Activity Summary

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Introduction

The relationship between the output current of a microinverter with its real and reactive power output was characterized in previous work. It is desired to formulate a closed-loop controller which allows a microinverter to be interfaced with a microgrid while also providing closed-loop *P* and *Q* controls. In this work, a CERTS microgrid compatible droop-based current-controller is introduced which satisfies the design specifications.

Description

As shown in Fig. 1, each microinverter will inject an RMS current, *I*, into the grid.

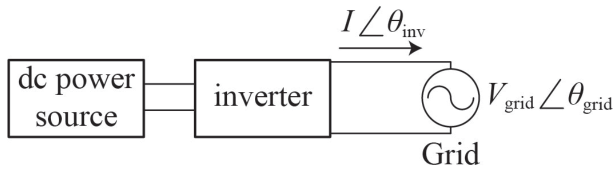

Fig. 1: Microinverter and grid utility interface

The relationship between *P*, *Q*, and the quantities shown in Fig. 1 are

$$P = I\,V_{grid}\cos\left(\theta_{inv} - \theta_{grid}\right) \tag{1}$$

$$Q = I\,V_{grid}\sin\left(\theta_{inv} - \theta_{grid}\right) \tag{2}$$

Since $\theta_{inv} - \theta_{grid}$ is typically small, than it can be concluded that *P* is proportional to *I* and *Q* is proportional to $\theta_{inv} - \theta_{grid}$. Since the microinverter current, *I*, and its phase with respect to the ac bus voltage are subject to complete control, the real and reactive power produced by the microinverter can be regulated.

A closed-loop controller is introduced where the measured microinverter terminal quantities are used to regulate the ac output current, $\imath_{out}$, such that *P* and *Q* are controlled using a CERTS compatible droop. As shown in Fig. 2, the inverter controller is formed using two outer setpoint loops and two inner regulation loops. The two outer loops are comprised of CERTS compatible *P*- ω and *Q*-*V* droops which are used to determine the power and reactive power setpoints, P^* and Q^*, respectively. P^* and Q^* can be expressed as

$$P^* = P_{\text{mpp}} + m_{\text{P}}\left(\omega_{\text{s}} - \omega_{\text{grid}}\right) \tag{3}$$

$$Q^* = m_{\text{Q}}\left(V_{\text{rated}} - V_{\text{grid}}\right) \tag{4}$$

where $\omega_s = 2\pi 60$ rad/s is the synchronous grid frequency, ω_{grid} is the measured grid frequency, V_{rated} is the nominal grid voltage, and V_{grid} is measured RMS grid voltage. m_P and m_Q are the droop gains. Since P_{mpp} is the PV maximum power, than $0 \leq P^* \leq P_{mpp}$ limitations must be enforced.

