An Overview of Various Control and Stability Techniques for Power-Sharing in Microgrids

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1 Introduction

Today, the conventional AC grid is based on large-scale power generation, and the major source of energy is exhaustive fuels such as diesel, coal and gas. Demand for electricity is increasing exponentially, leading to lower grid stability and reliability [1–3]. To meet the demand of power generation, new options open up in terms of renewable energy generation [4]. The effective involvement of various RERs-based generation results into many advantages like better environmental policies, lowers fossil-fuel-based generation, bidirectional power flow and utility end active participation.

The service grid finds difficulty to connect directly to distributed generators (DGs), which comprises of photovoltaic (PV) panel, wind turbine, hydro, storage devices, microturbines and fuel cells, as shown in Fig. 1; therefore, the need for the microgrid

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K. S. Sherpa et al. (eds.), *Advances in Smart Grid and Renewable Energy*,
Lecture Notes in Electrical Engineering 691,
https://doi.org/10.1007/978-981-15-7511-2_1

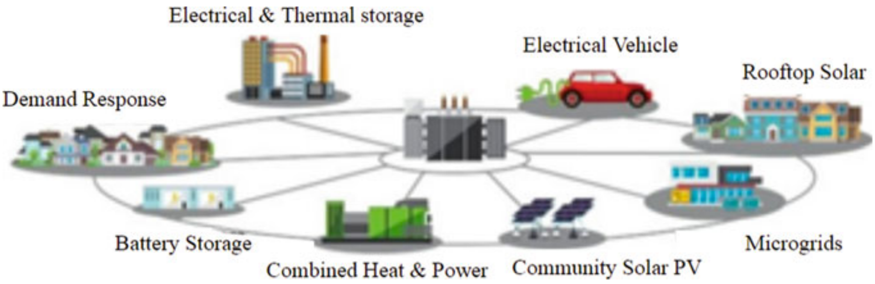

Fig. 1 Schematic representation of different DGs

arises [5]. Another most significant reason for establishing the concept of DGs is that they can respond to load demand at their place that it refers to as local generation [6, 7]. This interface consists of an energy storage, low distribution voltage consisting of DG and load units. DG units allow microgrid to play a major role as compared to classical generator. They possess a high degree of controllability and operability, thus maintaining the stability of power network [8].

The microgrid concept is essentially a dynamic system that integrates multiple DGs and uniform loads at distribution voltage level [9]. The intermittent characteristics of DGs which defy the power quality, stability, frequency and voltage manifest the requirement for new planning and operation approaches for microgrids [10]. Consequently, conventional optimization methods in new power systems have a critical concern in the operation of the microgrid.

Additionally, many literatures have also provided a large number of control strategies, as shown in Fig. 2, designed to quantify disturbance rejection, tracking of

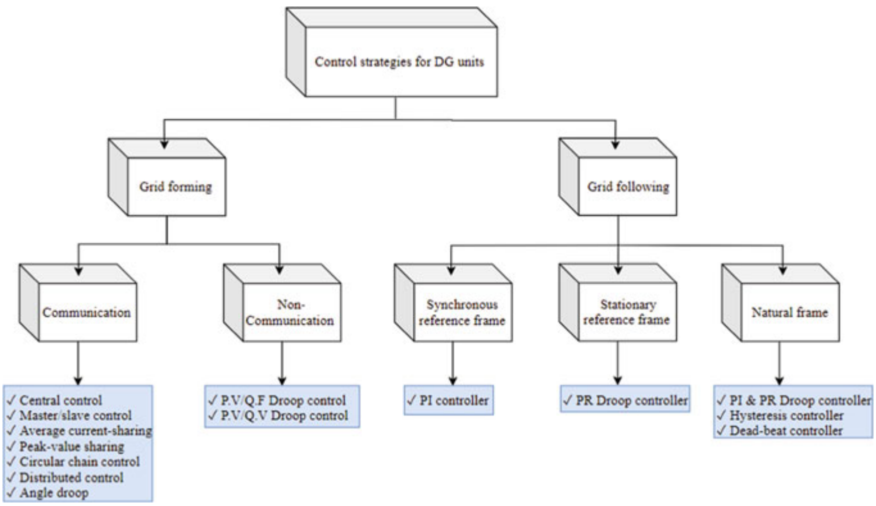

Fig. 2 Techniques of primary control [10]

inverter output (i.e., voltage and current) and power quality [10, 11]. Communication and non-communication are the two-classical control methods of load sharing in DG units: Communication control-based methods are summarized as condensed control, master and slave inverter control and dispersed control [12–15], whereas the non-communication control-based methods are classical droop control [16–19], virtual scheme-based method [20–23] and create- and reward-based method [24–26].

