CIGRE Study committe B4

PROPOSAL FOR THE CREATION OF A NEW WORKING GROUP

WG B4.108

NAME OF THE CONVENOR
Rong Zeng (CHINA)

TITLE
Roadmap and Technical Challenges for Integrated DC Power Grid

THE WG APPLIES TO DISTRIBUTION NETWORKS: YES

ENERGY TRANSITION
1 / Storage
4 / Sustainability and Climate Change
5 / Grids and Flexibility
6 / Solar PV and Wind

POTENTIAL BENEFIT OF WG WORK
2 / potential interest from a wide range of stakeholders
3 / likely to contribute to new or revised industry standards
4 / state-of-the-art or innovative solutions or directions
5 / Guide or survey on techniques, or updates on past work or brochures

STRATEGIC DIRECTION
1 / The electrical power system of the future reinforcing the End-to-End nature of CIGRE: respond to speed of changes in the industry by preparing and disseminating state-ofthe-art technological advances

SUSTAINABLE DEVELOPMENT GOAL
7 / Affordable and clean energy

BACKGROUND :

Under the increasing penetration of renewable generation and power-electronics-based technologies, future power systems are facing new operational and architectural challenges. Conventional AC networks are experiencing reduced system inertia, lower short-circuit ratios, and increasing interactions among power electronic devices, leading to greater challenges for secure and stable system operation. Meanwhile, the growing deployment of renewable energy sources, energy storage systems, data centers, and electric vehicles is accelerating the emergence of DC-based generation and load characteristics. As a result, the conventional AC system relying on multiple AC/DC/AC conversion stages is becoming increasingly constrained in terms of energy efficiency, system complexity, and coordination across voltage levels, limiting the efficient coordination of generation, networks, and loads.

To address these challenges, DC technologies have rapidly evolved in both transmission and local DC applications. Point-to-point HVDC, multi-terminal HVDC, and HVDC grids have become key solutions for bulk power transmission and asynchronous interconnection, while offshore wind HVDC connections, flexible DC distribution systems, DC-powered data centers, and transportation electrification applications are also developing rapidly. In parallel, CIGRE has conducted extensive studies through WG B4.52, WG B4.72, JWG C1/B4.58, WG B4.98, JWG C6/B4.37, and WG C6.31, covering HVDC system planning, DC grid architectures and modeling, AC/DC system integration, and medium-voltage DC distribution, thereby providing an important foundation for the broader deployment of DC technologies.

However, existing DC projects are generally focused on specific voltage levels or application domains, while generation and load integration still largely rely on AC networks and multiple power conversion stages. As DC technologies continue to develop and converge across the generation, transmission, distribution, and end-use sectors, future power systems are expected to evolve toward integrated DC power grids spanning multiple voltage levels and transmission and distribution functions.

Unlike the conventional transmission-oriented DC grid, the integrated DC power-grid concept emphasizes the coordinated interconnection of DC systems across multiple DC voltage levels including UHVDC, HVDC, MVDC and LVDC. The establishment of a continuous DC energy chain can significantly reduce intermediate AC/DC conversion stages, thereby improving overall system efficiency, flexibility, and coordinated operation of generation, networks, energy, and loads.

Therefore, there is a need to establish a new Working Group to investigate the development roadmap and technical challenges associated with future integrated DC power grids. The working group will address representative application scenarios and network architectures, roadmap, and technical challenges, and provide technical guidance for the evolution of future AC/DC integrated power systems and highly DC-based power networks.

PURPOSE / OBJECTIVE / BENEFIT OF THIS WORK :

The objectives of this working group are to:

1. Systematically study the network architectures, development roadmap, and technical challenges of integrated DC power grids across source–grid–load integrated application scenarios, and identify the principal system-level gaps and study needs.
2. Develop a CIGRE Technical Brochure providing a technology-neutral system-level framework for integrated DC power-grid development.

