Enhanced Droop Control Technique for Parallel Distributed Generations in AC Microgrid

Sahil Gaurav and Prashant Agnihotri

Abstract In a microgrid, distributed generations (DGs) such as solar photovoltaic and energy storages(ESs) are interfaced with the AC network through power electronic-based inverters. Due to the low inertia of the solar photovoltaic system, the inverter controls become crucial for improving the power quality. State-of-the-art conventional droop control in the inverters face problems such as large voltage and frequency deviations and improper reactive power sharing during various contingencies. This paper presents a simulation model of a stand-alone microgrid with solar photovoltaic source with an enhanced droop control technique which is able to mitigate the constraints of conventional droop control. In order to improve the transient response and appropriate reactive power sharing, proposed control technique explores the addition of derivative of active power for the frequency droop control and the rms output voltage from the inverter for the reactive power control. The simulation results of the proposed controller are obtained and compared with the conventional droop control methods using MATLAB/Simulink.

Keywords Islanded microgrid · Droop control · Distributed generations · Frequency stability · Power sharing

1 Introduction

Demand of on-site distributed power generation has increased due to rapid increase in renewable energy-based power generation. These distributed energy resources (DERs) such as solar photovoltaic produce DC which needs to be converted into AC using inverters in order to connect to the local AC distribution network in a microgrid (MG). There are two control modes of inverters in islanding mode while maintaining

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the reference voltage and frequency: (1) Wired control technique (communication channel-based control) such as master-slave control (MSC) system in which one voltage control inverter (VCI) acts as master, and other current control inverter (CCI) acts as slave. (2) Wireless control technique (non-communication channel-based control) such as droop control. The key advantages of droop control are its ease of implementation, accurate active power sharing, no requirement of communication channel between DG units, easy plug-and-play operation where inverters can be included and eliminated without fundamentally changing the settings of rest of the inverters. Thus, for multiple DERs integrated in the MG through inverter, it normally uses droop control technique for load sharing and control to improve the stability [1–3].

1.1 State-of-the-Art Methods and Gaps in the Existing Droop Control Strategies

Several droop control methods have been presented in the past such as generalized droop control (GDC), droop control based on artificial neuro-fuzzy interference system (ANFIS) integrating virtual impedance loop into conventional droop control and improved droop control using DC link. Among all the droop control techniques, the GDC [4] gives proper voltage and frequency control. However, it extremely relies on the lines or cables specifications connected between inverter interfaced distributed generations (IIDG) and load. Therefore, GDC is not feasible in case of large microgrid where several IIDGs are present, and calculation of equivalent line parameters is difficult. In [5], a droop control established on artificial neuro-fuzzy interference system (ANFIS) is implemented. This mitigates the problem of calculating line parameters; however, it increases the complexity of controller. The droop control implemented in [6] is able to mitigate the dependence of line impedance on accurate power sharing, but this controller is applicable only in case of HV microgrids. For making accurate reactive power sharing in droop control, adding virtual resistor and inductor is a method proposed in [7, 8], but it increases voltage drop, additional power loss and thus decreases efficiency. An islanded microgrid based on double-derivative-based droop controller is executed in [9]. It provides power sharing with damping attributes and improves the stability of the system, but it does not take consideration of accurate reactive power sharing and restoration of frequency at the rated value. Furthermore, the existing state-of-the-art techniques include the implementation of droop control strategies for inverters connected to load through similar transmission network. This may not be true in the practical consideration which may lead to improper reactive power sharing between the controls [10]. Therefore, in order to address the gaps in the existing droop control strategies, this paper presents a novel droop control strategy to achieve accurate active and reactive power sharing and maintain the frequency and voltage amplitude of the output voltage of each DG at the rated value. The proposed control algorithm utilizes feedback signals such as active power and its derivative and voltage signals which give better transient response, accurate real and reactive power sharing than the conventional droop control algorithms. The motivation to focus on optimum power sharing is for the reliable operation of microgrid and furthermore to reduce losses. Moreover, the restoration of the frequency using droop control in the islanded system in the event of a fault in the network using droop control methods is also a critical problem which is addressed in this paper.

1.2 Organization of the Paper

The rest of the paper is arranged as follows. Section 2 reviews the basics of power flow theory, conventional droop control and reverse droop control. Section 3 demonstrates the proposed droop control technique. Section 4 presents description of the case study. Simulation results and discussion are stated in Sect. 5, and subsequently, the conclusions are given in Sect. 6.

2 Review of Power Flow Theory and Droop Control

2.1 Power Flow Theory

Power flow theory helps to understand the power flow between inverters and loads through the lines and derivation of droop control.

