# 3

## *AC/DC Microgrids*

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## 1  Introduction

Today, the increasing necessity for integrating RERs in electric power generation resolves the existing dependency on imported fossil fuel (FF) resources. The need to protect nature and minimize the environmental contamination brought about by FF emissions has prompted the inescapable certainty of utilizing incorporated RESs in current microgrids. A microgrid is a practical approach to interlink DGRs to the electric grid. There are alternating current (AC), direct current (DC), and hybrid AC/DC microgrids, which are deliberated in this chapter. A hybrid AC/DC microgrid is wildly accepted and is a gateway to improve the framework reliability and previously stated issues. Currently, the, government authorities, and renewable energy (RE) sectors are growing. Subsequently, it is well understood that the operational observations, like that of intensity power systems, will be considered in the microgrid [1–6].

To manage our future energy demand, RE-based distributed generation (DG) units, such as wind, solar, hydropower, biomass, and fuel cells, are the solution to the problem, as mentioned earlier, if utilized in a correct manner. The critical feature of these RERs raises the concept of the hybrid microgrid, which reduces line failure and transmission loss, and ensures improved power quality, reliability, and stability in power demand and balancing.

A DGR-integrated microgrid is a localized, isolated grid, which is a small electric grid configuration with all DG protective devices, control with automation systems, communication, distributed storages, master controller, an energy storage system (ESS), smart switches, and loads either grid-connected or islanded mode.

Generally, most of the RE-based DG units directly supply DC (direct current) or AC (alternating current – i.e. variable frequency/voltage) output power. Thus, power electronic devices are considered as an essential factor in microgrid design, as it has a different load profile (AC/DC) and various DGs, which arises from the controls in the grid network.

Currently, the hybrid AC/DC microgrid is receiving much attention because of its ability to provide higher energy surety, quality, and security while also ensuring sustainability and energy efficiency. The imminent trend favors the hybrid AC/DC microgrid to the power grid as it provides the combinational advantages of both a DC and an AC grid. Typically, a hybrid AC/DC microgrid consists of dual generating sources, various interconnecting DGRs, and the critical load. Interestingly, the nature of a hybrid AC/DC microgrid removes multiple reverse power conversions of the individual grid and improves grid efficiency.

As a hybrid grid typically comprises various critical loads and ESSs, a bi-directional converter has significant importance in keeping reactive and real power import/export from power flow or utility grid among the AC and DC grid itself. Microgrids are divided into various types based on their mode of operation, types, sources, applications, and sizes, as shown in
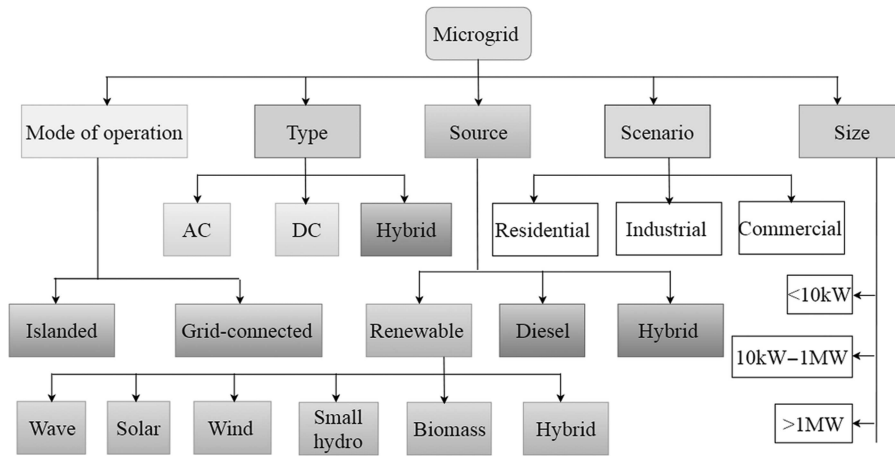
**FIGURE 3.1**
Microgrid classification

Figure 3.1. Based on mode of operation, microgrids are classified into two types: 1. island microgrids, 2. grid-connected (non-island) microgrids.

