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Editorial

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Optimal operation and energy management of microgrids

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The world's first distribution system, set up by Edison at the Pearl Street generating station, New York, USA, in 1882, marked the beginning of distributed generation (DG). Over time, through extensive research and development, this pioneering DG system evolved into the modern centralized system, macro-grids.

The strain on the present-day electrical macro-grids makes them vulnerable, as evidenced by large blackouts in various parts of the world over the past few years. With an increasing awareness of the environmental effects and limitations of fossil fuels and the high capital requirements of central power plants, DG at medium and low voltage levels is gaining importance.

Penetration of DG sources at the distribution level causes technical problems in the network operation, e.g., excessive voltage rise, increase in the fault level, *etc*., because the present electric power infrastructure at the distribution level is designed for current flows predominantly in one direction. To overcome these problems, the concept of microgrids has been developed as an energy management system and is already applied in several communities to provide benefits to customers.

Concept. A microgrid may consist of multiple generating sources making use of clean renewable sources of energy, customers, energy storage units, protective devices, *etc.*, within a clearly defined electrical boundary acting as a single controllable entity. It is akin to a miniaturized version of a power grid and can operate physically islanded or interconnected with the utility grid. Local generation allows better management in the case of emergencies, as has been demonstrated in several instances over the past few years. Microgrids thus can help make better use of energy generated, stored, and used at the local level, thereby enhancing local reliability and flexibility of the electric power system.

Several technologies, ranging from conventional, such as small hydro, micro gas turbines, diesel generating units, biofuel, and municipal waste, to renewable generation sources, such as wind turbines, photo-voltaic, and fuel cells, have been applied.

Operation. A microgrid can be operated in two modes of operation:
Connected to the grid. In this case, it provides quality of supply, global efficiency, flexibility of use, and reduced cost. In times of need, it can draw energy from the grid and supply energy to the grid in times of excess energy availability.
Operate autonomously isolated from the grid (i) under emergency during grid faults or (ii) as an energy source in remote locations where the cost of providing transmission lines may be very high.

Challenges and Amelioration. Although microgrids can be very useful in making use of renewable resources for electricity generation and providing electricity at reasonable cost even to remote communities, challenges exist. These challenges can be overcome by judicious design. Also, the integration of control and protection can make a significant contribution to the operation of the microgrid.

As electricity generation using wind and solar can be intermittent and unpredictable, and microgrids have relatively small capacity, they are vulnerable to random variations in generation and load. This may cause problems with operational capability and quality of supply.
Availability of wind and solar radiation may not match the time distribution of load demand. Thus, providing electricity to always meet the load in a regular way can be a challenge.
Design of a hybrid system becomes complicated through uncertain renewable energy supplies.
In an isolated mode, chances of P and Q shortages must be compensated instantly from somewhere.
Conventional distribution systems are supplied through one source at one end. Protection schemes are relatively simple. However, the presence of generation in the distribution system leads to a loss of coordination of protection devices as power flow in the distribution circuits can reverse.
Requires fast detection of islanding conditions to guarantee the safety, reliability, and integrity of the entire system.

Meeting these challenges requires:
Strategic deployment of distributed energy sources in respect of location, size, and technology to suit the requirement. An example is the integration of solar and wind sources in proper combination, using the strengths of one to overcome the weaknesses of the other.
Use of energy storage devices to balance load demand and generation by intermittent sources of generation.
Proper control techniques to manage the operation of all components.
Proper schemes for protection at the distribution level.

Role of Energy Storage. Energy storage is a critical element in the integration of DG into the microgrid and can impact the economic feasibility of the installation. It can help maintain stability, enable optimization of generation sources, improve power quality, allow black start of the system, exploit off-peak prices, and provide short-term power supply to act as a buffer not only to counteract power imbalances but also for critical customers in fault situations.

Currently, several types of energy storage technologies with different characteristics are available. These include small hydro pumped storage, batteries, high-speed flywheels, supercapacitors, compressed air, chemical conversion to Hydrogen for fuel cells, and super-heated gas. Flow batteries, superconducting magnetic energy storage, *etc*. The choice of technology to employ involves a trade-off between power and energy density.