This paper tries to show the strategies to control the DG unit with grid forming when different control and load-sharing methods of inverters are applied to microgrid. Section 2 gives an outline of the different communication control methods. In Sect. 3, different types of non-communication control methods are presented. Section 4 focuses on discussion prospects. Finally, Sect. 5 gives conclusion on the different methods of droop control.

2 Communication Control Methods

The primary control aims to properly regulate the voltage and share loads. Also, without using a secondary control, the amplitude of output frequency and voltage are near close to their ratings. But these control methods involve the communication link between the modules, which ultimately affect the cost of the whole system. Types of communication control methods are:

2.1 Central Limit Control (CLC)

Figure 3 shows the methods that are discussed in [12], which involves common synchronization signals and current sharing modules. A phase-locked loop (PLL) circuit is equalized between the output voltage, frequency and synchronization

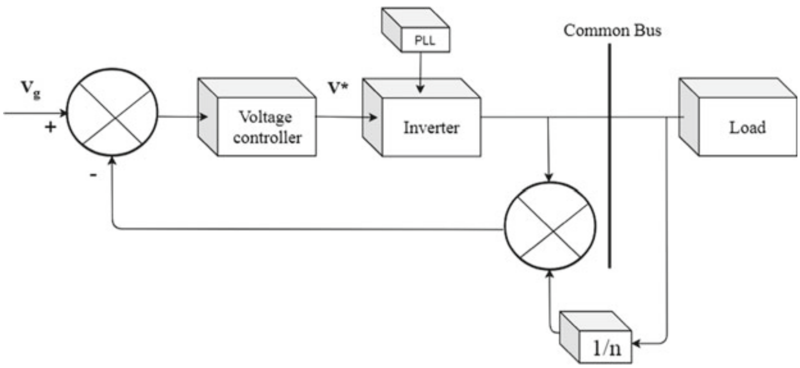

Fig. 3 Schematic for central limit control

signals. Each module also monitors the average current to achieve the same distribution.

The key benefit of such technique is that current sharing in both a steady and a transient state is continuous. Moreover, there is a centralized controller in this technique which restricts the system expansion. To achieve synchronization between the modules [12], high-bandwidth communication lines are required for the current transient through the converters; thus, this approach significantly increases reliability.

2.2 Master and Slave Inverter Control

With this kind of control method, the inverter is connected in parallel with the starting module acting as a master inverter. The master inverter is responsible for parallel control, while the other inverters act as slave inverter [10, 11]. Figure 4 depicts the schematic diagram for the master/slave scheme with a central controller. Through this control scheme, it is noticed that it has a good performance in power-sharing [12]. Once the master inverter fails, the improved control operation will switch to another inverter, becoming the new master. Therefore, parallel operation of such inverter would not get affected, but the drawback of this method is that the output current overshoot takes place during transients, and hence, transient performance is not good.

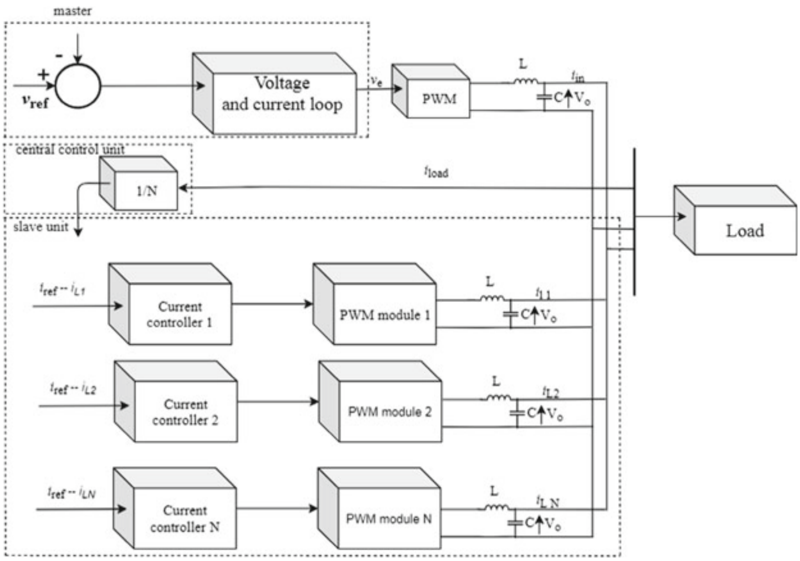

Fig. 4 Schematic diagram for master/slave scheme with central controller [13]