## 1.1 Island Mode

In this mode, a microgrid operates to satisfy the energy demand of local consumers. These types of microgrids are suitable for a load that is located remotely from the conventional grid. The design and development of these types of microgrids are more complicated due to their autonomous nature. Island mode microgrids are suitable for rural and remote areas where they, in turn, can help the societal or local community needs in many ways. The main reason behind a successful implementation of this type of microgrid is the availability of domestic energy resources. Based on the availability, these microgrids will use various types of energy sources such as mini-hydro, solar energy, wind energy, small diesel generators, and gas turbines, as shown in Figure 3.2.

## 1.2 Grid-Connected Mode

In this mode, microgrids are connected with the power grid. These types of microgrids play a significant role in integrating RE sources into the main grid and also help as an additional support to the utility when there are outages. For this reason, these grids can reduce overall losses and provide better congestion management, increased reliability, and an ability to reduce the gas emissions. Grid-connected microgrids are suitable for industrial and commercial purpose loads such as universities, shopping malls, office buildings, and significant residences. Based on the main grid point of view that these types of grids are acting as a controllable load with an excellent load demand profile.
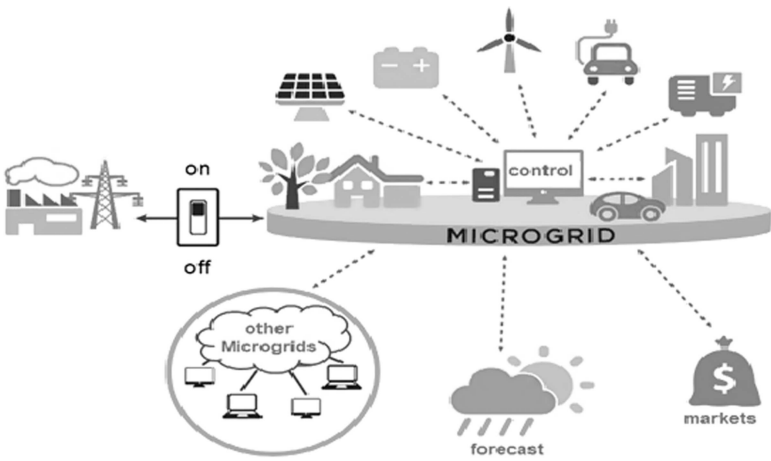
**FIGURE 3.2**
Sources and loads of the microgrid

The characteristics of both modes of operation are compared in Table 3.1. The choice of the mode of operation of the microgrids is mostly based on the application and availability of the resources.

## 2  Power Supply Types of Microgrids

Based on the types of operating power supply, microgrids are classified into DC grids, AC grids, and hybrid grids. Hybrid grids use both AC and DC power supply for their operations.

### 2.1  DC Microgrid

A DC microgrid is a highly efficient grid that avoids any power conversion studies. For this reason, DC microgrids are more economical than AC grids, because most of the energy sources are DC output sources like PV panels, batteries, and fuel cells. Similarly, most of the loads are also direct DC input

**TABLE 3.1**

Comparison of island and grid-connected microgrids

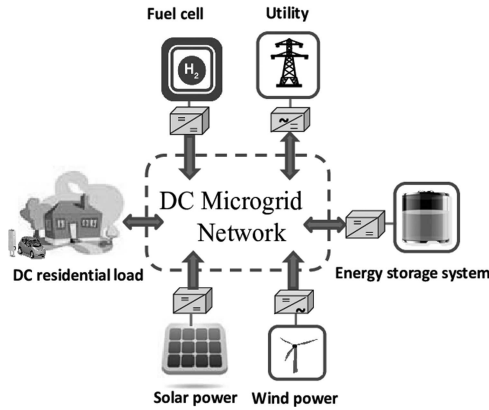| Characteristic | Autonomous | Grid Connected |
|---|---|---|
| Mode of operation | Isolated | Grid connected |
| Main drivers | Sustainability of remote and rural areas, efficiency | Power quality/reliability enhancement, efficiency, costs |
| Use of demand response | Critical | Desirable |
| Use of energy storage | For self-reliance | For responding to price signals |

**FIGURE 3.3**
A DC microgrid system

device. A DC microgrid layout is shown in Figure 3.3. A DC microgrid consists of a DC bus, which feeds DC loads connected to it. As most of the RERs are generating DC output as compared with AC generating sources, a DC microgrid is on advantage side, as frequency, power factor, and phase angle are eliminated. DC microgrids have the following benefits:

- Increase the partition of distributed solar energy resources
- More energy saving possibility and the additional cost of converters of DC/AC can connect the DC bus into the utility
- DC grid is designed in such a way that it can supply power during emergency or blackout condition via the same distribution lines
- Higher efficiency and cost-effective
- More reliable and stable
- Elimination of frequency, power factor, and phase angle
- DC loads can be connected directly

This microgrid uses the DC bus backbone support and is able to distribute the power supply to the electrical loads.

