A novel distributed control for hybrid AC/DC microgrid with consideration of power limit

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***Abstract*—Hybrid DC/AC microgrid is considered to be an effective structure to integrate different kinds of distributed sources and the control of each subgrid and interlinked converters (ILCs) is crucial for stable operation. The distributed control with consideration of power limit is proposed in this paper to improve power sharing accuracy and prevent power violation. Simulation results demonstrate the efficiency of the proposed method in an islanded hybrid microgrid under different scenarios.**

Keywords—distributed control, hybrid microgrid, droop control, power limit.

I. Introduction

AC distribution network is dominant now [1] and a large number of AC microgrids have been put into operation. In addition, the connection to utility grid needs the AC-microgrid as a medium. On the other hand, DC-characterised renewable sources and loads have been increasing rapidly in recent years. DC distributed generators (DGs) such as photovoltaic (PV) become more popular for the environmental friendliness and renewability. In the meanwhile, the DC loads such as LEDs are also widely used [2-4]. Thus, the use of hybrid AC/DC microgrid is an effective solution for the integration of various AC and DC sources and loads [5-7].

The AC DGs and loads are installed in AC subgrid and the DC subgrid includes DC renewable generators and DC loads. These two types of subgrids are connected by the interlinked converters (ILCs) and the main aim of ILCs is to control the power flow between DC/AC subgrids and achieve power sharing between them [8-9].

In this paper, a novel distributed control for hybrid AC/DC microgrid is proposed to obtain accurate power sharing with consideration of power limit of DGs. In the meanwhile, the proposed method allows multiple ILCs to work parallelly. The feasibility and effectiveness of the proposed scheme is verified by simulations.

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II. Control Analysis Of Hybrid AC/DC Microgrid

In this section, the structure of hybrid AC/DC microgrid will be analyzed and the control objective will be listed.

As seen in Fig. 1, the common hybrid AC/DC microgrid consists of DC subgrid, AC subgrid and the bidirectional DC/AC interlinked converters to link two types of subgrids.

A. DC Microgrid

The DC microgrid has dc renewable sources (RESs) like PV panels for MPPT control. In the meanwhile, the energy storage systems (ESSs) are used for grid-supporting and smoothing the grid power due to the intermittence of RESs and they can be controlled by decentralized method for power sharing like droop in Fig.2(a). However, the power sharing is influence heavily by line impedance with voltage difference *ΔV*. In addition, power limit of droop-controlled sources can not be solved well because the voltage in DC microgrid is not the common variable. Finally, DC loads are connected to dc bus and other kinds of sources like fuel-cells can also be linked to the dc bus.

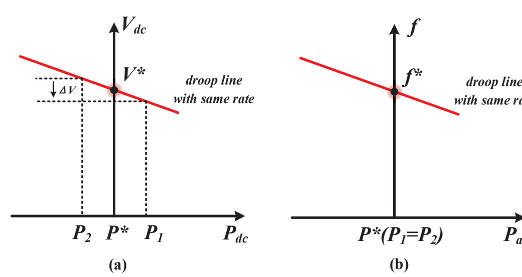

Fig. 2. Droop control in (a) DC microgrid and (b) AC microgrid

B. AC Microgrid

The AC microgrid are connected to utility grid by the intelligent transfer switch (ITS). The microgrid switches to islanding mode when ITS is open. In this case, the local ac generators like diesel generators and ESSs are responsible for AC grid-supporting and can be controlled by droop method for meeting the power demand of local load and power sharing which is described in Fig.2(b). In the meanwhile, the power limit can be realized by adding the integral term in the P/f