2.3 Average Current Sharing

Regardless of the master/slave control technique, there is no central unit in this method. Actually, this scheme requires a voltage synchronization and current sharing bus. A control signal is shared between DGs by voltage and current reference [12, 13]. In this approach, one converter is assigned to be master unit that operates in controlled voltage mode to establish the DC bus voltage, while the other converters are configured as slave converters operating in a current-controlled mode.

2.4 Peak-Value Current Sharing

For AC bus during the islanding condition, a dual-loop voltage controller with a converter is used to regulate the voltage. In this context, there is a proportional-resonant controller (PR) used for an internal and external current and voltage control loop, respectively, whereas other power converters are equipped with a current control loop in PR controller [12, 13].

2.5 Circular Chain Control

This control strategy as its name indicates is the scheme that DG interfaces are connected together in the form of circular chain. According to Arani et al. [12], all inverters form the chain and each inverter follows the inductive current of itself and the earlier inverters. In this control method, each inverter's output current and voltage are regulated by the outer voltage control loop and the inner current control loop, respectively.

2.6 Angle Droop Control

With conversational angle droop control, the active and reactive power is controlled by the amplifier and frequency of the voltage. Small angles can change the power-sharing of the microgrid between DGs [12–14]. Therefore, each inverter in the micro-grid is responsible to change its angle according to its active output power. This control method can be modified for active and reactive power control in the micro-grid in terms of the network characteristics. While implementing the angle droop control appears to be more difficult than standard droop control, the systems which use this technique can achieve greater stability margins.

2.7 Dispersed Control

The dispersed control is generally applied to converters connected in parallel [13–16]. In this type of control, the average current is shared. No central controller is used in each inverter, and every module is symmetric. There is also a good management of regulating and power-sharing, but there is no link between inverters. This debases the adaptability and repletion of the system. More conflicts are in this type of system since the number of parallel segments and connection line distances is increased.

3 Non-communication Control Methods

The control techniques that function with non-communications for control of electricity sharing are based on the droop concept [19, 20] Connecting remote inverters is often essential without communication. It can avoid the heavy costs and complexity and enhance supervision, system redundancy and reliability specifications [22, 25–27]. Moreover, because the plug and play function of the modules enable one unit barred to stop the system as a whole, it is less hard to stretch such a machine. Thus, communication strains, especially for lengthy distances and excessive investment costs, are often avoided.

3.1 Classical Droop Control

The classical droop control is also known as the primary control. The fundamental concept is to reduce the frequency when active power is increased and imitate the role of a synchronous generator. If the inverter's output impedance is especially efficient and reactive, then [12]:

$$P_i = \frac{E_i V \sin\alpha}{X} \tag{1}$$

$$Q_i = \frac{E_i V \cos\alpha - V^2}{X} \tag{2}$$

where E is the converter voltage amplitude; X is the coupling impedance; a is the angle of converter voltage; P_i and Q_i are the active and reactive powers, respectively; and V is the voltage amplitude in PCC.

The P_i and Q_i are particularly dependent on the power angle and voltage amplitude, respectively. With reference to Eqs. 1 and 2, the following assumption can be drawn and the characteristic droop control for $P - \omega$ and $Q - E$ is shown in Fig. 5.

A classical droop control block diagram is presented in Fig. 6.

