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Power Electronics for Microgrids and Islanded Operations

Ravinder S. Pawar[1], Manoj K. Devkar[2], Shubham R. Kale[3]
Associate Professor, Students
Department of Intelligent Motor Drives and Power Systems Unit
Christ College, Irinjalakuda, India
***Email**: ravinderpawarsss@gmail.com, manojkdevkar200@yahoo.com,*
kaler4shubham@rediffmail.com

Abstract

Microgrids are emerging as an important solution for reliable, sustainable and decentralized power generation. With increasing penetration of renewable energy sources like solar PV and wind, the role of power electronics becomes very critical in microgrid operation. Power electronic converters act as interface between distributed generation, storage systems and loads. In islanded operation, where microgrid is disconnected from utility grid, converters are responsible for maintaining voltage, frequency and power balance. This paper presents a detailed review on role of power electronics in microgrids, different converter topologies, control strategies, energy management and challenges during islanded mode. Various inverter control techniques like droop control, virtual synchronous generator and hierarchical control are discussed. The paper also highlights issues such as stability, power sharing, protection and synchronization.

KEYWORDS: *-Microgrid, Islanded mode, Power electronics converters, Droop control, Inverter control, Distributed generation, Energy storage*

INTRODUCTION

Microgrid is a small scale power system consisting of distributed energy resources (DERs), storage units and local loads. It can operate in two modes: grid connected mode and islanded mode. In grid connected mode, main grid supports voltage and frequency. But in islanded mode, microgrid itself must regulate these parameters. This makes power electronics very important.

Most renewable energy sources produce DC or variable frequency AC. Power electronic converters are required to convert this into usable AC supply. In islanded condition, these converters not only transfer power but also act as voltage and frequency source.

1. STRUCTURE OF A TYPICAL MICROGRID (ELABORATED)

A microgrid is formed by interconnecting several distributed energy resources (DERs), storage elements, power electronic converters and loads through a common electrical network. The arrangement can be AC microgrid, DC microgrid or hybrid AC–DC microgrid depending on application. The structure is designed in such a way that it can operate both with utility grid and independently in islanded condition.

The main building blocks of a typical microgrid are explained below.

2.1. Distributed Energy Resources (DERs)

These are small scale generation units located near the load center.

- **Solar Photovoltaic (PV):** Produces DC power. Output varies with sunlight and temperature. Requires DC–DC boost converter and inverter.
- **Wind Turbine Generator:** Produces variable frequency AC. Needs AC–DC rectifier and DC–AC inverter.
- **Fuel Cell / Microturbine / Diesel Generator:** Used as backup sources. Usually connected through power electronic interface.

These DERs are not directly connected to the AC bus. They always require converters for proper integration.

2.2. Energy Storage System (ESS)

Energy storage is very important for islanded operation because renewable sources are intermittent.

Common storage types:

- Lithium-ion batteries
- Supercapacitors
- Flywheel storage

Storage is connected through **bidirectional DC–DC converter** so that battery can be charged and discharged depending on power balance.

Functions of ESS in structure:

- Maintains power balance
- Supports during sudden load change
- Provides backup during generation shortage
- Improves stability of microgrid

2.3. Power Electronic Converters

Converters are the heart of microgrid structure. Every source and storage unit is interfaced through converters.

Converter	Purpose
DC–DC Boost	PV voltage regulation
AC–DC Rectifier	Wind energy conversion
Bidirectional DC–DC	Battery charging/discharging
Voltage Source Inverter (VSI)	Supply AC power to bus
Multilevel Inverter	Improve power quality

In islanded mode, VSI acts as voltage and frequency source for the microgrid.

2.4. Common AC / DC Bus

All sources and loads are connected to a common bus.

- **AC Bus:** Used in conventional microgrids where loads are AC.
- **DC Bus:** Used in DC microgrids for data centers, EV charging, telecom loads.
- **Hybrid Bus:** Combination of AC and DC buses connected through interlinking converter.

The bus acts as the central point for power exchange.

2.5 Loads

Microgrid supplies different types of loads:

- Residential loads
- Commercial loads
- Critical loads (hospitals, data centers)
- EV charging loads

Loads may be linear or non-linear. Power electronic converters must maintain good power quality for these loads.

2.6 Microgrid Controller (Energy Management System)

This is the brain of microgrid.

