energies

MDPI

Review

Frequency and Voltage Control Techniques through Inverter-Interfaced Distributed Energy Resources in Microgrids: A Review

Yousef Asadi [1], Mohsen Eskandari [2,*], Milad Mansouri [1], Andrey V. Savkin [2,*] and Erum Pathan [3]

[1] Department of Electrical Engineering, Bu-Ali Sina University, Hamedan 6516863611, Iran
[2] School of Electrical Engineering and Telecommunication, University of New South Wales, Sydney 2052, Australia
[3] Electronics Engineering Department, Quaid-e-Awam University of Engineering, Science and Technology, Nawabshah 67450, Pakistan
* Correspondence: m.eskandari@unsw.edu.au (M.E.); a.savkin@unsw.edu.au (A.V.S.)

Abstract: Microgrids (MG) are small-scale electric grids with local voltage control and power management systems to facilitate the high penetration and grid integration of renewable energy resources (RES). The distributed generation units (DGs), including RESs, are connected to (micro) grids through power electronics-based inverters. Therefore, new paradigms are required for voltage and frequency regulation by inverter-interfaced DGs (IIDGs). Notably, employing effective voltage and frequency regulation methods for establishing power-sharing among parallel inverters in MGs is the most critical issue. This paper provides a comprehensive study, comparison, and classification of control methods including communication-based, decentralized, and construction and compensation control techniques. The development of inverter-dominated MGs has caused limitations in employing classical control techniques due to their defective performance in handling non-linear models of IIDGs. To this end, this article reviews and illustrates advanced controllers that can deal with the challenges that are created due to the uncertain and arbitrary impedance characteristics of IIDGs in dynamics/transients.

Keywords: AC microgrids; advanced controllers; autonomous operation; frequency control; impedance shaping; inverter-interfaced distributed generation; power-sharing

check for updates

Citation: Asadi, Y.; Eskandari, M.; Mansouri, M.; Savkin, A.V.; Pathan, E. Frequency and Voltage Control Techniques through Inverter-Interfaced Distributed Energy Resources in Microgrids: A Review. *Energies* **2022**, *15*, 8580. https://doi.org/10.3390/en15228580

Academic Editors: José Matas and Tek Tjing Lie

Received: 20 September 2022
Accepted: 15 November 2022
Published: 16 November 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction

Electric power generation in conventional power systems includes serious issues such as high energy losses in power generation and transmission, high generation costs, carbon emissions, environmental concerns, and high investment costs for grid expansion [1]. Thus, distributed generation units (DGs) that include renewable energy resources (RES) (photovoltaics, wind turbines, hydrogen) are suitable alternatives and promising solutions for overcoming the stated challenges [2]. To make the DGs' operation compatible with the grid and maximize the benefits of DGs integration in productivity, the economy, energy efficiency, and the environment, researchers have considered the concept of microgrids (MG) [3]. An MG is a small-scale local grid capable of operating in both a grid-connected mode and islanded mode (isolated from the grid) and is capable of managing the transitions between these two modes.

The main characteristic of the MG is the capability for autonomous operation in the islanded mode, which improves the reliability of the local grid and can increase the resiliency of the power system [4,5]. The main variables utilized to control the performance of an MG are the voltage, frequency, and active and reactive power [6,7]. In the connected mode, the grid imposes the voltage and frequency, and the MG supplies the power deficit from the grid and trades the excess power generated in the MG with the grid [8]. In the islanded mode, the lack of access to the (stiff) grid has led the MG to perform autonomous voltage and frequency control [9]; moreover, power-sharing among DG units (for load tracking) should be implemented to maintain the production–consumption balance [10].

The frequency and voltage should be set autonomously in the islanded MG; however, power electronics-based inverters that interface DG units to the (micro) grid are used, which requires new paradigms in voltage and frequency regulations [11]. Notably, employing effective voltage and frequency regulation methods for establishing power-sharing among parallel grid-forming (GFM) inverters is the most important problem. Since there is a compromise between voltage/frequency regulation and power-sharing that imposes power quality issues and stability challenges, it is vital to ensure the MG's dynamic stability and the desired performance while realizing power-sharing through voltage/frequency regulation.

Therefore, the control architecture of an MG is implemented based on hierarchical control, including the primary, secondary, and tertiary levels [12–16]. Energy management is executed at the highest level, i.e., tertiary control, according to different power generation technologies and power ratings for minimizing operation costs with maximum efficiency and high reliability [17,18]. Furthermore, at the tertiary level, optimal setpoints are determined depending on the needs of the host power system grid (e.g., for voltage support, frequency regulation, etc.) [19,20], and this control level is responsible for coordinating the operation of multiple microgrids that interact with each other in the system [21–23]. The lowest level of hierarchical control is the primary control [24,25]. Primary control is responsible for controlling the critical variables of the MG (voltage and frequency), and power-sharing as well as power injection [26–29]. The secondary controller is responsible for power quality and compensates for the voltage and frequency deviations caused by the primary control by restoring their values to nominal values while preserving the power-sharing accuracy [30–33].

The main focus of this article is on the primary control level, which provides various control methods for voltage and frequency regulation/control and power-sharing. The review of control techniques is based on their dependence on the communication link and is divided into two categories: communication-based and decentralized methods without communication links [34–36]. In this review, various types of conventional classical control methods based on communication links, without communication links, and also construction and compensation-based techniques are explained, and the advantages/disadvantages of these methods are clarified.

The power system components, such as generators and transmission lines, are modelled by their equivalent impedances, which are used for system and stability analysis. The impedance characteristics of the inverters are also used for modelling, analysis, and design; however, in inverter-dominated MGs, the impedance characteristics of the GFM and grid-feeding (GFD) converters arbitrarily change due to disturbances and are uncertain in transients, e.g., in current limiting and fault ride-through (FRT) transients. Therefore, large disturbances created in the MG cannot be accurately modelled and, in general, the mathematical model for power electronics is highly non-linear and uncertain due to the fast operation and very small time scale. Therefore, using classical controllers in the context of inaccurate models of inverter-dominated MGs would not be effective, and advanced (non-linear) methods are needed for impedance shaping or to deal with uncertainties associated with modelling. This motivated us to review and add some advanced control techniques that can be used in inverter-based MGs. The classification of the control strategies for the inverter-based MGs is illustrated in Figure 1.

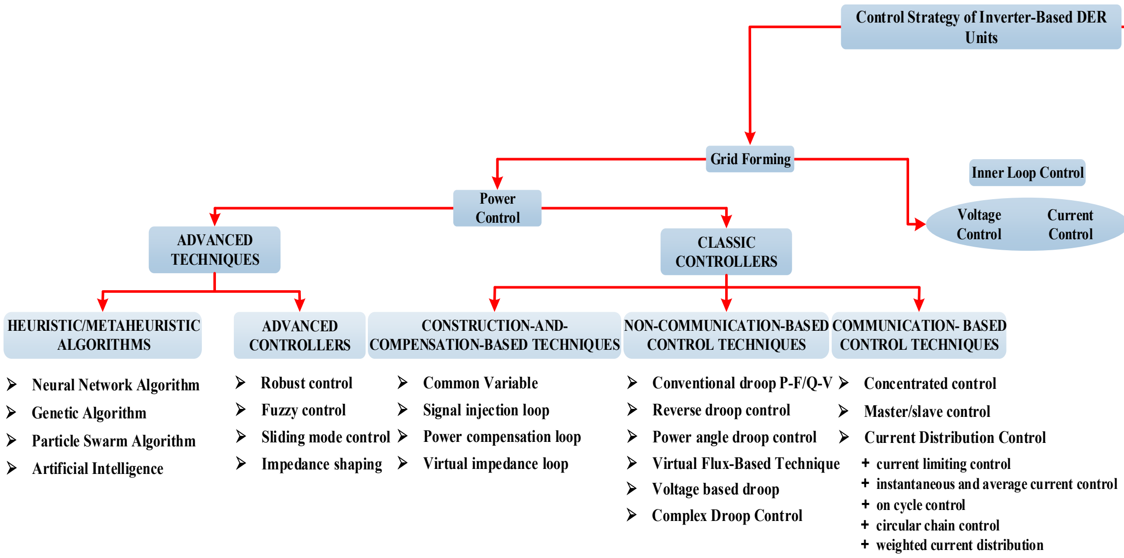


Figure 1. Classification of control techniques for parallel inverters.

The remainder of the paper is summarized as follows. Section 2 presents a brief discussion of communication-based control strategies for the parallel inverter. Control strategies based on non-communication, i.e., droop control, are described in Section 3. Construction and compensation control techniques are presented in Section 4 to cover the shortcomings of the droop-based controllers. Section 5 discusses advanced control techniques that can deal with the uncertainties and non-linearities of IIDGs in dynamics/transients. Section 6 discusses future trends related to MGs. Finally, Section 7 concludes the paper.

2. Communication-Based Control Strategies for Parallel Inverters

The communication-based control methods require a power management platform or supervisory control and data acquisition (SCADA) operation. These control methods are employed to provide power-sharing and voltage control, and their main advantage is eliminating the requirement for a secondary controller. The supervisory control receives information from all inverters and tries to maintain a balance in power-sharing between the inverters. In this regard, several different control techniques based on communication methods, such as the concentrate control method [33,37–39], master–slave control method [40–43], and current distribution control method [44–46], are discussed in the following subsections.

2.1. Concentrated Control

This control scheme cannot operate without a centralized controller to acquire the synchronization signals, as shown in Figure 2. The load current can be shared when the phase-locked loop (PLL) is used to ensure synchronization between the grid-feeding (GFD) voltage source converter and the grid [33]. This reference current needs to be assigned to all parallel-connected inverters by a high bandwidth communication link (HBWCL).

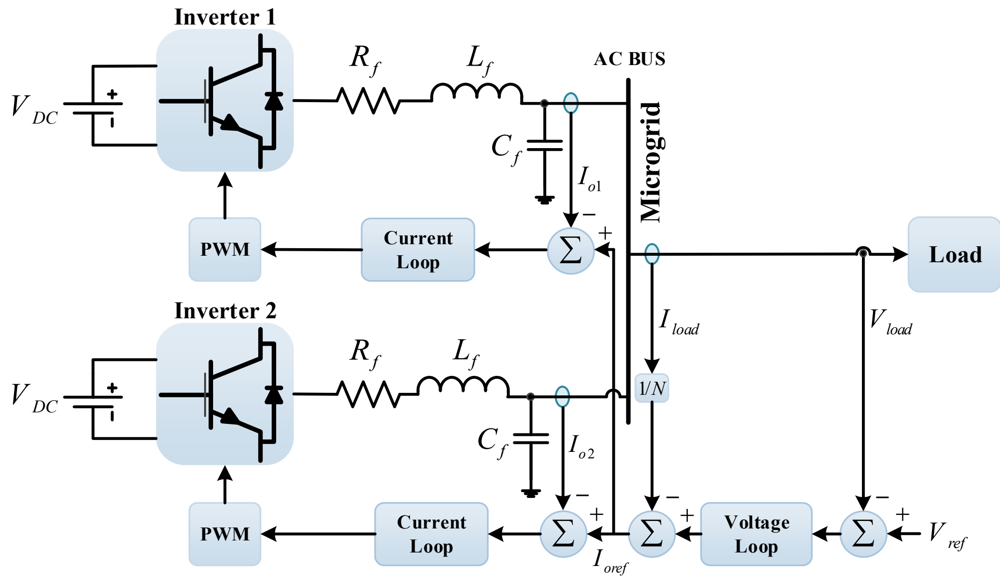


Figure 2. Control schematic of the concentrated/centralized communication-based control [33].

In [15,22,35,47–50], a communication-based control technique is presented so that the current sharing in the transient and steady state can be maintained using this technique; however, the centralized current controller cannot manage harmonics and prevent circulating currents among parallel inverters. To address this problem, high bandwidth communication is necessary; while it reduces reliability and expandability, it provides stable power-sharing in transient and sustained modes and constant voltage and frequency regulation [30,51].

2.2. Master–Slave Method

In the master–slave control strategy, one inverter acts as a master and the remaining inverters act as slaves. The master–slave control strategy diagram is illustrated in Figure 3. As suggested in [21,41,52], this technique is mainly based on the oscillating master/dedicated master. In the dedicated master, one inverter works in the voltage control mode and other inverters run in the current control mode. The master unit specifies the reference current for the slave units so that the slave unit follows the reference current. Yet, if the dedicated master suffers a single point of failure, it will significantly affect the stability of the whole system. In [21], the master oscillating technique is suggested to overcome this weakness. The master depends on the maximum inverter active power flow. This proposed technique improves reliability and increases the power-sharing accuracy, but it may lead to synchronization errors [53].

2.3. Current Distribution Control

Communication-based current distribution control strategies are employed to accomplish voltage regulation and power-sharing among parallel inverters, where power quality is a concern [16,49,54]. These techniques do not require a central control unit while keeping the output voltage amplitude and frequency close to the nominal values [35]. Hence, these control strategies can limit system reliability, flexibility, and scalability, as well as increase system costs due to the expensive and vulnerable communication link [33]. This technique can be further classified as depicted in Figure 4. It can be categorized into current limiting, average current sharing, circular chain control instantaneous current control, one cycle control, and weighted current distribution control techniques.

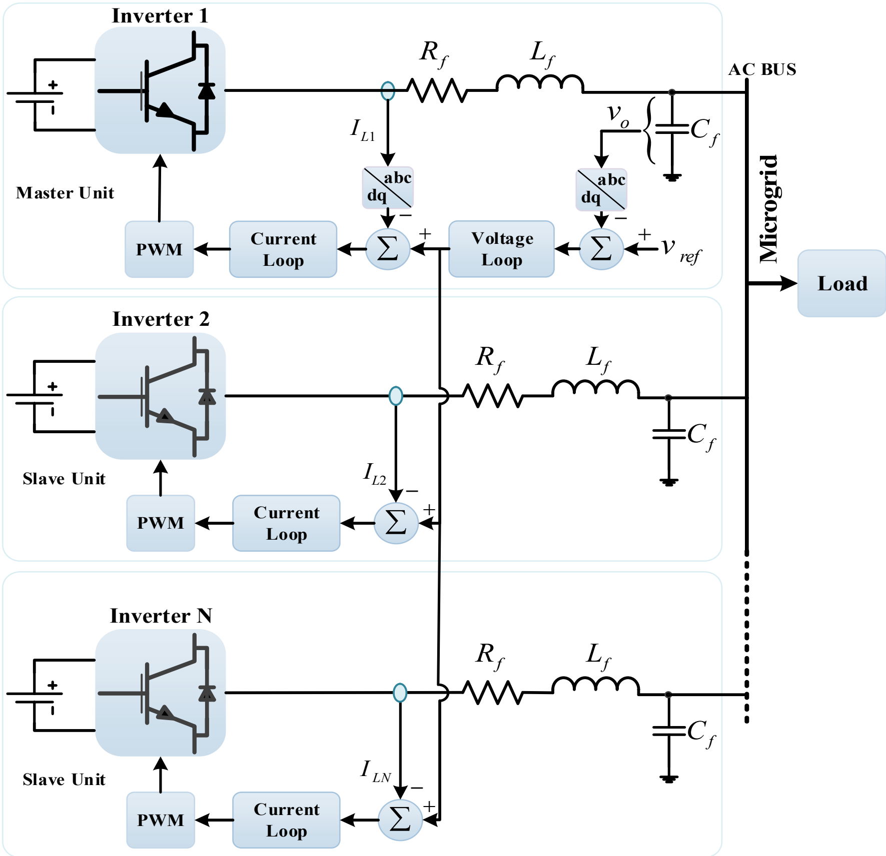


Figure 3. The control structure of the master–slave control [33].