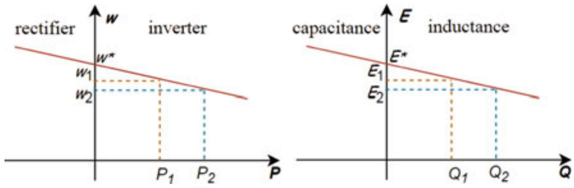

Fig. 5 Characteristic droop control for $P - \omega$ and $Q - E$ [10]

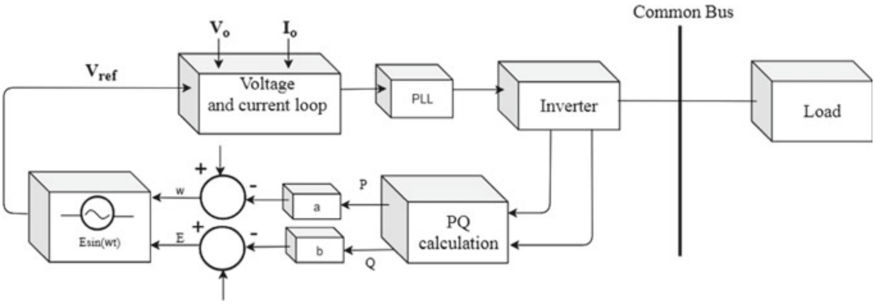

Fig. 6 Block diagram of classical droop control

As the classical droop control method is trustworthy, however, there are some disadvantages:

- Absence of multiple control targets.
- Instead of highly inductive line impedance, there should be mixed resistive and inductive line impedance as in microgrids.
- In microgrid, the voltage is overall not variable; therefore, it is hard to share reactive power within parallel inverters, and it can also produce circulating reactive current.
- This method only examines fundamental values and does not deal with voltage and current harmonics.

For minimizing above limitation, following methods are discussed in [22, 28].

- *Voltage Real Power Drooping or Frequency Reactive Power Boosting*: Droop/boost control method provides enhanced act [25–29] for controlling large resistive transmission line of AC microgrid with low voltage. But this method fully depends on the parameters of the system, which naturally decreases its utilization.
- *Droop-Based Method on Complex Line Impedance:* Issues like line impedance reliance, inaccurate P or Q law and sluggish transient response cannot be addressed or solved in classical droop method. In [29], when considering the influence of complex impedances, the controls solve the connected active and reactive power ratio, provide excellent dynamics and are more useful when the elements

of the line impedance and inductance resistance ($X \approx R$) in MV microgrids are comparable.

- *Power angle-based droop control method*: The phase angle of this distributed source voltage corresponds to the widely used system timing so that the energy requirements are shared between DGs [27]. With this method, a proper load sharing between DGs is achieved without a steady-state frequency drop. However, in the case of synchronization of native control boards, there is no defect in the processor crystal clock (digital), and the frequency differs slightly from that of every inverter and thus increases system instability.
- The droop control based on voltage is one of P/V type control methods. This strategy demonstrates band control of the AC microgrid islanded type steady energy [27]. It fully utilizes the voltage variable that is permitted. By linking the P/V droop control to Pdc, the voltage limit breach can be prevented if the continuous energy band is overflowing. However, this technique of control requires microsources to readily dispatch power. This control technique requires a multi-stage controller that impacts the system frequency.

3.2 Virtual Scheme-Based Method

Virtual impedance line droop control is a standard droop controller that does not give the proper reactive power distribution between parallel-associated inverters under a line impedance imbalance. The difference in the reactive power-sharing of an AC microgrid thus poses an important issue. Some experiments have been conducted via a quick control loop which copies the impedance in the row in Fig. 7 [10–13] to implement the virtual impedance in the droop control strategy.

The virtual impedance of output is selected primarily for the lead impedance of the line [21]. A summing strategy in this line permits the selection of the virtual impedance, to accomplish an adjusted share of reactive power if the voltage from each inverter is lowered to the AC bus [21–24].

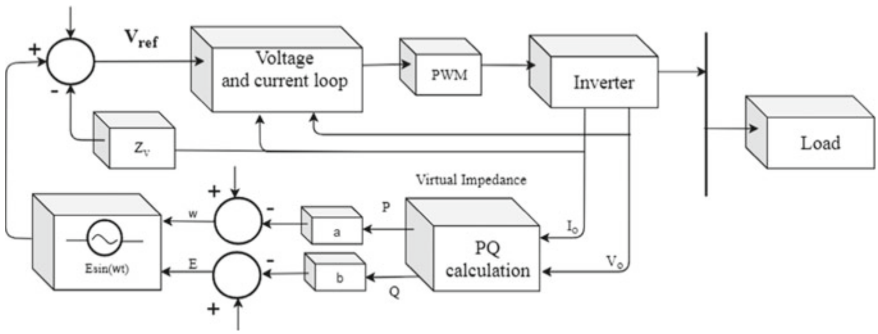

Fig. 7 Virtual impedance loop-based droop control

The estimation of virtual impedance is reduced using the summation method which reduces voltage control. Once the output voltage exceeds that of overline voltage, reactive power-sharing is improved.

