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A communication-free economical-sharing scheme for cascaded-type microgrids

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ABSTRACT

This paper proposes an economical-sharing scheme without the needs of any communications for islanded AC microgrids (MGs) fed by cascaded inverters. The output voltage phase angle of each distributed generator (DG) is regulated by its corresponding incremental cost. Then the equal incremental principle used to guarantee the economic optimality is realized by synchronization conditions. In addition, a modification method is introduced with considering the capacity constraints. Stability analysis of the proposed method is carried out, and the conditions for economic optimality and stability are obtained. Because the communications are not needed, the advantages in cost and reliability are obvious. Simulations and experiments are implemented to verify the effectiveness of the proposed scheme.

1. Introduction

As a result of a new concept for integrating renewable distributed resources in distributed energy system, microgrids (MGs) have attracted increasing research interest recently [1,2]. The MG technology, that integrates various types of DGs, energy storage elements and loads, has become an effective approach to solve the permeation of large-scale DGs to power grid [3,4]. Usually, the DGs in MGs are commonly connected by power electronic converters in paralleled or cascaded manners [5]. Different DGs have different generation costs [6,7]. From the economical perspective, the cost-effective DGs are expected to provide more power.

The economical operation approaches in MGs could be classified into the centralized, distributed and decentralized schemes. The centralized schemes in MGs hold the advantages of better voltage and frequency regulations, and flexible operation modes [8–10]. However, the control decisions are performed with global information, complicated central controllers and extensive communication networks, which increases the capital cost and system complexity, and reduces reliability of MGs.

The distributed schemes are performed depended on information exchange for each DG from its neighbors [11–16]. Xu et al. [17] introduced a distributed consensus algorithm to realize the equal incremental costs of all DGs for economical operation, *i.e.*, the equal incremental principle. The incremental cost is a derivative of the DG cost function with respect to output active power. To solve the economical dispatch problem, Zhang et al. [18] presented a distributed algorithm to realize the optimal economical operation. Further, Zhang et al. [19] introduced a consensus algorithm via selecting the incremental cost as a consensus variable. When the MGs are synchronized, the cost optimization is realized. Additionally, Yang et al. [20] focused on another consensus algorithm, which required a strongly connected communication topology to perform the equal incremental principle. However, [17–20] are highly dependent on communications for information exchange among the neighbouring DGs, and need no central controller compared to the centralized schemes.

Recently, decentralized approaches without any communi -cations have been proposed to deal with the power dispatch problem [21–23]. By emulating the behavior of a synchronous generator, droop control method as a well-known decentralized approach has been widely applied in MGs [24,25]. It aims to dispatch active and reactive power applying the deviation of frequency and output voltage by adjusting the droop coefficients only with locally information [26,27]. However, the economical operation of MGs is usually not guaranteed in terms of the traditional droop scheme. In order to reduce the total active generation costs (TAGC) of MGs in decentralized manners, Nutkani et al. [6] presented the linear droop schemes by designing the maximum or mean generation costs as the droop coefficients. Actually, the generation costs of DGs is a nonlinear function of the active power output [6,28], therefore, the TAGC of MGs might not be optimized efficiently. Further,

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Nutkani et al. [28] proposed a nonlinear droop control scheme with applying the nonlinear cost functions to the typical droop scheme. However, the optimal economical-sharing of MGs is not obtained yet. Although it is a suboptimal solution, it is able to realize plug-and-play and has a wide range of practical value. A decentralized economic operation in [29] is proposed to reduce the TAGC without communications for MGs consisting of paralleled inverters.

Although many methods for economical dispatch have been proposed, they are mainly focused on the MGs fed by paralleled inverters. Nowadays, the MG which is made up of cascaded inverters (cascaded-type MGs) has been recognized as an important alternative in the medium voltage applications [30–32]. The cascaded-type MGs in islanded operation mode are firstly introduced in [33]. However, to best of our knowledge, there are no studies about the economic dispatch problems for this structure in the previous literature via decentralized approaches.

To address these concerns above, this paper proposes a communication-free economical-sharing scheme for cascaded- type MGs in islanded mode. The frequency is used to drive all DGs synchronize under the resistance-inductance (RL) and resistance-capacitance (RC) load. When the MGs are in the steady state, the economical power dispatch is obtained by regulating the phase angle of each DG according to the equal incremental principle. The implementation of the method only needs the local information of each DG, therefore, it offers increased reliability. The application conditions of the proposed scheme are demonstrated clearly, which could ensure the economy and stability of cascaded-type MGs. Finally, the proposed scheme has been verified through simulations and experiments.