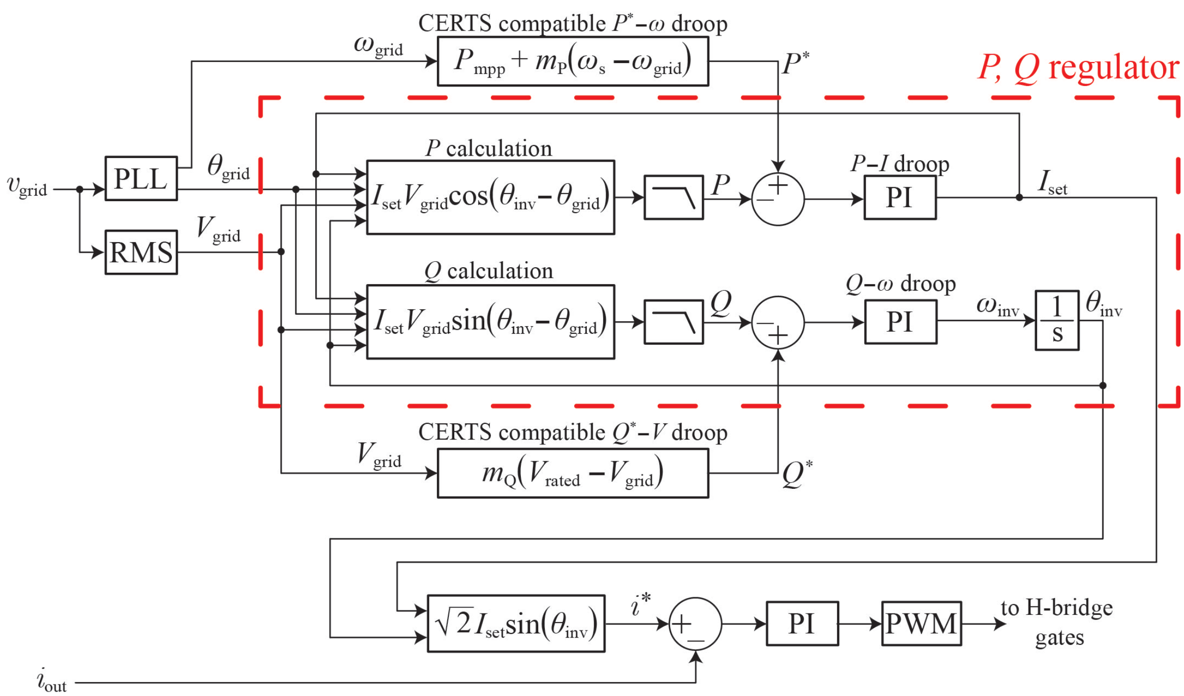

Fig. 2: CERTS compatible droop-based current controller

The two inner loops, as shown in Fig. 2, form a P,Q regulator so that $P \rightarrow P^*$ and $Q \rightarrow Q^*$. This is implemented using two PI controllers which act as P- I and Q-ω droops. Using this method, the RMS current command, I_{set}, will be proportional to the error between P and P^* while the inverter frequency, ω_{inv}, will be proportional to the error between Q and Q^*. These two proportionality relationships are based on equations (1)−(2). The RMS current, I_{set}, and inverter angle, θ_{inv}, commands are used to generate the microinverter ac current command shown in (5).

$$i^* = \sqrt{2} I_{\text{set}} \sin\left(\theta_{\text{inv}}\right) \tag{5}$$

A PI controller will ensure that the output ac current, i_{out}, closely follows i^*.

Simulation Results

The dynamics of a microinverter with the proposed droop controller under a typical CERTS microgrid transient are presented. As shown in Fig. 3, at $t = 1$ cycle an islanding transient occurs such that the grid frequency is increased by 0.05 Hz and the grid voltage decreases by 1%. The setpoint droop gains, m_P and m_Q, are chosen such that P^* is decreased from an initial value of 200 W to 180 W and Q^* is increased from an initial value of 0 VAR to 40 VAR. As shown in Fig. 3, $P \rightarrow$ 180 W and $Q \rightarrow$ 40 VAR.

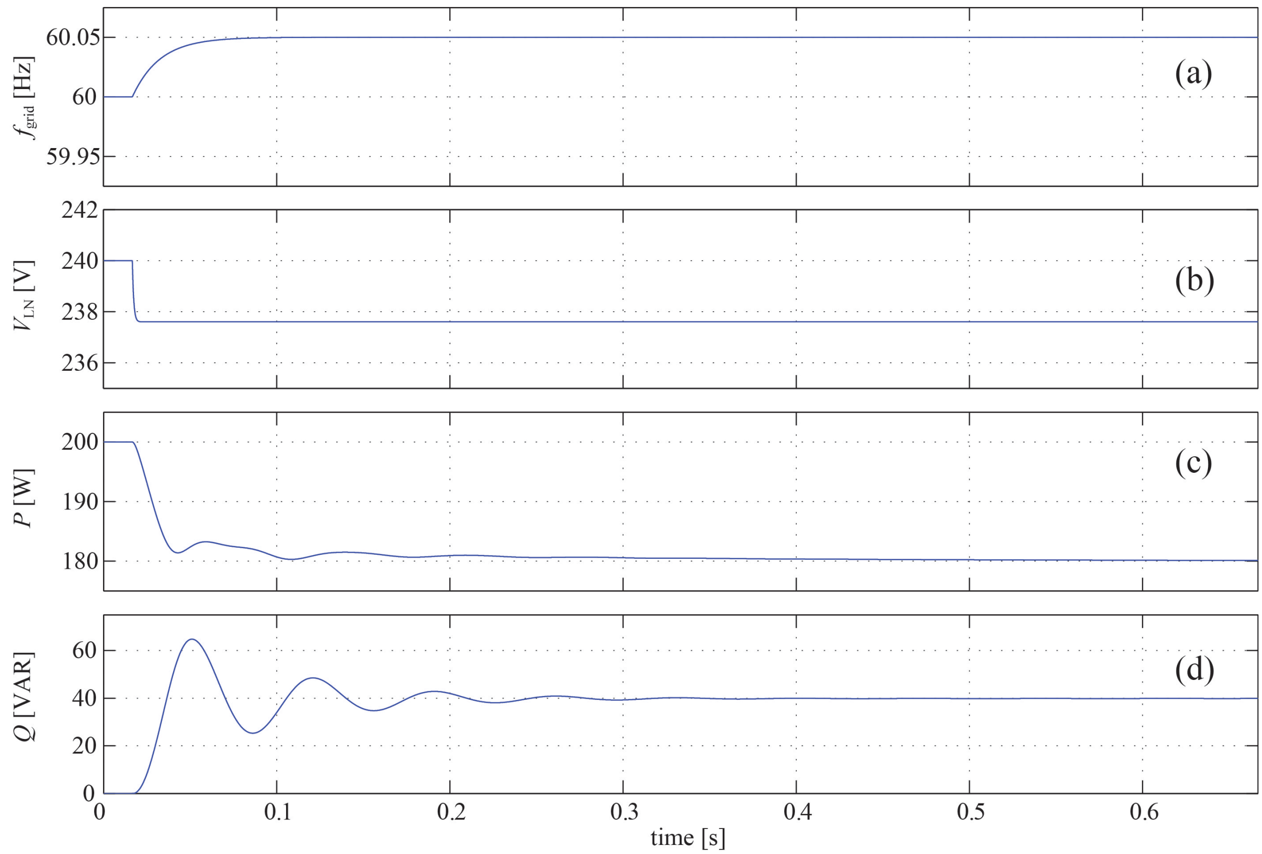

Fig. 3: (a) Grid frequency. (b) Grid voltage. (c) Microinverter power output. (d) Microinverter reactive power output.