At the current state of technology, batteries are considered the best choice to provide both power and energy densities. Their efficiency varies between 60%-80%. In addition to the better-known lead acid battery, various types of new batteries, including nickel-iron, nickel cadmium, nickel-metal hydride, and Lithium ion, have been developed in recent years and are in use for industrial applications. Considerations in battery deployment are the initial and maintenance cost, energy density and response time, charge and discharge cycle life, and environmental concerns.

Electric vehicles connected to the grid can also perform as energy storage units. As their numbers increase, with proper control, they can play a significant role in frequency stabilization in a microgrid in the future.

Energy storage units can be either distributed or centralized depending on the size of the microgrid. They require power electronics interfaces for access to the microgrid. For optimal operation and to derive the most benefit, it requires consideration of type, configuration, and the impact of energy storage systems on the microgrid.

Control Methodology. DG sources are inertia-less or have low inertia that can have a significant impact on the voltage and angle stability of the system. It can be compensated by connecting energy storage to the system, sometimes called "virtual inertia". With this control strategy, electronically interfaced DG will behave as a conventional generating system. Connecting energy storage systems requires integration of power electronics interface control in the overall operation of the microgrid.

Power and VAr injection throughout the distribution network provided by DG alters the original passive nature of the distribution network, thus affecting the network voltage profile. It makes it hard to perform voltage regulation, and coordinated voltage and VAr control may be required, thus necessitating a radical revision of control strategies.

Protection. Even though most low- and medium-voltage networks are laid out as meshes, they are operated as "normally open" using automatic and manually controlled switches. Most protection schemes at the distribution level are currently designed for radial lines with unidirectional power flow. The presence of generation in the distributed system may lead to a loss of coordination of commonly used simple protection devices, such as fuses, re-closers, over-current relays, and automatic sectionalizing schemes. It could also result in false tripping, undesirable network islanding, and prevention of automatic and asynchronous re-closing.

At a few special locations, these circuits are being operated as closed meshes using special schemes, such as power electronic devices, to control the interface between sections of a mesh. Also, better protective equipment, such as cheaper breakers and intelligent electronic devices for relaying, is being developed, which will ultimately aid in the protection of microgrids.

Protection schemes for diagnosis and isolation of faults to protect distribution systems that include DG need to be developed. It is also necessary to establish loss of mains requirements and develop methods for islanding detection.

DC Microgrids. One of the latest developments is the establishment of dc microgrids. Many electric energy utilization applications now require either dc or double conversion from ac to dc to ac. These include large data centers, commercial buildings using variable speed motor drives, electric vehicle charging stations, or anywhere power electronics-based devices are used. These involve interconnecting a localized grouping of electricity sources and loads. In these cases, electricity is either predominantly generated or distributed and used in dc form at up to 1,500 V dc. They can operate either connected to the traditional centralized grid or function autonomously as physical and/or economic conditions dictate.

Advantages of dc microgrids include the reduced or complete elimination of ac-dc conversion, reduction in losses, increased cost-efficiency, and grid decentralization.

However, because they are in the early stages of development, there is still a lack of suitable equipment for dc distribution coupled with a lack of application knowledge at the distribution level dc. Pathways for moving from the existing ac-centric power distribution systems to dc-based distribution systems are still evolving.

Concluding Remarks. Microgrids offer an organic combination of DG, energy storage, energy conversion devices, associated loads, monitoring, and protection in grid-connected and isolated modes of operation. They can be very useful in making use of renewable resources for electricity generation and provide electricity at a reasonable cost to remote, isolated communities. Thus, as an approach and strategy that focuses on energy efficiency management and enhances energy saving, microgrids offer an important pivotal position by providing engineering solutions for sustainable power systems.

However, challenges exist both in the optimal operation and energy management of the microgrid, but they can be overcome by judicious design and proper control techniques in the operation of the microgrid. Integration of protection and control can make a significant contribution. Papers in this Special Issue cover a variety of these challenges under different situations to enhance reliability while maintaining power quality performance indicators.

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