The outcomes of this working group will provide system planners, transmission system operators (TSOs), equipment manufacturers, and other stakeholders with a comprehensive system-level reference framework for future integrated DC power-grid development, supporting the coordinated evolution of hybrid AC/DC and highly DC-oriented power systems. The Technical Brochure will support:

1. Strategic planning and long-term investment decisions for future hybrid AC/DC and DC-dominated power system infrastructures;
2. Identification of technology gaps, technical challenges, and standardization needs associated with future DC grid development;
3. Identification of high-level interface and coordination needs across different voltage levels and application scenarios;
4. Development of transition pathways supporting the progressive evolution from conventional AC systems toward future power systems with increasing DC penetration;
5. Establishment of a common understanding among international stakeholders regarding the long-term evolution and development pathways of future integrated DC-grid architectures.

SCOPE :

This Working Group focuses on the system-level investigation of future integrated DC power grids, with emphasis on representative network architectures, development roadmaps, and key technical challenges. To keep the work focused and manageable within the planned duration, the Working Group will identify roadmaps, challenges, gaps, and needs for further study at a high level. Detailed or prescriptive requirements for equipment, control, and protection are not the focus of this scope.

Task 1- Architectures and application scenarios of the integrated DC power grid

This task focuses on typical architectures and system configurations of integrated DC power grids across different application scenarios. Particular emphasis will be placed on meshed HVDC and meshed MVDC architectures as representative analysis cases for future integrated DC power-grid development, while embedded LVDC applications and future super DC grid concepts will be addressed at an overview level, as boundary conditions and future outlook. The Working Group will study:

- Definition and architectural classification of integrated DC power grids, focusing on the functional roles across the full chain of source–grid–load DC systems. A unified classification framework will be established, covering spatial scales, functional characteristics, voltage levels, and network topologies;
- Local (embedded) DC-grid architectures, including typical applications such as data centers, industrial parks, building microgrids, electric mobility systems, ports, rail traction systems, shipboard power systems, and off-grid autonomous energy systems. These systems are characterized by embedded DC networks and source–storage–load coordination, operating mainly at LVDC or MVDC levels;
- Regional DC-grid architectures, including renewable DC collection systems, offshore wind collection systems, regional DC distribution networks, multi-terminal DC grids, and integrated energy hubs. These systems focus on regional renewable aggregation and coordination, operating mainly at MVDC or HVDC levels;
- Backbone DC-grid architectures, including cross-regional renewable power transmission, multi-terminal and meshed HVDC networks, offshore integrated DC grids, and future super DC grid concepts. These systems focus on large-scale renewable power optimization, DC interconnection across voltage levels, and coordinated operation across all voltage levels, operating mainly at HVDC/UHVDC levels.

Task 2 – Development roadmap of the integrated DC power grid

This task focuses on the phased development pathway of integrated DC power grids from current point applications toward future DC architectures. The Working Group will study:

- Phase I: The "Patching" Phase. DC technologies act as a "patch" to AC systems, addressing long-distance transmission, asynchronous interconnection, and local capacity expansion. Integrated DC grids appear mainly as point applications or early-stage chain structure;
- Phase II: The "Localized Dominance" Phase. DC technologies progressively dominate in areas such as UHV transmission, flexible distribution grids, offshore renewable integration, and LVDC loads. However, AC systems remain the backbone, while integrated DC networks begin to form localized multi-terminal and meshed DC networks;
- Phase III: The "Ubiquitous Penetration" Phase. DC technologies evolve toward networked deployment across generation, transmission, distribution, and end-use applications, forming a power-electronics-based, interconnected native DC architecture and enabling cross-regional, multi-layered, and hierarchically interconnected continuous DC energy systems. However, their long-term evolution may be influenced by technical, operational, economic, and societal bottlenecks that are not yet fully identified, potentially affecting the pace and scale of future deployment.