3.3 Create- and Reward-Based Methods

The classical droop control includes a few issues to be understood, such as line impedance reliance, incorrect power-sharing and moderate transient reaction [25–27]. Therefore, variations in the traditional droop control have been suggested to address these issues.

Figure 8 depicts the adaptive droop control which is proposed to extensively keep up the voltage magnitude with precise reactive power-sharing [25]. With the model, the most extreme reactive power $Q_{\max}$ is drawn from every unit and contrasted with a reference amount of reactive power Q_{ref}. Once the reactive power is maximized, it is not exactly with the reference value, and then it is after the traditional *Q/E* drop that the voltage amplitude is applied. To obtain a desired voltage amplitude, the distinction between the output reactive power Q and the Q_{ref} is used as an added value.

With the powerful droop control technique, the classical voltage droop can be modified as:

$$\Delta E = E - E^* = nP \tag{3}$$

where ΔE is zero for grid-connected mode, while the active power in islanded mode cannot be zero, hence, leading ΔE not be zero. Another issue is noticed when a change in load occurs that makes the voltage drop. The low voltage drop can be accomplished by choosing a lower droop coefficient. For quick reaction, it is required to choose a larger value for droop consistency. Changing $E^* - Vo$ by means

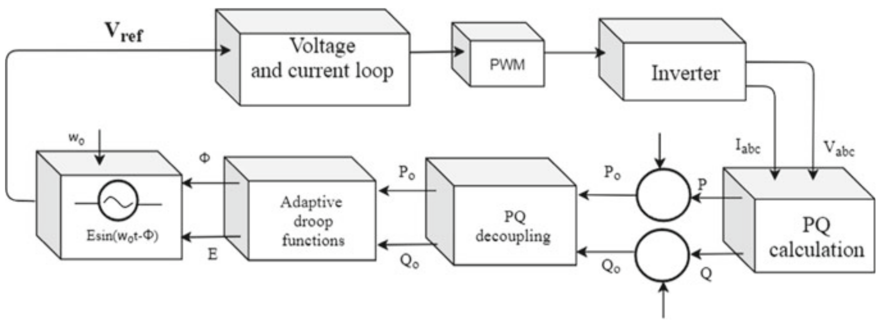

Fig. 8 Block diagram of closed-loop system with adaptive droop control

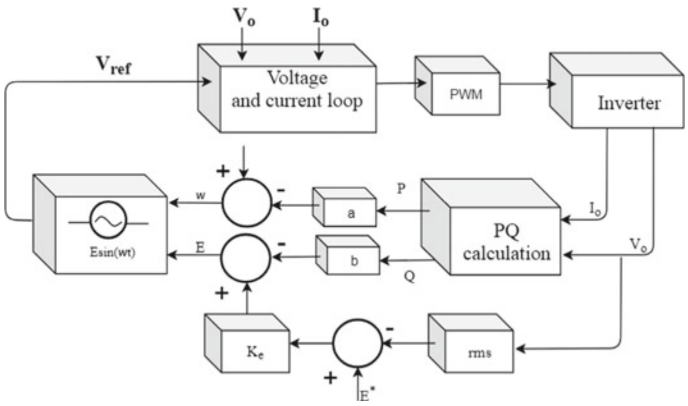

Fig. 9 Block diagram of powerful droop control

of a certain path through vital hypothesis, control regulation can achieve the voltage decrease.

This system is an expert in utilizing the enhanced droop controller exhibited in [26], and the approach is otherwise called powerful droop control. This control approach shown in Fig. 9 alters the droop condition by deducting the inverter output voltage RMS from the set point of voltage. In the perspective of the drop and load impact, this strategy remedies the voltage drop. In addition, the load tension is maintained in the rated value, but the reactivity share is poor.

4 Discussion

As discussed before, it was presumed that each of the proposed control procedure has its own particular qualities, favorable circumstances, disadvantages and applications. The droop control operation is mainly based on restricted system status estimates. These variables allocated to the DG totally and repeat themselves since they retain a strategic distance for a secure assignment from the fundamental communication interface. Conversely, there are some drawbacks in classical droop control.

