Unified Control Scheme of the Interlink Converter for Multi-voltage DC Distribution Systems

1st Chengwei Liu
Department of Electrical and Electronic Engineering
Imperial College London
London, U.K.
chengwei.liu20@imperial.ac.uk

2nd Vardan Saxena
Department of Electrical and Electronic Engineering
Imperial College London
London, U.K.
v.saxena23@imperial.ac.uk

3rd Adrià Junyent-Ferré
Department of Electrical and Electronic Engineering
Imperial College London
London, U.K.
adria.junyent-ferre@imperial.ac.uk

4th Yitong Li
School of Electrical Engineering
Xi'an Jiaotong University
Xi'an, China
yitongli@xjtu.edu.cn

5th Joan Marc Rodriguez-Bernuz
Department of Electrical Engineering
Universitat Politècnica de Catalunya
Barcelona, Spain
joan.marc.rodriguez@upc.edu

6th Kai Sun
Department of Electrical Engineering
Tsinghua University
Beijing, China
sun-kai@mail.tsinghua.edu.cn

***Abstract*—The need to build resilient distribution systems provides the incentive to decentralize voltage stability responsibilities across the entire network instead of the main grid. This requires the system to operate in various modes depending on the availability and location of the voltage sources. To facilitate seamless transitions between different operation modes, this paper presents a unified control scheme designed for the interlink converter connecting multi-voltage buses in distribution systems. Under normal conditions, the proposed scheme efficiently manages power flow. In the event of loss of a voltage control unit at one bus, the scheme autonomously provides voltage support to this bus to ensure the stable operation of the whole network. This is achieved without the need for mode detection and communication, thereby preventing instability risk due to the inaccurate or delayed mode transition. Moreover, the proposed scheme inherently supports input-series output-parallel converter configurations, achieving input voltage sharing and output current sharing without additional control loops. Simulation results validate the effectiveness and robustness of the proposed scheme.**

***Index Terms*—Distribution system, unified control, interlink converter, input-series-output-parallel configuration.**

I. INTRODUCTION

The widespread adoption of dc-based renewable energy sources, dc loads, and energy storage systems has made dc distribution systems promising solutions for diverse industrial applications, such as electric vehicle systems and photovoltaic energy systems [1]–[4]. Fig. 1 illustrates a schematic diagram of a dc distribution network with two voltage levels interconnected by an interlinking converter (ILC), which provides galvanic isolation, voltage matching, and power management.

In the traditional dc distribution system, voltage stability relies on the main grid, making the network poor resilience and susceptible to failures in case of a contingency. The increasing integration of distributed energy resources and energy storage systems is leading to a more decentralized grid architecture, which brings opportunities to reduce the dependency

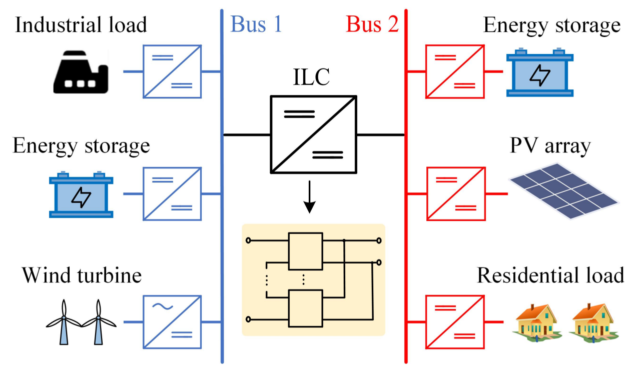

Fig. 1. Schematic of a dc distribution network.

on the main grid [5]. This transition could redistribute the responsibility for maintaining voltage stability across the entire network. Each bus is equipped with its own voltage source to maintain voltage stability and enable mutual voltage support, thus enhancing the system's overall stability and resilience. As a result, the network can operate in three modes depending on the location of the voltage sources as depicted in Fig. 2 [6]. Identifying these modes is crucial since they are relevant to the functionality and control of the ILC. In most situations, both buses have voltage sources, and the network can operate in balanced mode [6]. This allows the ILC to achieve power flow based on the energy management system. However, if one of the buses loses its voltage regulation capability due to issues such as a distributed generation outage, the network is shifted to an unbalanced mode. In such mode, the ILC should prioritize the provision of voltage support to the bus without the source to ensure the stable operation of the whole network. This makes the ILC act as a load on one side and a source on the other.

