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Secondary Control Strategies in the DC Microgrids

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Abstract: - Now, DC microgrids have become more popular for several reasons, including the lack of issues related to reactive power and frequency control, the direct integration of energy storage devices and solar photovoltaic, and the higher utilization of DC loads. A DC microgrid using several sources (distributed generation) is a popular research area. The main issue in such a DC microgrid is to provide good voltage regulation and proportional power sharing among all sources. Control strategy is very important to solve the above issue in order to maintain the reliability and stability of DC microgrids. Hence, a comprehensive review of DC microgrid control techniques is essential. Compared to other methods, hierarchical control is widely used to solve the aforementioned issue. It consists of three layers of control: primary control, secondary control, and tertiary control. At the primary level, to improve current sharing performance, droop control is usually applied. Secondary control is used for voltage regulation of the DC bus. A tertiary control is a higher-level control to achieve Optimization and economical grid operation. In traditional primary control, it is not possible to attain accurate power sharing and voltage regulation simultaneously. Thus, secondary control is required. So, this paper reviews the secondary level control techniques in the hierarchical control strategy for DC microgrids. Precisely, Centralized, distributed, and decentralized approach-based secondary control are reviewed. Several secondary control techniques have been thoroughly examined in terms of their advantages and disadvantages making this an excellent resource for both academics and business executives.

Keywords: Droop control, Hierarchical control, Distributed Control, Secondary control, DC Microgrid

I. INTRODUCTION

Recently, distributed generators (DGs) have gained much popularity as a way to resolve the issue of environmental pollution and decrease the necessity of fossil fuels in traditional power-generating systems [1-2]. To offset the shortage of electricity, particularly at remote locations where a power infrastructure is inaccessible, maximize the use of renewable energy sources (RESs) [3-4]. Renewable energy sources are part of the DGs, and their primary benefits are as follows: reducing loss in the distribution line, boosting reliability, lowering the chance of blackouts, being easily scalable, and supplying electricity to remote areas [5].

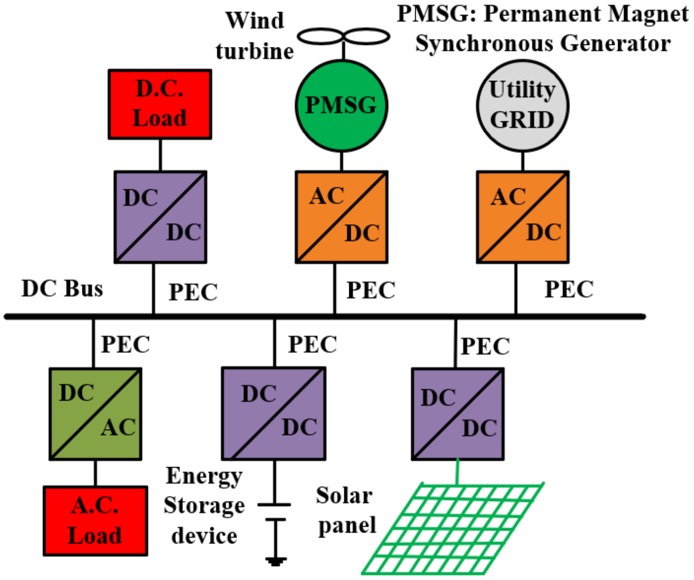

Fig. 1 Simple structure of a DC MG

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The combination of distributed generation (DGs) with regulated loads and energy-storing components, such as flywheels, batteries, and energy-saving capacitors, is the fundamental idea of microgrids (MGs) [6-7]. In 2002, R. H. Lasseter reintroduced the concept of microgrids as a future Low-Voltage Distribution System for combining DGs. It can function independently in island mode or grid-connected mode with existing power grid [8-9]. Contrary to AC microgrids, DC microgrids provide a lot of benefits. High efficiency, good power quality, low cost, simple grid synchronization, no inrush current issue, and easy control because it doesn't require frequency regulation or reactive power control [10-11]. So, this study focuses on a DC microgrid.

Fig. 1 displays the basic diagram of a multisource DC - microgrid, where a DC bus connects the load and the source. The DC microgrid's structure differs from that of the utility grid's ring or radial system [12]. A control strategy is required to resolve the following problem in a multiple-source DC microgrid: 1) current sharing among parallel sources [13-14]; 2) DC bus voltage regulation [15-17]; 3) power quality.