## 2.2 An AC Microgrid

In an AC microgrid all the loads are interfaced to an AC bus. In this type of microgrid, all the loads and distributed energy sources are connected to the AC bus in common. In an AC microgrid, all DERs and loads are connected to a standard AC bus as shown in Figure 3.4. The power sources, as well as storage devices, have been connected to AC bus via inverters and converters. The significant role will be played by the power electronic converters, which ensure the smooth operation of a microgrid.
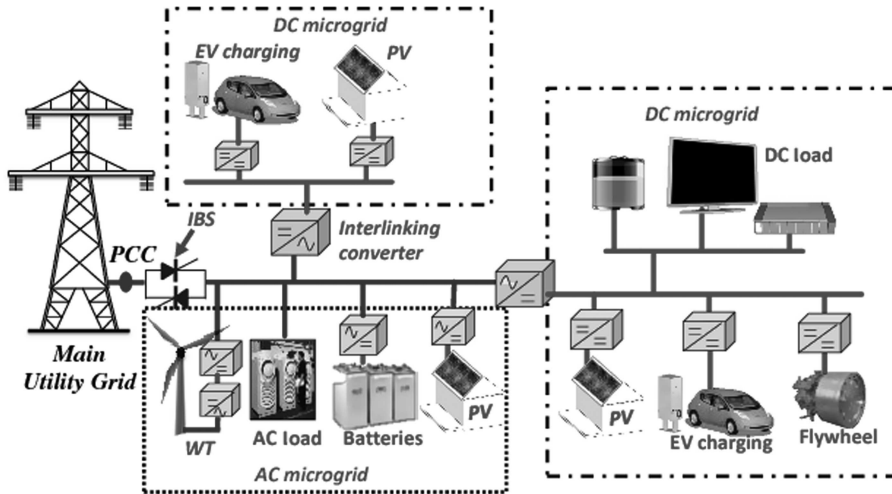
**FIGURE 3.4**
An AC microgrid and a DC microgrid

## 2.3  Inverter

The power electronic device that converts direct current to an alternating current power supply is called an inverter. The inverter design can finalize the voltage, power frequency, and output power. Inverters are broadly divided into single-phase inverters and three-phase inverters. Usually, the single-phase full-bridge inverter has four switches that tend to produce an AC output voltage by on and off switches, as shown in Figure 3.5.

The three-phase inverters are formed by operating or connecting three single-phase transformers simultaneously. The fundamental AC output is achieved by operating the switches at 60 degrees. The desired output frequency, power, and the terminal voltage is achieved by the control of the switching pattern of the switches. The microcontroller-based MOSFET H bridge inverter circuit shown in Figure 3.6 is controlled through pulse width modulation.
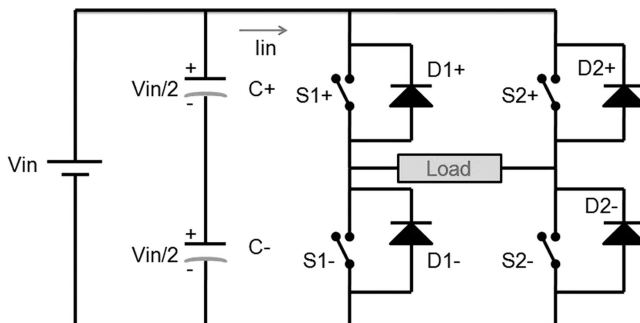