The demand for mode-specific functionality requires the

TABLE I
COMPARISON WITH THE EXISTING CONTROL METHODS

Category	Power control [9]	Dc transformer control [13]	Model-switch control [14]	Coordinated control [15]	**Proposed scheme**
Operation Mode	Only balanced	Only unbalanced	All modes	All modes	All modes
Seamless Transition	No	Yes	No	Yes	Yes
Inherent IVS/OCS	No	Yes	No	No	Yes
Application limitation	No	No	No	Limited to microgrids	No

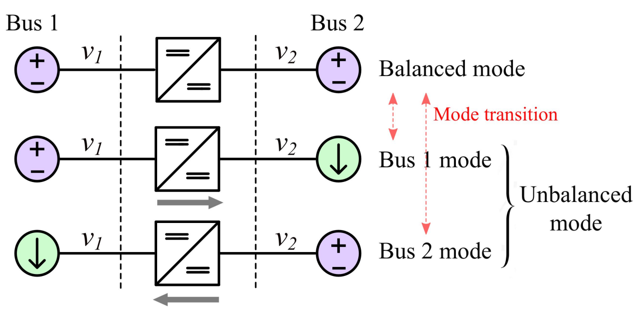

Fig. 2. Different operation modes. Note that the arrows indicate the direction of voltage support.

ILC to adjust control objectives autonomously for different operation modes. However, most state-of-the-art control methods for the ILC predominantly focus on either output voltage regulation [7] or power flow management [8], [9] while assuming the input as a stiff source, which can be only effective for one specific mode. In contrast, a unified control strategy was proposed in [10] to enable either power flow control or voltage regulation in different modes. However, this method is limited by its unidirectional voltage support, allowing voltage support from one bus to another but not vice versa, thereby rendering it ineffective in some unbalanced modes. To solve this issue, [11]–[13] proposed a scheme to make the ILC act as a dc transformer with dual voltage support capability. This allows the ILC to provide voltage support to any bus without a voltage source, regardless of which bus loses its voltage sources. However, these methods can not control the power flow in the balanced mode. A potential solution for the above methods is the mode-switch [14]. However, this requires the mode detection mechanism and communication system among networks, which can increase costs and cause non-seamless mode transitions that may destabilize the system, particularly during unintended mode changes. To address this problem, a coordinated power control was proposed for all three modes in [15]. However, this method is only limited to microgrids based on droop characteristics—i.e., a predefined power-voltage relationship on each bus, which may not be suitable for distribution systems.

Another challenge for the ILC arises from the limited voltage and current ratings of power devices. To address this, the input-series output-parallel (ISOP) configuration is implemented to reduce electrical stresses [16], [17]. However, this introduces the challenge of ensuring input-voltage-sharing (IVS) and output-current-sharing (OCS) among the module converters. To tackle this problem, many control strategies have been proposed. The common-duty-ratio control was proposed in [18], which applies a uniform duty ratio to all converter modules. However, achieving precise IVS and OCS is challenging due to parameter mismatches among modules. Therefore, control strategies utilizing dedicated IVS or OCS controllers have been proposed [19]–[21]. While these methods are effective, they introduce extra control loops, thereby increasing control complexity.

To fill this gap, this paper introduces a unified control scheme that integrates voltage support and current tracking control loops. This integration enables the autonomous adjustment of control objectives across various operation modes without mode detection and communication. As a result, it can eliminate the risks of instability due to inaccurate or delayed mode transitions, thereby ensuring seamless transitions and enhancing the network's stability. Furthermore, the proposed scheme is well-suited for the ISOP configuration, which can facilitate IVS and OCS without an extra control loop. A detailed comparison between the proposed scheme and other existing control methods is presented in Table I.

The rest of this paper is organized as follows: Section II outlines the unified control for a single converter for different modes and mode transitions. Section III expands on how this scheme applies to the ISOP configuration. Simulation results verify the effectiveness of the proposed control scheme in Section IV. Finally, Section V concludes the paper.