Distinctive varieties, like virtual scheme-based method and create- and reward-based method, have been suggested in researches to overcome the constraints of classical droop control. To add to this, the methods based on the virtual scheme can give precise sharing of reactive power between parallel-associated DG inverters. But this control technique presents a few constraints, such as lowering the voltage regulation and increasing in no load voltage.

Create- and reward-based scheme offers brilliant voltage regulation and reactive power-sharing. But these strategies result in load harmonic sharing and poor active power. Generally, for AC microgrid the central control procedures are to give an account of the conclusive points that can resolve the given issues:

Table 1 Possible benefits and drawbacks of communication-based control

	Communication-based control		
	Concentrated control	Master/slave control	Distributed control
Benefits	Continuous power-sharing in steady and transient conditions Control frequency and regulation of voltage	Easily recuperate output voltage Continuous power-sharing in steady and transient conditions	Symmetrical for every module Continuous power-sharing with constant voltage supply
Drawbacks	Communication with high bandwidth Low expandability and reliability	During transient's stage, it has high current overshoot Communicate with high bandwidth Low redundancy	Require bus communication Degrade the system's modularity

- Stability issue
- Harmonic load sharing
- Settlement within frequency and active power-sharing
- Integration of sustainable power source assets.

However, the possible benefits and drawbacks of communication and without communication-based control methods are shown in Tables 1 and 2, respectively.

5 Conclusions

This chapter shows a comprehensive study on DG unit load-sharing control techniques. The work contains droop methods which demonstrate improved efficiency in terms of additional services like impedance of the system, harmonic energy sharing and the appropriate voltage and energy control. In view of the discussion depends upon the survey, the varieties of the droop control procedure remove the basic drawbacks of the classical droop control (i.e., impact of the impedance imbalance on active and reactive power-sharing and frequency deviation). The survey also reveals that changing a single control technique for all applications or improving one variety's deficiency in classical droop control is alarming. Nevertheless, it is well understood that various variants of the droop control method are able to solve their own limitation and improve the microgrid's overview and performance.

Table 2 Possible benefits and drawbacks of non-communication-based control

	Benefits	Drawbacks
Conventional and variants on droop control		
Conventional frequent droop control	Implementation can be achieved without communication More flexibility, expandability and modularity	Poor harmonic sharing with slow dynamic response Low frequency and voltage regulation Physical parameters need to be considered
VPD/FQB droop control	Good for high resistive transmission lines Communication is not required	Physical parameters need to be considered Poor frequency & voltage regulation
Complex line impedance	Decoupled active and reactive controls Better regulated voltage	Line impedances need to be considered
Angle droop control	Improved regulated frequency	Need GPS signals Low power-sharing
Droop control with constant power band	Micro-source characteristic and specification are considered Operates with MPPT and functions with certain range Energy usage is more efficiently Limits low voltage limit issue	Dispatched abilities are required for micro-source Require multi-stage controllers and impact on system effectiveness
Virtual structure-based method		
Virtual output impedance control	Physical parameters are not concerned Good system stability and power-sharing	Voltage regulation is not guaranteed Controller requires relatively high bandwidth
Enhanced virtual impedance control	Able to manage both linear and nonlinear loads in power-sharing Mitigates the PCC harmonic voltage	Communicate with low-bandwidth Physical parameters need to be considered
Virtual frame transformation method	Decoupled active and reactive power controls	Difficult to achieve same angle of transformation for all DGs, physical parameters need to be considered
Constructed and compensated-based method		
Adaptive voltage droop control	Good voltage regulation Better power-sharing and system stability under heavy load condition	Physical parameters need to be considered

(continued)

Table 2 (continued)

	Benefits	Drawbacks
Synchronized reactive power compensation	Good power-sharing performances No need to consider the physical parameters	Low synchronized communication bandwidth
Droop control-based synchronized operations	Good power-sharing performances No need to consider the physical parameters Robust to communication delay	Low synchronized communication bandwidth
$Q - V$ dot control method	Like conventional droop control	It requires initial conditions Limits the steady-state solutions Quick destabilization
Common variable-based control method	Constant reactive power-sharing No need to consider the physical parameters	Difficult to get constant voltage due to long distance
Signal injection method	Can handle both linear and nonlinear loads No need to consider the physical parameters	Contains harmonic distortion in voltage

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