**FIGURE 3.5**
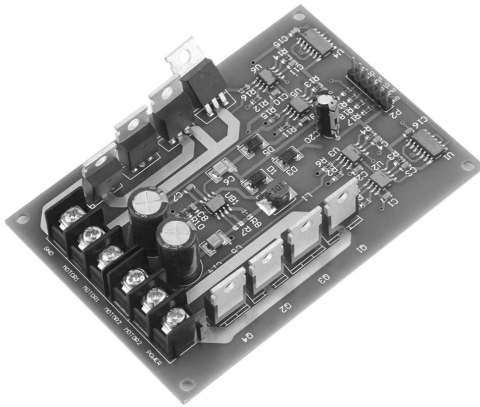Equivalent circuit of a single-phase full-bridge inverter

**FIGURE 3.6**
MOSFET H bridge inverter

## 2.4 Boost Converter

The DC to DC conversion of power is done; a device is called Boost Converter. It is used to improve the voltage and bring down the current. One of the significant sources of a microgrid is solar power, which supplies DC power supply. The solar arrays are not able to meet the load straightaway. Generally, the boost converters role is to increase the voltage. The boost converter circuit is shown in Figure 3.7, and it is operated in two modes. The first mode is closed switch, and the next mode is an open switch. In the first case that energy is saved in the inductor as magnetic power.

Due to the off position of the switch, the capacitance gets blocked from the power supply. When the switch is moved to the next state, then the inductance is connected in series with the source to the improvement of voltage. The inductor and capacitor values are the deciding factor of the output voltage, as shown in Figure 3.8.

## 2.5 AC/DC Microgrid

An AC/DC microgrid has both an AC bus and a DC bus. This novel idea of microgrid encourages the strong interconnection of distributed energy
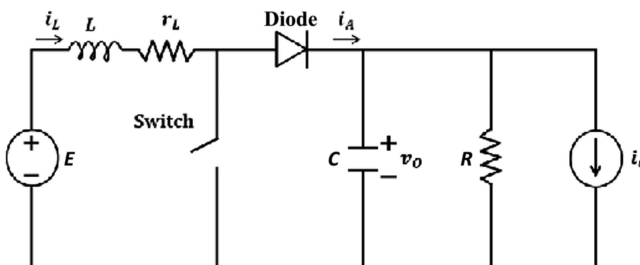


**FIGURE 3.7**
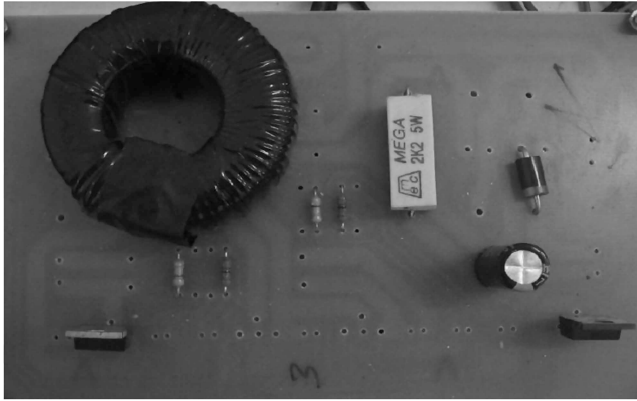Equivalent circuit of a boost converter

**FIGURE 3.8**
DC-DC boost converter

systems. For the interconnected power systems, the microgrids are acting as a controlled cell of the entire network. To the consumer, the microgrid is able to meet all the requirements such as enhanced local reliability and ensure fewer losses, voltage improvement, better efficiency, and better voltage sag profile. The intelligent coordination of microgrids and the utility grid ensures better connectivity with lesser interconnection.