II. Proposed Unified Control Scheme

Fig. 3 shows the block diagram of the proposed unified control scheme tailored for a modular converter of the ILC. This scheme is designed to be topology-independent, allowing for its application across various dc-dc converters. In this paper, the modular converter is chosen as the dual active bridge (DAB) converter for illustration. For the sake of simplicity, single-phase shift modulation is implemented, which the power transfer from bus 1 to bus 2, P_{12}, can be expressed as [22]:

$$P_{12} = \frac{N v_1 v_2 d(1-d)}{2 f_s L} \tag{1}$$

where v_1 and v_2 are the voltages of buses 1 and 2, respectively. N is the transformer's turns ratio, L is the leakage inductor, f_s is the switching frequency and d is the phase shift.

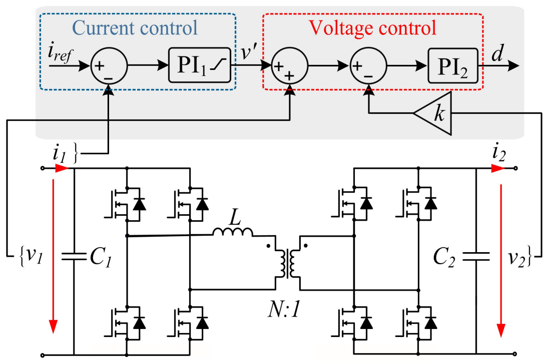

Fig. 3. Control block diagram of the proposed unified control scheme.

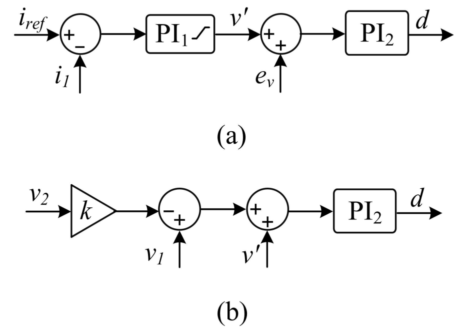

Fig. 4. The proposed scheme in different modes. (a) Balanced mode. (b) Unbalanced mode.

The proposed scheme tunes the phase shift d through the current control and voltage control. The voltage control regulates the voltage ratios k of two buses within the network to enable bidirectional voltage support, where k is set as the nominal voltage ratio across the two buses. Meanwhile, the current control can achieve power flow control by introducing a voltage shift v' to the voltage control. To avoid over-adjustments of v', a saturation component is employed inside the PI controller of the current control. Given that the current control is to adjust the voltage control, the bandwidth of the voltage control should be much larger than that of the current control. The implementation of this scheme across various modes and mode transitions is discussed as follows. It is noted that the proposed scheme is tailored for effective operation in different modes, which is unlike the conventional outer-voltage and inner-current control for dynamic response. Furthermore, it is assumed that, in unbalanced operation, the non-faulty DC bus possesses sufficient capacity to provide voltage support to the faulty bus.

A. Balanced Mode

In the balanced mode, both buses have voltage sources to maintain their voltage stability. Therefore, v_1 and v_2 remain constant with v_1 equating to kv_2 naturally. Consequently, the proposed scheme can be simplified as shown in Fig. 4a, where there is the current control with an additional PI controller in series. The variable e_v denotes the minor discrepancy between v_1 and kv_2 considering the operational variations.

As depicted in Fig. 4a, two cascaded PI controllers are employed. The first PI controller can regulate i_1 to align with i_{ref} precisely, which i_{ref} is derived from the upper controller based on the energy management system [23]. The second PI controller then fine-tunes its output v' to compensate for the voltage error e_v. Therefore, active power flow control can be achieved in the balanced mode.

B. Unbalanced Mode

In the unbalanced mode, only one bus has voltage sources while the other bus acts as the load. Therefore, the ILC's priority shifts to provide voltage support for the bus lacking the voltage source to maintain the voltage stability across the network. In such scenarios, the proposed scheme can be regarded as shown in Fig. 4b, where the impact of the current controller is represented by the constant disturbance v'. This can be achieved by designing the bandwidth of voltage control significantly higher than the current control.