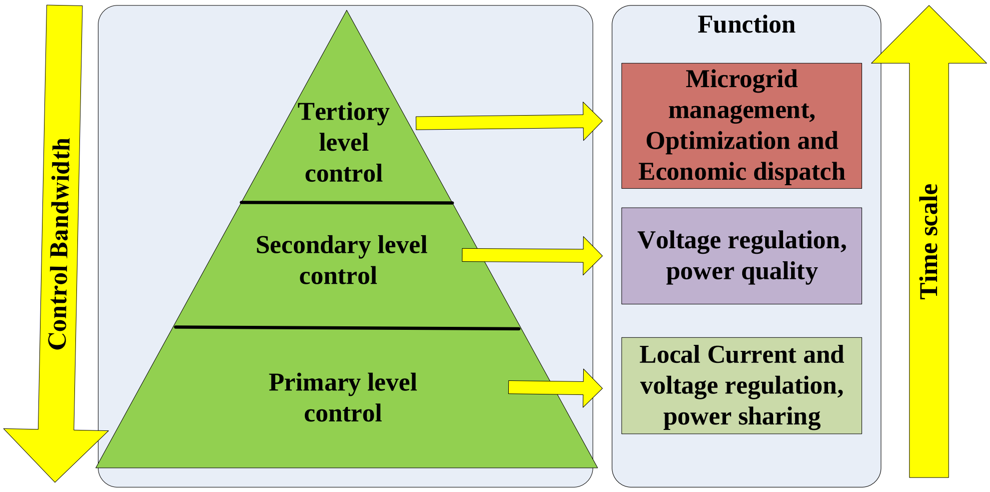

Fig. 2 Hierarchical architecture

A hierarchical control strategy is frequently used to solve the above control problem [18]. It is made up of a digital communication link and a local converter. Fig. 2 displays the three layers of the hierarchical control strategy: primary layer control, secondary layer control, and tertiary layer control. Primary-level control is a lower-level control that combines power-sharing control with regulation of voltage and current. Secondary-level control, situated next to primary-level control, serves as a point of reference for local control aimed at correcting voltage variation and enhancing power quality. The highest-level control is the tertiary-level control, which addresses the issue of power and energy management and optimisation of the microgrid [19-20]. Operating time and control bandwidth are used to distinguish the functionalities of each level. When switching from a primary control layer to a tertiary control layer, reduce the control bandwidth while increasing the operating time [18].

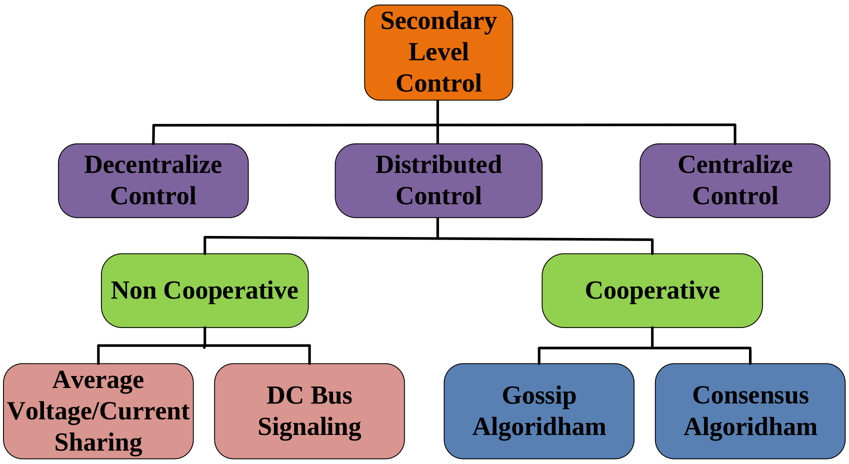

Fig. 3 Overview of the paper

The droop control technique used in primary control ensures proportional current sharing among all sources if a droop gain is significantly greater than the resistance of the line. Nevertheless, as mentioned in [21], if a large droop gain is used, the DC bus voltage will significantly drop from its nominal reference voltage. result in, if just primary control is employed, DC bus voltage regulation and current sharing accuracy are not achieved simultaneously. Hence, it required a secondary-level control technique.

Most of the present literature reviews only the primary control techniques. So, the main goal of this study is the review of secondary control techniques in a hierarchically controlled DC microgrid. The review technique used in this study is shown in Fig. 3. The paper is organized in the following manner: In Section 2, primary-level control is discussed. Section 3 discusses various secondary-level control approaches, including centralize, decentralized, and distributed approaches. A summary of secondary control is provided in Section 4, and a conclusion is provided in Section 5.

II. PRIMARY LEVEL CONTROL

The primary level control is a local level control without a communication link. Inner loop control and outer loop control make up primary control. The purpose of inner loop control is voltage regulation and current control. Droop control's primary function is to act as an outer loop control, giving the inner loop control a point of reference. Droop control makes the system more reliable and modular [18].

A. Conventional Droop Control

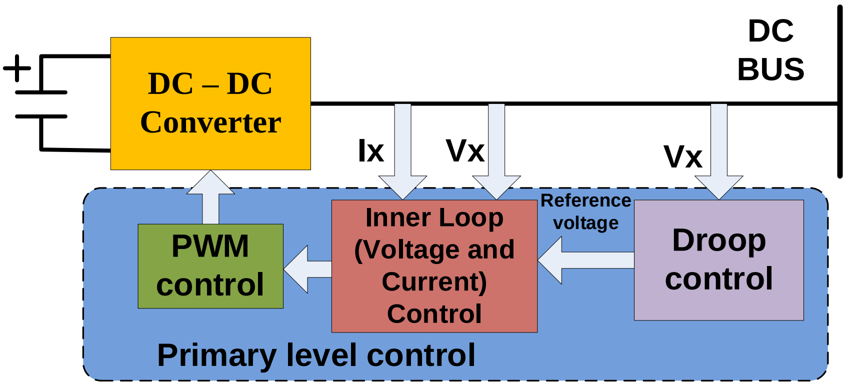

Fig. 4 primary controls (droop control) for power sharing [22]

