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# A novel design of architecture and control for multiple microgrids with hybrid AC/DC connection

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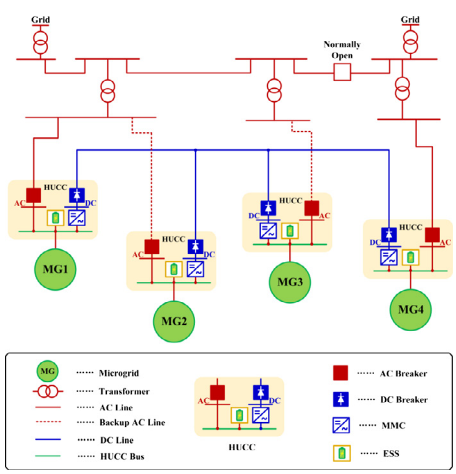
## HIGHLIGHTS

- Proposes an advanced microgrid interface based on MMC and energy storage system for multiple microgrids.
- Proposes a novel architecture for multiple microgrids with hybrid AC/DC connection.
- Proposes different control schemes for multiple microgrids under various operation conditions.
- The large-scale integration of distributed renewable energies in multiple microgrids is enhanced.
- The optimal use of distributed generators in multiple microgrids is realized.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Microgrid provides an effective approach to utilize distributed renewable energies (DREs). Given the ongoing transformation of distribution system with high penetration of DREs, coordinating and consuming a large amount of distributed generators (DGs) within one single microgrid has become increasingly infeasible. Interconnecting multiple microgrids as a microgrid cluster is an effective way to improve the operation quality of large-scale DG integration. As the keys to the microgrid clusters, the flexible configurations and coordinated operation among multiple microgrids have not been adequately addressed. In order to solve this problem, a novel architecture for multiple microgrids and its coordinated control schemes are designed. Firstly, the advanced microgrid interface named hybrid unit of common coupling (HUCC) is designed and utilized in replacement of the conventional point of common coupling (PCC). The HUCC employs modular multilevel converter (MMC) as its core component and provides both AC and DC interfaces. Then, this paper puts forward a HUCC-based architecture for multiple microgrids where microgrids are grid-connected via the AC interfaces and interconnected via the DC interfaces. Based on the proposed architecture, coordinated control schemes under different operation scenarios are came up with at last. A case study of the HUCC-based multiple microgrids is performed in PSCAD/EMTDC on the basis of the demonstration project in Guangxi, China. The simulation results show that the interconnected microgrids with the proposed architecture and control schemes operates effectively and efficiently under different operation scenarios. The

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**Nomenclature**

| | |
|---|---|
| $N$ | number of transformers |
| $M$ | number of microgrids |
| $i$ | transformer index, $i \in [1, N]$ |
| $j$ | microgrid index, $j \in [1, M]$ |
| $P_T^i$ | active power of the $i$-th transformer (MW) |
| $P_{T\max}^i$ | maximum active power supply capacity of the $i$-th transformer (MW) |
| $P_C^j$ | active power of the $j$-th microgrid (MW) |
| $P_{C\max}^j$ | maximum active power supply capacity of the $j$-th microgrid (MW) |
| $P_E^j$ | active power of the energy storage system (ESS) in the $j$-th microgrid (MW) |
| $P_{E\max}^j$ | maximum active power supply capacity of the ESS in the $j$-th microgrid (MW) |
| $P_G^j$ | total power of distributed generators (DGs) in the $j$-th microgrid (MW) |
| $P_L^j$ | total loads of the $j$-th microgrid (MW) |
| $U_{DC}^j$ | DC voltage of the hybrid unit of common coupling (HUCC) in the $j$-th microgrid (kV) |
| $U_{DC}^{j*}$ | reference DC voltage of the HUCC in the $j$-th microgrid (kV) |
| $f_{MG}^j$ | frequency of the $j$-th microgrid (Hz) |
| $f_{MG}^{j*}$ | rated frequency of the $j$-th microgrid (Hz) |
| $V_{MG}^j$ | voltage of the $j$-th microgrid (kV) |
| $V_{MG}^{j*}$ | rated voltage of the $j$-th microgrid (kV) |
| $THD_{MG}^j$ | total harmonic distortion of the $j$-th microgrid |
| $\varepsilon_1$ | limit on microgrid frequency deviation |
| $\varepsilon_2$ | limit on microgrid voltage deviation |
| $\varepsilon_3$ | limit on DC voltage deviation |
| $\delta$ | limit on total harmonic distortion of microgrid |
| $NMG$ | normal microgrid index |
| $T_{U_{DC}}^j$ | adjustment time of the DC voltage of the $j$-th microgrid (s) |
| $\Delta t$ | allowable DC voltage adjustment time (s) |
| $U'_{DC}$ | rapid DC voltage change |
| $\sigma$ | limit on rapid voltage change of DC voltage |