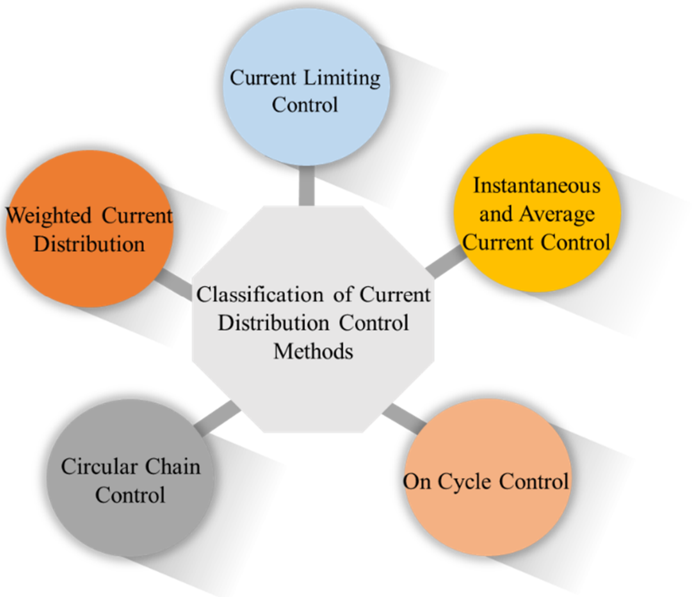


Figure 4. Classification of the communication-based current distribution control strategy.

(1) The current limiting control is designed to reduce harmonics and avoid power quality issues while limiting the output current of the inverter. Novel current-limiting control techniques are suggested to improve power quality and reduce harmonic current [55,56].

(2) The average and instantaneous current control techniques are based on inter-unit communication, in contrast to the master–slave control method. This technique

requires reference synchronization for the voltage and current at the point of common coupling (PCC) to have better current sharing and voltage regulation. Figure 5 shows the structure of this control method. Yet, this technique reduces the flexibility and reliability of the system [16].

(3) The one-cycle control method combines a vector and bipolar operation with an extra simple communication link among the parallel inverters. Thus, the circulating current among parallel inverters can be reduced. This control technique has advantages, such as constant switching frequency, no reference calculation, simple system wiring, and lack of need for multipliers, while providing more flexibility [4,57].

(4) The circular chain control method, which is also known as the 3C method, is illustrated in Figure 6. In this technique, each unit is connected in a circular configuration that uses internal current control to track the inductor current of consecutive parallel inverter units for achieving equal current distribution among the parallel inverters [31,44].

(5) The weighting current distribution control technique has been proposed to achieve current sharing among inverters with different power ratings. It gets a weighted output current by simply adding a simple circuit for each inverter. In this technique, each inverter has current and voltage controllers for a fast dynamic response, stability, and an improved weighted current controller for achieving current sharing among the inverters [45,58].

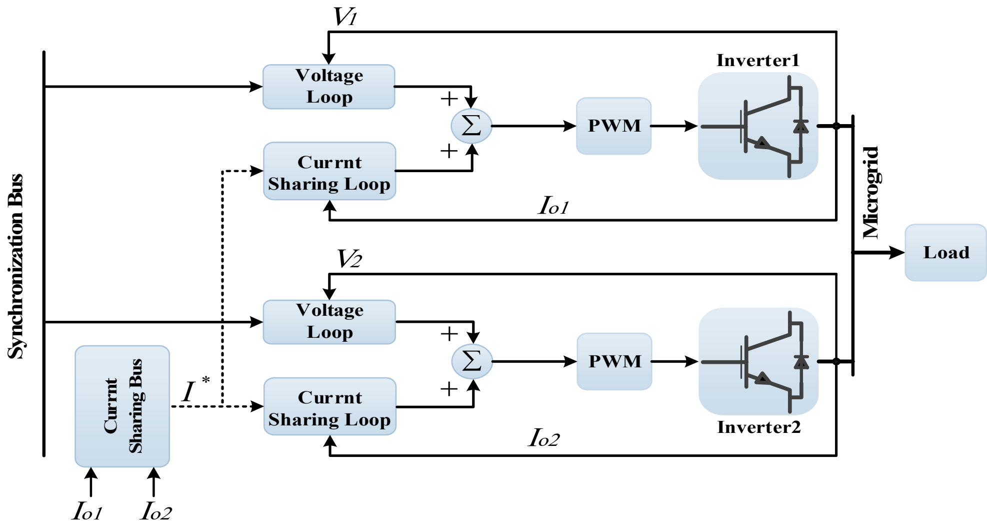


Figure 5. Average and instantaneous current control [35].

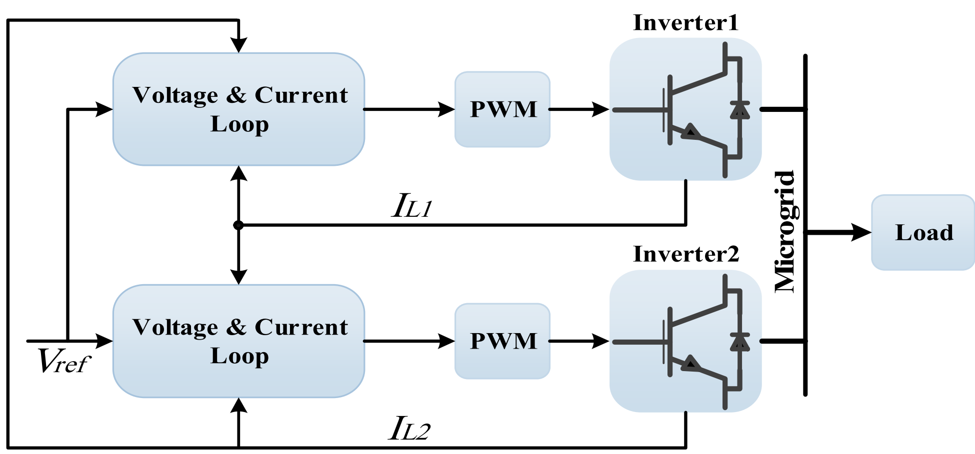


Figure 6. Circular chain communication-based control strategy [44].

2.4. Summary of Communication-Based Control Strategies

The merits and demerits of communication-based parallel inverter control techniques are summarized in Table 1.

Table 1. The merits and demerits of communication-based parallel inverter control techniques.

Control Techniques	Merits	Demerits
Concentrated control	• Simple control mechanism. • voltage and frequency regulation • power-sharing in transient and steady-state modes.	• High bandwidth links are required. • Slow response • Low reliability and expendability
Master–slave control	• Output voltage recovery is simple • Power-sharing in steady-state • Reduce system failure chances because of slave inverters.	• During transient, high overshoot • High bandwidth is required • Less redundancy • The efficiency of the technique is only in close communication between DGs. • Dependence of the system on the master unit.
Current Distribution Control	• Symmetrical for each unit • Constant voltage and frequency	• Individual control is required for each inverter • Communication is required • Low modularity • Tracking mechanism error

3. Non-Communication-Based Control Strategies for IIDGs in Autonomous MGs

The decentralized control techniques used for GFM voltage source inverters are based on the conventional droop control technique known as wireless methods [59]. The droop-based GFM inverters are responsible for regulating the fundamental variables of MGs (i.e., voltage and frequency) and controlling the output power of IIDGs. The classification of droop-based control methods is shown in Figure 1. In this section, each of these methods is explained in detail.

3.1. $f - P$ and $V - Q$ Droop Controllers

The conventional droop method originates from the principle of the (physical) power balance in synchronous generators in bulk power systems. The imbalance between the prim over mechanical power to the generator and the electromagnetic field (due to output active power) causes a change in the rotor speed, which appears as frequency deviations. Similarly, a change in the output reactive power leads to a change in the voltage magnitude. The frequency–power droop control method is inherent to the operation of conventional DG units, such as synchronous generators, and it can be artificially created for IIDGs.

According to Figure 7, the relationship between frequency−active power and voltage−reactive power can be extracted as follows. The power flow from the inverter to the grid can be mathematically modeled as the following equations [35].

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \frac{E}{Z}\left(\begin{bmatrix} E & 0 \\ 0 & E \end{bmatrix} - \psi(\delta)\begin{bmatrix} V & 0 \\ 0 & V \end{bmatrix}\right)\begin{bmatrix} \cos(\theta) \\ \sin(\theta) \end{bmatrix} \quad (1)$$

where

$$\psi(\delta_{ij}) = \begin{bmatrix} \cos(\delta) & -\sin(\delta) \\ \sin(\delta) & \cos(\delta) \end{bmatrix}; \quad (2)$$

where Z and θ represent the line impedance and phase angle; E and δ are the inverter's output voltage and phase angle; P and Q are the active and reactive power; and V is the AC bus voltage, respectively.

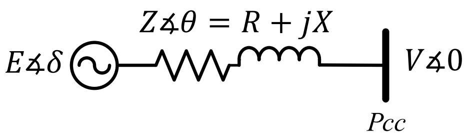


Figure 7. Equivalent circuit of a DG unit connected to the common AC bus.

In medium and high-voltage grids, Z is dominantly inductive, so the resistive part of Equations (1) and (2) can be neglected. Therefore, δ gives a small phase difference between E and V ($\sin\delta \approx \delta$ & $\cos\delta \approx 1$) [60] and thus Equations (1) and (2) can be rewritten as

$$P \approx \frac{EV\delta}{X} \quad (3)$$

$$Q \approx \frac{E(E-V)}{X} \quad (4)$$

According to Equations (3) and (4), the active power can be controlled by the frequency (as the frequency variation dynamically controls the power angle), and the reactive power is controlled by regulating the voltage magnitude, as shown in Figure 8 [61]. Therefore, in droop-based MGs, the active and reactive power of IIDGs can be controlled by adjusting the droop coefficients [62–64]. Consequently, the voltage and frequency droop control for medium and high-voltage grids can be defined according to Equations (5) and (6) [65].

$$f = f_{nom} - m_p P \quad (5)$$

$$V = V_{nom} - n_q Q \quad (6)$$

where, $V_{nom}, f_{nom}, P_{max}, Q_{max}, P, Q, m_p, n_q$ are the nominal voltage, nominal frequency, nominal active power, nominal reactive power, average active power, and average reactive power—which is the $f-P$ and $V-Q$ droop coefficients—respectively. Equations (5) and (6) can be displayed by drawing the line slope diagram in Figure 8.

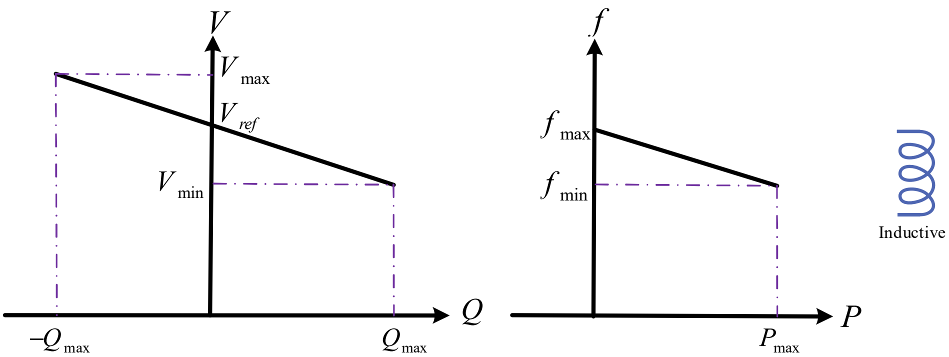


Figure 8. The principle of voltage–reactive power ($V-Q$) and frequency–active power ($f-P$) droop control [63].

The active and reactive droop characteristic values must be obtained with high accuracy because the stability of the system depends on them [66].

$$m_p = \frac{f_{max} - f_{min}}{P_{max}} \quad (7)$$

$$n_q = \frac{V_{max} - V_{min}}{2Q_{max}} \tag{8}$$

Remark 1. The $f - P$ droop reveals an acceptable performance in terms of power-sharing accuracy and dynamic response (even in grids with a low X/R ratio where the grid impedance is not purely inductive) since the sensitivity of the power-to-phase angle is very high (proportional to V^2/Z) [67]; however, the problem is with the reactive power-sharing via the $V - Q$ droop, as the voltage is not a global variable and changes over the power network. Furthermore, the cross-coupling between two $f - P$ and $V - Q$ is high when the $X/R \approx 1$, which may make the system unstable if the grid impedance is relatively low regarding the power rating of the IIDGs.

3.2. Reverse Droop Control

The conventional droop controller is mainly suitable for high-voltage grids based on pure inductive line impedances. Given this, for low-voltage distribution grids, where the line impedance is dominantly resistive, the conventional droop is not effective. Thus, the reverse droop control technique is used based on pure resistive line impedance at low-voltage distribution grids. Therefore, the active power is controlled by a voltage magnitude, whereas the reactive power is controlled with the phase angle or frequency [68]. Hence, for the low-voltage grids when the inductance is negligible and the line impedance is entirely resistive, bringing Equations (1) and (2) into consideration $(\sin\delta \approx \delta \text{ \& } \cos\delta \approx 1)$ yields:

$$V = V_{nom} - n_p P \tag{9}$$

$$f = f_{nom} + m_q Q \tag{10}$$

Equations (9) and (10) can be displayed as the slope of the line in Figure 9.

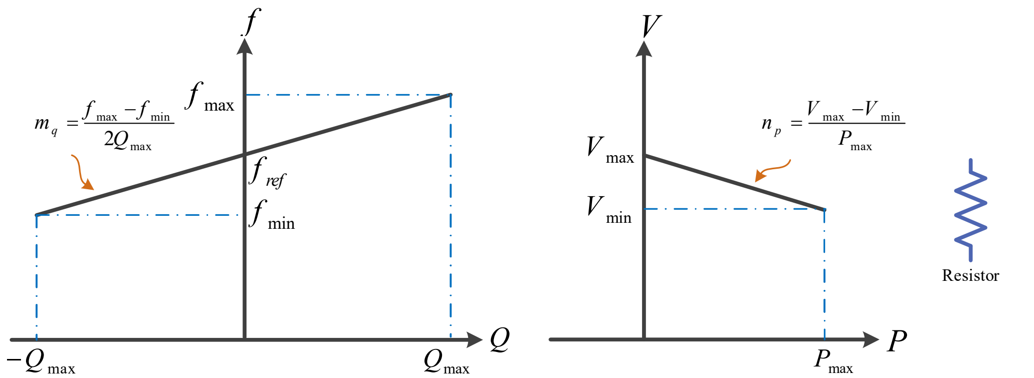


Figure 9. The principle of frequency–reactive power ($f - Q$) and voltage–active power ($V - P$) droop control [63].