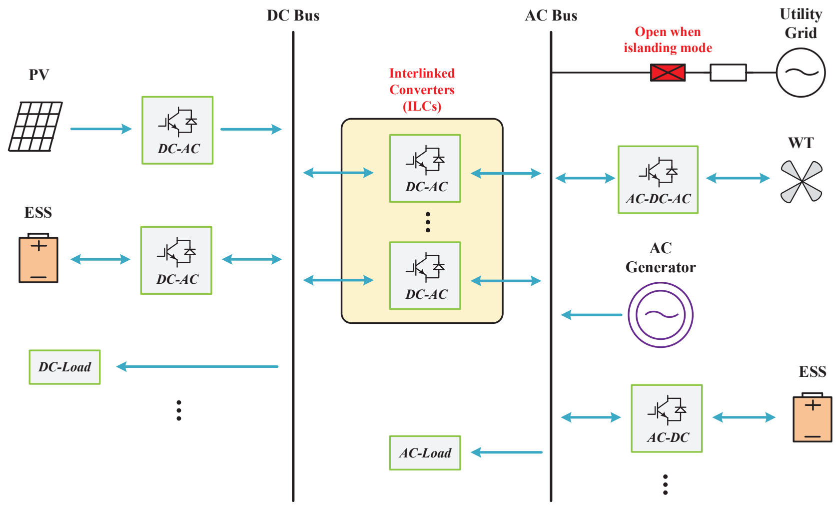

Fig. 1. Hybrid AC/DC microgrid structure

droop. The RESs in AC grid like wind turbines (WTs) are controlled in MPPT mode.

C. *Interlinked converters for DC/AC coordination*

As discussed in the aforementioned sections, the DC and AC microgrids both have the grid-supporting abilities which indicates that the voltages of ILCs in both DC/AC sides are clamped and the ILCs can only be controlled in current mode. The main aim of ILCs control is to determine the correct current reference for global power sharing of MG.

III. The Proposed Control Strategy

In this section, the control scheme of DC subgrid, AC subgrid and ILCs will be designed and illustrated in detail for aims of proper power interaction and power limit control.

A. *DC microgrid control*

From the analysis of Section II, the distributed control with low bandwidth communication (LBC) is used in this paper.

The communication network can be illustrated by graphical representation in Fig.3 (a). In the graph, nodes represent DGs and edges represent communication links that can be bidirectional to form an undigraph or not (digraph). Each node shares its information, such as measurement values of power or voltage to its neighbors. Note that DG_i denotes the *i-th* DG unit.

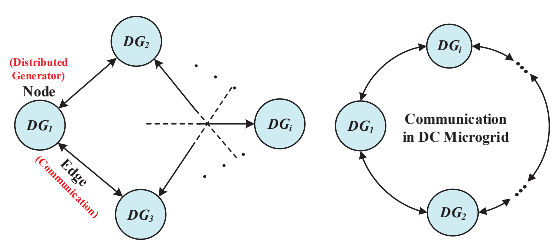

Fig. 3. (a) Graphical representation of communication network and (b) Designed LBC network in DC microgrid

The communication network is designed to improve the reliability of microgrid and optimize the structure and cost. In the proposed control, a bidirectional sparse LBC network is used as illustrated in Fig.3 (b) and to simplify the analysis, the communication network of each DG is set to be identical. The circular communication graph is considered as a reliable structure with enough redundance to endure the case of any single point failure [2].

According to the designed communication network, a distributed droop control strategy is proposed for islanded DC subgrid and is expressed in (1)-(3).

$$P_i = \underbrace{k_i \bullet p_i}_{normalization} \tag{1}$$

$$V_i = V_{dc}{}^{*} - \underbrace{k_1(P_i - P^{*})}_{droop} + \delta V \tag{2}$$

$$\delta V = (k_{p2} + \frac{k_{i2}}{s})\bullet\left(\underbrace{(P_{i-1} - P_i)\bullet EN_{i-1} + (P_{i+1} - P_i)\bullet EN_{i+1}}_{power-sharing}\right) \underbrace{- DEN_i \bullet (k_{p3} + \frac{k_{i3}}{s})(P_i - P^*)}_{power-limit} \tag{3}$$

Where p_i is the actual measured power of *i-th* DG. P_i is the modified power based on power ratings of *i-th* DG and is calculated with coefficient k_i. P^* is the normalization power limit of DGs. In (2), the improved droop with adding δV from distributed algorithm is used and k_1 is droop coefficient. Besides, the droop term is set by upper saturation of zero to cooperate with power-limit controller. In (3), the consensus control is modified with EN_i and power limit term. EN_i and DEN_i is the logic signal which are illustrated in TABLE I. $k_{p,i2}$ is the PI coefficient of power sharing controller and $k_{p,i3}$ is the PI coefficient of power limit controller, respectively.

