Micro-Grids: Concept and Challenges in Practical Implementation

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Strain on 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 high capital requirements of central power plants, distributed generation (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 micro-grid has been developed as an energy management system and is already applied in a number of communities to provide benefits to customers.

Concept

Micro-grids can help make better use of energy generated, stored and used at a local level, thereby enhancing local reliability and flexibility of the electric power system. A micro-grid may consist of multiple generating sources making use of clean renewable sources of energy, customers, energy storage units, etc. within a clearly defined electrical boundary acting as a single controllable entity and be able to operate physically islanded or interconnected with the utility grid. Local generation allows better management in case of emergencies as has been demonstrated in a number of instances recently.

A number of technologies, ranging from conventional, such as small hydro, micro gas turbines, diesel generating units, biofuel, municipal waste, to renewable generation sources such as wind turbines, photo-voltaic and fuel-cells have been applied. An illustrative example of a micro-grid is shown in Fig. 1.

Operation

A micro-grid can be operated in two modes of operation:

1 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.

2 Operate autonomously isolated from the grid (i) under emergency during grid faults or (ii) as energy source in remote locations where cost of providing transmission lines may be very high.

Challenges and Amelioration

Although micro-grids 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, integration of protection and control can make a significant contribution in the operation of the micro-grid.

Electricity generation using wind and solar can be intermittent and unpredictable. They depend highly on the weather systems. Long term and even short time ahead forecast techniques for both wind (gusts) and solar (clouds) still lack the desired accuracy. As micro-grids have relatively small capacity, they are vulnerable to random

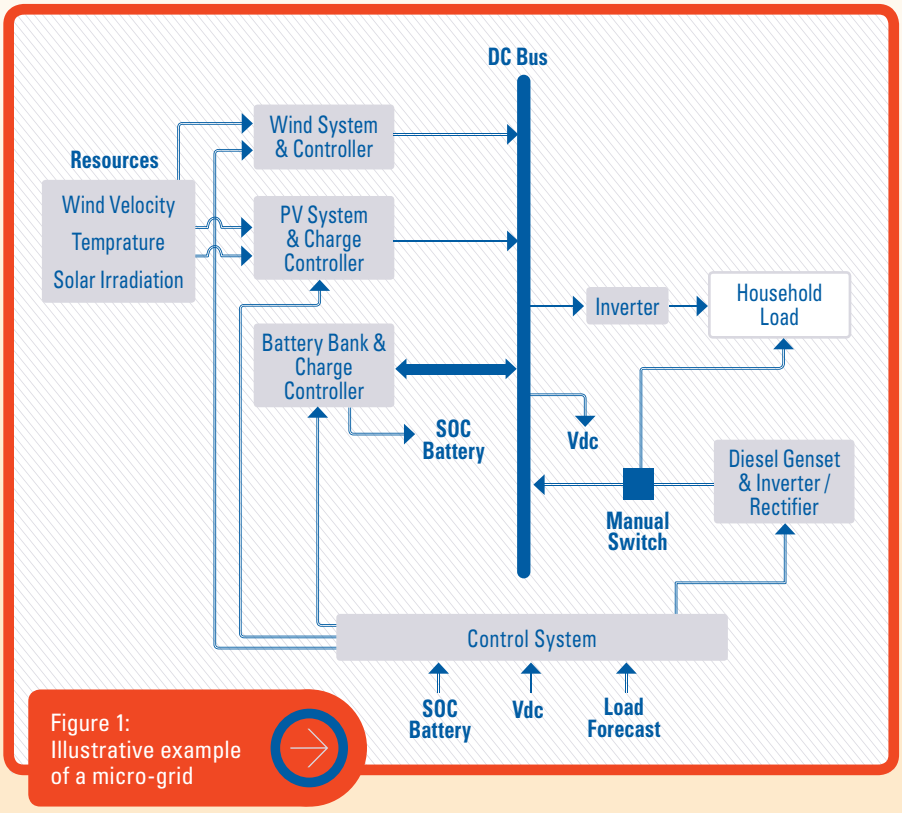


Figure 1: Illustrative example of a micro-grid

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 meet load at all times in a regular way can be a challenge.

- Design of a hybrid system becomes complicated through uncertain renewable energy supplies.

- In isolated mode, chances of P and Q shortages that must be compensated instantly from somewhere.

- Conventional distribution systems are supplied through one source at one end. Protection schemes are relatively simple. However, presence of generation in the distribution system leads to loss of coordination of protection devices.