The real and reactive power at the inverter end in Fig. 1 can be expressed by Eqs. (1) and (2), respectively, [5]:

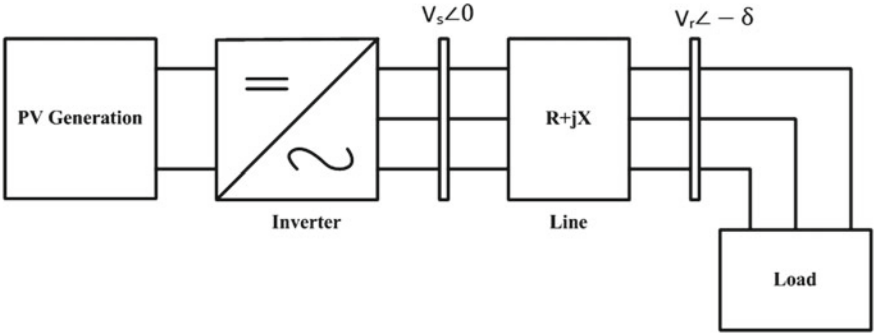


Fig. 1 Single-DG-based MG with a combined inverter

$$P = \frac{V_s^2}{Z}\cos\theta - \frac{V_s V_r}{Z}\cos(\theta + \delta) \tag{1}$$

$$Q = \frac{V_s^2}{Z}\sin\theta - \frac{V_s V_r}{Z}\sin(\theta + \delta) \tag{2}$$

where θ is the line impedance angle. Equations (1) and (2) can be further modified by considering $Z = R + jX$, which come up with equations (3) and (4), respectively.

$$P = \frac{V_s}{R^2 + X^2}[R(V_s - V_r\cos\delta) + XV_r\sin\delta] \tag{3}$$

$$Q = \frac{V_s}{R^2 + X^2}[-RV_r\sin\delta + X(V_s - V_r\cos\delta)] \tag{4}$$

2.2 Droop Control Techniques

Droop techniques are broadly classified into two categories: conventional and reverse droops.

Conventional Droop In case of inductive line, assuming $Z \approx X$, results in negligible R and $\theta = 90°$, and a negligible power angle results in:

$$P = \frac{V_s V_r}{X}\sin(\delta) \approx \frac{V_s V_r}{X}\delta \tag{5}$$

$$Q = \frac{V_s V_r}{X}\cos(\delta) - \frac{V_r^2}{X} \approx \frac{V_s V_r - V_r^2}{X} \approx \frac{V_r}{X}(V_s - V_r) \tag{6}$$

Equations (5) and (6) depict that the active power transmission occurs between lines due to phase shift angle δ, and reactive power transmission occurs due to the voltage magnitude difference [11]. These equations laid the principle of conventional droop Eqs. (7) and (8):

$$w = w^* - n_p\tilde{P} \tag{7}$$

$$V = V^* - m_q\tilde{Q} \tag{8}$$

where w and w^* are the output and the nominal frequency, respectively, $\tilde{P}$ & $\tilde{Q}$ are the measured average real and reactive power obtained at the inverter output side, n_p and m_q are the P–f droop coefficient and Q–V droop coefficient, respectively, V is magnitude of output voltage of inverter, and V^* is the rated voltage amplitude. The schematic representation of conventional droop equation is shown in Fig. 2.

The above droop equations cannot be approximated in the case of distribution lines used in microgrids, which is resistive in nature. The reverse droop equations can be found by the similar above technique. It has opposite characteristics, as reference frequency depends on the reactive power output, and reference voltage depends on the real-power output.

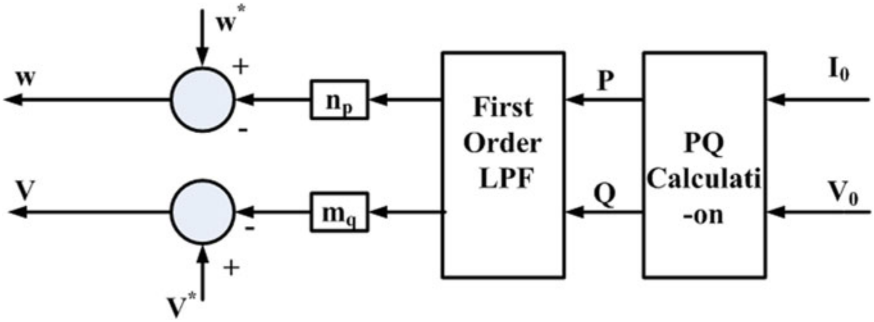


Fig. 2 Topology of conventional droop control

Table 1 Droop control versus reverse droop [12]

	Conventional droop	Reverse droop
Compatible with HV	Yes	No
Compatible with rotating generators	Yes	No
Active power dispatch	Yes	No
Direct voltage control	No	Yes

However, It is preferred to implement conventional droop in microgrid distribution units due to several limitations of reverse droop mentioned in Table 1.