The steady-state equilibrium satisfies:

$$\underbrace{v_1 + v'}_{v_1'} = kv_2 \tag{2}$$

According to (2), the proposed scheme can regulate the voltage ratio between v_1' and v_2 to be k. To ensure that v_1' closely approximates v_1, a saturation component is implemented for v'. Based on (2), the proposed scheme makes the ILC behave like a transformer, but a dc transformer. Like a conventional transformer, a voltage source on either side can maintain the voltage on the other side automatically. Consequently, the ILC can provide voltage support to the bus lacking a voltage source regardless of the location of voltage sources, thereby accommodating the unbalanced modes effectively. Notably, the proposed scheme focuses on regulating the voltage ratio between buses rather than controlling their individual voltages. Consequently, voltage discrepancies on one bus could proportionally affect the other bus. However, this is not seen as a drawback as these discrepancies are typically minor in practical operations. The primary role of the ILC is to maintain voltage stability, while precise voltage regulation is managed by other power converters within each bus to ensure that all terminal voltages meet the required specifications.

It is noted that the range of v' is crucial for the effectiveness of the proposed scheme. In the balanced mode, v' addresses the voltage discrepancy e_v, whereas, in the unbalanced mode, it shifts the steady-state voltage relationship. Therefore, the range of v' could be defined as follows:

$$v' \in [kv_2^{min} - v_1^{max}, kv_2^{max} - v_1^{min}] \tag{3}$$

where the superscripts max and min represent the maximum and minimum bus voltages.

C. Mode Transition

1) Balanced to unbalanced mode: During the transition from balanced to unbalanced mode, one of the buses could

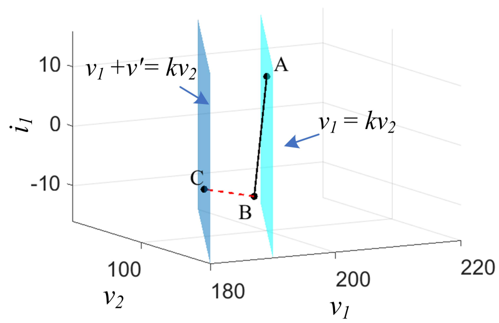

Fig. 5. Mode transition process from balanced mode to bus 2 mode

lose its voltage regulation capability. Given that the bandwidth of voltage control is much larger than that of current control, voltage control predominantly manages the system's dynamic response, with the current control being treated as the constant disturbance v'. For each v', the voltage controller is capable of establishing the steady-state condition as (2). Thus, irrespective of which bus experiences a voltage source outage, the other bus can effectively provide voltage support for the affected bus.

The impact of v' is to determine the system's final steady-state condition. Since i_{ref} is determined by the upper control system that exhibits a slow response, it cannot be adjusted quickly and is considered constant during mode transition dynamic responses. This makes the response of current control unpredictable. For example, while the actual power flow needs to be injected from bus 2 to bus 1 to offset the voltage loss on the bus 1 side, i_{ref} might still suggest the opposite direction of power flow. This discrepancy could result in a continuous increase in v' until it reaches its maximum limit. Alternatively, v' could decrease to its minimum limit or adjust to an intermediate value depending on the i_{ref}.

Fig. 5 illustrates the mode transition from balanced to bus 2 mode. Initially, the ILC operates in the balanced mode to manage power flow. When the voltage source of the bus 1 is disconnected, there is a voltage drop due to capacitor discharge on the bus 1. Therefore, the ILC should compensate for this drop by injecting current from bus 2 to bus 1, thereby moving the operation to point B. As the voltage control completes its response, the transition process steps into the second stage, where the current control takes effect. With i_{ref} treated as a constant, a persistent mismatch between i_{ref} and i_1 causes v' to reach its lower limit, thereby moving the operation from point B to C where the ILC reaches the steady-state condition.

2) Unbalanced to balanced mode: When the distribution network shifts from unbalanced to balanced mode, the re-engagement of voltage sources can make the voltage of the bus that previously lacked a voltage source return to its rated value and re-establish voltage stability. Therefore, the proposed scheme can be simplified as shown in Fig. 4a, where the current controller can achieve power flow effectively.

