed generation, range of impedance, characteristics with two-way power flow must be taken care of during the designing process.

- (ii)
  The protection devices such as DC circuit breakers, fuses and grounding

Conclusion

Protection of any system is the utmost signification factor. The primary concern is the availability of continual and supreme quality of power. It should be taken care of while ensuring system safety, reliability and security. Initially, this work illustrates the architecture of AC microgrid, DC microgrid and hybrid AC/DC microgrid. The prime focus of this paper is on the protection challenges for AC and DC microgrid. The different protection approaches for both AC and DC microgrid are

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.