3 Proposed Droop Control Technique

This paper proposes an enhanced droop control strategy which includes additional feedback controller parameters proportional to the active power flow and its derivative for frequency control and voltage control as described in Eqs. (9)–(10). Schematic representation of proposed droop control is represented in Fig. 3. Compared to the state-of-the-art droop controllers, the modified frequency control provides an additional damping and virtual inertia effect to quickly restore the frequency during contingencies and updated droop equations to ensure proper reactive power sharing between the DGs:

$$w = w^* - n_p\tilde{P} - n_d\frac{d\tilde{P}}{dt} \tag{9}$$

$$V = (m_p + \frac{m_i}{s})[(V^* - V_0) - m_q\tilde{Q}] \tag{10}$$

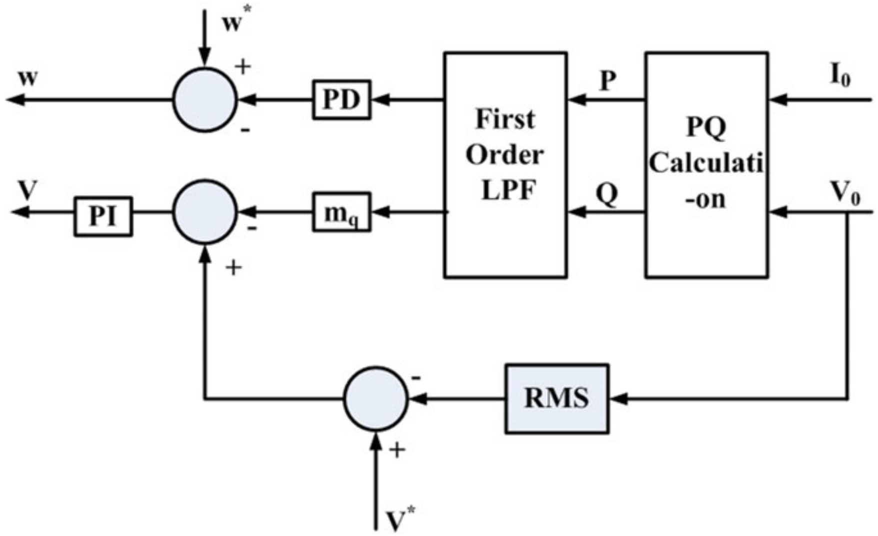


Fig. 3 Topology of proposed droop control

where n_d is frequency derivative droop coefficient, m_p and m_i are the proportional-integral control parameters for enhanced droop control, $\tilde{P}$ and $\tilde{Q}$ are the average real and reactive power output obtained from the first-order low pass filter, respectively, and V_0 is the inverter output voltage.

The addition of derivative terms in the frequency droop equation enhances the transient response and reduces deviation of frequency from rated value. Further, the addition of proportional-integral term and rms output voltage from inverter in the voltage droop equation provides appropriate reactive power sharing in spite of the line impedances mismatch and supply volatge at the rated value. The combination of both equations allows to restore the frequency at rated value.

4 Simulation Model and Operation

The simulation model shown in Fig. 4 consists of two solar photovoltaic solar PV panels and associated energy storage systems. Due to the intermittent nature of DGs, a closed-loop boost converter changes the voltage at necessary level for the inverter. The controllers provide a sinusoidal voltage reference signals to a pulse width modulation (PWM) signal generator and which gives input to the gate drive of inverter. LCL filter is used for converting the inverter output into sinusoidal shape. The transmission lines connecting the solar PV to the load through the inverter are of same ratings but with different lengths leading to different reactive power