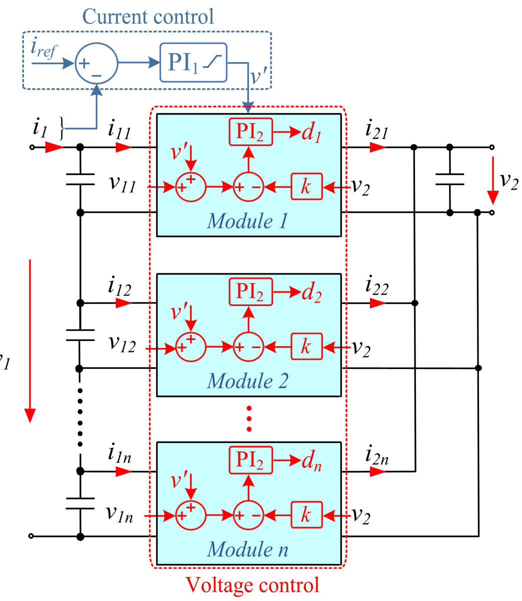

Fig. 6. The proposed scheme for the ISOP configuration.

III. Implementation of the Proposed Scheme for ISOP Configuration

Fig. 6 illustrates the schematic of the proposed control scheme tailored for the ISOP configuration. This setup incorporates the voltage control in each module converter, paired with a singular current control whose output is distributed among all the voltage control. Regardless of the operation modes, the steady-state voltage relationship across converters is maintained as follows:

$$v_{1i} + v' = kv_2 \qquad i = 1, 2...n \tag{4}$$

where v_{1i} is the voltage at converter i on the bus 1, and v_2 is the bus 2 voltage. According to (4), all v_{1i} could be equal naturally in the steady state regardless of parameter differences, thereby achieving IVS automatically. The power conservation satisfies:

$$v_{1i} i_{1i} = v_2 i_{2i} \qquad i = 1, 2...n \tag{5}$$

where i_{1i} and i_{2i} are the currents at converter i on the two buses, respectively. In the steady state, all capacitor voltages are maintained constant, ensuring zero average current through each capacitor. This facilitates equal current distribution across bus 1. Since the voltages on both sides are balanced, $i_{21} = i_{22}... = i_{2n}$, thereby ensuring the OCS.

The proposed scheme effectively realizes IVS and OCS without additional control loops, thereby simplifying control complexity. Furthermore, the requirement of only a single current sensor reduces hardware demands. These characteristics make the proposed scheme well-suited for ISOP configuration.

It is noted that the parameter design of the proposed controller can be achieved by a two-step approach: The design process initiates with the unbalanced mode, wherein voltage control plays a dominant role, with the current control being

TABLE II
SYSTEM PARAMETER

Parameter	Description	Value
v_1	Bus 1 rated voltage	600 V
v_2	Bus 2 rated voltage	100 V
v_{1i}	Module converter rated voltage on bus 1 side	200 V
n	Number of the module converter	3
k	Voltage ratio of module converter	2
f	Switching frequency	50 kHz
L	Nominal inductance of module converter	20 μH
$C_{1/2}$	Input and output capacitor	470μF
N	Turns ratio of the transformer	2

treated as the constant disturbance. This simplifies the control scheme to involve just a single PI controller configuration, thereby facilitating its parameter design process. With the voltage control parameters established, the PI controller of the current control can be obtained by considering the smaller bandwidth of the voltage control. Each step aligns with conventional PI controller tuning methodologies, which are well-established and thus omitted from further discussion in this work.

IV. Simulation Results

To validate the effectiveness of the proposed scheme, dc distribution systems with two buses interconnected by an ILC are implemented as shown in Fig. 1. Each bus consists of a voltage source and a resistive load, and the ILC employs three DAB converters in an ISOP configuration based on the switching model. Key parameters are in Table II. According to (1), the maximum power of each module converter is 5 kW. During normal operation, bus voltage deviations are kept within 3%, thus the v' is constrained with ± 9 based on (3). To emulate steady-state tolerances and parameter dispersion, the bus 2 voltage is biased to 102 V and the inductances of three converters are deliberately set at 22 mH, 20 mH, and 18 mH.