A hybrid microgrid system is shown in Figure 3.9. Different types of AC and DC energy sources are, and its load are connected in the AC and DC bus to frame the configuration. The AC and DC links are connected through the transformers and two four-quadrant operating three-phase converters or in-verters. An AC grid is interconnected with the distribution grid. The converters
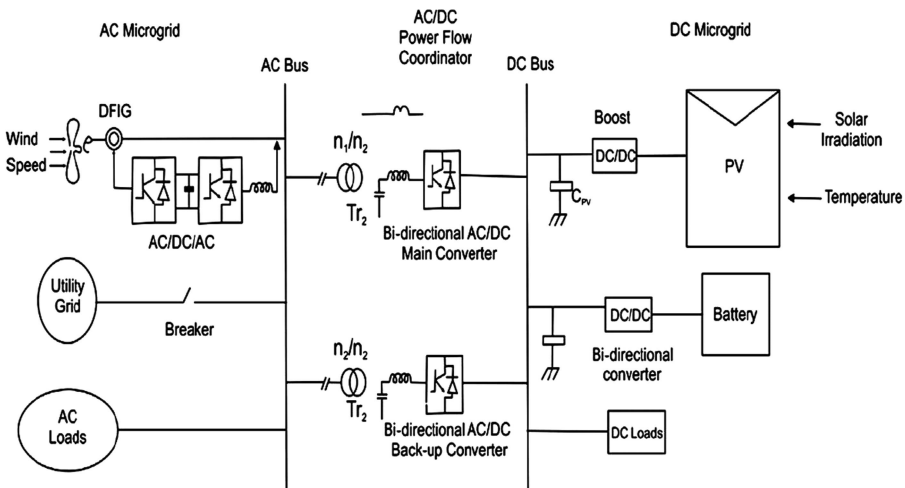
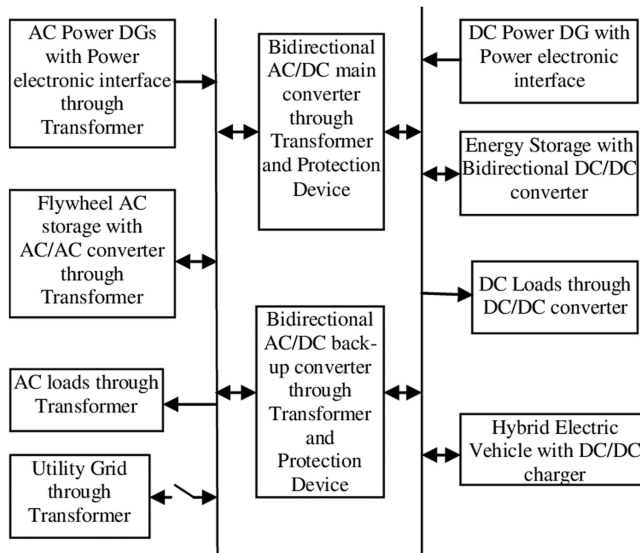

**FIGURE 3.9**
AC and DC microgrids
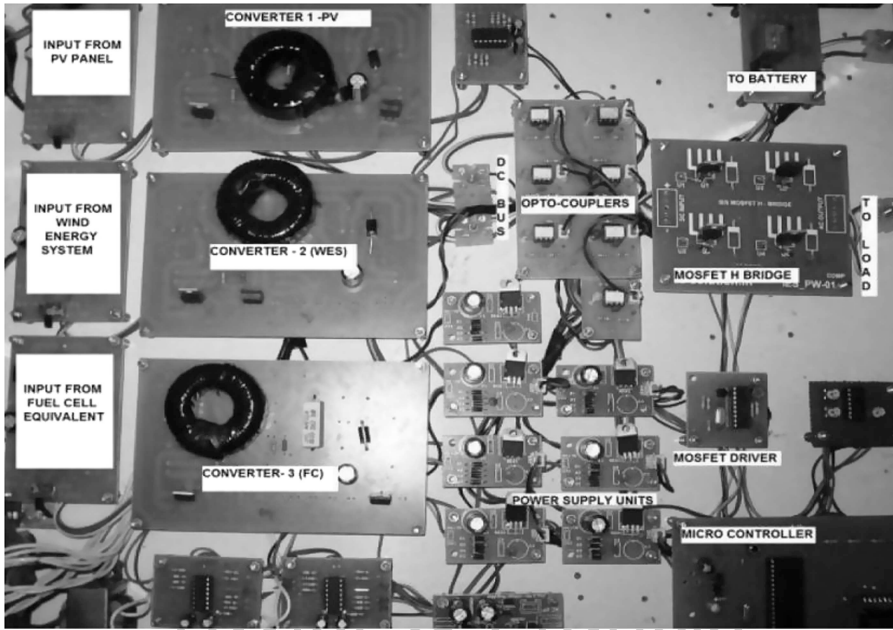
**FIGURE 3.10**
Layout of AC/DC micro-grid

interconnect the AC and DC grids with their sources, loads, and batteries. The AC bus is connected with the distribution side bus by the transformer with a proper circuit breaker. The array of solar panels is interconnected with the DC bus through the boost converter to inject power into the network. A doubly-fed induction generator-based system is interconnected with the AC bus through the power electronic converters, as shown in Figure 3.10.

A battery connected with a DC/DC converter is connected with the bus as an energy storage device. Variable loads are interconnected to the DC and AC buses in the hybrid microgrid. The solar panel is connected in both series and shunt. As the radiation level and temperature changes, the output power of the solar panels is varied.