The rest of the paper is organized as follows. Section 2 describes the economical optimization of the cascaded-type MG. The proposed communication-free economical-sharing scheme is introduced in Section 3. Stability analysis of the proposed scheme is presented in Section 4. Then, the simulation validations in Section 5 and the experimental results in Section 6 are provided to verify the effectiveness and performance of the proposed scheme. Finally the paper is concluded in Section 7.

2. Economical optimization of cascaded-type MGs

2.1. Cascaded-type MGs

The cascaded-type MG comprises a series of cascaded inverters [30–32] connected with the point of common coupling (PCC). It is shown in Fig. 1, in which L_f, r_f are the filter inductance and its corresponding series resistance. C_f, r_d are the filter capacitance and its corresponding series resistance. The equivalent circuit of cascaded-type MGs is shown in Fig. 2. $V_i e^{j\delta_i}$ is the output voltage of *ith* DG, $V_{PCC} e^{j\delta_{PCC}}$ is the voltage of the PCC, V_i and V_{PCC} are the amplitudes of the corresponding voltages, δ_i and δ_{PCC} are the phase angles of the corresponding voltages. z_{PCC}, z_{line}, and y' are load impedance, line impedance, and equivalent admittance, respectively. By Kirchhoff laws, the obtained load voltage is presented as:

$$V_{PCC} e^{j\delta_{PCC}} = y' z_{PCC} \sum_{i=1}^{n} V_i e^{j\delta_i} \tag{1}$$

$$y' = \frac{1}{z_{PCC} + z_{line}} \tag{2}$$

For convenience, y' is denoted as:

$$Y' = |Y'| e^{j\theta'} \tag{3}$$

where $|Y'|$ and θ' are the modulus and phase angle of y', respectively. After obtaining the load voltage, it is easy to get the expressions of output active power P_i and reactive power Q_i of the *ith* DG,

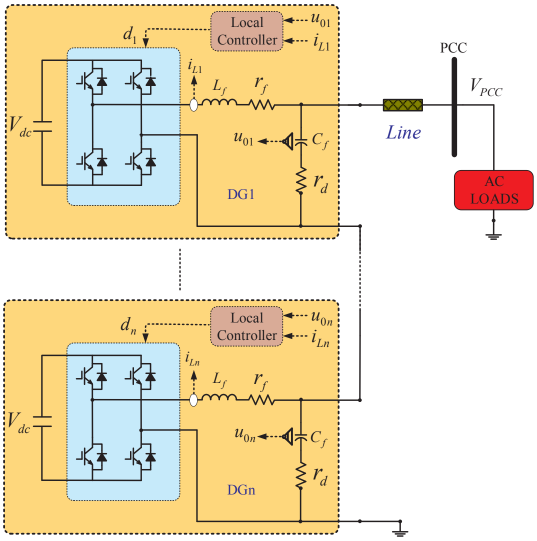

Fig. 1. Structure of cascaded-type MG.

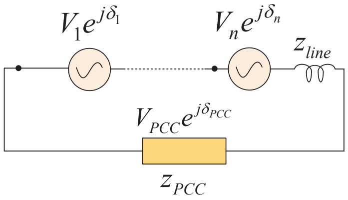

Fig. 2. Equivalent circuit of cascaded-type MG.

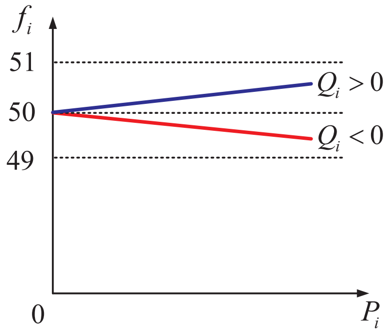

Fig. 3. Characteristics of the proposed *P-f* scheme.

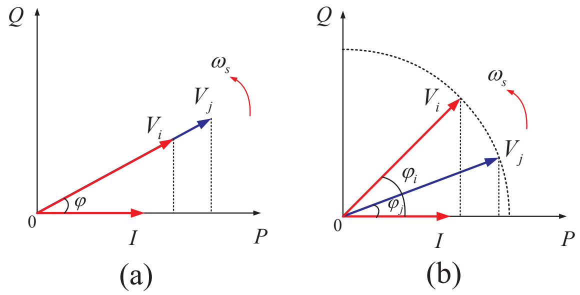

Fig. 4. Real power sharing for cascaded-type MGs via changing (a) the magnitude of V_i, (b) the phase angle φ_i.

$$P_i = V_i |Y'| \sum_{j=1}^{n} V_j \cos(\delta_i - \delta_j - \theta') \tag{4}$$

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