Task 3 – Key technical challenges for the integrated DC power grid

This task focuses on the key technical challenges associated with the future development of integrated DC power grids. The challenges will be considered at system level; detailed equipment requirements and specific technical solutions will not be developed. The Working Group will study:

- **Voltage transformation and interconnection challenges**, including coordination across multiple DC voltage levels, compatibility of AC/DC and DC/DC interfaces, voltage regulation under varying operating conditions, and interoperability among heterogeneous equipment;
- **Fault interruption and protection challenges**, including DC fault current evolution, interruption capability of DC circuit breakers, fault detection and discrimination in multi-terminal DC systems, and selective protection coordination;
- **DC grid controller challenges**, including multi-controller interaction and stability, coordination of hierarchical and distributed control architectures, interoperability among controllers, and resilient operation under disturbances and communication delays.

Limitation of Scope:

This Working Group focuses on the system-level investigation of integrated DC power grids, including application scenarios, network architectures, development roadmaps, operational modes, prioritized technical challenges, and needs for further study. The objective is to establish a unified, technology-neutral framework for future DC grid development.

The following topics are explicitly excluded from the scope of this Working Group:

- **Detailed equipment design and optimization:** Internal topology design, component sizing, thermal management, hardware implementation, and performance optimization of converters, DC circuit breakers, DC/DC converters, or other power electronic equipment;
- **Device-level control algorithm development:** Design, tuning, validation, or implementation of converter control algorithms, protection logic, modulation strategies, or inner control loops. Only the system-level functional roles and coordination frameworks of controllers will be considered.
- **Detailed modelling and simulation**: Electromagnetic transient (EMT) modelling of individual equipment, detailed dynamic model validation, hardware-in-the-loop testing, or time-domain simulation for specific operating conditions.
- **Protection implementation**: Detailed relay design, protection settings, communication protocols, vendor-specific protection solutions, or implementation of protection functions. Only system-level protection architectures and coordination principles will be addressed.
- **Project-specific planning**: Feasibility studies, site selection, capacity sizing, or economic analysis for any particular demonstration project, regional grid, or national power system.
- **Standard development:** Drafting or mandating of technical standards, equipment specifications, performance requirements, or certification procedures.

Existing CIGRE Working Groups addressing these specific topics (e.g., WG B4.60 on reliability, JWG C1/B4.58 on planning) will be referenced and leveraged where appropriate, but their detailed work will not be duplicated.

Remark:

The objective of this Working Group is to complement, rather than duplicate, existing CIGRE activities related to DC grid architectures, power electronic technologies, and the evolution of future power systems.

WG B4.52 (HVDC Grid Feasibility Study, 2009–2013) investigated the feasibility of HVDC grid from point-to-point transmission schemes toward networked grids operating at a single voltage level and embedded within AC systems. Building on this work, the proposed Working Group extends the scope to an integrated DC-grid architecture spanning the source–grid–load DC chain, enabled by high penetration of renewable energy and emerging DC-based applications.

WG B4.72 (DC Grid Test Systems and Benchmark Models, 2016–2020) focused on the development of benchmark models and simulation platforms for DC grids. Building on these outcomes, the proposed Working Group focuses on representative integrated DC-grid configurations under different application scenarios and their development pathways.

WG B4.60 (DC Grid Reliability, 2013–2016) addressed methodologies for reliability assessment of DC grids. In contrast, the proposed Working Group does not develop new reliability assessment methods but focuses on analyzing structural characteristics and evolutionary pathways of different integrated DC-grid architectures.

JWG C1/B4.58 (VSC-HVDC Transmission Systems Planning, 2025–2027) primarily focuses on planning methodologies for AC-embedded VSC-HVDC transmission systems. Building on this work, the proposed Working Group addresses integrated DC-grid architectures and their evolution across diverse application domains.

WG C6.31 (MVDC Grid Feasibility Study, 2015–2020) focused on the feasibility of MVDC distribution grids. Building on this work, the proposed Working Group emphasizes coordination among HVDC, MVDC, and LVDC systems, and full-chain DC architectures spanning source, grid, and load.