Fig. 4 displays a block diagram of the droop control technique for each local DG. A well-designed inner control loop produces the DC output voltage of the converter Vx, which rapidly reaches the reference voltage V_x^{ref}, i.e.,

$$V_x = V_x^{ref} \qquad (1)$$

The voltage reference V_x^{ref} is produced by a droop controller,

$$V_x^{ref} = V^n - k_x I_x \qquad (2)$$

The droop gain, output current, and nominal DC voltage, of the xth DG are represented by the variables $k_x,$ I_x and V^n, respectively. The DC bus voltage,

$$V_{bus} = V^n - R_x I_x \qquad (3)$$

Using equations 1, 2, and 3, we obtain,

$$V_{bus} = V^n - (R_x + k_x) I_x \qquad (4)$$

This suggests that

$$(R_{ix} + k_x) I_x = \left(R_y + k_y\right) I_y\,,\ \forall_{x,\ y} \qquad (5)$$

Based on equation (5), the power sharing ratio may be determined to be inversely proportional to the sum of the droop gain k_x and the line resistance R_x.

When compared to line resistance, the droop gain is significantly greater, giving $k_x \gg R_x$ so, we have,

$$\frac{I_x}{I_y} = \frac{R_y + k_y}{R_x + k_x} \approx \frac{k_y}{k_i} \qquad \forall_{x,\ y} \qquad (6)$$

From equation (6), it is shown that for appropriate droop gain, all DERs will share power proportionately [22].

The traditional droop control technique in primary level control has two main drawbacks. First, current sharing accuracy decreases because of the differences in output voltages of each converter. Due to the additional voltage drop produced by the line resistance, accuracy is further reduced. Second, voltage drop is caused by droop action [23].

B. Tradeoff in Conventional Droop Control

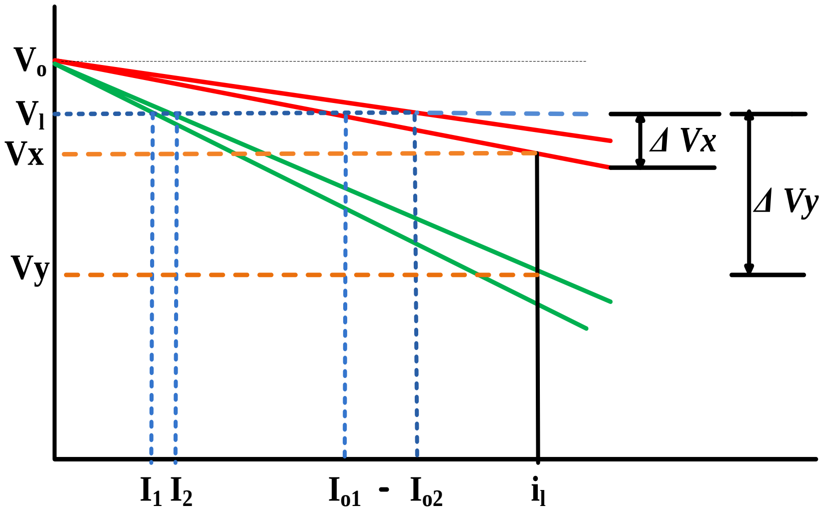

Fig. 5 Performance of droop control [18]

Fig. 5 shows that when a large droop gain is used, the difference in the converter's output current (I_1-I_2) is very small, indicating good current sharing accuracy, but the voltage drop, ΔVy, is very large, indicating poor voltage regulation. whereas a small droop gain causes a very huge difference in the converter's output current (I_{01}-I_{02}), indicating a significant reduction in current sharing accuracy, but the voltage drop ΔVx is very small, indicating good voltage regulation. This leads to a mismatch between current sharing accuracy and voltage regulation performance in the droop control scheme. To address this issue, secondary-level control is required [18].

III. SECONDARY CONTROL

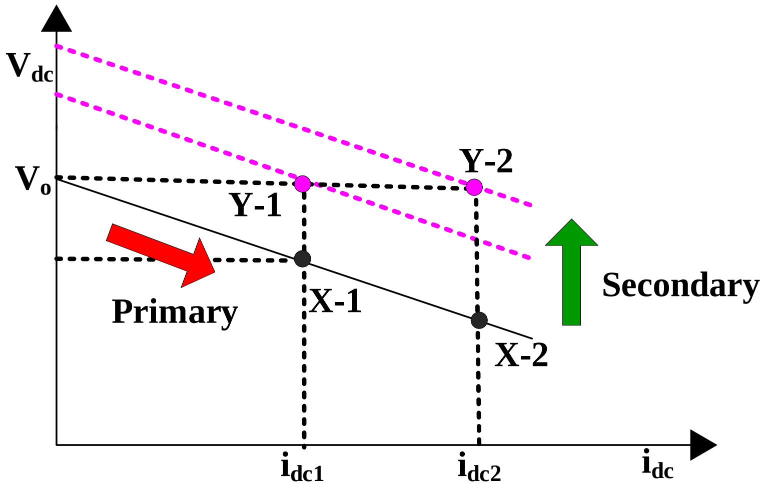

Fig. 6 Concept of secondary control [18]