After substituting $V_{grid} = 0.99 \times 240$ V, $Q^* = 40$ VAR, and $P^* = 180$ W into (1)−(2) and solving the non-linear expressions, the exact values of $\theta_{inv} - \theta_{grid}$ and I_{set} needed to satisfy the P^* and Q^* are 12.49° and 0.776 A, respectively. The dynamic response for $\theta_{inv} - \theta_{grid}$ and I_{set} as generated by proposed controller are shown in Fig. 4. It can be seen that $\theta_{inv} - \theta_{grid}$ and I_{set} converge to the nominal values of 12.49° and 0.776 A, respectively, so that $P \rightarrow P^*$ and $Q \rightarrow Q^*$.

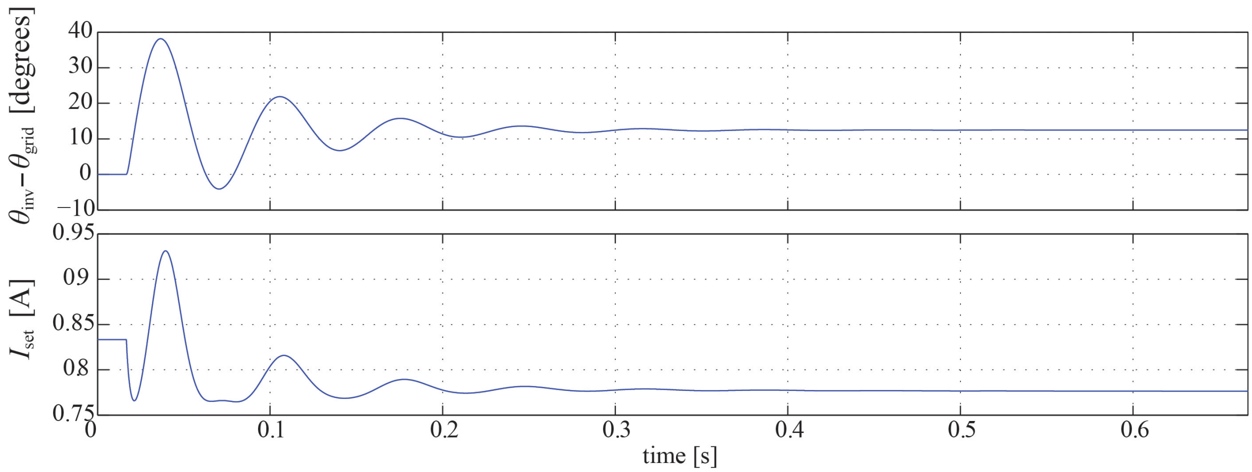

Fig. 4: Dynamics of phase-shift and RMS current commands

The microinverter output current and ac current command dynamics are shown in Fig. 5. Since $i_{out} \rightarrow i^*$, it can be concluded that the desired control objectives are satisfied.

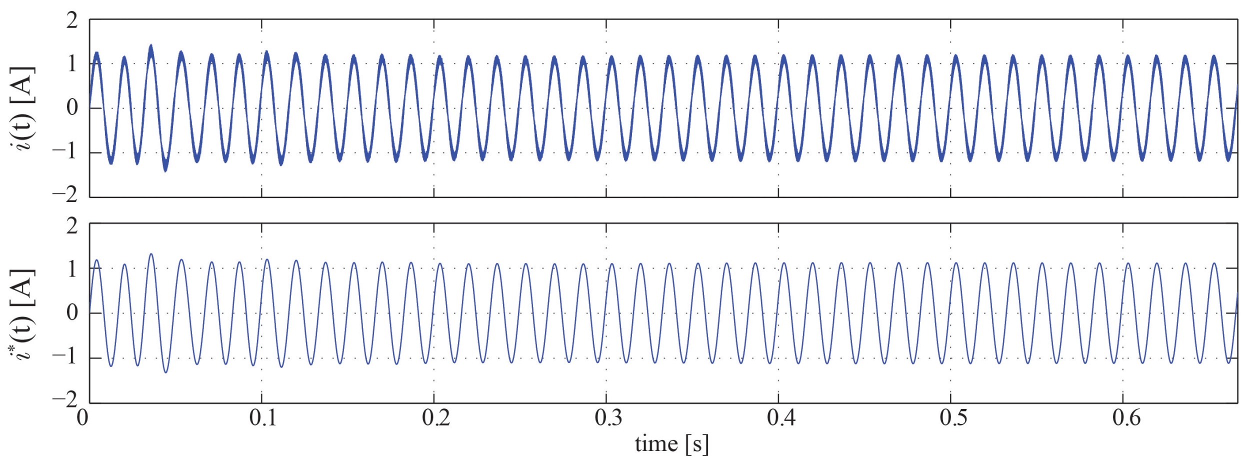

Fig. 5: (Top) Microinverter output current. (Bottom) Commanded output current.