Remark 2. The problem with the $V - P$ droop control is that the sensitivity of the power to the voltage difference at the grid is not high (proportional to the voltage magnitude), and thus it reveals a very poor dynamic response; moreover, the voltage is a local variable that is against the accurate active power-sharing in the resistive grids. These two issues are critical for IIDGs to avoid reaching overload/current conditions. Therefore, the inverse droop has not been a popular solution and the power system community prefers to use the conventional $f - P$ and $V - Q$ droops by addressing their shortcomings (i.e., stability concerns in low-voltage grids with low X/R ratio and inaccurate reactive power-sharing). Impedance shaping is the most promising solution, which is discussed in this paper in the advanced controller section.

The simplicity of the droop method is the main advantage, where communication isn't necessary among IIDGs. Therefore, high flexibility, plug-and-play, modularity, and reliability can be guaranteed, however, there are challenges for researchers. These challenges include the lack of proper harmonic current sharing, performance dependency on grid impedance, poor power quality due to voltage/frequency deviations, and the problem of circulating a reactive current among IIDGs, voltage regulation, and reactive power-sharing [69,70]. In complementing and overcoming the disadvantages of the conventional/reverse droop method, improved droop methods are discussed in detail in the next section.

3.3. Modified Droop Control

To solve the shortcomings of conventional droop and inverse droop control mentioned in Sections 3.1 and 3.2, modified droop control is introduced, which can be categorized as follows.

- Power angle droop control
- Virtual flux-based technique
- Voltage-based technique
- Complex droop control technique

3.3.1. Power Angle Droop Control

This technique shares stable power among inverters without frequency excursions [71]. Nevertheless, stability conditions under variable loads have not been studied. In [72], high gain angle droop control ensures proper load sharing, especially in weak system conditions; however, it harms the overall stability of the system. The angle droop control technique has been investigated in detail in [61], namely angle droop without communication to power-sharing between IIDGs, and secondly, angle droop control with minimum communication for enabling the feedback controller to establish economic power-sharing, considering a resistive power grid; however, the angle droop method needs an accurate time frame, e.g., GPS, for synchronization of the inverters, which is the major drawback.

3.3.2. Virtual Flux-Based Technique

Researchers have proposed a novel modified control strategy in [73] and [74] that will act based on the direct virtual flux droop method. The active power, phase angle, and reactive power are proportional to the flux for increasing the controller's ability. Figure 10 shows the expressed control scheme, in which by controlling the flux amplitude and phase angle (instead of the output voltage of the inverter), the appropriate power-sharing can be achieved. Consequently, this control technique is simple and more effective and does not require pulse width modulation modulators and multi-closed loops; however, the fault ride-through of the inverter is questionable and it is not clear how current limiting is implemented.

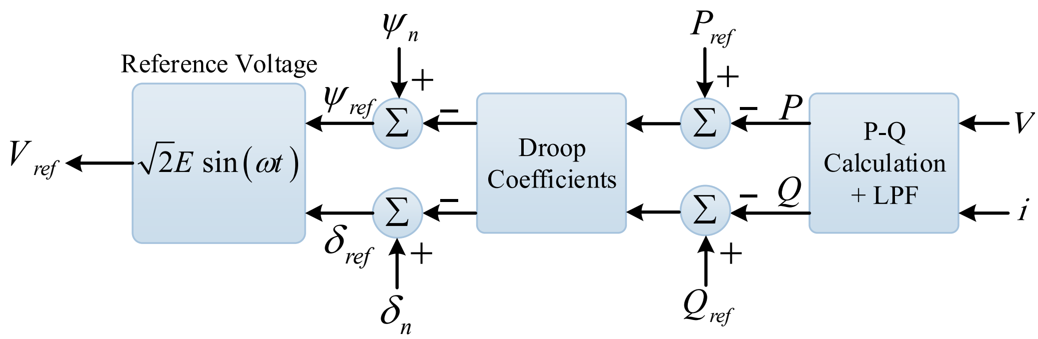


Figure 10. Virtual flux-based modified droop technique [74].

3.3.3. Current and DC Voltage-Based Droop

MG performance and stability are mainly based on power control strategies; however, the power control techniques have a slow dynamic response and stability issues. Given this, the VI-based droop characteristics have been proposed in [75,76], wherein this strategy can provide a fast dynamic response and improve system stability under load variation;

however, this strategy is valid for small-size inverters with a limited current capacity, mainly because the voltage is not a global variable [77,78]. The researchers in [79] have proposed voltage-based droop control techniques, as shown in Figure 11. The $P - V$ droop is categorized into two control loops, namely the droop control loop V_g-V_{dc} and P-V_g droop and a constant power band control loop. Firstly, power needs to be balanced between the generated power or input DC source, and absorbed power at the AC grid side can be balanced by using the V_g/V_{dc} droop control loop of the GFM voltage source inverter. AC power changes are based on the V_{dc} (DC link) voltage changes of power sources.

$$V_g = V_{g,nom} + n(V_{dc} - V_{dc,nom}) \tag{11}$$

As for the inverter, the DC side power converter nominal voltage and the grid power converter nominal voltage are $V_{dc,nom}$ and $V_{g,nom}$, respectively, with $n > 0$.

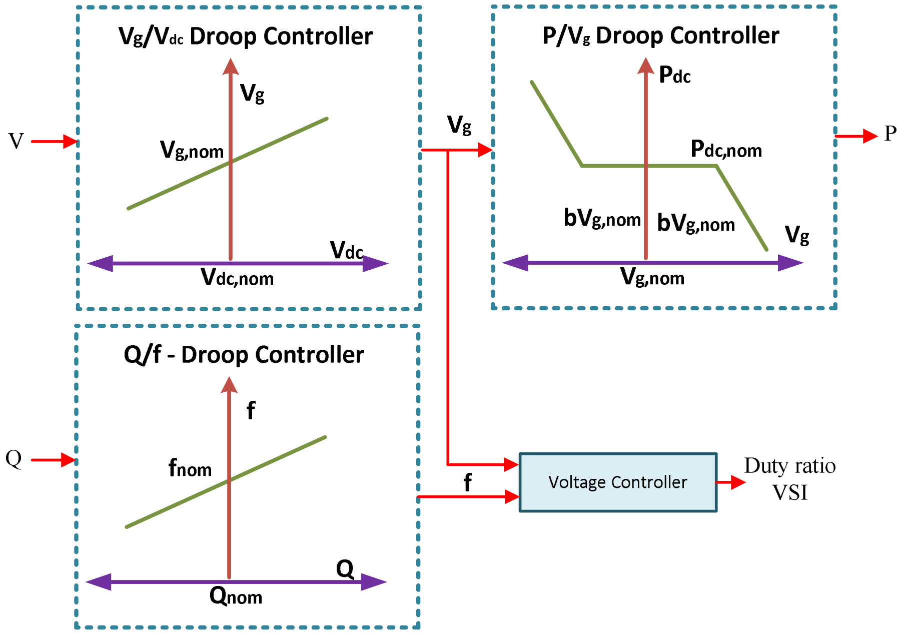


Figure 11. Voltage-based droop controller with a constant power band [78].

Secondly, the $P - V_g$ droop with a constant power band is used to limit the significant deviation of the AC voltage [35,76].

$$P_{dc} = \begin{cases} P_{dc,nom} - K_p\big(V_g - (1+b)\big)V_{g,nom} & if\ V_g \succ (1+b)V_{g,nom} \\ P_{dc,nom} & if\ (1-b)V_{g,nom} \prec V_g \prec (1+b)V_{g,nom} \\ P_{dc,nom} - K_p\big(V_g - (1-b)\big)V_{g,nom} & if\ V \prec (1-b)V_{g,nom} \end{cases} \tag{12}$$

where K_p, $P_{dc,\ nom}$, and b are the power droop gain, rated active power of the converter, and width of the band, respectively. The width of the band is mainly based on the nature of the renewable energy sources. This droop technique adjusts the output power of the IIDG unit [80]. The constant power band relies on the characteristics of the generator to avoid frequent changes in the power of given IIDGs.

3.3.4. Complex Droop Control

In distribution grids that contain feeders with a complex impedance, neither the resistance nor the reactance of the line can be neglected relative to each other. In some cases, the line resistance may be equal to or even greater than the line reactance, creating a feeder system with a low X/R ratio. Compared with the L-type or R-type droop, the RL-type droop inherently considers the coupling between the active power and reactive power; however, the power decoupling performance under complex impedances is more difficult [81].

Therefore, the inverters are seen as RL-type inverters, and Equations (1) and (2), which describe the complex network, are rewritten as follows

$$f - f_{ref} = -K_p \frac{X}{R^2 + X^2}\left(P - P_{ref}\right) + \frac{R}{R^2 + X^2} K_p \left(Q - Q_{ref}\right) \quad (13)$$

$$V - V_{ref} = -K_q \frac{R}{R^2 + X^2}\left(P - P_{ref}\right) - K_q \frac{X}{R^2 + X^2}\left(Q - Q_{ref}\right) \quad (14)$$

With small changes in the power angle and voltage magnitude in this control technique, imbalance and instability occurs. The control technique in [82] has been presented and can simplify the equations for active and reactive power coupled with complex impedance and provide an acceptable dynamic performance in low-voltage MGs when $\frac{X}{R} \approx 1$. In this case, the droop functions can be expressed as

$$f = f_{ref} - K_p(P - Q) \quad (15)$$

$$V = V_{ref} - K_q(P - Q) \quad (16)$$

Instability and overcurrent due to large circulating transient currents originate from the oscillatory behavior and the phase angle shift among the inverters. To overcome this challenge, the authors in [83,84] presented the droop/gain control technique by adding integral terms and derivatives at the low-voltage distributed droop controller, which resulted in achieving the desired dynamic response. The equations for this control technique are given in Equations (17) and (18).

$$V = V_{ref} + K_p\left(P - P_{ref}\right) + K_{pd}\frac{dP}{dt} \quad (17)$$

$$f = f_{ref} + K_q\left(Q - Q_{ref}\right) + K_{qd}\frac{dQ}{dt} \quad (18)$$

However, this is only suitable for low-voltage MGs. If the distance between the inverters increases, then the characteristics of the line impedance have to be changed from a low- to medium voltage distributed grid, while the current peak could appear due to the initial phase error [79].

3.4. Summary of Decentralized Droop-Based Control Techniques

A comparison between conventional and modified droop controllers is given in Table 2, and the merits and demerits of the modified droop control techniques are briefly mentioned in Table 3.

Table 2. Comparison between conventional and modified droop controller.

Configuration	Flexibility	Harmonic Current Sharing	Line Impedance	Dynamic Response	Integration to Renewable Technology	Reactive Power-Sharing
Conventional droop	High	Poor	Affect the performance	Slow	Poor	Good
Modified droop	Low	Good	Overcome by virtual impedance	Fast	Good	Better

Table 3. Merits and demerits of non-communication-based droop control techniques for parallel inverter.

Concept	Merits	Demerits	Authors
Conventional Power-sharing Techniques			
$f - P$ & $V - Q$	Easy implementation (plug-play) communication less high reliability	Proper power-sharing, voltage and frequency regulation aren't provided, physical parameters of the system also affected system performance harmonic load sharing, as well as the slow dynamic response	[2,85,86]
Reverse power-sharing droop			
$V - P$ & $f - Q$	Non-communication easy to implement (plug-and-play), high reliability for the resistive line.	Limitation: low-voltage grid Do not utilize maximum RES Do not provide Q sharing	[78,87]
Modified power-sharing droop			
Angle power-sharing droop with supplementary loop	Constant frequency regulation	Poor Q power-sharing and communication (GPS) singles are required	[61,71,72]
Derivative with virtual impedance and conventional power-sharing control Virtual impedance with power transformation frame and conventional sharing.	Minimizing transient time accurate power-sharing Dynamic performance is acceptable and active/reactive power control is also not coupled.	Not easy to proper selection to gain of a filter and the derivative term For all DGs: Not easy the selection of same transformation angle	[60,88,89]
Adaptive power-sharing droop with derivative Adaptive power-sharing controller with optimization and algorithm Bifurcation theory and Kura moto Oscillator non-linear model and fuzzy adaptive	suppress circulating current reduced frequency fluctuation and improve transient. System stability and power-sharing are ameliorated. Improve frequency and voltage. stable in certain case	Virtual reactance is necessary, which is based on the internal voltage controller bandwidth for minimizing the circulating current. Therefore, the controlling of output impedance voltage, and the angle is hard, do not have significant improvement and complex control strategy. Complex, applied in limited cases, no hardware implementation, power-sharing. Not easy to implement in multiple DGs	[84,90–96]
Frequency signal-injection droop	Suitable for linear and non-linear loads	Voltage controller cannot control the harmonic problem and not easy to implement	[23,97–99]
Voltage-based droop	Ideal control for MGs with low voltage levels that are purely resistive, and for power balancing.	Difficulty in practical implementation Voltage varies during load changes	[76,100]
Virtual flux control	Simple and ameliorate the frequency loop	The dynamic response is not fast	[73,74]
V/I droop control	The dynamic response is improved, suitable for small DGs and PQ sharing is also desired.	Not suitable for the heavy load. Small droop gain create oscillation.	[75,101]
Hierarchical power-sharing droop control with multilayer controller	Voltage, frequency deviation and power-sharing performance better.	Communication is required	[85,102,103]

4. Construction and Compensation Droop Control Method

Modifying some of the droop-based control techniques and taking into account more limitations has led to the creation of construction and compensation droop control techniques, which are among the most effective solutions for IIDGs at the MG level. The classification of the control structure is shown in Figure 1. In this section, the details of each method are explained.

4.1. Common Variable

To achieve accurate sharing of active and reactive power among parallel inverters, a common variable-based compensation droop technique is used. This technique works in a short-distance inverter-grid connection. In [104–106], a reactive power-sharing scheme is presented, which considers the controller to adjust the common load bus voltage, and the equation for this strategy is represented in Equation (19).

$$V_i = K_q \int \left(V_{ref} - V_{com} \right) dt \tag{19}$$

where V_i is the voltage magnitude of the inverter as the control input, K_q is the integral gain, V_{ref} is the reference signal, and V_{com} is the common load voltage magnitude at the input. The control input is generated by an integral controller that will regulate the common load voltage to track a reference signal voltage, where the reference signal gives,

$$V_{ref} = V^* - D_Q Q_i \tag{20}$$

where V^* is the linear function of a local reference signal and reactive power output, Q_i. The steady-state gain is the reciprocal of D_Q, which takes into account the steady-state stability. The V_{ref} V_{com} should be near zero to make sure that the injected reactive power is at a minimum. Thus, steady-state Q (MVAr) is calculated as:

$$Q = \frac{V^* - V_{com}}{D_Q} \tag{21}$$

As in (21), the reactive power control will not be affected by the MG's parameters. Likewise, [106] has proposed a control technique for improving the active power-sharing control by introducing the integral controller as given in (22), but with the addition of the input power, P_i.

$$V_i = \int \left[K_e (V^* - V_{com}) - K_q P_i \right] dt \tag{22}$$

4.2. Signal Injection Loop

The signal injection droop compensation technique is mentioned in [23,97,98], and the method of this control approach is displayed in Figure 12. Among the benefits of this approach, the load sharing is suitable for linear, and non-linear loads, and automatic control of system parameters, such as the line impedance mismatch or inverter parameters. Furthermore, this approach has drawbacks, such as having high-frequency components that must be measured and constructed, greater complexity, deviation of the output voltage amplitude, the creation of inter-harmonics, and resonance caused by an injected signal can increase transmission loss and deteriorate the power quality [99].