Fig. 7 illustrates the waveforms of bus 1 current i_1 and bus 2 voltage v_2. At $t = 0.25$ s, i_{ref} changes from -5 A to -10 A. The results demonstrate that the proposed control scheme effectively manages the power flow. It is noted that the current regulation response exhibits relatively slower dynamics since the bandwidth of the current controller is intentionally designed to be significantly lower than that of the voltage controller. This is not considered as the drawback, since i_{ref}, determined by higher-level system management, typically changes infrequently.

At $t = 0.35$ s, bus 2 experiences a voltage source outage, causing an immediate voltage drop due to capacitor discharge. The proposed controller rapidly compensates for this decrease by injecting current into bus 2 to provide voltage support. After the voltage controller stabilizes the bus voltage, the control process transitions into a second stage governed by the current controller. With i_{ref} held constant, a persistent mismatch between i_{ref} and the measured current i_1 causes

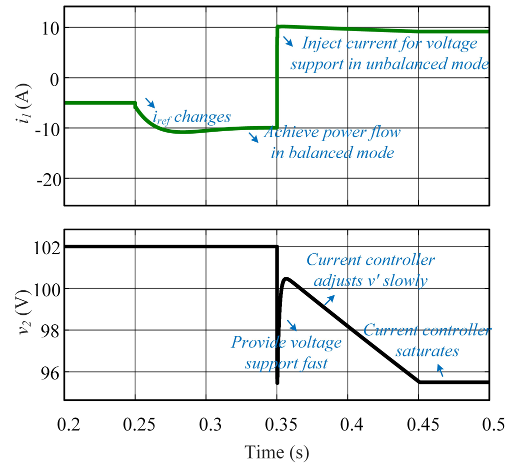

Fig. 7. Operation waveform of dc distribution systems.

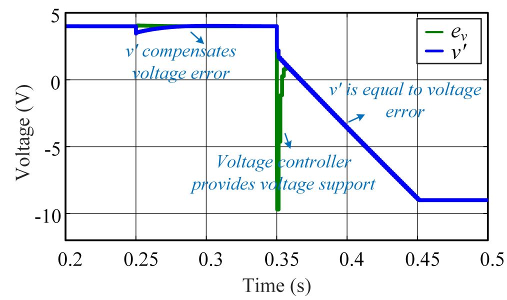

Fig. 8. Comparison between v' and actual voltage error.

the control signal v' to saturate at its lower boundary, making v_2 maintained with small deviation. This is acceptable as the primary function of the ILC is to maintain voltage stability, with precise voltage regulation typically managed by additional converters within each bus to maintain specified terminal voltage levels. It is noted that a similar response would occur if bus 1 experienced a voltage source outage, which thus are omitted here.

To illustrate the decoupling between voltage and current control loops, Fig. 8 compares control variable v' and the actual voltage error e_v. It is observed that v' effectively compensates the e_v during the balanced mode. During mode transitions, e_v rapidly converges to match v' and then follows the adjustments of v', which shows the bandwidth of the voltage control is much faster than the current control, thereby verifying the decoupling. This result is consistent with the analysis presented in Section II-C1.

Fig. 9 further shows the bus 1 side voltage v_{1i} and bus 2 side current i_{2i} of each DAB converter module. Despite inherent inductance discrepancies across the modules, the results verify that IVS and OCS are naturally achieved in a steady state, validating the suitability of the proposed control scheme for ISOP applications.

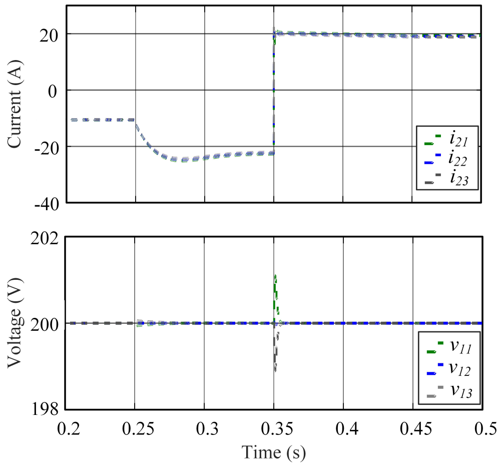

Fig. 9. Voltage and current waveform of each module converter.