The DC bus voltage of the droop-controlled DC microgrid will be regulated by means of a secondary control technique [24]. A concept of secondary control in hierarchical structure-based DC microgrids is displayed in Fig. 6. Vo is a nominal voltage of the DC bus. When a primary control is used, the DC bus voltage is shifted from the nominal voltage Vo to X_1 at the idc_1 load current and X_2 at the i_{dc2} load current, respectively. After the implementation of secondary control, the voltage is shifted from X_1 to Y_1 and X_2 to Y_2, respectively, which verifies that the system is always working at the desired voltage level. Consequently, removing voltage variation to enhance current/load sharing performance is a primary objective of secondary level control [18]. A communication link is used to establish secondary control. On that basis, it is classified into three types: (i) Centralize secondary control; (ii) Decentralized secondary control; and (iii) Distributed secondary control [10].

A. Centralize Secondary Control

Fig. 7 shows a centralized secondary control scheme for DC microgrids in which all DERs within the microgrid are controlled locally using primary control. Secondary control consists of a microgrid central control unit (MGCC). It measures the different parameters interested to be controlled from the remote measuring block using a low-bandwidth communication link, compares them to a reference signal, generates an error signal that is processed by the secondary controller, and generates an operating point for the primary controller given back to the primary control by using low-bandwidth communication [24].

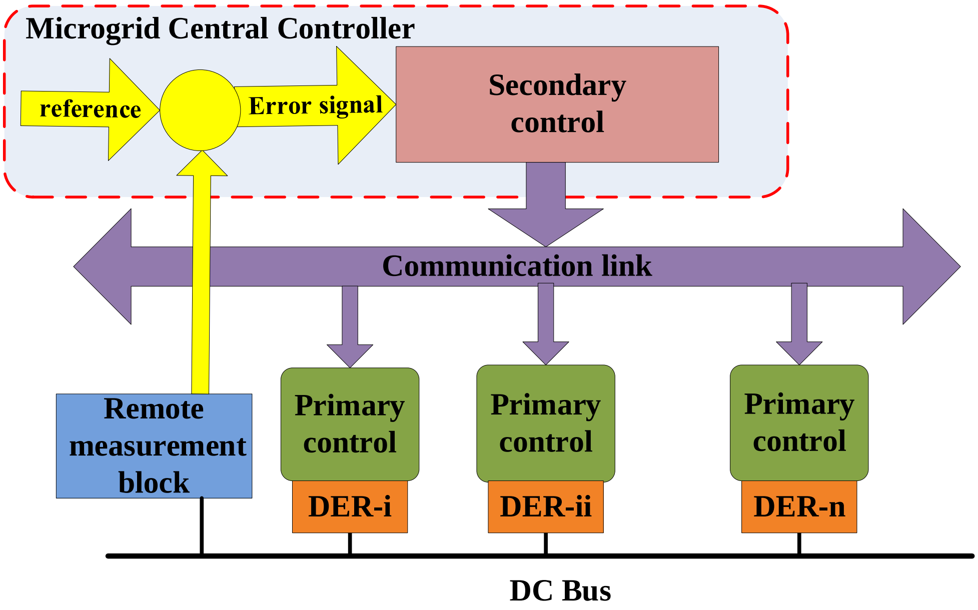

Fig. 7 Centralize secondary controls [24]

In [26], a new self-directed, communication-based, state event driven, hybrid control is developed for a DC microgrid. Event driven secondary controllers and state driven primary controllers are used. This structure simultaneously enhances control and fulfils other purposes, like reducing processing pressure, communication pressure, and the cost of the system. [27] proposed a secondary control technique for the compensation of unbalanced voltage to the point of common coupling. The PI control is used for generating the reference signal for the primary control. Secondary control communicates with all DGs by using low-bandwidth communication. [28] offers a centralized power flow control technique linked to an EV in a DC microgrid. Each agent in the DC microgrid has an operational mode that is established based on information about the grid's availability, battery SoC level, wind power source, and the status of the EV connection or disconnection. Additionally, [29] proposes an algorithm for centralised controls in DC microgrids to regulate power flow. The control method ensures MPPT, constraints for exchanging power with the utility grid, and DC bus voltage ripple compensation. The key benefit of this system is that there is not much traffic in a communication network because it uses unidirectional communication from remote measurement to MGCC and from MGCC to all DERs. And also monitor the whole system as much as possible to improve controllability. But a principal drawback is that the control act is only dependent on the MGCC. If problems arise with MGCC, it will result in an immediate outage of the whole system. That means this system suffers from a single point of failure [24]. Also, the requirement of large communication, decreased reliability, and restricted plug-and-play capability are some drawbacks of this control technique.

B. Decentralize Secondary Control

As displayed in Fig. 8, decentralized control is implemented for local regulation based on local measurements. In this scheme, there is no requirement of a centralized controller and communication network between the different sources; each parallel unit can work separately depending only on the local controllers and local measurement, which enhances system reliability very much [18].