JWG C6/B4.37 (Medium Voltage DC Distribution Systems 2018-2022) focused on the engineering fundamentals of a single voltage level like MVDC system topologies and protection schemes. Building on this work, the proposed Working Group broadens the perspective to an integrated, full-chain architecture, investigating the roadmap and technical challenges of a source-grid-load integrated DC grid.

WG B4.76 (DC-DC Converters in HVDC Grids and for Connections to HVDC Systems, TB 827, 2021) evaluated the feasibility, design, and control of DC-DC converters for DC transmission grids, including the interconnection of HVDC and MVDC systems, at the converter level. Building on this work, the proposed Working Group addresses the system-level roles of DC transformers and voltage transformation equipment in interconnecting multiple DC voltage levels within integrated DC power grids.

JWG A3/B4.34 (Technical Requirements and Specifications of State-of-the-Art HVDC Switching Equipment, TB683, 2017) and JWG B4/A3.80 (Design, Test and Application of HVDC Circuit Breakers, TB 873, 2022) addressed HVDC switching equipment and DC circuit breakers at the equipment level, from technical requirements to design, testing, and application. Building on these works, the proposed Working Group focuses on the system-level functional roles and coordination of fault interruption technologies across integrated DC-grid architectures.

WG B4/B5.59 (Protection and Local Control of HVDC Grids, 2015–2018) focused on protection architectures and local control implementation for HVDC grids. Building on this work, the proposed Working Group investigates system-level protection coordination across integrated DC power grids.

WG B4.58 (Control Methodologies for Direct Voltage and Power Flow in a Meshed HVDC Grid, 2014–2017) focused on voltage and power flow control methodologies for meshed HVDC grids. Building on this work, the proposed Working Group focuses on system-level controller architectures and coordination mechanisms across integrated DC power grids.

This Working Group focuses on the network architectures and development roadmap of integrated DC power grids across diverse application scenarios, including renewable energy DC collection and direct supply systems, offshore integrated DC grids, data center DC power supply systems, DC systems for industrial and transport electrification, etc. The proposed roadmap aims to provide a technology-neutral reference framework and should not be interpreted as a mandatory prediction of implementation timelines, investment scales, or specific technology deployment pathways.

This Working Group will maintain coordination and information exchange with relevant Study Committees and Working Groups, including SC C6, SC C1, SC A3, SC B5 and other related Study Committees, to ensure alignment of work, avoid scope overlap, and facilitate the sharing of technical knowledge. A liaison member nominated by SC C1 will participate throughout the Working Group. Where appropriate, representatives from other related Study Committees and Working Groups may be invited to participate as corresponding members or liaison representatives to enhance communication and coordination throughout the course of the work.

To avoid duplication, the Working Group will coordinate and exchange information with IEC /ACTAD Task Team 7 (TT7), “DC Grids standardization,” through established CIGRE–IEC liaison channels and subject to the applicable liaison procedures. The exchange will cover relevant terminology, references, and identified standardization gaps. This Working Group will not draft standards.

Relevant IEC reference: IEC TS 63471:2023, DC voltages for HVDC grids.

DELIVERABLES AND EVENTS

Deliverables Types
Annual progress and activity report to Study Committee
Electra report
Future connections
Technical Brochure and Executive Summary in Electra
Tutorial
Webinar

Deliverables schedule

Future connect. | Q4 | 2026 | Future connection

Technical Brochure | Q4 | 2028 | Technical Brochure and Executive Summary in Electra

Webinar | Q1 | 2029 | Webinar

Time schedule

Q3 | 2026 | Recruit members

Q4 | 2026 | Develop final work plan

Q1 | 2028 | Draft TB for SC review

Q4 | 2028 | Final TB

APPROVAL BY TECHNICAL COUNCIL CHAIRMAN:
Rannveig S J Loken
August 06th, 2026