V. Conclusions

This paper proposes a unified control scheme of the ILC for adaptable control capabilities. The proposed scheme integrates both voltage and current control: the voltage control makes the ILC behave like a dc transformer to provide voltage support bidirectionally, while the current control can introduce a voltage shift for effective power flow management. This allows the proposed scheme to manage various operation modes and ensure smooth mode transitions without the need for mode detection and communication, thereby enhancing voltage stability across the network. In addition, the proposed scheme can achieve IVS and OCS without additional control loops, making it particularly suitable for the ISOP configuration. The effectiveness of the proposed scheme was verified by simulation tests.

VI. Acknowledgment

This work was supported by the Ayrton Funds through UKRI's project "Moving IMPACT" [UKRI314].

References

[1] P. Franzese, D. D. Patel, A. A. S. Mohamed, D. Iannuzzi, B. Fahimi, M. Risso, and J. M. Miller, "Fast dc charging infrastructures for electric vehicles: Overview of technologies, standards, and challenges," *IEEE Transactions on Transportation Electrification*, vol. 9, no. 3, pp. 3780–3800, 2023.

[2] Y. Wang, Y. Zhang, Y. Wang, L. Zhu, Y. Guan, S.-Z. Chen, G. Zhang, and L. Yang, "A dual-active-bridge with half-bridge submodules dc solid-state transformer for dc distribution networks," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 9, no. 2, pp. 1891–1904, 2021.

[3] X. Liu, X. Liu, Y. Jiang, T. Zhang, and B. Hao, "Photovoltaics and energy storage integrated flexible direct current distribution systems of buildings: Definition, technology review, and application," *CSEE Journal of Power and Energy Systems*, vol. 9, no. 3, pp. 829–845, 2023.

[4] M. Lu, W. Mu, M. Qin, A. Koehler, J. Fang, and S. M. Goetz, "Differential detection of feeder and mesh impedances through a series–parallel direct-injection soft open point," *IEEE Transactions on Power Electronics*, vol. 40, no. 1, pp. 1964–1973, 2025.

[5] N. Shaukat, M. R. Islam, M. M. Rahman, B. Khan, B. Ullah, S. M. Ali, and A. Fekih, "Decentralized, democratized, and decarbonized future electric power distribution grids: A survey on the paradigm shift from the conventional power system to micro grid structures," *IEEE Access*, vol. 11, pp. 60 957–60 987, 2023.

[6] Y. Gu, Y. Li, H.-J. Yoo, T.-T. Nguyen, X. Xiang, H.-M. Kim, A. Junyent-Ferre, and T. C. Green, "Transfverter: Imbuing transformer-like properties in an interlink converter for robust control of a hybrid ac–dc microgrid," *IEEE Transactions on Power Electronics*, vol. 34, no. 11, pp. 11 332–11 341, 2019.

[7] S. Shao, L. Chen, Z. Shan, F. Gao, H. Chen, D. Sha, and T. Dragičević, "Modeling and advanced control of dual-active-bridge dc–dc converters: A review," *IEEE Transactions on Power Electronics*, vol. 37, no. 2, pp. 1524–1547, 2022.

[8] P. Lin, P. Wang, C. Jin, J. Xiao, X. Li, F. Guo, and C. Zhang, "A distributed power management strategy for multi-paralleled bidirectional interlinking converters in hybrid ac/dc microgrids," *IEEE Transactions on Smart Grid*, vol. 10, no. 5, pp. 5696–5711, 2019.

[9] Z. Xiao, W. Lei, G. Gao, X. Zhang, and L. Hu, "Dual-terminal voltage feedforward based direct power control scheme and stability analysis of dual active bridge converter in dc microgrid systems," *IEEE Transactions on Power Electronics*, vol. 38, no. 4, pp. 4475–4492, 2023.