Functions include:

- Power flow management
- Control of converters
- Load sharing between sources
- Mode change between grid-connected and islanded
- Monitoring voltage, frequency and state of charge of battery

Controller works at primary, secondary and tertiary levels.

Component	Function
Solar PV	DC power generation
Wind Turbine	Variable AC generation
Battery Storage	Energy backup and balancing
Power Electronic Converters	Interface and control
Loads	Residential/Commercial

Component	Function
Controller	Energy management

3. ROLE OF POWER ELECTRONICS IN MICROGRIDS (ELABORATED)

Power electronics is the key enabling technology that makes microgrid operation possible. Since most distributed energy resources produce variable, DC, or uncontrolled electrical output, converters are necessary to process, control and deliver power in a usable form. In islanded mode, their role becomes even more critical because there is no support from the utility grid for maintaining voltage and frequency. In such case, inverters behave like controlled voltage sources and take full responsibility of system stability.

The major roles of power electronics in microgrids are explained below.

3.1 Integration of Renewable Energy Sources

Renewable sources such as solar PV, wind turbine, and fuel cells cannot be directly connected to the AC microgrid.

- **Solar PV** produces low voltage DC which varies with irradiation. A **DC–DC boost converter** with MPPT is used to extract maximum power and regulate voltage.
- **Wind turbines** produce variable frequency AC. An **AC–DC rectifier** followed by DC link and inverter is required.
- **Fuel cells** also produce DC and need DC–DC conditioning.

Power electronic interfaces make these sources compatible with the microgrid bus and allow controlled power injection.

3.2 Voltage and Frequency Regulation

In islanded operation, there is no stiff grid to maintain rated voltage and frequency. Voltage Source Inverters (VSI) must regulate these parameters.

- Inverters operate using **droop control** or **VSG control** to maintain system frequency.
- Voltage control loop ensures constant RMS voltage at AC bus.
- Fast switching and PWM control helps in quick dynamic response.

Thus, converters act as **virtual generators** in islanded microgrid.

3.3 Power Quality Improvement

Microgrids often supply sensitive and nonlinear loads. Power electronic converters improve power quality by:

- Reducing harmonics using PWM and multilevel inverters
- Maintaining sinusoidal output voltage
- Providing reactive power compensation
- Balancing unbalanced loads

Active filtering capability of inverters reduces THD significantly.

3.4 Power Sharing Among Multiple Sources

In microgrids, several inverters operate in parallel. Proper load sharing is essential.

- Droop control allows proportional sharing of active and reactive power.
- Virtual impedance method reduces circulating current between inverters.
- Secondary control corrects voltage and frequency deviations.

This sharing is achieved without heavy communication, mainly through control algorithms in converters.

3.5 Islanding Detection and Protection

Power electronic converters help in fast islanding detection.

- Monitoring voltage, frequency and rate of change of frequency (ROCOF)
- Active methods like impedance shifting
- Quick disconnection from grid using converter control signals

During faults, converters limit fault current which protects devices but also requires new protection strategies.

3.6 Synchronization with Main Grid

When reconnecting to utility grid, microgrid parameters must match.

- Phase Locked Loop (PLL) in inverter measures grid phase angle.
- Voltage magnitude, frequency and phase are matched before closing PCC breaker.
- Smooth transition is achieved by gradual control of inverter output.

3.7 Bidirectional Power Flow Control

Converters allow bidirectional power flow between storage, sources and loads.

- Battery charging during excess generation
- Discharging during peak load
- Exporting extra power to grid in grid-connected mode

This flexibility is only possible due to power electronic interfaces.

3.8 Fast Dynamic Response

Due to high switching frequency, converters respond quickly to:

- Sudden load changes
- Source fluctuation
- Fault conditions

This fast response improves microgrid stability in islanded condition.

4. CONVERTER TOPOLOGIES USED IN MICROGRIDS (ELABORATED)

Different types of power electronic converters are used in microgrids depending on the nature of source, storage element and load. Since microgrids contain DC sources, AC sources, storage devices and AC/DC loads, multiple conversion stages are required. Proper selection of converter topology improves efficiency, reliability and power quality of the system.

4.1 DC–DC Converters

DC–DC converters are mainly used to interface DC sources like solar PV, fuel cells and batteries with the DC link or DC bus of the microgrid.

