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 problems. The proposed method can adaptively regulate the DG unit thanks to the equivalent impedance, and the effect of the mismatch in feeder impedance is compensated to share the reactive power accurately. The proposed control strategy can be implemented directly without any requirement of pre-knowledge of the feeder impedances. Simulations are performed to validate the effectiveness of the proposed control approach.

Index Terms – Distributed generation (DG), droop control, microgrid, and virtual impedance.

I. INTRODUCTION

For the operation of autonomous microgrids, it is very important to share the load demand in proportion to DG rated power. 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], [3]. In [2], the accurate power sharing is realized by incorporating the line voltage drop into the power control scheme. In [3], by introducing the proper virtual impedances, the equivalent DG unit impedance are designed to be inversely proportion to the DG rating, and the reactive power sharing errors are eliminated. However, all of these methods require the impedance information, which is not easily available; the impedance estimation algorithm will make the control system more complex.

In this paper, an adaptive virtual impedance control method is applied to DG units in islanded microgrids, and the communication is utilized to tune the virtual impedances adaptively in order to compensate the mismatch in feeder’s impedance. 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. Principle of Droop Control

The conventional frequency and voltage magnitude droop controls in a DG unit are given in (1) and (2):

\[ f_{DG} = f^* - D_f \cdot P_{ave} \]  \hspace{1cm} (1)
\[ E_{DG} = E^* - D_E \cdot Q_{ave} \]  \hspace{1cm} (2)

where \( f^* \) and \( E^* \) are the nominal and reference angular frequencies of the DG unit, respectively; \( E^* \) and \( E_{DG} \) are the nominal and reference DG voltage magnitudes, respectively; \( P_{ave} \) and \( Q_{ave} \) are the calculated power after low-pass filter with time constant \( \tau \) as shown in (3), (4), respectively; \( D_f \) and \( D_E \) are the real and reactive power droop slopes, respectively. From the reference voltage magnitude and angular frequency, the reference voltage \( V_{ref} \) of DG unit can be obtained accordingly:

\[ P_{ave} = \frac{1}{2(\tau s + 1)} \left( V_c \cdot I_{L,\text{ref}} - V_{c,\text{delay}} \cdot I_{L,\text{delay}} \right) \]  \hspace{1cm} (3)
\[ Q_{ave} = \frac{1}{2(\tau s + 1)} \left( V_c \cdot I_{L,\text{ref}} - V_{c,\text{delay}} \cdot I_{L,\text{delay}} \right) \]  \hspace{1cm} (4)

B. Adaptive Virtual Impedance

The block diagram of the adaptive virtual impedance control is illustrated in Fig. 1. The inverters transmit the information of the respective reactive power outputs \( Q_i \) and \( Q_j \) to the microgrid central control (MGCC). The MGCC determines the total reactive power supplied by the inverters in the microgrid by considering the total rated reactive powers of the inverters. The calculated value is broadcast to all inverters in the microgrid and each inverter determines the respective reactive power demand \( Q'_i \) and \( Q'_j \) by multiplying the received value with its rated power as shown in (5), so that each reactive power can be shared proportionally.

\[ Q'_i = \sum_{j=1}^{i} \frac{Q_{\text{avd},i}}{Q_{\text{avd},i}} \]  \hspace{1cm} (5)

As shown in Fig. 1, the difference between the measured reactive power \( Q_{\text{ave},i} \) and the reactive power demand \( Q'_i \) is obtained to adjust the DG virtual impedance through the integral controller:

\[ L_{vir} = L_{vir} + \frac{k_{Q}}{s} \left( Q_{\text{ave},i} - Q'_i \right) \]  \hspace{1cm} (6)

where \( L_{vir} \) is the static virtual inductance which is used to ensure the equivalent inductive DG impedance; \( L_{vir} \) is the adaptive equivalent virtual inductance; \( k_{Q} \) is the integral gain to adjust the virtual inductance. To emulate the behavior of virtual impedance, its associated voltage drop \( V_{vir} \) is calculated as (7):

\[ V_{vir} = -\omega_{DG} \cdot L_{vir} \cdot I_{L,\text{delay}} \]  \hspace{1cm} (7)
C. Double-Loop Voltage Tracking Scheme

The modified voltage reference \( V_{ref} \) is obtained by combining the voltage reference from droop control and the voltage drop due to the virtual impedance as shown in Fig. 1. Afterward, the double-loop voltage controller is applied to track the modified voltage reference. In double-loop voltage controller, the outer loop uses a proportional controller tuned at the fundamental frequency in (8):

\[
G_{\text{oi}}(s) = k_v \frac{2k_v \omega_0 s}{s^2 + 2\omega_0 s + (2\pi f_{\text{om}})^2},
\]

(8)

where \( k_v \) is the outer loop proportional gain, \( k_v \) is the gain of the resonant controller at fundamental frequency, and \( \omega_0 \) is the cutoff bandwidth of the resonant controller.

The inner loop is a simple proportional control with the filter inductor current feedback:

\[
G_{\text{ci}}(s) = K_{\text{inner}}
\]

(9)

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 two identical DG units and several linear loads. The system parameters used in the simulation are listed in Table I. The MGCC exchanges the required information with DG local controller through low bandwidth communication links. Under the same power rating, the two DG units shall share the load demand equally.

Fig. 3(b) shows the reactive powers of the DG units. Due to the mismatched feeder impedances, there is significant reactive power sharing error with the conventional droop control method. On the other hand, the proposed compensation method can effectively adjust the reactive power sharing error to be almost zero.

Fig. 3(a) shows the real power of the DG units. Before the compensation, the real power is accurately shared with the conventional droop control method. On the other hand, the proposed compensation method can effectively adjust the reactive power sharing error to be almost zero.

IV. CONCLUSION

A control strategy to improve reactive power sharing in an islanded microgrid has been proposed and validated. A low bandwidth communication is employed to exchange all information to tune adaptive virtual impedances. The control strategy does not require any pre-knowledge of the feeder impedances, and is straightforward to implement in practice.

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