4.3. Power Compensation Loop

A modified control strategy including a power compensation loop, which significantly reduces the reactive power-sharing error, is investigated in [107,108], and the diagram of this control method is presented in Figure 13. In this method, it detects reactive power-sharing faults by injecting real reactive power coupling disturbances that are activated by low bandwidth synchronization flag signals from the central controller. Accurate reactive power-sharing is achieved by manipulating the coupling of the real injected transient reactive power and employing an integrator. The reactive power-sharing accuracy could be improved when the reactive power-sharing control error is calculated by inserting an active power transient coupling term and rectifying the errors by using a slow integral, which can be described as,

$$\omega = \omega_o - (D_p P + D_Q Q) \tag{23}$$

$$E = E_o - D_Q Q + \left(\frac{K_c}{s}\right)(P - P_{ave}) \tag{24}$$

where the integral gain K_c should be the same for all DG units.

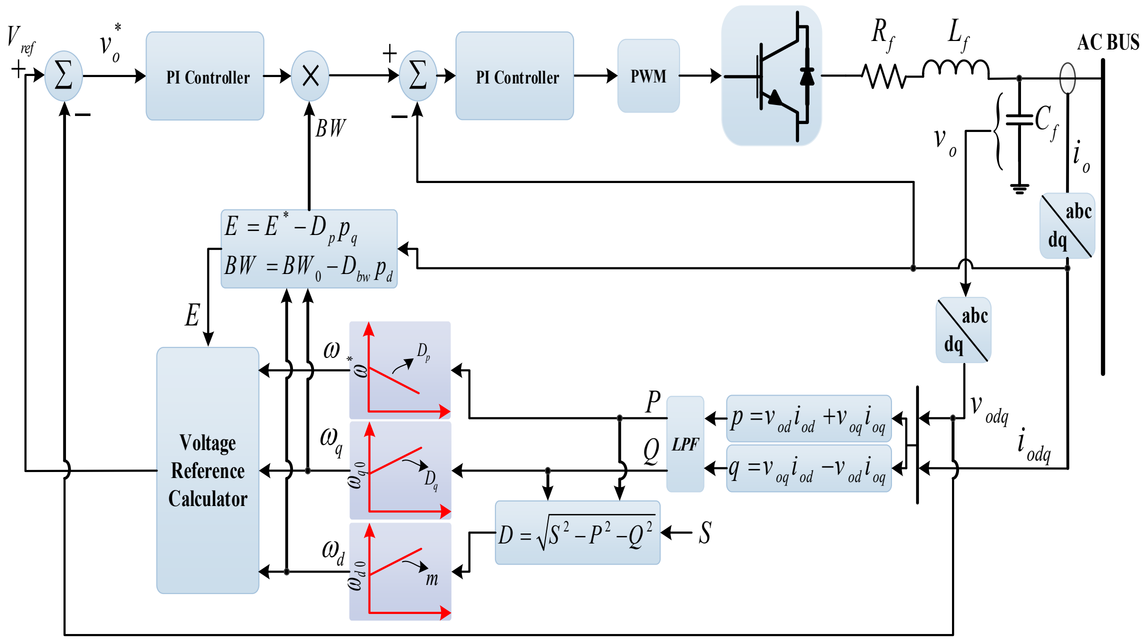


Figure 12. Compensation droop-based signal injection control technique [23].

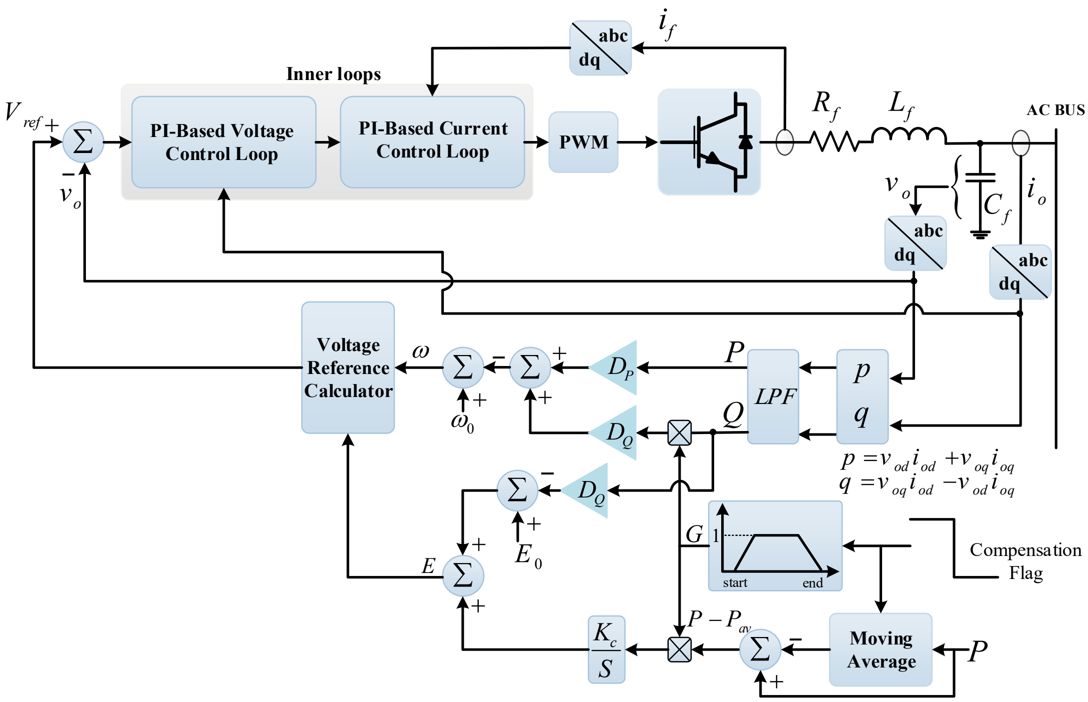


Figure 13. Compensation droop-based power compensation loop technique [107].

Figure 13 shows the diagram of the proposed control strategy, where P_0 and Q_0 are the measured powers before the low pass filter (LPF). When compensation is not active, the conventional $f-P$ and $V-Q$ droop methods perform power-sharing. When compensation comes into play, the traditional droop control is replaced by (9) and (10). In this diagram, the G unit is the soft compensation gain, and it is proposed for the compensation method, which can avoid excess power fluctuations and overcurrent during the compensation transient. The gain G slowly increases to the nominal value at the beginning of each compensation. After compensation, G slowly returns to zero, meaning that the droop controller slowly returns to a normal droop control mode.

4.4. Virtual Impedance Loop

In this section, the virtual impedance loop technique is presented as the latest approach to improve the droop technique and overcome the limitations of line impedance ($\frac{X}{R} \approx 1$) [38,109–117]. As a result, in this approach, by adding virtual inductance, a fast droop response has been achieved to decouple active and reactive power coupling, stabilize the frequency adjustment, and maintain the active power balance with minimal physical line losses [51]. Consequently, the expected voltage can be modified as,

$$V_{ref} = V^* - Z_D i_o \tag{25}$$

where Z_D, i_o, V^*, and V_{ref} are the virtual impedance, output current, under no-load condition output voltage, and reference generation voltage, respectively. Figure 14 shows the purely inductive virtual impedance technique $Z_D = L_D$ [49], which proposed the behavior of the controller without considering the steady-state frequency changes and the transient stability issue, so the transient response is not satisfactory. Recently, modified virtual output impedance methods have been proposed to improve transient response and harmonic current sharing [53]. In [24], to overcome the limitations and drawbacks of [118], integral terms are added to the conventional virtual impedance loop after the reference signal generator, resulting in an improved transient response. Approaches [24] and [118] are not applicable for online uninterruptible power supply (UPS) due to incorrect current distribution. According to the limitations mentioned in [119], to improve harmonic power-sharing, a decentralized controller with virtual resistive output impedance has been used in both linear and non-linear load conditions.

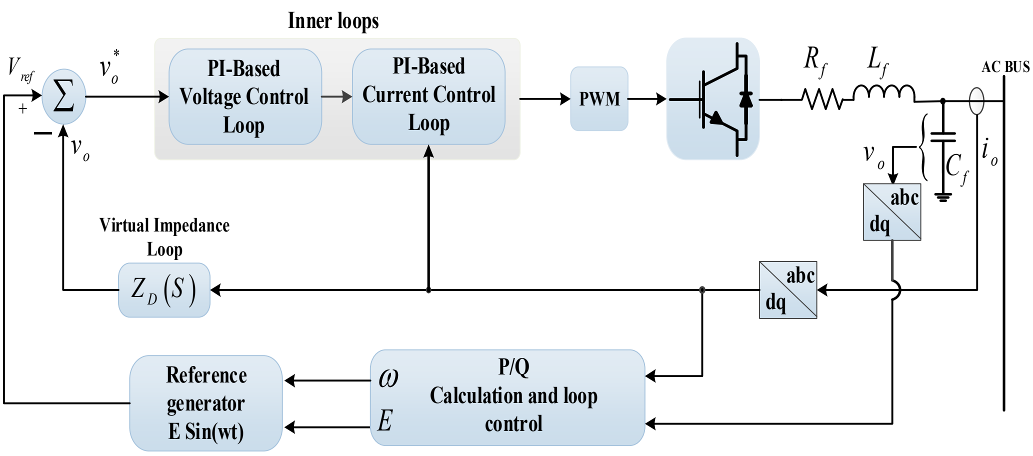


Figure 14. Compensation-droop-based virtual impedance-based control scheme [75].

The techniques mentioned so far are classified as classical control techniques. These control techniques are only designed for particular conditions, and these methods use control loops/PI-based controllers or other linear controllers.

5. Advanced Control Strategies for Inverter-Based IIDGs

Today, MGs have experienced extensive progress in integrating renewable energy resources, energy storage systems, and diverse loads. As a result, classical control techniques are ineffective for dealing with the limitations that develop in MGs and have disadvantages, such as:

- Distorted/imbalanced conditions and weak grid connection: Inefficiency of classical control techniques under these conditions and eliminating/countering the uncertainties generated in the upstream grid.
- The effect of the line impedance on power-sharing accuracy: Ineffectiveness of droop-based control methods and interaction of PI-based control loops under low X/R ratio line impedance conditions.
- Non-linear loads: In MGs, loads are topologically unknown and parametrically uncertain, and can be a source of unknown dynamics that cannot be accurately modeled by classical controllers.
- Lack of flexibility for impedance shaping of IIDGs: The GFM and GFD voltage source converters require different impedance characteristics for stable operation under different grid conditions; however, there is a lack of a sufficient degree of freedom for impedance shaping in conventional methods.

As a result, advanced control methods have been presented to solve the challenges raised, as presented in the sequel.

5.1. Robust Control

Conventional controllers based on PID/PI/PR controllers are inefficient for overcoming disturbances caused by internal and external factors, and, as a result, the stability of the MG has been affected [120]. Robust control techniques are the best solution for overcoming the uncertainties, disturbances, and non-linear nature of RESs/loads/power electronic equipment. A robust controller should be able to consider all the parameter variations for efficient MG consolidation under different operating conditions. In [121], a robust H_∞ controller is evaluated for AC voltage and frequency regulation in an MG under different loading conditions, and its performance is compared with a droop control method. This method proposed a multi-level control, including a droop control loop, voltage control loop, current control loop, and inductance-capacitor-inductance filter control loop and coupling circuit. In [122], a supervisory controller is proposed to control secondary AC voltage and frequency in autonomous AC MGs to overcome possible limitations. In [123], an improved droop-based control scheme is developed to solve the stability problem and increase the power-sharing accuracy in the grid-connected MG that was investigated. A robust MG stabilizer (inspired by the power system stabilizer (PSS)) has been proposed in [124], which dampens low-frequency oscillations (LFO) in MGs that are provoked by the interaction of droop controllers through the power network.

In the grid-connected operating mode, the grid synchronization is performed by a PLL. The basic drawback of PLL is instability following disturbances/faults in the upstream weak grid [125,126]. To deal with this defect, a robust PLL is proposed in [127]. This controller improves the stability margin of the system under FRT transient conditions and is robust against grid/MG impedance variations, weak grid connections, and distorted grid conditions. Furthermore, the robust PLL reveals a better performance in frequency estimation when being used in the synthesis of virtual inertia and frequency support. The block diagram of this control method is shown in Figure 15.

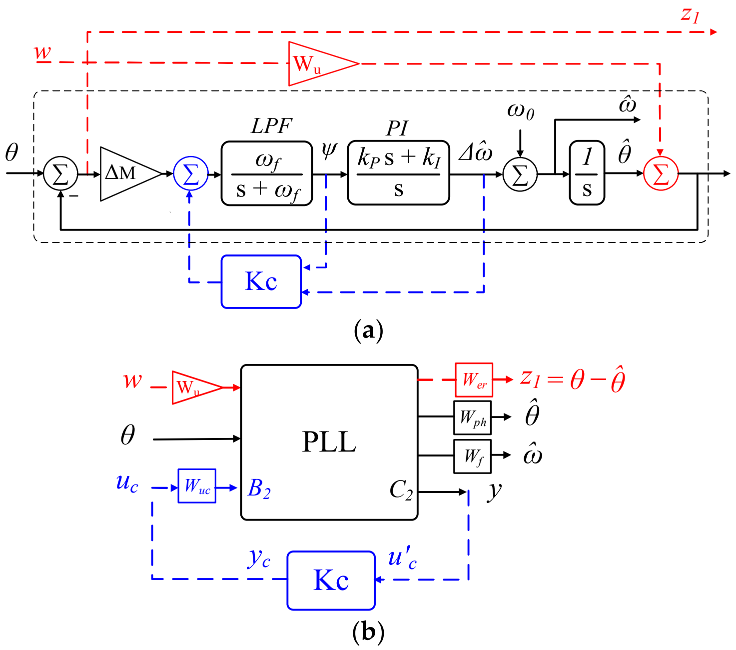


Figure 15. The structure of the robust controller scheme: (**a**) block diagram representing the control loop of the robust PLL; (**b**) generalized robust PLL diagram [127].

5.2. Fuzzy Control

A fuzzy control system is an approach that applied $if - then$ rules to implement fuzzy logic to the fuzzified inputs (in the (0,1) interval instead of 0/I) to deal with uncertainties in the system parameters. Therefore, this approach is effective for making the controller adaptive by linking the output (system response) to the wide range of input variables [128]. In [129], a Takagi–Sugeno (TS) fuzzy control is proposed to regulate the AC voltage and achieve accurate power-sharing in decentralized island microgrids. In [130], fuzzy control is proposed to improve the frequency response of a wind turbine system, which requires an accurate model of the tilt angle control, wind storage system, and wind speed. In [131], a fuzzy controller is applied at the secondary level to reduce voltage and frequency deviations during disturbances. With the development of MGs and the use of multi-bus MGs, droop-based controllers for power-sharing have been affected by line impedance [132,133]. Due to the low impedance of power lines, the conventional droop is inefficient; as a result, a fuzzy-based consensus control is introduced in [134] to deal with this inefficiency, see Figure 16.