• Boost Converter for PV Systems

Solar PV output voltage is low and varies with irradiance. A boost converter is used to:

- Step up PV voltage to required DC link level
- Implement MPPT (Maximum Power Point Tracking)
- Provide regulated DC output

The duty cycle of boost converter is controlled using MPPT algorithms such as Perturb & Observe or Incremental Conductance.

Advantages:

- Simple structure
- High efficiency
- Easy control

• Bidirectional DC–DC Converter for Battery

Battery storage requires charging as well as discharging. Bidirectional converters allow power flow in both directions.

- Operates in **buck mode** during charging
- Operates in **boost mode** during discharging
- Maintains DC bus voltage constant

This converter is very important in islanded operation to balance power.

Common topologies:

- Half bridge bidirectional
- Full bridge bidirectional
- Interleaved bidirectional converter

• Buck–Boost Converter for Voltage Regulation

When input voltage may be higher or lower than required DC bus voltage, buck-boost converter is used.

- Regulates voltage under varying conditions
- Used with fuel cells and supercapacitors
- Provides flexible voltage control

4.2 DC–AC Inverters

Inverters convert DC link voltage into AC supply for AC bus and loads. Voltage Source Inverters (VSI) are most widely used in microgrids.

• Single Phase Inverter

Used in small residential microgrids and low power applications.

- Supplies single phase loads

- Simple control structure
- Suitable for rooftop solar systems

• Three Phase Inverter

Used in commercial and industrial microgrids.

- Supplies three phase AC loads
- Provides balanced three phase output
- Supports higher power rating

These inverters operate using SPWM or SVPWM techniques for better waveform.

• Multilevel Inverter

Used when high power quality and low harmonic distortion is required.

Types include:

- Diode clamped (NPC)
- Flying capacitor
- Cascaded H-bridge

Advantages:

- Low THD
- Reduced filter size
- Better voltage waveform
- Suitable for medium voltage microgrids

4.3 AC–DC Converters

AC–DC converters are used when AC sources or AC loads are part of the microgrid.

• For Wind Energy Systems

Wind generators produce variable frequency AC. AC–DC rectifier is used to convert it into DC.

- Diode bridge rectifier (simple but uncontrolled)
- PWM rectifier (controlled, better power factor)

The DC output is then fed to inverter.

5. INVERTER CONTROL IN ISLANDED MICROGRID

In islanded operation, inverter acts as voltage source. Major control techniques are:

5.1 Droop Control

Most popular technique. It mimics behavior of synchronous generator.

- P–f droop: Active power controls frequency
- Q–V droop: Reactive power controls voltage

Droop equation:

f=f0−kp(P−P0)f = f_0 - k_p (P - P_0)f=f0−kp(P−P0) V=V0−kq(Q−Q0)V = V_0 - k_q (Q - Q_0)V=V0−kq(Q−Q0)

This allows power sharing without communication.

5.2 Virtual Synchronous Generator (VSG)

Inverter is controlled to behave like synchronous generator with inertia. It improves stability and transient response.

5.3 Voltage and Current Control Loops

Inner current loop and outer voltage loop ensures stable output.

6. HIERARCHICAL CONTROL OF MICROGRIDS

Microgrid control is divided into three levels:

Level	Function
Primary	Droop control, local stability
Secondary	Frequency and voltage restoration
Tertiary	Power flow optimization with grid

Primary control is fastest and works without communication.

POWER SHARING IN ISLANDED MODE

Multiple inverters should share load proportionally. Droop control enables this. But line impedance mismatch causes errors.

Solutions:

- Virtual impedance method
- Adaptive droop control

- Communication based secondary control

ENERGY STORAGE INTEGRATION

Battery is important for islanded operation.

Functions:

- Maintain power balance
- Support during load change
- Provide backup

Bidirectional DC–DC converters are used to charge and discharge battery.

POWER QUALITY ISSUES

Microgrids face problems like:

- Voltage harmonics
- Frequency fluctuation
- Unbalanced loads

Multilevel inverters and PWM techniques are used to reduce harmonics.

PROTECTION IN ISLANDED MICROGRIDS

Conventional protection fails due to low fault current. Power electronic converters limit current.

