Distributed Adaptive Virtual Impedance Control to Eliminate Reactive Power Sharing Errors in Single-Phase Islanded Microgrids

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***Abstract*—This paper proposes an enhanced distributed generation (DG) unit with an adaptive virtual impedance control approach in order to address the inaccurate reactive power sharing problem. The proposed method can adaptively regulate the DG virtual impedance, and the effect of the mismatch in feeder impedances is compensated to share the reactive power accurately. The proposed control strategy is fully distributed and the need for the microgrid central controller is eliminated. Furthermore, the proposed method can be directly implemented without requirement of pre-knowledge of the feeder impedances. Simulations are performed to validate the effectiveness of the proposed control approach.**

***Index Terms*—Droop control, distributed generation (DG), microgrid, real and reactive power sharing, virtual impedance.**

I. INTRODUCTION

For the operation of islanded microgrids, the load power demands must be properly shared according to the power ratings of the DG units to avoid overstressing and delay aging of the sources. In order to realize the power sharing successfully without the communication between DG units, the frequency and voltage droop controllers have been reported in [1]. Due to the mismatched feeder impedance, the voltage droop control commonly results in poor reactive power sharing [2]. To solve the inaccurate power-sharing problem, a few improved methods have been introduced. In [3], while the accurate power sharing is realized by incorporating the line voltage drop into the power control scheme, the information about feeder impedances is required which is not easily available. In [4], by adaptively regulating the DG virtual impedances, the effect of mismatched feeder impedances is compensated and the accurate power-sharing is achieved. However, this method requires helps from a microgrid central controller (MGCC) which increases the system cost and reduces the system reliability.

In this paper, a distributed adaptive virtual impedance control method is applied to DG units in islanded microgrids in which the microgrid central controller is needless. The DG virtual impedance is adaptively tuned in order to compensate the mismatch in feeder's impedances and the communication is utilized to tune the virtual impedances based on its neighbor reactive power information. Once the virtual impedance is tuned for a given load operating point, the accurate reactive power sharing is achieved. The proposed control strategy is verified by the digital simulation.

II. PROPOSED CONTROL APPROACH

A. Droop Controller

The conventional frequency and voltage magnitude droop controls in the i^{th} DG unit are given in (1) and (2):

$$\omega_i = \omega_0 - m_i P_i \,, \tag{1}$$

$$E_i = E_0 - n_i Q_i \,, \tag{2}$$

where ω_0 and ω_i are the nominal and reference angular frequencies of the i^{th} DG unit, respectively; E_0 and E_i are the nominal and reference DG voltage magnitudes, respectively; P_i and Q_i are the DG output power after low-pass filter; m_i and n_i are the real and reactive power droop slopes, respectively. With the derived angular frequency and voltage magnitude from (1) and (2), the instantaneous voltage reference $v_{droop,i}$ is obtained accordingly as

$$v_{droop,i} = E_i \sin\left(\int \omega_i \, dt\right). \tag{3}$$

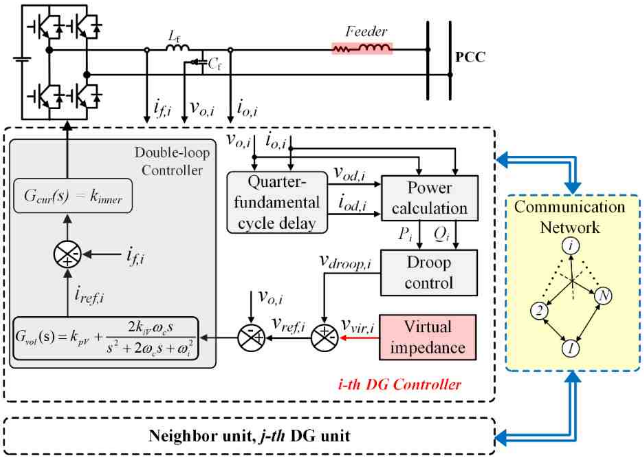

Fig. 1. Proposed control scheme.

B. Adaptive Virtual Impedance

To remove the reactive power sharing errors, an adaptive virtual impedance regulation is introduced in this paper in which the i^{th} DG virtual impedance $L_{vir,i}$ is regulated around its nominal value as

$$L_{vir,i} = \bar{L}_{vir,i} + \tilde{L}_{vir,i} \,, \tag{4}$$

where the $\bar{L}_{vir,i}$ is a nominal inductance, and $\tilde{L}_{vir,i}$ represents its perturbation.

As can be seen in Fig. 1, thanks to the help of low bandwidth communication link (LBC), the i^{th} DG controller gathers the information about the DG output reactive powers of its neighbor DG units. After that, the update rule for $\tilde{L}_{vir,i}$ to eliminate the reactive power sharing errors is given as

$$\tilde{L}_{vir,i} = \frac{k_{iQ}}{s}\left(n_i Q_i - \frac{1}{|N_i|}\sum_{j=1}^{N_i} n_j Q_j\right), \tag{5}$$

where k_{iQ} is the integral gain to adjust the virtual inductance; N_i is the communication neighbor set of the i^{th} DG unit; and $|N_i|$ is denoted as the cardinality of N_i.