5.3. Sliding Mode Control

Control techniques based on proportional–integral (PI), proportional resonance (PR), and predictive deadbeat (DB) have not performed well in non-linear systems such as microgrids. As a result, sliding mode control (SMC) has been developed in non-linear systems. This control approach has advantages, such as robustness and impermeability against parameter changes and noise, as well as the ability to determine the sliding mode in a limited time [135,136]. In [137], an SMC-based control approach is employed to control the AC voltage and frequency in an islanded AC microgrid with an arbitrary topology. In [138], a fractional-order SMC provides terminal voltage and frequency regulation of a DER unit, which also exhibits robustness against unbalanced and/or distorted load currents. A decentralized SMC strategy is proposed in [139] to improve the stability, power-sharing, and robustness to non-linear and unbalanced loads in microgrids. In [140], a robust efficient decentralized voltage/frequency control strategy is presented, which increases power-sharing and system stability under the influence of unbalanced loads. This control strategy includes three separate controllers based on SMC and Lyapunov theory to improve active/reactive power-sharing and voltage regulation. It has been investigated that GFM inverters reveal arbitrary/resistive impedance at current limiting, which makes the MG unstable at FRT transients [141]. To address this issue, sliding mode control is proposed in [141] to make the MG system securely pass FRT transients. The proposed controller slides the control system of the GFM inverter on a stable manifold that bypasses unstable modes.

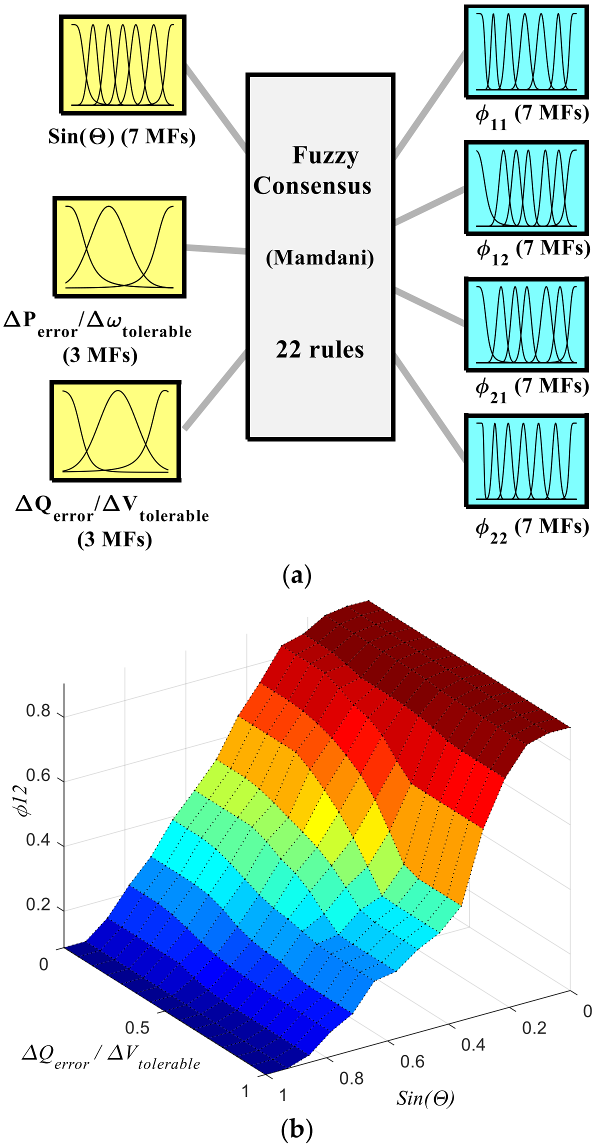


Figure 16. Fuzzy Interface System (FIS) for the consensus-based droop control: (**a**) FIS diagram including three inputs and four outputs, (**b**) Fuzzy surface [134].

5.4. Impedance Shaping

The arbitrary output impedance behavior of each of the GFM/GFD voltage source converters in the islanded/grid-connected conditions and in critical situations, such as disturbances/faults—which leads to instability—cannot be solved by conventional PI-based nested control loops [124,142]. In this light, the impedance shaping method is critical for meeting the required impedance characteristics in isolated/grid-connected conditions, and to establish decoupled $f - P$ and $V - Q$ loops by avoiding cross-coupling between them, which can highly affect the stability of the MG. The impedance shaping method is a promising solution for identifying and improving the dynamic performance of IIDG units in modern power systems. Yet, only relying on classic control loops in the control system of inverters is not effective for dealing with serious power grid problems. To address this issue and facilitate flexible impedance shaping, a new control structure has been proposed in [143,144], which is called the optimal voltage regulator (OVR), see Figure 17.

The proposed controller is based on the optimal state feedback control and optimality refers to the optimal impedance shaping based on the power-sharing control target and the grid requirement. Furthermore, the proposed controller is able to work in both the GFD (grid-connected) and GFM (islanded) modes without the requirement of a dedicated PLL in the grid-feeding mode and change in the control structure in the transition from GFD to GFM modes.

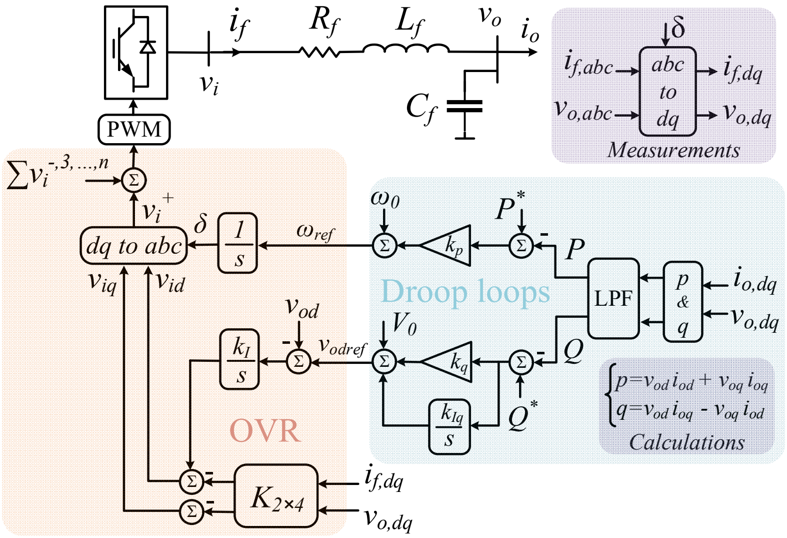


Figure 17. The structure of the optimal voltage regulator for IIDGs [141].

Time domain non-linear simulation results in MATLAB Simulink are provided, in Figures 18–20, to evaluate the importance of impedance shaping and defect performance of the conventional PI-based GFM and GFD power converters in low-voltage and weak grids. In Figure 18, the performance of the GFM power converters in an islanded MG with a low X/R ratio of line impedance (X/R = 1) is shown. After the error/disturbance caused by microgrid islanding, PI-based control techniques are not able to deal with the disturbance. As a result, the MG's variables (frequency and active and reactive powers) have become unstable and unbalanced. Furthermore, in the GFD mode of operation of the converter with high output impedance, this control technique is ineffective in dealing with current limitations, the results of which can be seen in Figure 19. The control structure based on impedance shaping prevents the collapse of network variables thanks to its flexible functionality as the GFM and GFD converter. The results can be seen in Figure 20.

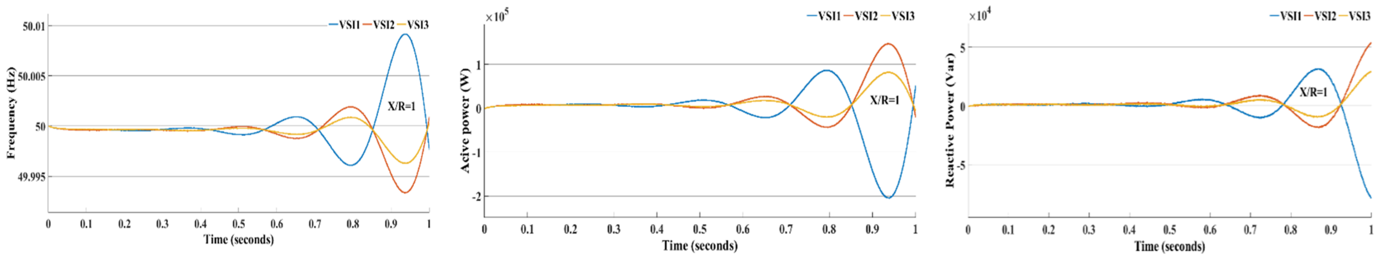
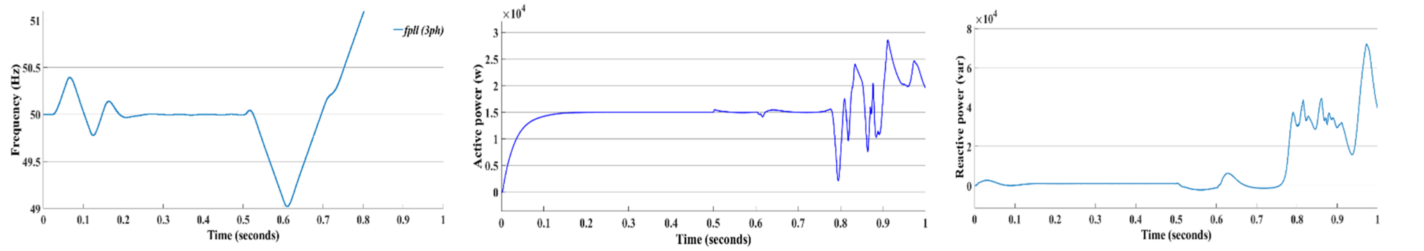
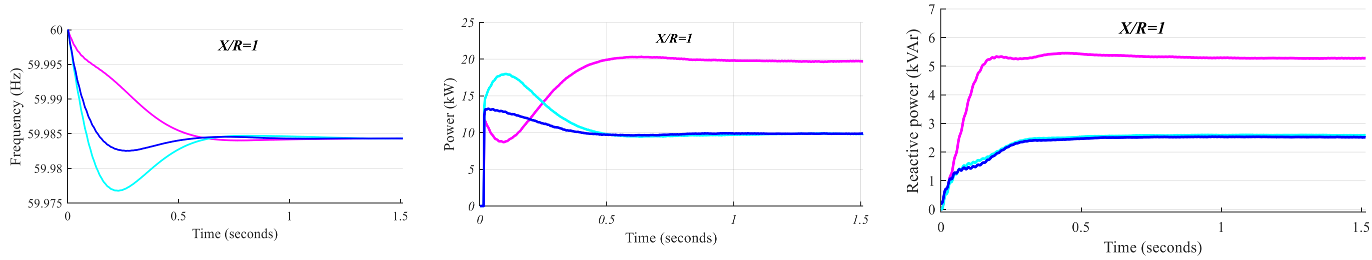


Figure 18. Unstable power-sharing performance among three PI-based GFM inverters in a meshed MG with low X/R ratio: (**a**) frequency; (**b**) active power; (**c**) reactive power.



(**a**) (**b**) (**c**)

Figure 19. Poor performance of the PI-based GFD inverters in weak grids with high impedance: (**a**) frequency; (**b**) active power; (**c**) reactive power.



(**a**) (**b**) (**c**)

Figure 20. Promising power-sharing performance among three OVRs in a low-voltage MG with meshed topology and *X/R* = 1: (**a**) frequency; (**b**) active power; (**c**) reactive power.

5.5. Summary Heuristic/Meta-Heuristic Algorithms

In addition to the advanced methods, heuristic/meta-heuristic algorithms are used according to their advanced features for solving the model in advanced control techniques, which are mentioned in Table 4.

Table 4. Heuristic/meta-heuristic algorithms used in advanced control techniques.

Control Method	Control Strategies	Highlights of Control Strategies
Advanced control strategies based on heuristic/meta-heuristic algorithms	1. Neural Network Algorithm 2. Genetic Algorithm 3. Particle Swarm Algorithm 4. Artificial Intelligence	1. Neural networks are used for voltage and frequency control, improving power-sharing, and increasing MG stability margin [145]. 2. Genetic algorithm is used to determine the optimized virtual impedance to minimize the global reactive power-sharing error of the MG [146]. 3. Particle swarm optimization (PSO) is used to solve the design problem of various MG components and controller parameters as an optimization problem formulated to increase MG stability that leads to improved power-sharing and voltage and current stability [147–149]. 4. An artificial intelligence-based (Icosφ) controller is proposed for power-sharing and power quality improvement in smart MG systems, where various uncertainties caused by load changes, MG battery state of charge, and power tariffs based on power availability in MGs are considered [150].

6. Future Trends in the High-Performance Inverter-Based Grids

Further investigation of the challenges will help to improve the voltage and frequency control strategies of IIDGs in MGs. The views and challenges mentioned below can provide the basis for the design of the AC MGs with advanced control strategies.

- The dynamics of variable loads still affect the stability of IIDGs in two operating modes, connected/islanded, at the MG level; as a result, unsolved challenges remain for achieving voltage and frequency stability at the MG level [151,152].
- The contemplation of sensitivity issues with non-linear droop controller-based strategies [153] is necessary.
- Increased reliability in droop control systems based on robust controllers leads to accurate sharing of active and reactive powers among high penetration levels of IIDGs. With the development of research in this field, more solutions can be obtained [154].
- Droop methods with the aim of cost optimization, in which non-linear control methods and droop gains are variable, are open research fields, and the dynamic stability of the MG system under the influence of variable droop gains should be evaluated. Considering that the droop coefficients are adaptively changed based on the cost function using real-time optimization techniques, different computational and traceable optimization techniques are needed to increase the reliability of microgrids [152].
- The accurate power-sharing from islanded to grid-connected modes has been investigated with hybrid control and non-linear loads [155,156] and using intelligent methods [157].
- The performance and stability of droop controllers in MGs with a networked topology, as stressed in [158–160], need further investigation and analysis.
- Impedance shaping has been effective in stability analysis and inverter-based DER control design, including advanced control techniques. Due to the defective performance of virtual inductance loops [143,161], control methods for IIDG units are presented in [143,144]. In these methods, a degree of freedom of the optimal impedance-shaping mechanism is considered. Adaptive impedance shaping considering changes in MG structure due to plug-and-play, load changes, grid reconfiguration, and transients from islanded to grid-connected modes are among the open topics in these methods.
- The FRT transients modeling, stability analysis, and stabilization have recently attained significant attention [141,162] and are a future trend.
- Considering the different applications of battery energy storage systems (BESS) in MGs, their impact on MG economic dynamics [163,164], the different time scales of BESS application, and their joint dynamic performances in steady state, modified, and advanced droop mechanisms are needed for BESS control.

7. Conclusions

In this paper, a technically profound overview of the strategies of communication-based centralized methods, decentralized droop-based control, construction and compensation techniques, and advanced controllers for voltage and frequency control for power-sharing among parallel inverters in AC MGs was presented. Among the advantages of the communication link-based control techniques is the appropriate power-sharing, but they possess low reliability and redundancy. The decentralized droop-based control techniques are another class of control methods that are superior to the communication-based method. Among the advantages and disadvantages of this class of controllers are flexibility, modularity, higher reliability, slow dynamic response, poor power quality, and lack of proper power-sharing due to uncertainty in the output impedance. Given this, to address the problems of droop control techniques based on communication/non-communication links, construction and compensation control techniques have been proposed. Considering the limitations of conventional control techniques in dealing with uncertainty and non-linearities, advanced control methods have been proposed to handle these challenges. Furthermore, in the last section, considering the development of power systems, the future trends in voltage and frequency control—especially in power-sharing control techniques—were discussed.