proposed architecture and control schemes not only enhance the large-scale integration of DREs, but realize the optimal use of DGs as well.



## 1. Introduction

Distributed renewable energies (DREs) have been regarded as an effective tool to deal with future energy and environment crisis worldwide [1,2]. As the concerns for environmental pollution caused by fossil fuels keep rising and the energy policies sustain improvement, the DG penetration in distribution systems is increasing rapidly [3–5]. At the same time, the configuration and operation of distribution system is also experiencing fast development and transformation [6,7].

Microgrid is an aggregation of distributed generators (DGs), energy storage systems (ESSs) and local loads [8]. It is put forward to solve the ongoing transformation of distribution power system with the integration of various distributed renewable energies [9–11]. Microgrid has both grid-connected and islanded modes [12]. Over the years, microgrid has been proved to be one of the most effective patterns to utilize DGs in medium and low voltage distribution systems [13,14]. Due to its operational flexibility and reliability, microgrid provides an excellent platform where the utility grid, DGs, ESSs and local loads interact positively with each other [15]. Even though DGs can be controlled appropriately in microgrid, a single microgrid is incapable of incorporating a large amount of DGs [16,17].

The multiple microgrids concept is a cluster of microgrids that accommodate a large number of DGs via local integration [18]. On the one hand, multiple microgrids mitigate the limitation on DG penetration of a single microgrid; on the other hand, the system reliability is enhanced due to less influence of every single DG. As a result, the focus on the organization of DGs has shifted from a single microgrid to multiple microgrids in areas that are abundant in DREs [19,20].

Compared with a single microgrid, multiple microgrids reach power balance through the cooperation among all the microgrids. So far, the research on multiple microgrids mainly focuses on system control, optimization and management, aiming to improve the reliability and economy of the system via proper control and operation strategies. The control architecture of multiple microgrids is firstly studied in the European Research Project titled "More Microgrids: Advanced Architectures and Control Concepts for More Microgrids" within the 6th Framework Programme (2002–2006). The control architecture consists of three levels, namely the Distribution Management System (DMS), the Central Autonomous Management Controller (CAMC) and the MicroGrid System Central Controller (MGCC) [21]. Ref. [22] simplifies the control architecture of multiple microgrids to two levels and enhances the system reliability by introducing a reserve capacity mechanism. Ref. [23] introduces a bi-level control framework to reduce the loss-of-load probability in power networks that consists of several residential/commercial communities. In [24], a self-decision making method for load management utilizing multi-agent systems is proposed. The method reduces the peak load of a smart distribution network feeder and is applicable for multiple feeders. Ref. [25] decomposes the dispatching decision among multiple microgrids into inter-temporal decision and real-time scheduling decision to realize the economic operation of the system. Ref. [26] proposes a method of simultaneous allocation of electric vehicle parking lots and distributed renewable resources. Economic objectives and system loss are both considered in the method. In [27], an intelligent energy management system that considers demand response is proposed for trading and managing power in multiple microgrids. The researches above put forward coordination strategies from different perspectives to meet the operation requirements and objectives of multiple microgrids. Nevertheless, the multiple microgrids that are investigated are connected to the utility gird via parallel synchronous connection. Moreover, the coordination approaches of the multiple microgrids are not thoroughly developed, thus limiting the operational flexibility and economy of the multiple microgrids to a certain extent.

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