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 delaying 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):

$$\omega_i = \omega_0 - m_iP_i,$$  \hspace{1cm} (1)

$$E_i = E_0 - n_iQ_i,$$ \hspace{1cm} (2)

where $\omega_0$ and $\omega_i$ 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 reference $v_{\text{droop},i}$ is obtained accordingly as

$$v_{\text{droop},i} = E_i \sin (\omega_i \,dt). \hspace{1cm} (3)$$

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 $L_{\text{vir},i}$ is regulated around its nominal value as

$$L_{\text{vir},i} = L_{\text{vir},i} + \hat{L}_{\text{vir},i}, \hspace{1cm} (4)$$

where the $\hat{L}_{\text{vir},i}$ is a nominal inductance, and $\hat{L}_{\text{vir},i}$ 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 $\hat{L}_{\text{vir},i}$ to eliminate the reactive power sharing errors is given as

$$\hat{L}_{\text{vir},i} = \frac{k_{Q}}{s} \left( n_{i}Q_{i} - \frac{1}{N_{s}} \sum_{j=1}^{N_{s}} n_{j}Q_{j} \right), \hspace{1cm} (5)$$

where $k_Q$ is the integral gain to adjust the virtual inductance; $N_{s}$ is the communication neighbor set of the $i^{th}$ DG unit; and $\left|N_{s}\right|$ is denoted as the cardinality of $N_{s}$.

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

$$L_{\text{vir},i} = L_{\text{vir},i} + \frac{k_{Q}}{s} \left( n_{i}Q_{i} - \frac{1}{N_{s}} \sum_{j=1}^{N_{s}} n_{j}Q_{j} \right). \hspace{1cm} (6)$$

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

$$v_{\text{vir},i} = - (\alpha_i L_{\text{vir},i}) i_{i\text{adj}}, \hspace{1cm} (7)$$

where $i_{i\text{adj}}$ is delayed component for a quarter fundamental cycle of the
PVk is the resonant current. Then, the voltage reference vref,i for the voltage control loop is obtained as

\[ v_{\text{ref},i} = v_{\text{w},i} + \omega_r I_{\text{w},i} \]

(9)

C. Double-Loop Voltage Tracking Scheme

With the voltage reference \( V_{\text{ref}} \) 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:

\[ G_{\text{lp}}(s) = k_p + \frac{2k_p \omega_r s}{s^2 + 2\omega_r s + \omega_r^2} \]

(10)

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

\[ G_{\text{lc}}(s) = k_{\text{inner}} \]