Author Contributions: Conceptualization, E.P. and M.E.; methodology, Y.A., M.E; software, Y.A., M.E; validation, Y.A., M.E; formal analysis, E.P., Y.A. and M.M.; investigation, Y.A., M.M.; resources, E.P., Y.A, M.M. and M.E.; data curation, Y.A., M.M.; writing—original draft preparation, E.P., Y.A.; writing—review and editing, M.E.,; visualization, E.P., Y.A. and M.M.; supervision, M.E., A.V.S.; project administration, M.E.; funding acquisition, A.V.S. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Australian Research Council, DP190102501.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Moriarty, P.; Honnery, D. Renewable Energy and Energy Reductions or Solar Geoengineering for Climate Change Mitigation? *Energies* **2022**, *15*, 7315. [CrossRef]
2. Moradi, M.H.; Eskandari, M.; Hosseinian, S.M. Operational Strategy Optimization in an Optimal Sized Smart Microgrid. *IEEE Trans. Smart Grid* **2014**, *6*, 1087–1095. [CrossRef]
3. Moradi, M.H.; Eskandari, M. A hybrid method for simultaneous optimization of DG capacity and operational strategy in microgrids considering uncertainty in electricity price forecasting. *Renew. Energy* **2014**, *68*, 697–714. [CrossRef]
4. Mansouri, M.; Eskandari, M.; Asadi, Y.; Siano, P.; Alhelou, H.H. Pre-Perturbation Operational Strategy Scheduling in Microgrids by Two-Stage Adjustable Robust Optimization. *IEEE Access* **2022**, *10*, 74655–74670. [CrossRef]
5. Anttila, S.; Döhler, J.S.; Oliveira, J.G.; Boström, C. Grid Forming Inverters: A Review of the State of the Art of Key Elements for Microgrid Operation. *Energies* **2022**, *15*, 5517. [CrossRef]
6. Lin, X.; Chen, X.; Kang, Y.; Duan, S.; Chen, J. Parallel three-phase UPS inverters with a new control technique. In Proceedings of the 2002 IEEE 33rd Annual IEEE Power Electronics Specialists Conference, Proceedings (Cat. No. 02CH37289), Cairns, Australia, 23–27 June 2002. [CrossRef]
7. Chandorkar, M.; Divan, D.; Adapa, R. Control of parallel connected inverters in standalone AC supply systems. *IEEE Trans. Ind. Appl.* **1993**, *29*, 136–143. [CrossRef]
8. Karimi, H.; Nikkhajoei, H.; Iravani, M.R. Control of an electronically-coupled distributed resource unit subsequent to an islanding event. *IEEE Trans. Power Del.* **2008**, *23*, 493–501. [CrossRef]
9. Katiraei, F.; Iravani, M.R.; Lehn, P.W. Micro-grid autonomous operation during and subsequent to islanding process. *IEEE Trans. Power Del.* **2005**, *20*, 248–257. [CrossRef]
10. Sayed, K.; Almutairi, A.; Albagami, N.; Alrumayh, O.; Abo-Khalil, A.G.; Saleeb, H. A Review of DC-AC Converters for Electric Vehicle Applications. *Energies* **2022**, *15*, 1241. [CrossRef]
11. Rocabert, J.; Luna, A.; Blaabjerg, F.; Rodríguez, P. Control of Power Converters in AC Microgrids. *IEEE Trans. Power Electron.* **2012**, *27*, 4734–4749. [CrossRef]
12. Wang, G.; Wang, X.; Wang, F.; Han, Z. Research on Hierarchical Control Strategy of AC/DC Hybrid Microgrid Based on Power Coordination Control. *Appl. Sci.* **2020**, *10*, 7603. [CrossRef]
13. Bidram, A.; Davoudi, A. Hierarchical Structure of Microgrids Control System. *IEEE Trans. Smart Grid* **2012**, *3*, 1963–1976. [CrossRef]
14. Olivares, D.E.; Mehrizi-Sani, A.; Etemadi, A.H.; Cañizares, C.A.; Iravani, R.; Kazerani, M.; Hajimiragha, A.H.; Gomis-Bellmunt, O.; Saeedifard, M.; Palma-Behnke, R.; et al. Trends in microgrid control. *IEEE Trans. Smart Grid* **2014**, *5*, 1905–1919. [CrossRef]
15. Yamashita, D.Y.; Vechiu, I.; Gaubert, J.-P. A review of hierarchical control for building microgrids. *Renew. Sustain. Energy Rev.* **2019**, *118*, 109523. [CrossRef]
16. Vasquez, J.C.; Guerrero, J.M.; Miret, J.; Castilla, M.; de Vicuna, L.G. Hierarchical Control of Intelligent Microgrids. *IEEE Ind. Electron. Mag.* **2010**, *4*, 23–29. [CrossRef]
17. Razmi, D.; Lu, T. A Literature Review of the Control Challenges of Distributed Energy Resources Based on Microgrids (MGs): Past, Present and Future. *Energies* **2022**, *15*, 4676. [CrossRef]
18. Marín, L.G.; Sumner, M.; Muñoz-Carpintero, D.; Köbrich, D.; Pholboon, S.; Sáez, D.; Núñez, A. Hierarchical energy man-agement system for microgrid operation based on robust model predictive control. *Energies* **2019**, *12*, 4453. [CrossRef]
19. Zheng, C.; Eskandari, M.; Li, M.; Sun, Z. GA−Reinforced Deep Neural Network for Net Electric Load Forecasting in Microgrids with Renewable Energy Resources for Scheduling Battery Energy Storage Systems. *Algorithms* **2022**, *15*, 338. [CrossRef]
20. Moradi, M.H.; Eskandari, M.; Showkati, H. A hybrid method for simultaneous optimization of DG capacity and opera-tional strategy in microgrids utilizing renewable energy resources. *Int. J. Electr. Power Energy Syst.* **2014**, *56*, 241–258. [CrossRef]
21. Chaudhary, G.; Lamb, J.J.; Burheim, O.S.; Austbø, B. Review of energy storage and energy management system control strategies in microgrids. *Energies* **2021**, *14*, 4929. [CrossRef]

22. Palizban, O.; Kauhaniemi, K. Hierarchical control structure in microgrids with distributed generation: Island and grid-connected mode. *Renew. Sustain. Energy Rev.* **2015**, *44*, 797–813. [CrossRef]
23. Ahmethodzic, L.; Music, M. Comprehensive review of trends in microgrid control. *Renew. Energy Focus* **2021**, *38*, 84–96. [CrossRef]
24. Hu, J.; Shan, Y.; Guerrero, J.M.; Ioinovici, A.; Chan, K.W.; Rodriguez, J. Model predictive control of microgrids—An overview. *Renew. Sustain. Energy Rev.* **2021**, *136*, 110422. [CrossRef]
25. Bevrani, H.; Francois, B.; Ise, T. *Microgrid Dynamics and Control*; John Wiley & Sons: Hoboken, NJ, USA, 2017.
26. Sarkar, S.K.; Roni, H.K.; Datta, D.; Das, S.K.; Pota, H.R. Improved Design of High-Performance Controller for Voltage Control of Islanded Microgrid. *IEEE Syst. J.* **2018**, *13*, 1786–1795. [CrossRef]
27. Monica, P.; Kowsalya, M. Control strategies of parallel operated inverters in renewable energy application: A review. *Renew. Sustain. Energy Rev.* **2016**, *65*, 885–901. [CrossRef]
28. Han, Y.; Li, H.; Shen, P.; Coelho, E.A.A.; Guerrero, J.M. Review of Active and Reactive Power Sharing Strategies in Hierarchical Controlled Microgrids. *IEEE Trans. Power Electron.* **2017**, *32*, 2427–2451. [CrossRef]
29. Han, H.; Hou, X.; Yang, J.; Wu, J.; Su, M.; Guerrero, J.M. Review of Power Sharing Control Strategies for Islanding Operation of AC Microgrids. *IEEE Trans. Smart Grid* **2016**, *7*, 200–215. [CrossRef]
30. Das, S.; Nutkani, I.U.; Teixeira, C.A. Decentralized Master–Slave Control for Series-Cascaded Islanded AC Mi-crogrid. *IEEE Trans. Ind. Electron.* **2021**, *69*, 5942–5951. [CrossRef]
31. Sun, X.; Wong, L.-K.; Lee, Y.-S.; Xu, D. Design and analysis of an optimal controller for parallel multi-inverter systems. *IEEE Trans. Circuits Syst. II Express Briefs* **2006**, *53*, 56–61. [CrossRef]
32. Guerrero, J.M.; Chandorkar, M.; Lee, T.-L.; Loh, P.C. Advanced Control Architectures for Intelligent Microgrids—Part I: Decentralized and Hierarchical Control. *IEEE Trans. Ind. Electron.* **2013**, *60*, 1254–1262. [CrossRef]
33. Asadi, Y.; Eskandari, M.; Mansouri, M.; Chaharmahali, S.; Moradi, M.H.; Tahriri, M.S. Adaptive Neural Network for a Stabilizing Shunt Active Power Filter in Distorted Weak Grids. *Appl. Sci.* **2022**, *12*, 8060. [CrossRef]
34. Blaabjerg, F.; Teodorescu, R.; Liserre, M.; Timbus, A.V. Overview of Control and Grid Synchronization for Distributed Power Generation Systems. *IEEE Trans. Ind. Electron.* **2006**, *53*, 1398–1409. [CrossRef]
35. Vandoorn, T.L.; De Kooning, J.D.M.; Meersman, B.; Vandevelde, L. Review of primary control strategies for islanded microgrids with power-electronic interfaces. *Renew. Sustain. Energy Rev.* **2013**, *19*, 613–628. [CrossRef]
36. Kreishan, M.; Zobaa, A. Optimal Allocation and Operation of Droop-Controlled Islanded Microgrids: A Review. *Energies* **2021**, *14*, 4653. [CrossRef]
37. Guerrero, J.M.; Hang, L.; Uceda, J. Control of Distributed Uninterruptible Power Supply Systems. *IEEE Trans. Ind. Electron.* **2008**, *55*, 2845–2859. [CrossRef]
38. Li, C.; Savaghebi, M.; Guerrero, J.M.; Coelho, E.A.A.; Vasquez, J.C. Operation Cost Minimization of Droop-Controlled AC Microgrids Using Multiagent-Based Distributed Control. *Energies* **2016**, *9*, 717. [CrossRef]
39. Kawabata, T.; Sashida, N.; Yamamoto, Y.; Ogasawara, K.; Yamasaki, Y. Parallel processing inverter system. *IEEE Trans. Power Electron.* **1991**, *6*, 442–450. [CrossRef]
40. Thunes, J.; Kerkman, R.; Schlegel, D.; Rowan, T. Current regulator instabilities on parallel voltage-source inverters. *IEEE Trans. Ind. Appl.* **1999**, *35*, 70–77. [CrossRef]
41. Chen, J.-F.; Chu, C.-L. Combination voltage-controlled and current-controlled PWM inverters for UPS parallel operation. *IEEE Trans. Power Electron.* **1995**, *10*, 547–558. [CrossRef]
42. Pogaku, N.; Prodanovic, M.; Green, T.C. Modeling, analysis and testing of autonomous operation of an invert-er-based microgrid. *IEEE Trans. Power Electron.* **2007**, *22*, 613–625. [CrossRef]
43. Holtz, J.; Werner, K.-H. Multi-inverter UPS system with redundant load sharing control. *IEEE Trans. Ind. Electron.* **1990**, *37*, 506–513. [CrossRef]
44. Wu, T.-F.; Chen, Y.-K.; Huang, Y.-H. 3C strategy for inverters in parallel operation achieving an equal current distribution. *IEEE Trans. Ind. Electron.* **2000**, *47*, 273–281. [CrossRef]
45. Liang, H.; Zhuang, W. Stochastic Modeling and Optimization in a Microgrid: A Survey. *Energies* **2014**, *7*, 2027–2050. [CrossRef]
46. Borrega, M.; Marroyo, L.; González, R.; Balda, J.; Agorreta, J.L. Modeling and Control of a Master–Slave PV Inverter With N-Paralleled Inverters and Three-Phase Three-Limb Inductors. *IEEE Trans. Power Electron.* **2012**, *28*, 2842–2855. [CrossRef]
47. Abdelaziz, M.M.A.; Shaaban, M.F.; Farag, H.E.; El-Saadany, E.F. A Multistage Centralized Control Scheme for Islanded Microgrids with PEVs. *IEEE Trans. Sustain. Energy* **2014**, *5*, 927–937. [CrossRef]
48. Alsafran, A.S.; Daniels, M.W. Consensus Control for Reactive Power Sharing Using an Adaptive Virtual Impedance Approach. *Energies* **2020**, *13*, 2026. [CrossRef]
49. Rajesh, K.S.; Dash, S.S.; Rajagopal, R.; Sridhar, R. A review on control of ac microgrid. *Renew. Sustain. Energy Rev.* **2017**, *71*, 814–819. [CrossRef]
50. Espín-Sarzosa, D.; Palma-Behnke, R.; Núñez-Mata, O. Energy Management Systems for Microgrids: Main Existing Trends in Centralized Control Architectures. *Energies* **2020**, *13*, 547. [CrossRef]
51. Yang, Y.; Qin, Y.; Tan, S.-C.; Hui, S.Y.R. Reducing Distribution Power Loss of Islanded AC Microgrids Using Distributed Electric Springs with Predictive Control. *IEEE Trans. Ind. Electron.* **2020**, *67*, 9001–9011. [CrossRef]
52. Jeong, B.-C. Modified Master–Slave Controller for Stable Power Supply of Energy Storage Based Microgrid. *Energies* **2022**, *15*, 4245. [CrossRef]