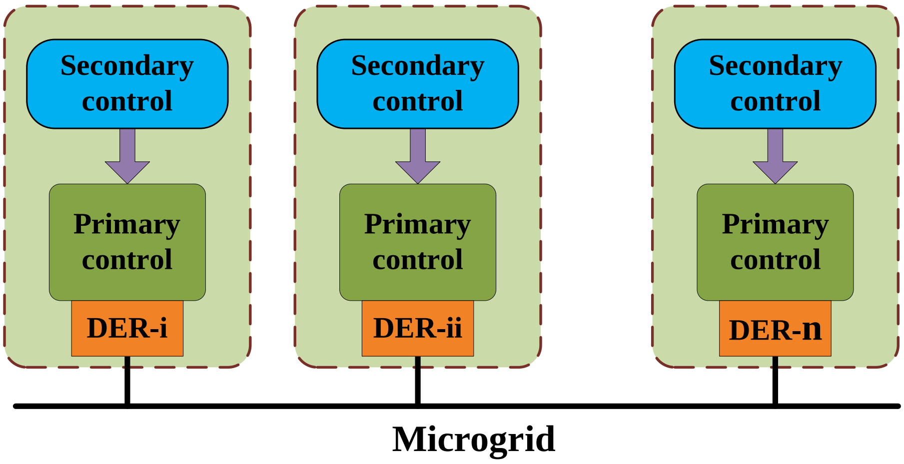

Fig. 8 Decentralize Secondary Control [25]

Reference [30] proposed a distributed control scheme implemented at the local level in DC microgrids. In this scheme, the effect of line resistance is nullified by using virtual negative resistance feedback. The proportional controller is used to modify the efficient droop gain to simultaneously accomplish good voltage regulation and precise load sharing. In [31], secondary control was decentralized in LVDC MG. In this method, two droop controls are merged, one at the primary level for current and power sharing and the other at the secondary level for voltage regulation. The main objective of the presented work is to adjust the dc reference voltage by adding a small ac voltage to the reference dc voltage. In [32], an improved voltage compensation method is proposed for a parallel converter. where optimal droop gain is selected on the basis of minimization of line losses. Source voltage reference is adjusted according to feeder current using a feed-forward link, which enhances voltage regulation with load sharing. In [33], we proposed a communication-free control for an island DC microgrid. It uses a decentralized leaky integral controller for the restoration of secondary voltage with current sharing. In this method, the unavailability of global data optimization is not possible.

C. Distributed Secondary Control

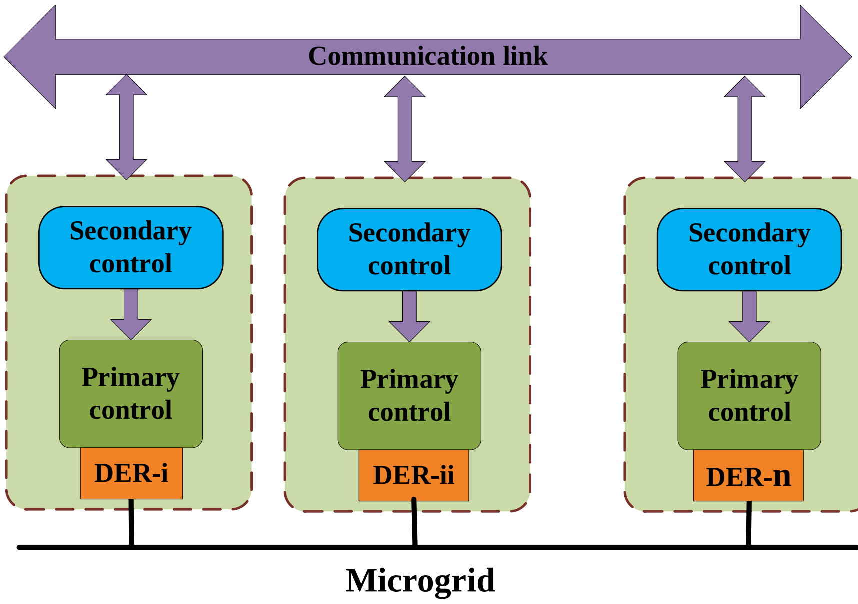

Fig. 9 Distributed secondary control [24]

The microgrid centralised control technique has a few drawbacks, like suffering from a single point of failure, not achieving the plug-and-play ability that is the most efficient requirement of microgrids, etc. Also, in decentralizing control, optimisation is not possible due to a lack of global information. To solve the above issue, the literature suggests a distributed secondary level of control [22].

A fully distributed secondary-level control system is exposed in Fig. 9. Each DG contains both the controller for primary control and the controller for secondary control. Each DGS secondary controller collects the required information (measured current, droop gain, and voltage) of all other DG elements within the microgrid by utilizing the low-bandwidth communication network, processes it, and generates the required control signal, which is transmitted to the primary controller for eliminating steady-state errors [24]. There are three categories of distributed secondary level control: (1) average voltage/current sharing control techniques; (2) DC bus signal control techniques; and (3) cooperative control techniques [18].

i Average Voltage/ Current Sharing Technique

Reference [34], proposed an improved secondary-level control method. Three different PI controls are used in this method: (1) average voltage control, (2) average current control, and (3) average droop coefficient control. The average voltage controller is utilized to control a local DC bus voltage. The average droop controller and average current controller work jointly for control of the droop coefficient; hence, every converter within the microgrid has equal equivalent output impedance, which improves the dynamic performance of the system with rapid variations in load current conditions. In [35], a proposed average voltage sharing control scheme aims for exact voltage regulation while securing the reliability of the system against failure of a communication link or converter. The bi-proper anti-wind-up concept is used for the design of the distributed secondary controller. For the adjustment of the reference set point, other pilot bus regulations are integrated.