- Requires fast detection of islanding conditions to guarantee 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 micro-grid and can impact the economic feasibility of the installation. It can help maintain stability, allow 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, super-capacitors, compressed air, chemical conversion to Hydrogen for fuel cells, super heated gas. flow batteries, superconducting magnetic energy storage, etc. Which 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, several types of new batteries have been developed in recent years, Fig. 2, 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 micro-grid in the future.

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

Control Methodology

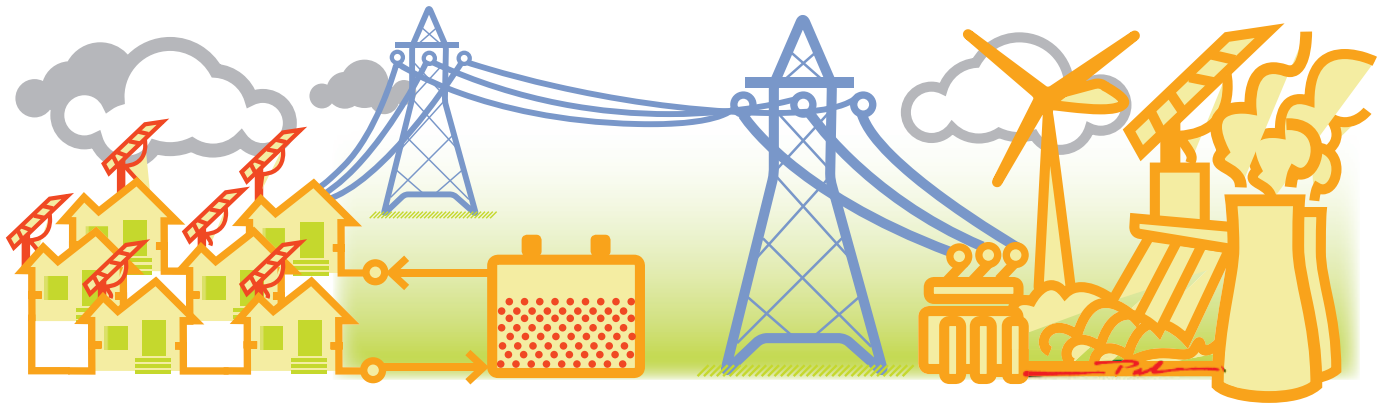
Distributed generation sources are inertia-less or have low inertia that can have a significant impact on voltage and angle stability of the system. It can be compensated by connecting energy-storage to the system, sometimes called "virtual inertia". With this control strategy, electronically interfaced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

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 LV and MV 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 distribution system may lead to loss of coordination of commonly used simple protection devices, such as fuses, re-closers, over-current relays, automatic sectionalizing schemes. It could also result in false tripping, undesirable network islanding, 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



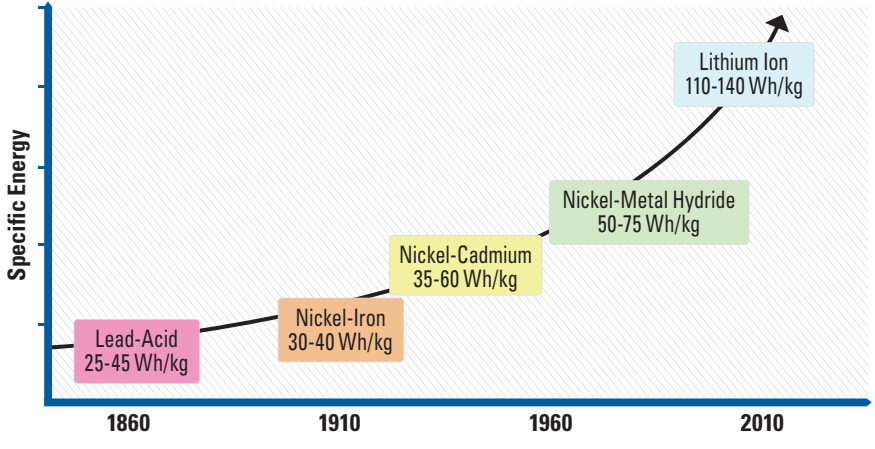


Figure 2. Characteristics of various types of batteries (source EPRI 2008)

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 that will ultimately aid in the protection of micro-grids.

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

DC Micro-Grids

One of the latest developments is the establishment of dc micro-grids. 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 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 1500 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 micro-grids are: reduced or complete elimination of ac-dc conversion, reduction in losses, more economical and decentralization of the grid.

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

Concluding Remarks

Micro-grids can be very useful in making use of renewable resources for electricity generation. They can also provide electricity at reasonable cost to remote, isolated communities.

However, challenges exist but they can be overcome by judicious design and proper control techniques in the operation of the micro-grid. Integration of protection and control can make a significant contribution. ■

For Om Malik's biography, see page 25.