TABLE I. LOGIC OPERATION

Trigger condition	EN_i	DEN_i
$P_i < P^*$	1	0
$P_i > P^*$	0	1

From the controller combined by Eq. (1)-(3), the objectives of the controllers can be achieved. 1) accurate power sharing, 2) power limit of droop-controlled DGs, 3) the common variable of voltage. In addition, the voltage restoration can also be realized by this type of LBC networks [4] but it is out of the scope of this paper.

B. *AC microgrid control*

Because of the synchronization nature of frequency, the PI droop is adopted and given by

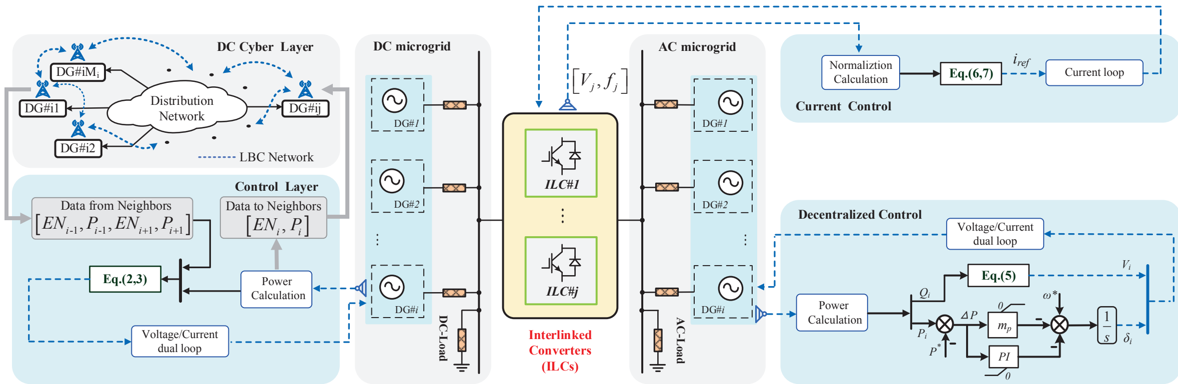

Fig. 4. Control structure of the whole system

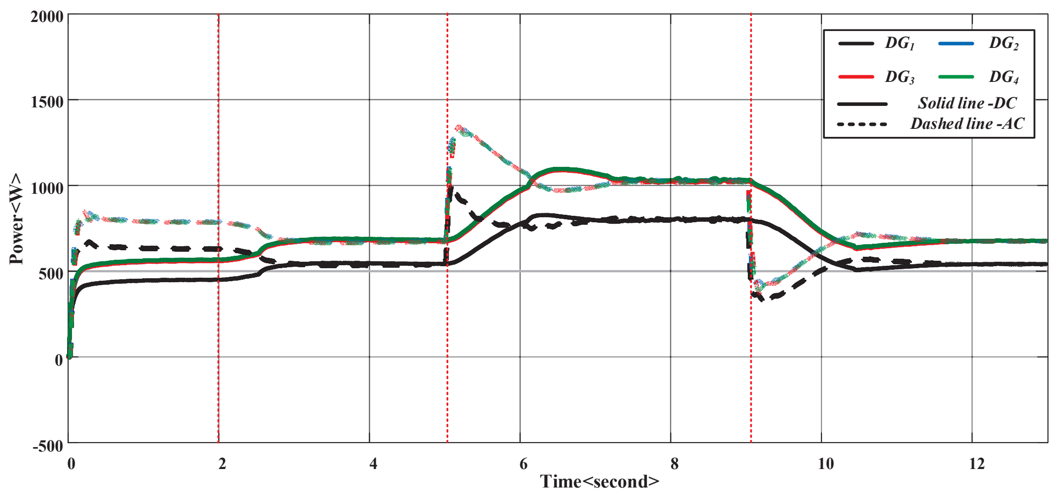

Fig. 3. Simulation results of output power of DGs

$$\omega_i = \omega^* - \left(m_p \left(P_i - P^*\right) + en_i \bullet \frac{m_i}{s} \left(P_i - P^*\right) \right) \qquad (4)$$