Reference [36] proposed a distribution control with slow communication speed. It introduces the voltage sensitivity matrix for improved voltage regulation and power sharing. This is accomplished without using the proportional integration control in the secondary-level control. Reference [37-38] proposed a simple current average control and a voltage average control in a secondary control loop to compute average voltage and average current to restore the DC bus voltage and improve the current sharing accuracy in a DC microgrid. The distributed droop control proposed in Reference [38] operates on a variable droop resistance that is automatically adjusted in response to inequality in the converter's output currents, unequal line resistance, and errors in output voltage. Reference [15] proposes a secondary control method for reducing line loss, improved load sharing, and voltage regulation. Use an online algorithm in this approach to determine the optimal voltage shift with constant droops. The optimisation process makes use of the cost function. In this approach, all DGs communicate with all other DGs through low-bandwidth communication links. It improves communication requirements, and the system is not easily scalable.

ii DC Bus Signaling Technique

The DBS (DC Bus Signal) scheme is one of the low-cost and reliable distributed control methods without DCLs. This technique determines the mode of operation based on the measurement of the DC bus voltage. It is implemented on the basis of the setting of the voltage threshold, which determines the working mode of all integrated converters within the microgrid. The choice of voltage thresholds should be crucial in order to prevent the system from becoming unstable. An excessively small difference between the voltage levels may affect the sensor's accuracy; an excessively large variance will lead to inadequate voltage control, which will cause the DC bus voltage to fluctuate more than is permitted [8]. In [39], the proposed distribution secondary level control techniques depend on a DC bus signal. The DC bus voltage threshold in this system governs the actions of power electronic interface converters for sources and loads in order to control the nanogrid.

iii Cooperative Control

In an average current/voltage sharing approach, all DGs communicate with all other DGs through low-bandwidth communication links. It improves communication requirements, and the system is not easily scalable. To solve this issue in the literature, cooperative control is suggested.

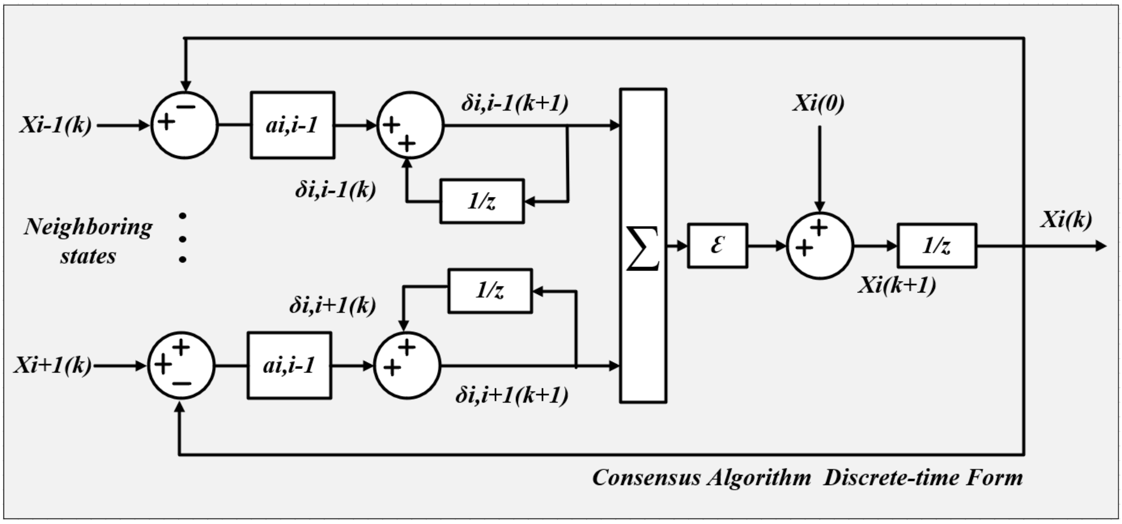

Fig. 10 Principles of a Consensus algorithms [42]

The key objective of a cooperative distributed control scheme is to estimate control protocols at the local level, which force every node to have equal steady-state constant values, identified as consensus values. To solve this problem, different distributed control protocols are presented in the literature, like the consensus algorithm [40-41]. Fig. 10 displays the principle of a consensus algorithms.

Reference [40] proposes secondary control using event-triggering based communication for the DC microgrid. System disturbances like delay communications, converter failure, and load changes are known as events in this technique. Communication is possible only at times of disturbance, which considerably reduces the communication burden. A dynamic consensus-based voltage observer and a current regulator were applied to enhance voltage regulation and load/current sharing performance. Reference [41] proposed a distributed secondary level controller to aim for precise current sharing among all agents and voltage regulation in a DC microgrid within a finite time. Compared to usual distributed secondary control methods, this scheme reduces chattering and overshoots, which are important for critical loads. Reference [13] proposes a secondary controller in a distributed approach on the basis of the voltage shifting concept. It exchanges only one variable, λ-factor, through the LBC link with the neighbor. The λ-factor is calculated using power output and voltage. Secondary controls only use a simple integrator to generate the voltage-shifting term from the average λ-factor.