[10] X. Li, W. Jiang, J. Wang, P. Wang, and X. Wu, "An autonomous control scheme of global smooth transitions for bidirectional dc-dc converter in dc microgrid," *IEEE Transactions on Energy Conversion*, vol. 36, no. 2, pp. 950–960, 2021.

[11] H. Shi and K. Sun, "Bridge-to-bridge independent control method for dual-active-bridge interlinking converter," *IEEE Transactions on Power Electronics*, vol. 37, no. 8, pp. 8757–8761, 2022.

[12] C. Gómez-Aleixandre, Á. Navarro-Rodríguez, M. Langwasser, P. García, and M. Liserre, "Weighted dc virtual generator control scheme for interlinking converters in dc microgrids," *IEEE Transactions on Industrial Electronics*, 2023.

[13] J. Ma, Y. Zou, M. Zhu, S. Wen, Y. Chen, and P. Lin, "Quasi-transformer mode control of interlinking converter for multivoltage levels dc grids," *IEEE Transactions on Power Electronics*, vol. 40, no. 5, pp. 7398–7413, 2025.

[14] J. Yao, W. Chen, C. Xue, Y. Yuan, and T. Wang, "An isop hybrid dc transformer combining multiple srcs and dab converters to interconnect mvdc and lvdc distribution networks," *IEEE Transactions on Power Electronics*, vol. 35, no. 11, pp. 11 442–11 452, 2020.

[15] X. Li, L. Guo, Y. Li, C. Hong, Y. Zhang, Z. Guo, D. Huang, and C. Wang, "Flexible interlinking and coordinated power control of multiple dc microgrids clusters," *IEEE Transactions on Sustainable Energy*, vol. 9, no. 2, pp. 904–915, 2018.

[16] B. Zhao, Q. Song, J. Li, W. Liu, G. Liu, and Y. Zhao, "High-frequency-link dc transformer based on switched capacitor for medium-voltage dc power distribution application," *IEEE Transactions on Power Electronics*, vol. 31, no. 7, pp. 4766–4777, 2016.

[17] Y. Zhuang, F. Liu, Y. Huang, S. Wang, S. Pan, X. Zha, and X. Diao, "A multiport dc solid-state transformer for mvdc integration interface of multiple distributed energy sources and dc loads in distribution network," *IEEE Transactions on Power Electronics*, vol. 37, no. 2, pp. 2283–2296, 2022.

[18] J. Shi, J. Luo, and X. He, "Common-duty-ratio control of input-series output-parallel connected phase-shift full-bridge dc–dc converter modules," *IEEE Transactions on Power Electronics*, vol. 26, no. 11, pp. 3318–3329, 2011.

[19] L. Qu, D. Zhang, and Z. Bao, "Output current-differential control scheme for input-series–output-parallel-connected modular dc–dc converters," *IEEE Transactions on Power Electronics*, vol. 32, no. 7, pp. 5699–5711, 2017.

[20] Y. Wang, Y. Guan, O. B. Fosso, M. Molinas, S.-Z. Chen, and Y. Zhang, "An input-voltage-sharing control strategy of input-series-output-parallel isolated bidirectional dc/dc converter for dc distribution network," *IEEE Transactions on Power Electronics*, vol. 37, no. 2, pp. 1592–1604, 2022.

[21] W. Zhou, J. You, H. Peng, and L. Zhang, "Automatic input voltage sharing of isop converter using duty ratio feedforward control without interconnection and input voltage monitor," *IEEE Transactions on Power Electronics*, pp. 1–13, 2025.

[22] S. Shao, L. Chen, Z. Shan, F. Gao, H. Chen, D. Sha, and T. Dragičević, "Modeling and advanced control of dual-active-bridge dc–dc converters: A review," *IEEE Transactions on Power Electronics*, vol. 37, no. 2, pp. 1524–1547, 2021.

[23] Y. Han, K. Zhang, H. Li, E. A. A. Coelho, and J. M. Guerrero, "Mas-based distributed coordinated control and optimization in microgrid and microgrid clusters: A comprehensive overview," *IEEE Transactions on Power Electronics*, vol. 33, no. 8, pp. 6488–6508, 2018.