Form (4) and (5), the i^{th} DG virtual impedance is determined as

$$L_{vir,i} = \bar{L}_{vir,i} + \frac{k_{iQ}}{s}\left(n_i Q_i - \frac{1}{|N_i|}\sum_{j=1}^{N_i} n_j Q_j\right). \tag{6}$$

Then, the voltage drop $v_{vir,i}$ due to the virtual impedance becomes

$$v_{vir,i} = -\left(\omega_i L_{vir,i}\right) i_{od,i} \,, \tag{7}$$

where $i_{od,i}$ is delayed component for a quarter fundamental cycle of the

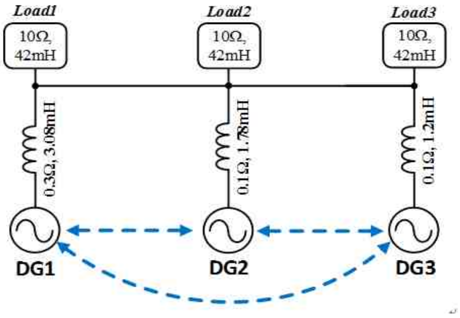

Fig. 2. Simulated microgrid configuration.

TABLE I
DG SYSTEM PARAMETERS

Parameter	Values
Nominal operating voltage *(rms)*	120*V (60Hz)*
Sampling-switching frequency	10*kHz*
DC link voltage (V_{dc})	200*V*
LC Filter (L_f / C_f /R_d)	1.203*mH* /20*uF* /1*Ω*
Frequency droop coefficient, m_i	0.00143 *Rad/(Sec·W)*
Voltage droop coefficient, n_i	0.00167 *V/Var*

DG line current $i_{o,i}$. Then, the voltage reference $v_{ref,i}$ for the voltage control loop is obtained as

$$\begin{aligned} v_{ref,i} &= v_{droop,i} - v_{vir,i} \\ &= v_{droop,i} + \omega_i L_{vir,i} i_{od,i} \end{aligned} \tag{8}$$

C. Double-Loop Voltage Tracking Scheme

With the voltage reference V_{ref} in (8), the double-loop voltage controller in Fig. 1 is applied to generate the desired output voltage. In the double-loop voltage controller, the outer loop uses a non-ideal proportional–resonant (PR) controller tuned at the fundamental frequency:

$$G_{Vol}(s) = k_{pv} + \frac{2k_{iv}\omega_c s}{s^2 + 2\omega_c s + \omega_{DG}^2}, \tag{9}$$

where k_{PV} is the outer loop proportional gain, k_{iV} is the resonant controller gain at the fundamental frequency, and ω_c is the cutoff frequency of the resonant controller. The inner loop has a simple proportional control gain k_{inner} with the filter inductor current feedback, which provides sufficient damping to the output LC filter:

$$G_{Cur}(s) = k_{inner}. \tag{10}$$

III. SIMULATION RESULTS

The proposed power control strategy has been verified with PSIM simulations. As shown in Fig. 2, the simulated microgrid is composed of three identical DG units and several linear loads. The system parameters used in the simulation are listed in Table I. Each DG unit can exchanges the required information with two others through low bandwidth communication links. Under the same power rating, the three DG units shall share the load demand equally.

The system performances with the proposed control method are shown in Fig. 3. At the beginning, the system operates under conventional method with Load1 and Load2 at the PCC. At t = 5s, the proposed adaptive virtual impedance control scheme is activated. To investigate the performance of the proposed control scheme when the load changes, Load3 is connected to and disconnected from the PCC at t = 10s and 15s, respectively, while Load1 and Load2 are remained connected.

As shown in Fig. 3, while the active load powers can be accurately shared among DG units with conventional droop controller, the accurate reactive-power-sharing cannot be achieved due to the mismatched feeder impedance effect. However, when the proposed method is activated, the reactive-power-sharing errors are completely eliminated even though the load demand has changes as can be seen in Fig. 3(a). Furthermore, the proposed control scheme causes only a small transient variation for the active power sharing between DG units, and the perfect active power sharing is maintained at the steady-state with the proposed control scheme as shown in Fig. 3(b).

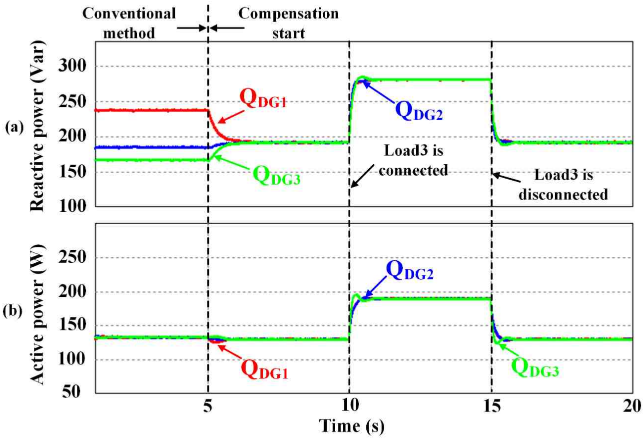

Fig. 3. Power sharing performance. (a) Real power. (b) Reactive power

IV. CONCLUSIONS

In this paper, we proposed an enhanced virtual impedance control scheme to achieve accurate active and reactive power sharing in a single-phase islanded microgrid. By adjusting the DG virtual impedances, the accurate reactive-power-sharing is always achieved even though the feeder impedances are mismatched each other. Furthermore, the proposed control strategy does not require any knowledge of the detailed microgrid configuration, feeder impedances, or load power information. More importantly, the need of a microgrid central controller is mitigated. Finally, the feasibility of the proposed scheme is demonstrated via simulation.

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