53. Zhang, C.; Chen, G.; Guo, Z.; Wu, W. An Alternating-master-salve Parallel Control Research for Single Phase Paralleled Inverters Based on CAN Bus. In Proceedings of the 2006 CES/IEEE 5th International Power Electronics and Motion Control Conference, Shanghai, China, 14–16 August 2006.
54. Tan, J.; Lin, H.; Zhang, J.; Ying, J. A novel load sharing control technique for paralleled inverters. In Proceedings of the IEEE 34th Annual Conference on Power Electronics Specialist, Acapulco, Mexico, 15–19 June 2003. [CrossRef]
55. Ogasawara, S.; Takagaki, J.; Akagi, H.; Nabae, A. A novel control scheme of a parallel current-controlled PWM inverter. *IEEE Trans. Ind. Appl.* **1992**, *28*, 1023–1030. [CrossRef]
56. Chen, L.; Xiao, L.; Yan, Y. A novel parallel inverter system based on coupled inductors. In Proceedings of the 25th International Telecommunications Energy Conference, Yokohama, Japan, 23 October 2003; pp. 46–50.
57. Chen, Y.; Smedley, K.M. One-Cycle-Controlled Three-Phase Grid-Connected Inverters and Their Parallel Operation. *IEEE Trans. Ind. Appl.* **2008**, *44*, 663–671. [CrossRef]
58. Wu, T.-F.; Wu, Y.-E.; Hsieh, H.-M.; Chen, Y.-K. Current Weighting Distribution Control Strategy for Multi-Inverter Systems to Achieve Current Sharing. *IEEE Trans. Power Electron.* **2007**, *22*, 160–168. [CrossRef]
59. Sikder, S.H.; Rahman, M.; Sarkar, S.K.; Das, S.K. Fractional Order Robust PID Controller Design for Voltage Control of Islanded Microgrid. In Proceedings of the 2018 4th International Conference on Electrical Engineering and Information & Communication Technology (iCEEiCT), Dhaka, Bangladesh, 13–15 September 2018; pp. 234–239. [CrossRef]
60. Li, Y.W.; Kao, C.-N. An Accurate Power Control Strategy for Power-Electronics-Interfaced Distributed Generation Units Operating in a Low-Voltage Multibus Microgrid. *IEEE Trans. Power Electron.* **2009**, *24*, 2977–2988. [CrossRef]
61. Natesan, C.; Ajithan, S.; Mani, S.; Kandhasamy, P. Applicability of Droop Regulation Technique in Microgrid—A Survey. *Eng. J.* **2014**, *18*, 23–36. [CrossRef]
62. Zamora, R.; Srivastava, A.K. Controls for microgrids with storage: Review, challenges, and research needs. *Renew. Sustain. Energy Rev.* **2010**, *14*, 2009–2018. [CrossRef]
63. Guerrero, J.M.; Vasquez, J.C.; Matas, J.; Castilla, M.; de Vicuna, L.G. Control Strategy for Flexible Microgrid Based on Parallel Line-Interactive UPS Systems. *IEEE Trans. Ind. Electron.* **2008**, *56*, 726–736. [CrossRef]
64. Hou, X.; Sun, Y.; Yuan, W.; Han, H.; Zhong, C.; Guerrero, J.M. Conventional P-ω/QV droop control in highly resistive line of low-voltage converter-based AC microgrid. *Energies* **2016**, *9*, 943. [CrossRef]
65. Llaria, A.; Curea, O.; Jiménez, J.; Camblong, H. Survey on microgrids: Unplanned islanding and related inverter control techniques. *Renew. Energy* **2011**, *36*, 2052–2061. [CrossRef]
66. Coelho, E.; Cortizo, P.; Garcia, P. Small-signal stability for parallel-connected inverters in stand-alone AC supply systems. *IEEE Trans. Ind. Appl.* **2002**, *38*, 533–542. [CrossRef]
67. Eskandari, M.; Li, L. A novel small signal model of multi-bus microgrids for modeling interaction of droop controllers through the power network. In Proceedings of the 2017 20th International Conference on Electrical Machines and Systems (ICEMS), Sydney, Australia, 11–14 August 2017; pp. 1–6.
68. Wu, D.; Tang, F.; Vasquez, J.C.; Guerrero, J.M. Control and analysis of droop and reverse droop con-trollers for distributed generations. In Proceedings of the 2014 IEEE 11th International Multi-Conference on Systems, Signals & Devices (SSD14), Barcelona, Spain, 11–14 February 2014; pp. 1–5.
69. Guerrero, J.M.; Matas, J.; De Vicuñna, L.G.; Castilla, M.; Miret, J. Wireless-Control Strategy for Parallel Operation of Distributed-Generation Inverters. *IEEE Trans. Ind. Electron.* **2006**, *53*, 1461–1470. [CrossRef]
70. Guerrero, J.M.; Vasquez, J.C.; Teodorescu, R. Hierarchical control of droop-controlled DC and AC microgrids—A general approach towards standardization. *IEEE Trans. Ind. Electron.* **2009**, *58*, 4305–4310. [CrossRef]
71. Skea, J.; Anderson, D.; Green, T.; Gross, R.; Heptonstall, P.; Leach, M. Intermittent renewable generation and the cost of maintaining power system reliability. *IET Gener. Transm. Distrib.* **2008**, *2*, 82–89. [CrossRef]
72. Majumder, R.; Chaudhuri, B.; Ghosh, A.; Majumder, R.; Ledwich, G.; Zare, F. Improvement of Stability and Load Sharing in an Autonomous Microgrid Using Supplementary Droop Control Loop. *IEEE Trans. Power Syst.* **2010**, *25*, 796–808. [CrossRef]
73. Solanki, A.; Nasiri, A.; Bhavaraju, V.; Familiant, Y.L.; Fu, Q. A New Framework for Microgrid Management: Virtual Droop Control. *IEEE Trans. Smart Grid* **2015**, *7*, 554–566. [CrossRef]
74. Hu, J.; Zhu, J.; Dorrell, D.G.; Guerrero, J.M. Virtual Flux Droop Method—A New Control Strategy of Inverters in Microgrids. *IEEE Trans. Power Electron.* **2013**, *29*, 4704–4711. [CrossRef]
75. Golsorkhi, M.S.; Lu, D.D.C. A Control Method for Inverter-Based Islanded Microgrids Based on V-I Droop Characteristics. *IEEE Trans. Power Deliv.* **2014**, *30*, 1196–1204. [CrossRef]
76. Vandoorn, T.L.; Meersman, B.; Degroote, L.; Renders, B.; Vandevelde, L. A Control Strategy for Islanded Microgrids With DC-Link Voltage Control. *IEEE Trans. Power Deliv.* **2011**, *26*, 703–713. [CrossRef]
77. Heidari, S.; Hatami, A.; Eskandari, M. An intelligent capacity management system for interface converter in AC-DC hybrid microgrids. *Appl. Energy* **2022**, *316*, 119112. [CrossRef]
78. Auy-Yeung, J.; Vanalme, G.M.A.; Myrzik, J.M.A.; Karaliolios, P.; Bongaerts, M.; Bozelie, J.; Kling, W.L. Development of a Voltage and Frequency Control Strategy for an Autonomous LV Network with Distributed Generators. In Proceedings of the 2009 44th International Universities Power Engineering Conference, Glasgow, UK, 1–4 September 2009.
79. Guerrero, J.M.; Berbel, N.; Matas, J.; de Vicuna, L.G.; Miret, J. Decentralized Control for Parallel Operation of Distributed Generation Inverters Using Resistive Output Impedance. *IEEE Trans. Ind. Electron.* **2017**, *54*, 994–1004. [CrossRef]

80. Sun, Y.; Zhong, C.; Hou, X.; Yang, J.; Han, H.; Guerrero, J.M. Distributed cooperative synchronization strategy for multi-bus microgrids. *Int. J. Electr. Power Energy Syst.* **2017**, *86*, 18–28. [CrossRef]
81. Yao, W.; Chen, M.; Matas, J.; Guerrero, J.M.; Qian, Z.-M. Design and Analysis of the Droop Control Method for Parallel Inverters Considering the Impact of the Complex Impedance on the Power Sharing. *IEEE Trans. Ind. Electron.* **2010**, *58*, 576–588. [CrossRef]
82. Wang, J.; Song, Y.; Monti, A.; Jing, W. Design of a high performance deadbeat-type current controller for LCL-filtered grid-parallel inverters. In Proceedings of the 2015 IEEE 6th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), Aachen, Germany, 22–25 June 2015; pp. 1–8. [CrossRef]
83. Guan, Y.; Wu, W.; Guo, X.; Gu, H. An improved droop controller for grid-connected voltage source inverter in microgrid. In Proceedings of the 2nd International Symposium on Power Electronics for Distributed Generation Systems, Hefei, China, 16–18 June 2010; 823–828. [CrossRef]
84. Mohamed, Y.A.-R.I.; El-Saadany, E.F. Adaptive Decentralized Droop Controller to Preserve Power Sharing Stability of Paralleled Inverters in Distributed Generation Microgrids. *IEEE Trans. Power Electron.* **2008**, *23*, 2806–2816. [CrossRef]
85. Guerrero, J.M.; Vasquez, J.C.; Matas, J.; de Vicuna, L.G.; Castilla, M. Hierarchical Control of Droop-Controlled AC and DC Microgrids—A General Approach Toward Standardization. *IEEE Trans. Ind. Electron.* **2011**, *58*, 158–172. [CrossRef]
86. Guerrero, J.; Matas, J.; de Vicuna, L.; Berbel, N.; Sosa, J. Wireless-control strategy for parallel operation of distributed generation inverters. *IEEE Trans. Ind. Electron.* **2005**, *2*, 845–850. [CrossRef]
87. Hatziargyriou, N.; Jenkins, N.; Strbac, G.; Lopes, J.P.; Ruela, J.; Engler, A.; Oyarzabal, J.; Kariniotakis, G.; Amorim, A. *MICROGRIDS—Large Scale Integration of Micro-Generation to Low Voltage Grids*; University of Athens: Athens, Greece, 2006; pp. 1–24. [CrossRef]
88. Lee, C.-T.; Chuang, C.-C.; Chu, C.-C.; Cheng, P.-T. Control strategies for distributed energy resources interface converters in the low voltage Microgrid. In Proceedings of the 2009 IEEE Energy Conversion Congress and Exposition, San Jose, CA, USA, 20–24 September 2009; pp. 2022–2029. [CrossRef]
89. Guerrero, J.M.; GarciadeVicuna, L.; Matas, J.; Castilla, M.; Miret, J. Output Impedance Design of Parallel-Connected {UPS} Inverters with Wireless Load-Sharing Control. *IEEE Trans. Ind. Electron.* **2005**, *52*, 1126–1135. [CrossRef]
90. Rokrok, E.; Golshan, M. Adaptive voltage droop scheme for voltage source converters in an islanded multibus microgrid. *IET Gener. Transm. Distrib.* **2010**, *4*, 562–578. [CrossRef]
91. Hassanzahraee, M.; Bakhshai, A. Adaptive transient power control strategy for parallel-connected inverters in an islanded microgrid. In Proceedings of the IECON 2012-38th Annual Conference on IEEE Industrial Electronics Society, Montreal, QC, Canada, 25–28 October 2012; pp. 5926–5931. [CrossRef]
92. Ahn, S.-J.; Park, J.-W.; Chung, I.-Y.; Moon, S.-I.; Kang, S.-H.; Nam, S.-R. Power-Sharing Method of Multiple Distributed Generators Considering Control Modes and Configurations of a Microgrid. *IEEE Trans. Power Deliv.* **2010**, *25*, 2007–2016. [CrossRef]
93. Yu, K.; Ai, Q.; Wang, S.; Ni, J.; Lv, T. Analysis and Optimization of Droop Controller for Microgrid System Based on Small-Signal Dynamic Model. *IEEE Trans. Smart Grid* **2015**, *7*, 1–11. [CrossRef]
94. Díaz, G.; González-morán, C.; Gómez-aleixandre, J.; Diez, A. Scheduling of Droop Coefficients for Frequency and Voltage Regu-lation in Isolated Microgrids. *IEEE Trans. Power Syst.* **2010**, *25*, 489–496. [CrossRef]
95. Maulik, A.; Das, D. Optimal Operation of Droop-Controlled Islanded Microgrids. *IEEE Trans. Sustain. Energy* **2017**, *9*, 1337–1348. [CrossRef]
96. Sahyoun, S.; Djouadi, S.; Shankar, M. Optimal Control of Droop Controlled Inverters in Islanded Microgrids. *IFAC-PapersOnLine* **2015**, *48*, 363–368. [CrossRef]
97. Tuladhar, A.; Jin, H.; Unger, T.; Mauch, K. Parallel operation of single phase inverter modules with no control interconnections. In Proceedings of the APEC 97-Applied Power Electronics Conference, Atlanta, GA, USA, 27 February 1997. [CrossRef]
98. Perreault, D.J.; Selders, R.L.; Kassakian, J.G. Frequency-based current-sharing techniques for paralleled power converters. *IEEE Trans. Power Electron.* **1998**, *13*, 626–634. [CrossRef]
99. He, J.; Li, Y.W.; Guerrero, J.M.; Blaabjerg, F.; Vasquez, J.C. An Islanding Microgrid Power Sharing Approach Using Enhanced Virtual Impedance Control Scheme. *IEEE Trans. Power Electron.* **2013**, *28*, 5272–5282. [CrossRef]
100. Shafiee, Q.; Vasquez, J.C.; Guerrero, J.M. Distributed secondary control for islanded MicroGrids—A networked control systems approach. In Proceedings of the IECON 2012—38th Annual Conference on IEEE Industrial Electronics Society, Montreal, QC, Canada, 25–28 October 2012; pp. 5637–5642.
101. Li, Y.; Fan, L. Stability Analysis of Two Parallel Converters with Voltage-Current Droop Control. *IEEE Trans. Power Deliv.* **2017**, *32*. [CrossRef]
102. Vasquez, J.C.; Guerrero, J.M.; Savaghebi, M.; Eloy-Garcia, J.; Teodorescu, R. Modeling, Analysis, and Design of Stationary-Reference-Frame Droop-Controlled Parallel Three-Phase Voltage Source Inverters. *IEEE Trans. Ind. Electron.* **2012**, *60*, 1271–1280. [CrossRef]
103. Neves, R.V.A.; Machado, R.Q.; Oliveira, V.A.; Wang, X.; Blaabjerg, F. Multitask Fuzzy Secondary Controller for AC Microgrid Operating in Stand-Alone and Grid-Tied Mode. *IEEE Trans. Smart Grid* **2018**, *10*, 5640–5649. [CrossRef]
104. Eskandari, M.; Li, L.; Moradi, M.H. Decentralized Optimal Servo Control System for Implementing Instantaneous Reactive Power Sharing in Microgrids. *IEEE Trans. Sustain. Energy* **2017**, *9*, 525–537. [CrossRef]
105. Sao, C.K.; Lehn, P.W. Control and Power Management of Converter Fed Microgrids. *IEEE Trans. Power Syst.* **2008**, *23*, 1088–1098. [CrossRef]