$$V_i = V^* - nQ_i \qquad (5)$$

Where $m_{p,i}$ is the PI droop coefficient of droop-controlled DGs respectively. When P_i exceeds the normalization power P^*, the proportional droop term is saturated and PI droop term is activated with enabling signal en_i turning from 0 to 1 which can also be illustrated in Fig. 4. In this way, the power limit control is obtained.

C. ILCs control

As described in section II. C, the ILCs are controlled in current mode and the main objective is to obtain the proper current reference. In order to coordinate the whole hybrid microgrid and to achieve the global power sharing among DC/AC sources, the f/V normalization with PI controller is adopted and is illustrated by

$$i_{j\_ref} = \left(k_{p4} + \frac{k_{i4}}{s}\right)\left(\left(V_j - V^*\right) - \lambda\left(f_j - f^*\right)\right) \qquad (6)$$

where $k_{p,i4}$ is the PI coefficient of current controller, respectively. V_j and f_j are the droop-voltage and measured-frequency of *j-th* ILC. The normalization coefficient λ is determined by the power rating of DC/AC microgrid and droop coefficients. The specific value can be calculated by

$$\lambda = \frac{k_1}{m_p} \qquad (7)$$

By integrating the above control methods of DC/AC subgrids and ILCs, the overall control structure of the microgrid is shown in Fig. 5.

IV. Simulation Results

The simulation based on Matlab/Simulink is implemented to validate the proposed method. The parameters of the system with 4 DC-DGs, 4 AC-DGs (the power rating of DG_1/ $DG_{2,3,4}$ is 8/11 and the power limit of DC-DG_1/AC-DG_1 is both 800W) and one ILCs are listed in TABLE II.

TABLE II. PARAMETERS FOR SIMULATION

Parameter	Symbol	Value
System Parameters		
Frequency	f^*	50Hz
AC-Voltage	V^*	311V
DC-Voltage	V_{dc}^*	400V
Normalized power	P^*	1100W
Initial load demand	$P_{dc\text{-}load}/P_{ac\text{-}load}$	2000W/3000W
Control Parameters		
PI droop coefficient	m_p/m_i	0.0001/0.001
P-V droop coefficient	k_1	0.0025

PI of distributed control	k_{p2}/k_{i2}	0.01/1
PI of power limit control	k_{p3}/k_{i3}	1/10
PI of ILCs controller	k_{p4}/k_{i4}	0.2/10

The simulation result is shown in Fig. 5. Before 2s, the control of ILCs is not activated. In this case, DC/AC subgrids have no power transmission but accurate power sharing based on power ratings of DGs is achieved among DGs in their own subgrids. At 2s, the control of ILCs is enabled and the power sharing among DC/AC subgrids is realized in the steady state. From 5s on, the hybrid microgrid encounters 2.5KW impact load and the power limit function of $DG_{1,5}$ controls their output power at 800W. The other DGs are responsible for left-power sharing and grid-supporting. At 9s, the load shedding of 2.5KW happens and power limit function is deactivated. As can be seen in Fig. 6, the mode transition of power limit is smooth which is beneficial for stability of the system.

V. Conclusion

This paper proposes a novel distributed control for hybrid AC/DC microgrid with consideration of power limit to improve the power sharing accuracy. The distributed method only uses information of neighbors in DC subgrid and thus, avoid the single point of failure and decrease the cost. To simply the design of control scheme, the normalization method is adopted for different power-rated DGs. Finally, the simulation studies have been carried out to validate its effectiveness.

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