Reference [43] proposes a novel distributed secondary control technique with a fixed current sharing ratio based on a new parameter, virtual voltage drops. In [44], references use nonlinear distributed control. It is used for triggering communication that significantly reduces communication pressure. Disturbance is designed as an event. It is complicated to implement in a real microgrid. Reference [45] proposes distributed secondary control to provide adjustable current sharing and voltage restoration for DC microgrids with time delays. For achieving an adjustable current sharing ratio amongst DC converters, this approach uses a time-varying droop gain. A distributed control system based on multi-agent deep reinforcement learning was presented in Reference [46]. A deep deterministic policy gradient (DDPG) approach is used by the secondary controller in online deep reinforcement learning (DRL). A distributed fixed-time secondary control system based on dynamic consensus is proposed in references [16], [47] for achieving voltage regulation of the DC bus and current sharing among the converters within a fixed settling time. In secondary loop reference [47], use a voltage observer and current regulator, and in reference [16], for accelerating convergence, use fraction-based feedback signals and sign functions.

Reference [48] suggests a distributed cooperative control approach for accurate oscillatory current-sharing in DC microgrids, which shares both the oscillatory and DC components of current among microgrids. The voltage drops in the DC microgrid generated by the droop controller are compensated by a voltage observer. In reference [49], the enhanced distributed secondary control (IDSC) of DC microgrids based on the dynamic consensus method was presented. The IDSC is comprised of an average current controller and an average distributed integral voltage compensator. An ideal current sharing controller for DC microgrids based on consensus was presented in Reference

[50]. Consensus-based average voltage and ideal current estimators are used for each converter. The droop characteristic of the converter is modified based on the error between these estimates with respect to the converter's current/voltage. References [48-50] use two variable voltage and current that are shared and use two secondary loops. Reference [51] proposed distributed cooperative control in a DC microgrid of multiple DC electric springs for voltage regulation by sharing only one variable with neighbors. A distributed event-triggered control technique for average voltage regulation and load current sharing in DC microgrids was proposed in [14], [52-53]. Each local controller only talks with its neighbour when the triggering condition is met in an event-triggered mechanism that is evaluated locally.

The Gossip algorithm is similarly popular in distributed control. The main advantages of this algorithm are the elimination of SPOF and the robustness of the unreliable wireless network. But it is executed asynchronously, randomly choosing any one node that estimates the control signal exchange with other nodes to update them to the global estimation [54-55].

IV. SUMMARIZATION

Using only primary control, good voltage regulation and exact power sharing cannot be accomplished simultaneously, which requires secondary control. Based on communication requirements, secondary control techniques are grouped into three categories of control: centralized secondary control, distributed secondary control, and decentralized secondary control. Give a comparison of all three controls in Table 1. Centralize and distributed control; use the communication link for control action. Therefore, reduce the reliability of both control strategies. A single point of failure is one of the key disadvantages of centralized control. Decentralized control is locally implemented, hence the lack of global information. According to the number of references for each category, the recently distributed control strategy is very popular. Table 2 displays a comparison of different approach in distributed secondary control technique for DC microgrid and Table 3 shows a comparison of cooperative control approach in the distributed secondary control techniques.

Table-1 Comparison of centralize, decentralized, and distributed secondary control techniques in DC microgrids

Particular	Centralize control	Decentralized control	Distributed control
References	[24, 26 - 29]	[30 - 33]	[41-50]
Communication	DCL (Low Bandwidth)	-	DCL (Low Bandwidth)
MGCC	Available	Not available	Not available
Single point of failure	Main issue	No issue	No issue
Reliability	less	Very High	Very high
Modularity	less	High	Moderate
Plug and Play Capability	No	Yes	Yes
Advantages	▪ Strong observability, ▪ proper coordination, ▪ global information is available for optimization	▪ Less complex, ▪ easy implementation, ▪ Regulation depends only on local measurement, ▪ Improve stability	▪ Improved immunity to SPOF, ▪ Improve stability, ▪ Improve reliability
Disadvantages	▪ Single point of failure,	▪ global information is not available,	▪ Complex interaction network,

	▪ huge communication link, ▪ stability is reduced	▪ limit system optimization, ▪ moderate stability	▪ Rigorous mathematical analysis ▪ communication delay
Application	Small scale DC microgrid	DC microgrid	DC microgrid

Table-2 Comparison of different approaches in distributed secondary control

Reference	**Approach**	**Principle**	**Features**	**Advantages**	**Disadvantages**	**Application**
[34]	Average current sharing	Droop gain variation method	Averaging droop gain	● Accurate proportional load sharing, ● Dc bus voltage restoration, ● Improve transient stability (with fast changing load current), ● Resilience to converter failure, ● Low cost due to use of microcontroller	● Fully connected communication network is required, ● Communication speed is slow, ● Communication pressure is highly increase	DC microgrid with fast changing load, Practical industrial applications
[36]	Average voltage sharing	Merge droop gain variation and voltage shifting method	Voltage sensitivity matrix	● Improved power sharing, ● Improved voltage regulation, ● Improve transient stability, ● No requirement of extra PI controller	● Fully connected communication network is required, ● Communication speed is slow, ● Communication pressure is highly increase	In dc microgrid with bidirectional DGs.
[39]	DC bus signaling	Switch the mode according to voltage level	Dc bus provide the control signal	● Increase reliability, Low cost, communication link is not required	● Stability depends on selection of voltage threshold	Hybrid nanogrid