A capacitor is connected to the solar panel terminal to eliminate the ripple factor of the power output of the solar power plant. The bi-directional DC/DC converter is connected between the DC bus and the battery, which helps the charging and discharging of the battery when the microgrid operates in grid-connected mode. The boost converter, main converter, and bi-directional converter will share the bus, and the wind generation system ensures double fed induction into the buses, as shown in Figure 3.11.

## 3  Distributed Generation Sources-Based Microgrids

A distributed energy resource is a comparatively small source of energy that can be combined to provide the power necessary to meet the energy

**FIGURE 3.11**
Prototype of AC/DC microgrid

demand – based on the sources, connected microgrids are classified as RE, conventional source, and hybrid source. Continuous advancement of grid technologies supports microgrids to integrate different types of fossil and non-fossil resources to be integrated for better power flow and enhancements. Different types of sources, such as microturbines, Stirling engines, and IC engines, are used. Sources such as solar, wind, micro-hydro, diesel, and CHP are exhibiting different characteristics, as shown in Table 3.2.

Distributed generator technologies needed to have specific converters and interface devices are used to inject the power into the grid. This is possible because of the development of advanced power electronic interfaces. The bi-directional converters are very useful and most common in the microgrids due to its ability towards power flow control on both directions. From no-load to full-load operations, the bi-directional converters can manage a stable power supply.

## 4  Scenario-Based Microgrids

Based on the application or scenario, the microgrids are classified as

- Institutional microgrids
- Remote island microgrids

**TABLE 3.2**

Characteristic comparison of distributed energy sources

| Characteristics | Solar | Wind | Micro-hydro | Diesel | CHP |
|---|---|---|---|---|---|
| Availability | Geographical location dependent | Geographical location dependent | Geographical location dependent | Any time | Dependent on source |
| Output power | DC | AC | AC | AC | AC |
| Control | Uncontrollable | Uncontrollable | Uncontrollable | Controllable | Dependent on source |
| Typical interface | Power electronic converter (DC-AC-DC) | Power electronic converter (AC-DC-AC) | Induction generator | None | Synchronous generator |
| Power flow control | MPPT and & DC-link voltage control | MPPT and pitch and torque control | Controllable | Controllable | AVR and governor |

- Military microgrids
- Residence and industrial microgrids

## 4.1 Campus Environment or Institutional Microgrids

This type of microgrid is campus- or institution-based power grid. This type of microgrid has several loads on the campus and is more straight-forward to manage comparatively. These types of microgrids are connected in distribution grids, as shown in Figure 3.12.

## 4.2 Remote Island Microgrids

This type of microgrid is never connected to the main grid. It is usually installed in remote places where the distribution grid is costlier or not possible due to a lack of supply power. This type of microgrid is operated under island mode, mainly in rural areas, as shown in Figure 3.13.

## 4.3 Military Microgrids

This type of microgrid is specific to military defence applications and is implemented in its base camp. It is developed to ensure the power supply without disturbance at emergencies, as shown in Figure 3.14. They



**FIGURE 3.12**
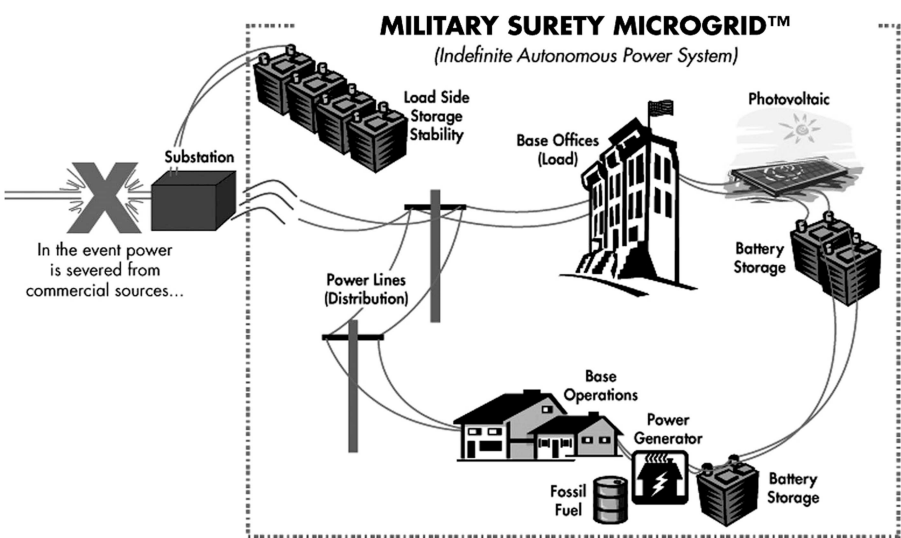Campus environment microgrids

**FIGURE 3.13**
Rural microgrids



**FIGURE 3.14**
Military base camp microgrid

**FIGURE 3.15**
Industrial and commercial microgrids

also acts as a backup for the main power supply, which has better physical and cybersecurity with all the necessary infrastructure.

