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A microgrid cluster structure and its autonomous coordination control strategy

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ABSTRACT

This paper proposes a microgrid cluster structure and its autonomous coordination control strategy. Unlike existing microgrids that are purely AC or DC, the microgrid cluster studied here is an interconnected system with multiple AC and DC microgrids, which enables mutual power support among microgrids and improves the utilization of renewable energy sources (RES). The proposed microgrid cluster structure is composed of power exchange unit (PEU), energy pool (EP), AC microgrids, and DC microgrids. PEU is used to coordinate power exchange among microgrids and EP. Meanwhile, the power coordinated control method combining the normalized droop-based control and adaptive control is proposed for PEU, which can effectively realize mutual power support among microgrids and reduce the bus voltage or frequency deviation in microgrids. In addition, the adaptive control strategy of PEU can ensure that the bigger the normalized index of microgrid is, the larger the active power exchange coefficient is, which can make all of microgrids operate around the rated state as much as possible. Besides, EP is mainly used to balance the system power, and the hierarchical coordinated control method of EP is proposed to stabilize the dc-link voltage and reasonably allocate the net exchange power of PEU. The proposed control strategy has been verified by the simulation and experimental results.

1. Introduction

With increasing depletion of traditional fossil fuels and the intensification of global energy crisis, the renewable energy sources (RES) such as solar energy and wind energy are widely used [1,2]. Microgrid, consisting of RES, energy storages, power converters and local loads, has been used to manage RES effectively [3,4]. However, the single microgrid has some disadvantages such as the limited capacity and the weak anti-disturbance ability. Coupled with the intermittent output power of RES and the variability of loads [5], how to improve the power supply reliability of microgrid need to be urgently solved.

An effective solution is to integrate the geographically adjacent microgrid together to form a microgrid cluster, which can realize the energy dispatching and mutual power support among microgrids [6,7]. Multiple microgrids can be interconnected directly by the AC link, which can reduce the investment costs [8–11]. However, synchronization algorithm must be employed for microgrids to improve the reliability of connection. While, that makes it difficult to operate microgrids on different frequency due to the synchronization. In order to regulate the frequency separately, the back-to-back converters are used to connect the geographically adjacent microgrids in [12]. Nevertheless, the synchronization algorithm is still necessary due to the AC link connection, and the number of interface converters has been doubled. To restrain this drawback, an architecture of multiple microgrids system based on the DC link connection is proposed in [13]. However, when all of microgrids operate on overload or underload state, it is difficult to regulate the operation state of microgrids because there is no energy storage on DC link. Focusing on these problems, this paper proposes a microgrid cluster structure based on the DC link connection as shown in Fig. 1, which is composed of power exchange unit (PEU), energy pool (EP), AC microgrids, and DC microgrids. All of microgrids are connected to the common DC link through PEU, which allow different microgrids to operate on different frequency or voltage. Moreover, the synchronization scheme can be neglected as compared to the AC link connection mode. Wherein, in order to buffer the system power fluctuation, some of the energy storage batteries are connected together to form EP through Bi-DC/DC converters. In addition, for improving the power supply reliability of microgrid cluster, the dc-link of EP is designed as ring network, which belongs to the standby network.

Compared with the single microgrid, the power coordinated control

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Nomenclature

$u_{abc,n}$	AC bus voltage of the n^{th} AC microgrid (V)
$u_{dc,m}$	DC bus voltage of the m^{th} DC microgrid (V)
$i_{abc,n}$	output current of the n^{th} DC/AC in PEU (A)
$i_{dc,m}$	output current of the m^{th} DC/DC in PEU (A)
f_n	operate frequency of n^{th} AC microgrid (Hz)
θ_n	phase angle of the n^{th} AC microgrid (rad)
$U_{ac,n}$	the RMS of the n^{th} AC microgrid (V)
k_p	active power exchange coefficient of PEU
k_q	reactive power exchange coefficient of PEU
α	the base number
γ'_{th}	the start threshold for the active power exchange of PEU
$P_{ac,n}$	exchanged active power of the n^{th} DC/AC in PEU (kW)
$i^*_{abc,n}$	reference current of the n^{th} DC/AC in PEU (A)
$i^*_{dc,m}$	reference current of the m^{th} DC/DC in PEU (A)
i_k	output current of the k^{th} Bi-DC/DC converter (A)
$i^*_{ref,k}$	reference current of k^{th} Bi-DC/DC converter (A)
$i_{bat,k}$	discharge current of k^{th} group energy storage (A)
$P_{bat,k}$	the output power of the k^{th} Bi-DC/DC (kW)
$P^*_{bat,k}$	output power reference of k^{th} Bi-DC/DC (kW)
SOC_i	SOC of the i^{th} energy storage battery
$S_{N,i}$	the rated capacity of the i^{th} Bi-DC/DC (kW)
u_{ref}	the reference dc-link voltage (V)
k_{init}	the initial active power exchange coefficient of PEU
$P_{dc,m}$	exchanged active power of the m^{th} DC/DC in PEU (kW)