[41]	Cooperative	Dynamic consensus	Finite time controller	● proportional current sharing, ● Average voltage regulation, ● fast response, ● reduce overshoot and chattering, ● plug and play capacity, ● resilience to link failure, and converter failure, ● change communication topology type disturbances	● Rigorous mathematical analysis is required.	Autonomous DC microgrid

Table-3 Comparison of cooperative control approaches in distributed secondary control

References	**Number of Secondary loop**	**Exchange Variable**	**Load**	**DC bus voltage use as a feedback**	**Communication pressure**	**Event triggering algorithm**	**Fixed time algorithm**	**Plug and play analysis**	**Stability analysis**	**Features**
[48]	3	Voltage and current	Linear	No	Reduce	No	No	Yes	No	❖ Simultaneously transmit oscillatory current and DC current with voltage regulation. ❖ Use 4 primary controllers and 3 secondary controllers, which increase the complexity of the system.
[49]	2	Voltage and current	Linear	No	Reduce	No	No	No	Yes	❖ A fixed current sharing ratio is used.
[50]	3	Voltage and current	Linear	No	Reduce	No	No	No	Yes	❖ Use a higher value of weight to reduce the convergence time that makes

										the system unstable.
[51]	1	Power	Linear	No	Reduce very much	No	No	No	No	❖ Only consider the voltage regulation issue.
[13]	1	λ factor	Linear & nonlinear	Yes	Reduce very much	No	No	Yes	Yes	❖ no requirement of prior information about the configuration. ❖ Increase the sampling time system becomes unstable, so the selection of sampling time is critical for the successful working of the microgrid. ❖ Performance is different for a resistive load and a constant power load.
[43]	1	Virtual voltage drops	Linear & nonlinear	No	Reduce very much	No	No	Yes	Yes	❖ Use a pre-determined fixed current sharing ratio; therefore, it is unsuitable for microgrids with rapidly fluctuating loads and (RES) Renewable Energy Sources that operates intermittently.
[45]	1	Virtual voltage drops	Linear & nonlinear	No	Reduce very much	No	No	No	Yes	❖ Time varying droop gain is used. ❖ Not easily implemented in practice because the current sharing ratio may change randomly.

[46]	2	Voltage and current	Linear	No	Reduce	No	No	No	No	❖ In this scheme, control action is required on the current and previous state of the control variable, so large memory is required. ❖ Practical application of RL is not possible.
[47]	2	Voltage and current	Linear	Yes	Reduce	No	Yes	Yes	Yes	❖ Not dependent on the initial state of the variable ❖ The convergence speed is high. ❖ Regulating the settling time becomes challenging when complex, steady conditions are involved.
[16]	1	Voltage correction term	Linear & nonlinear	No	Reduce very much	No	Yes	Yes	Yes	❖ Not dependent on the initial state of the variable, ❖ A fixed current sharing ratio is used.
[52]	1	Voltage and current	Linear	Yes	Reduce very much	Yes	No	Yes	No	❖ Required a high bandwidth controller
[53]	2	Current	Linear	No	Reduce	Yes	No	No	Yes	❖ Issue in finding out all acceptable communication topology and weight, ❖ The dynamic impact of line capacitance and inductance are not considered. ❖ The reference voltage V_{ref} is updated on aperiodic basis

	by the event-triggered control algorithm. Thus, the sawtooth-like waveform is produced by voltage references that increase or decrease linearly until a new event is triggered.

V. CONCLUSION

A primary control is local-level control and does not use any communication link, which mainly uses droop control for exact power sharing. In this scheme, if selecting a higher droop gain, proportional current sharing is achieved, but simultaneously, voltage regulation is very poor. To overcome this problem, secondary control is used. Dependent on available communication, secondary control is classified into three different methods: centralizes, decentralized and distributed. The centralized control scheme uses the MGCC, which communicates with all other units through a low-bandwidth communication link. Central control finds global information for optimisation and is more accurate to achieve desired functionality, but suffers from a single point of failure and also necessitates a large communication network. Decentralized control, a highly efficient methodology that only depends on local variables, improves reliability and modularity. The key disadvantage of this technique is that the whole system information is not available; hence, there is a problem of optimization. This problem can be solved by a distributed secondary control technique, which achieves the same functionality as centralized control but is free from single points of failure. In the average voltage/current sharing approach, all DGs communicate with all other DGs via a low-bandwidth communication channel. It improves communication requirements. The cooperative approach used a consensus algorithm in which communication was required only with neighboring agents instead of each agent in the system, so a sparse communication network exists, which reduces communication stress very well. Still, rigorous mathematical analysis of cooperative control schemes remains a challenging issue. Also, low convergence rates and time delays are important. In light of the future work on distributed control techniques, ongoing research and development is needed to identify novel control protocols and algorithms that improve the existing ones in terms of convergence speed, increased system stability, and enhanced reliability.

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