New protection methods:

- Differential protection
- Communication based protection
- Adaptive relays

ISLANDING DETECTION METHODS

Two types:

- Passive methods (voltage, frequency monitoring)
- Active methods (impedance measurement)

Fast detection is necessary to switch control mode.

SYNCHRONIZATION WITH GRID

Before reconnection, microgrid voltage, phase and frequency must match grid.

Phase Locked Loop (PLL) is used for synchronization.

CHALLENGES IN ISLANDED MICROGRID OPERATION

- Stability issues due to inverter dynamics
- Power sharing errors
- Communication delays
- Protection difficulty
- Control complexity

FUTURE TRENDS

- AI based energy management
- Smart inverters with communication
- DC microgrids
- Solid state transformers in microgrids

ILLUSTRATIVE FIGURE

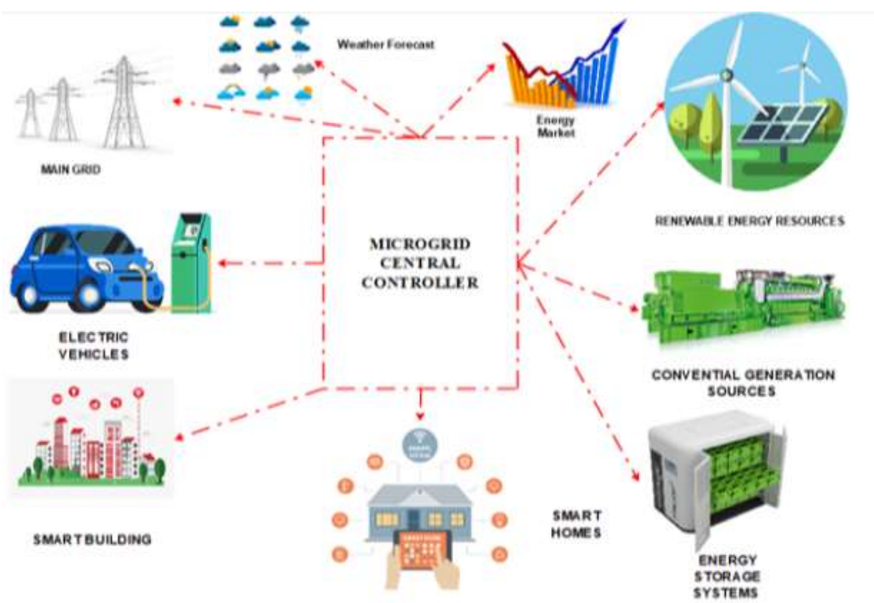

Figure 1: Basic structure of islanded microgrid

COMPARISON OF CONTROL TECHNIQUES

Technique	Communication	Stability	Complexity
Droop	No	Moderate	Low
VSG	No	High	Medium
Hierarchical	Yes	Very High	High

CONCLUSION

Power electronics is backbone of microgrid and specially important during islanded operation. Converters not only transfer energy but also control voltage, frequency and power sharing. Techniques like droop control and VSG makes inverter behave like synchronous machine. However, challenges like protection, stability and control coordination still exists. With advancement in smart converters and control algorithms, microgrids will become more reliable and efficient in future.

REFERENCES

1. R. Lasseter, “Microgrids,” IEEE Power Engineering Society, 2002.
2. J. Guerrero et al., “Hierarchical control of droop-controlled AC microgrids,” IEEE Trans. Industrial Electronics, 2011.
3. N. Pogaku, M. Prodanovic, T. Green, “Modeling and analysis of droop controlled inverters,” IEEE Trans. Power Electronics, 2007.
4. J. M. Guerrero, “Virtual synchronous generator control,” IEEE IECON, 2014.
5. H. Bevrani, “Microgrid dynamics and control,” Wiley, 2017.
6. Y. Li, D. Vilathgamuwa, “Control of inverter in islanded microgrid,” IEEE Trans. Power Delivery, 2008.
7. T. Dragicevic, “Advanced control of microgrids,” IEEE Trans. Smart Grid, 2016.
8. M. Chandorkar, “Control of parallel inverters in standalone AC supply,” IEEE Trans. Industry Applications, 1993.
9. S. Chowdhury, “Microgrids and active distribution networks,” IET, 2009.
10. A. Tuladhar, “Parallel operation of inverters in microgrid,” IEEE APEC, 1997.