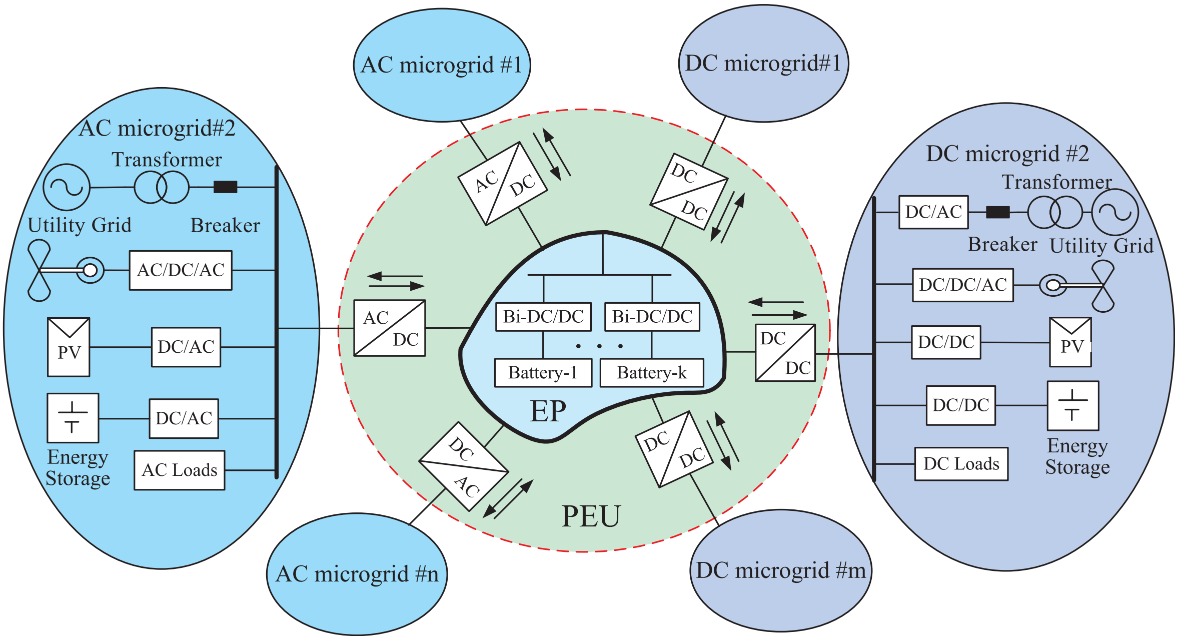

Fig. 1. The structure of the proposed microgrid cluster.

for microgrid cluster is more complicated, which should consider the power optimization allocation and mutual power support among microgrids. For that, some optimization approaches and centralized control methods are widely researched [14–23]. Refs. [14–16] proposed the economy optimized management method for multiple microgrids system, which can minimize the electricity cost and optimize the economic performance of multiple microgrids system. Ref. [17] proposed the management technique based on dynamic multicriteria decision-making, which includes the available surplus power, reliability, supply security, power loss, electricity cost, and CO_2 emissions. Refs. [18,19] adopted the particle swarm optimization and heuristic-based optimization approach to select the suitable adjacent microgrids, so as to support each other under emergencies. Refs. [20,21] presents a centralized multi-microgrid operation controller to achieve smooth and coordinated operations among hybrid AC/DC microgrids with electric vehicle. Ref. [22] presents a data-driven control method for interlinked AC/DC microgrids via model-free adaptive control and dual-droop control, which can provide dc voltage and ac frequency support while keeping accurate proportional active power sharing between ac and dc microgrids. Ref. [23] presents a novel architecture for multiple microgrids and its coordinated control schemes, which can effectively coordinate operation among multiple microgrids and realize the optimal use of RES. However, the control strategies mentioned above heavily rely on the communication, which reduces system's reliability.

For this reason, the distributed control strategy is developed to control clustered microgrids. Wherein, the droop control has been proved an effective method. The energy coordination management method based on the droop control for hybrid AC/DC microgrid is proposed in [24,25], which can achieve the effective control for power exchange in hybrid AC/DC microgrid. However, in this control method, the power exchange between two microgrids is enforced all the time, which results in the additional power loss due to the unnecessary power exchange behaviors. To restrain this drawback, the modified control method has been developed to schedule the power exchange between two subgrids [26–28]. It allows the power exchange only when the subgrids operate in a certain threshold values, which can effectively avoid the energy loss caused by the frequent power exchange in interlinking converters.

It is worth noting that the aforementioned decentralized control strategies are mostly confined to the power coordination control for single or two subgrids, which cannot be directly applied in microgrid cluster composed of multiple AC and DC microgrids. For that, a droop frequency control is proposed for the interlinking converter to improve frequency control performance and achieve autonomous power sharing [13]. However, it may lead to the dc-link voltage violent fluctuation. Ref. [29] proposes a decentralized power management method for the hybrid microgrid to make the interacted subgrids operate in coordination and mutual support, which can ensure the corrected relative changes of ac frequencies and dc voltages in all of subgrids equal. However, owing to taking a closed-loop control for the ac frequencies