## 4.4 Residence and Industrial Microgrids

These microgrids are installed in industry and provide a more reliable power supply to industries and residences, as shown in Figure 3.15. The operation of microgrids ensures less power loss and considerable savings in the tariff.

## 5 Size of the Microgrids

Based on the size or capacity of a microgrid it is classified as a nano grid, a medium microgrid, or a big microgrid. Nano grids are smaller microgrids with a capacity that is below less than 10 KW; between 10 KW to 1 MW is considered a medium-level microgrid. Greater than 1 MW is regarded as a big microgrid. This capacity level varies from one country to another country. The size of the microgrid mainly depends on the load side demand. These microgrids generally have standards and guidelines. IEEE 1547.4, with the support of IEEE P1547.8, is a microgrid IEEE standard. It is also governed by IEEE 1547.6, which set the standard for secondary network distribution systems. IEEE P2030 covers the interoperability standards of the microgrid. Usually, these

**TABLE 3.3**

Key benefits and challenges of AC, DC, and hybrid AC/DC microgrids

| AC Microgrid | DC Microgrid | Hybrid AC/DC microgrid |
|---|---|---|
| **Key Benefits** | | |
| Plug-in approach for all DGRs | DC produced/stored by PV systems, fuel cells, and batteries | Best for both AC and DC power generation units as a source |
| Well-developed interconnection, products standards, and codes | DC used by increasing the number of electrical devices | Similar benefits to DC microgrids |
| Familiarity with the design of AC LV electrical systems | Lower conversion requirements | |
| | AC to DC conversion is more comfortable and cheaper than DC to AC | |
| | Reduction in number of devices required (e.g. batteries chargers) | |
| | Improvement in reliability, as there are fewer points of failure | |
| **Addressable challenges** | | |
| Increased times of conversion requirements | Lack of existing applications for DC LV distribution systems | Control of the system is a challenge |
| Energy losses in the conversion | Current lack of approved standards and codes for all the LV side DC types of equipment | |
| More equipment and devices are required | Complex design of DC LV distribution systems | |
| | Complicated procedures for approved/recognized DC low voltage system architecture | |
| | Sophisticated safety and protection practices compared with AC LV distribution systems | |
| | Infrastructure upgrade required from AC to DC systems | |

**TABLE 3.4**

Comparison of AC and DC microgrids

| AC | Factors | DC |
| --- | --- | --- |
| Several energy conversions reduce the efficiency | Conversion of energy | Less conversion associated increase efficiency |
| Less efficient due to loss | Transmission efficiency | Increased efficiency |
| External disturbances create problem | Stability | No external disturbance |
| Required | Synchronization | No issue |
| Less | Reliability | High |
| Complex | Microgrid controls | Simple |
| Cheap, less complicated, and better protection schemes | Protection system | Costly, less straightforward, and complex protection components |
| Electrical AC loads | Suitability | Electrical DC loads |
| Complex numbers are involved | Calculation procedure | Only real numbers are used |

standards are mainly concentrated on the area of load flow, fault analysis, quality of power, steady-state stability, and transient stability. The communication protocols used in the microgrids are power line carrier, broadband over power line, leased telephone line, GSM communications, LAN/WAN/Internet communications, and optical fiber communications.

## 6  Comparison of AC and DC Microgrid

There are advantages and challenges associated with the use of AC, DC, or hybrid microgrids. Table 3.3 summarizes the possible benefits and challenges.

Apart from the advantages and challenges, there are few differences between the AC and DC microgrids. We identified a few factors, such as conversion efficiency, transmission efficiency, stability, synchronization, power supply reliability, microgrid controls, protection system, suitability, and calculation methods, on which the comparative study is built. Table 3.4 summarizes the comparison of AC and DC microgrids.

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