106. Eskandari, M.; Li, L.; Moradi, M.H.; Siano, P.; Blaabjerg, F. Simultaneous reactive power sharing and voltage regulation in an autonomous networked microgrid. *IET Gener. Transm. Distrib.* **2020**, *14*, 1366–1377. [CrossRef]
107. He, J.; Li, Y.W. An Enhanced Microgrid Load Demand Sharing Strategy. *IEEE Trans. Power Electron.* **2012**, *27*, 3984–3995. [CrossRef]
108. He, J.; Li, Y.W. An accurate reactive power sharing control strategy for DG units in a microgrid. In Proceedings of the 8th International Conference on Power Electronics—ECCE Asia, Jeju, Korea, 30 May–3 June 2011; pp. 551–556.
109. Vasquez, J.C.; Guerrero, J.M.; Member, S.; Luna, A.; Rodríguez, P.; Teodorescu, R. Adaptive Droop Control Applied to Volt-age-Source Inverters Operating in Grid-Connected and Islanded Modes. *IEEE Trans. Ind. Electron.* **2009**, *56*, 4088–4096. [CrossRef]
110. Buraimoh, E.; Aluko, A.O.; Oni, O.E.; Davidson, I.E. Decentralized Virtual Impedance- Conventional Droop Control for Power Sharing for Inverter-Based Distributed Energy Resources of a Microgrid. *Energies* **2022**, *15*, 4439. [CrossRef]
111. Axelrod, B.; Berkovich, Y.; Ioinovici, A. Using Enhanced Virtual Impedance Control Scheme. In Proceedings of the 2003 International Symposium on Circuits and Systems, ISCAS 2003, Bangkok, Thailand, 25–28 May 2003; Volume 3, pp. 5272–5282.
112. Guerrero, J.M.; Loh, P.C.; Lee, T.-L.; Chandorkar, M. Advanced Control Architectures for Intelligent Microgrids—Part II: Power Quality, Energy Storage, and AC/DC Microgrids. *IEEE Trans. Ind. Electron.* **2012**, *60*, 1263–1270. [CrossRef]
113. Eskandari, M. Intelligent and Robust Control Strategy for Improving Microgrids Operation and Stability. Ph.D. Thesis, OPUS, Open Publications of UTS Scholars, Ultimo, Australia, 2020.
114. He, J.; Li, Y.W. Analysis, Design, and Implementation of Virtual Impedance for Power Electronics Interfaced Distributed Generation. *IEEE Trans. Ind. Appl.* **2011**, *47*, 2525–2538. [CrossRef]
115. Lyu, Z.; Wei, Q.; Zhang, Y.; Zhao, J.; Manla, E. Adaptive Virtual Impedance Droop Control Based on Consensus Control of Reactive Current. *Energies* **2018**, *11*, 1801. [CrossRef]
116. Li, Y.; Li, Y.W. Virtual frequency-voltage frame control of inverter based low voltage microgrid. In Proceedings of the 2009 IEEE Electrical Power & Energy Conference (EPEC), Montreal, QC, Canada, 22–23 October 2009; pp. 1–6. [CrossRef]
117. Li, Y.; Li, Y.W. Power Management of Inverter Interfaced Autonomous Microgrid Based on Virtual Frequency-Voltage Frame. *IEEE Trans. Smart Grid* **2011**, *2*, 30–40. [CrossRef]
118. Guerrero, J.; De Vicuna, L.G.; Matas, J.; Miret, J. Steady-state invariant-frequency control of parallel redundant uninterruptible power supplies. In Proceedings of the IEEE 2002 28th Annual Conference of the Industrial Electronics Society, Sevilla, Spain, 5–8 November 2002. [CrossRef]
119. Panjaitan, S.D.; Kurnianto, R.; Sanjaya, B.W.; Turner, M.C. Control of Parallel Inverters for High Power Quality and Sharing Accuracy in Single-Phase AC Microgrids. In Proceedings of the 2018 UKACC 12th International Conference on Control (CONTROL), Sheffield, UK, 5–7 September 2018; pp. 50–55. [CrossRef]
120. Mohammadi, F.; Mohammadi-Ivatloo, B.; Gharehpetian, G.B.; Ali, M.H.; Wei, W.; Erdinc, O.; Shirkhani, M. Robust Control Strategies for Microgrids: A Review. *IEEE Syst. J.* **2021**, *16*, 2401–2412. [CrossRef]
121. Sedhom, B.E.; El-Saadawi, M.M.; Hatata, A.Y.; Elhosseini, M.A.; Abd-Raboh, E.E. Robust Control Technique in an Autonomous Microgrid: A Multi-stage H∞ Controller Based on Harmony Search Algorithm. *Iran. J. Sci. Technol. Trans. Electr. Eng.* **2019**, *44*, 377–402. [CrossRef]
122. Ge, P.; Dou, X.; Quan, X.; Hu, Q.; Sheng, W.; Wu, Z.; Gu, W. Extended-State-Observer-Based Distributed Robust Secondary Voltage and Frequency Control for an Autonomous Microgrid. *IEEE Trans. Sustain. Energy* **2018**, *11*, 195–205. [CrossRef]
123. Imran, R.M.; Wang, S.; Flaih, F.M.F. DQ-Voltage Droop Control and Robust Secondary Restoration with Eligibility to Operate During Communication Failure in Autonomous Microgrid. *IEEE Access* **2018**, *7*, 6353–6361. [CrossRef]
124. Eskandari, M.; Savkin, A.V. A Critical Aspect of Dynamic Stability in Autonomous Microgrids: Interaction of Droop Controllers Through the Power Network. *IEEE Trans. Ind. Inform.* **2021**, *18*, 3159–3170. [CrossRef]
125. Hossen, T.; Sadeque, F. On Stability, Ancillary Services, Operation, and Security of Smart Inverters. *arXiv* **2021**, arXiv:2112.06787.
126. Tuckey, A.; Round, S. Grid-Forming Inverters for Grid-Connected Microgrids: Developing "good citizens" to ensure the continued flow of stable, reliable power. *IEEE Electrif. Mag.* **2022**, *10*, 39–51. [CrossRef]
127. Eskandari, M.; Savkin, A.V. Robust PLL Synchronization Unit for Grid-Feeding Converters in Micro/Weak Grids. *IEEE Trans. Ind. Inform.* **2022**. [CrossRef]
128. Karimi, A.; Khayat, Y.; Naderi, M.; Dragičević, T.; Mirzaei, R.; Blaabjerg, F.; Bevrani, H. Inertia response improve-ment in AC microgrids: A fuzzy-based virtual synchronous generator control. *IEEE Trans. Power Electron.* **2019**, *35*, 4321–4331. [CrossRef]
129. Hosseinalizadeh, T.; Kebriaei, H.; Salmasi, F.R. Decentralised robust T-S fuzzy controller for a parallel islanded AC microgrid. *IET Gener. Transm. Distrib.* **2019**, *13*, 1589–1598. [CrossRef]
130. Zhang, S.; Mishra, Y.; Shahidehpour, M. Fuzzy-Logic Based Frequency Controller for Wind Farms Augmented with Energy Storage Systems. *IEEE Trans. Power Syst.* **2016**, *31*, 1595–1603. [CrossRef]
131. Andalib-Bin-Karim, C.; Liang, X.; Zhang, H. Fuzzy-Secondary-Controller-Based Virtual Synchronous Generator Control Scheme for Interfacing Inverters of Renewable Distributed Generation in Microgrids. *IEEE Trans. Ind. Appl.* **2017**, *54*, 1047–1061. [CrossRef]
132. Moradi, M.H.; Eskandari, M.; Siano, P. Safe transition from connection mode to islanding mode in Microgrids. In Proceedings of the 2016 24th Iranian Conference on Electrical Engineering (ICEE), Shiraz, Iran, 10–12 May 2016; pp. 1902–1907. [CrossRef]
133. Han, H.; Liu, Y.; Sun, Y.; Su, M.; Guerrero, J.M. An Improved Droop Control Strategy for Reactive Power Sharing in Islanded Microgrid. *IEEE Trans. Power Electron.* **2014**, *30*, 3133–3141. [CrossRef]

134. Eskandari, M.; Li, L.; Moradi, M.H. Improving power sharing in islanded networked microgrids using fuzzy-based consensus control. *Sustain. Energy Grids Netw.* **2018**, *16*, 259–269. [CrossRef]
135. Mohamed, Y.A.R.I.; El-Saadany, E.F. Robust high bandwidth discrete-time predictive current control with pre-dictive internal model—A unified approach for voltage-source PWM converters. *IEEE Trans. Power Electron.* **2008**, *23*, 126–136. [CrossRef]
136. Delghavi, M.B.; Yazdani, A. Islanded-mode control of electronically coupled distributed-resource units under un-balanced and nonlinear load conditions. *IEEE Trans. Power Deliv.* **2010**, *26*, 661–673. [CrossRef]
137. Cucuzzella, M.; Incremona, G.P.; Ferrara, A. Decentralized Sliding Mode Control of Islanded AC Microgrids With Arbitrary Topology. *IEEE Trans. Ind. Electron.* **2017**, *64*, 6706–6713. [CrossRef]
138. Delghavi, M.B.; Shoja-Majidabad, S.; Yazdani, A. Fractional-Order Sliding-Mode Control of Islanded Distributed Energy Resource Systems. *IEEE Trans. Sustain. Energy* **2016**, *7*, 1482–1491. [CrossRef]
139. Baghaee, H.R.; Mirsalim, M.; Gharehpetian, G.B.; Talebi, H.A. A Decentralized Power Management and Sliding Mode Control Strategy for Hybrid AC/DC Microgrids including Renewable Energy Resources. *IEEE Trans. Ind. Inform.* **2017**, *1*. [CrossRef]
140. Baghaee, H.R.; Mirsalim, M.; Gharehpetian, G.B.; Talebi, H.A. Decentralized Sliding Mode Control of WG/PV/FC Microgrids Under Unbalanced and Nonlinear Load Conditions for On- and Off-Grid Modes. *IEEE Syst. J.* **2017**, *12*, 3108–3119. [CrossRef]
141. Eskandari, M.; Savkin, A.V. On the Impact of Fault Ride-Through on Transient Stability of Autonomous Microgrids: Nonlinear Analysis and Solution. *IEEE Trans. Smart Grid* **2020**, *12*, 999–1010. [CrossRef]
142. Harnefors, L.; Wang, X.; Yepes, A.G.; Blaabjerg, F. Passivity-Based Stability Assessment of Grid-Connected VSCs—An Overview. *IEEE J. Emerg. Sel. Top. Power Electron.* **2015**, *4*, 116–125. [CrossRef]
143. Eskandari, M.; Li, L.; Moradi, M.H.; Siano, P.; Blaabjerg, F. Optimal Voltage Regulator for Inverter Interfaced Distributed Generation Units Part I: Control System. *IEEE Trans. Sustain. Energy* **2020**, *11*, 2813–2824. [CrossRef]
144. Eskandari, M.; Blaabjerg, F.; Li, L.; Moradi, M.H.; Siano, P. Optimal voltage regulator for inverter interfaced dis-tributed generation units part II: Application. *IEEE Trans. Sustain. Energy* **2020**, *11*, 2825–2835. [CrossRef]
145. Vigneysh, T.; Kumarappan, N. Artificial Neural Network Based Droop-Control Technique for Accurate Power Sharing in an Islanded Microgrid. *Int. J. Comput. Intell. Syst.* **2016**, *9*, 827–838. [CrossRef]
146. Zhu, Y.; Zhuo, F.; Wang, F.; Liu, B.; Gou, R.; Zhao, Y. A Virtual Impedance Optimization Method for Reactive Power Sharing in Networked Microgrid. *IEEE Trans. Power Electron.* **2015**, *31*, 2890–2904. [CrossRef]
147. Zhang, L.; Zheng, H.; Hu, Q.; Su, B.; Lyu, L. An Adaptive Droop Control Strategy for Islanded Microgrid Based on Improved Particle Swarm Optimization. *IEEE Access* **2020**, *8*, 3579–3593. [CrossRef]
148. Valedsaravi, S.; El Aroudi, A.; Barrado-Rodrigo, J.A.; Issa, W.; Martínez-Salamero, L. Control Design and Parameter Tuning for Islanded Microgrids by Combining Different Optimization Algorithms. *Energies* **2022**, *15*, 3756. [CrossRef]
149. Hassan, M.A.; Abido, M.A. Optimal Design of Microgrids in Autonomous and Grid-Connected Modes Using Particle Swarm Optimization. *IEEE Trans. Power Electron.* **2010**, *26*, 755–769. [CrossRef]
150. Nair, D.R.; Nair, M.G.; Thakur, T. A Smart Microgrid System with Artificial Intelligence for Power-Sharing and Power Quality Improvement. *Energies* **2022**, *15*, 5409. [CrossRef]
151. Micro Grid Operational Issues and Challenges in Smart Grid Scenario While Heterogeneous Micro Level Generations Are Predominant. *Int. J. Innov. Technol. Explor. Eng.* **2019**, *8*, 908–917. [CrossRef]
152. Vadi, S.; Padmanaban, S.; Bayindir, R.; Blaabjerg, F.; Mihet-Popa, L. A Review on Optimization and Control Methods Used to Provide Transient Stability in Microgrids. *Energies* **2019**, *12*, 3582. [CrossRef]
153. Wang, R.; Sun, Q.; Gui, Y.; Ma, D. Exponential-function-based droop control for islanded microgrids. *J. Mod. Power Syst. Clean Energy* **2019**, *7*, 899–912. [CrossRef]
154. Bhaduri, R.; Saravana, G.R.; Vaskar, C. Supervisory Controller for Power Management of Microgrid Using Hybrid Technique. *Trans. Electr. Electron. Mater.* **2019**, *21*, 30–47. [CrossRef]
155. Najafi, P.; Viki, A.H.; Shahparasti, M. Evaluation of Feasible Interlinking Converters in a Bipolar Hybrid Microgrid. *J. Mod. Power Syst. Clean Energy* **2020**, *8*, 305–314. [CrossRef]
156. Norouzi, M.; Aghaei, J.; Pirouzi, S.; Niknam, T.; Lehtonen, M. Flexible operation of grid-connected microgrid using ES. *IET Gener. Transm. Distrib.* **2019**, *14*, 254–264. [CrossRef]
157. Begum, M.; Eskandari, M.; Abuhilaleh, M.; Li, L.; Zhu, J. Fuzzy-Based Distributed Cooperative Secondary Control with Stability Analysis for Microgrids. *Electronics* **2021**, *10*, 399. [CrossRef]
158. Eskandari, M.; Li, L.; Moradi, M.H.; Siano, P. A nodal approach based state-space model of droop-based autonomous networked microgrids. *Sustain. Energy Grids Netw.* **2019**, *18*, 100216. [CrossRef]
159. Eskandari, M.; Li, L.; Moradi, M.H.; Wang, F.; Blaabjerg, F. A Control System for Stable Operation of Autonomous Networked Microgrids. *IEEE Trans. Power Deliv.* **2019**, *35*, 1633–1647. [CrossRef]
160. Eskandari, M.; Li, L.; Moradi, M.H.; Siano, P.; Blaabjerg, F. Active Power Sharing and Frequency Restoration in an Autonomous Networked Microgrid. *IEEE Trans. Power Syst.* **2019**, *34*, 4706–4717. [CrossRef]
161. Eskandari, M.; Li, L. Microgrid operation improvement by adaptive virtual impedance. *IET Renew. Power Gener.* **2018**, *13*, 296–307. [CrossRef]
162. Mahamedi, B.; Eskandari, M.; Fletcher, J.E.; Zhu, J. Sequence-Based Control Strategy with Current Limiting for the Fault Ride-Through of Inverter-Interfaced Distributed Generators. *IEEE Trans. Sustain. Energy* **2018**, *11*, 165–174. [CrossRef]

163. Eskandari, M.; Rajabi, A.; Savkin, A.V.; Moradi, M.H.; Dong, Z.Y. Battery energy storage systems (BESSs) and the economy-dynamics of microgrids: Review, analysis, and classification for standardization of BESSs applications. *J. Energy Storage* **2022**, *55*. [CrossRef]
164. Moradi, M.H.; Eskandari, M.; Hosseinian, S.M. Cooperative control strategy of energy storage systems and micro sources for stabilizing microgrids in different operation modes. *Int. J. Electr. Power Energy Syst.* **2016**, *78*, 390–400. [CrossRef]