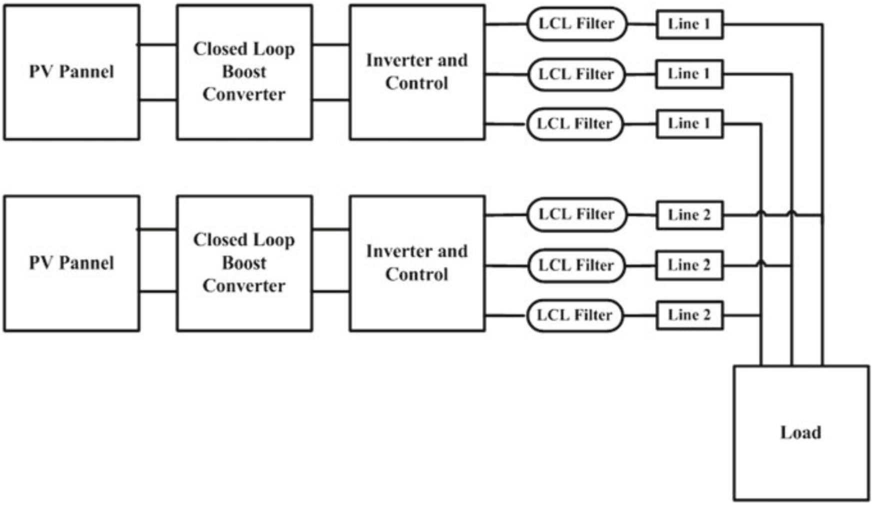


Fig. 4 Simulated microgrid model

requirement. Power demand in the microgrid is modeled as common load having characteristics of constant impedance.

Droop control-based inverter in islanding microgrid shown in Fig. 5 consists of three controllers: (1) Droop controller provides the reference voltage to the voltage controller and reference frequency to the voltage and current controller based on the power measured from the inverter output side. (2) Outer voltage control loop converts this reference voltage into the reference current in dq-frame using the filter capacitor voltage and the filter output current. (3) Further the inner current control loop gives the final reference output voltage using filter capacitor voltage and inverter output current. These reference voltages are used to generate the pulses using sinusoidal pulse width modulation (SPWM) technique, and these pulses are fed to the gate drives of inverter.

5 Simulation Results

This section presents the performance of enhanced droop control technique with line impedance mismatches. Furthermore, the performance of the proposed controller is compared with the conventional droop control technique through the simulation performed in MATLAB/Simulink.

The reference frequency provided by the enhanced droop controller and conventional droop controller to both inverter 1 and inverter 2 is shown in Fig. 6a, b, respectively. The reference frequency provided by the enhanced droop controller is restored to the rated frequency and is free from oscillations. A fault is injected at

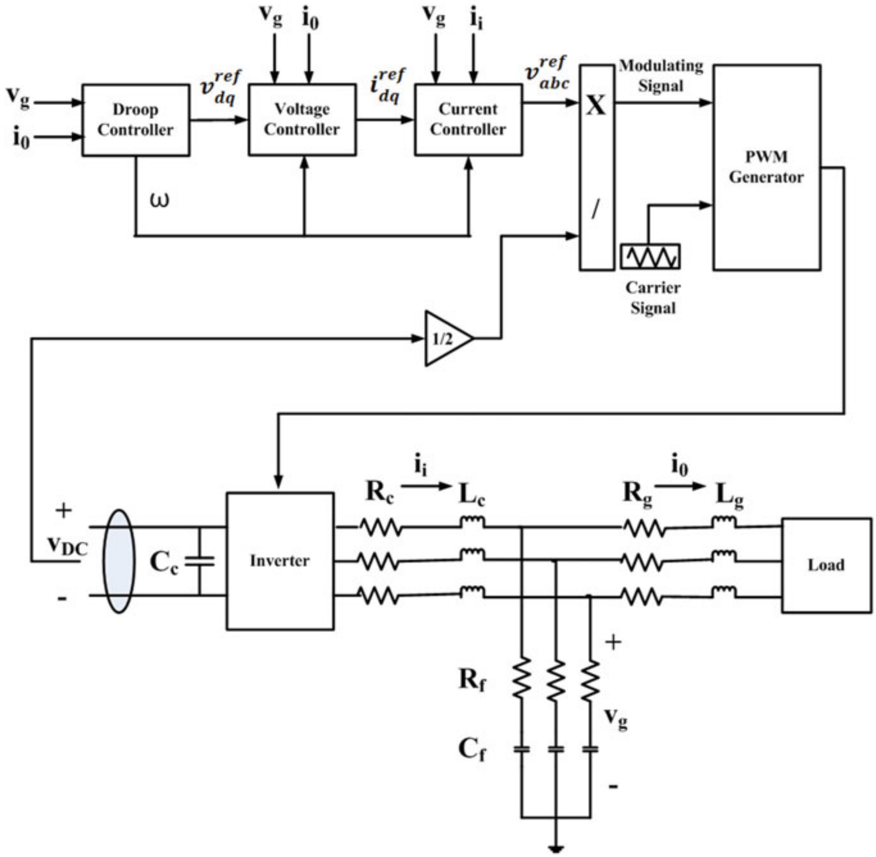
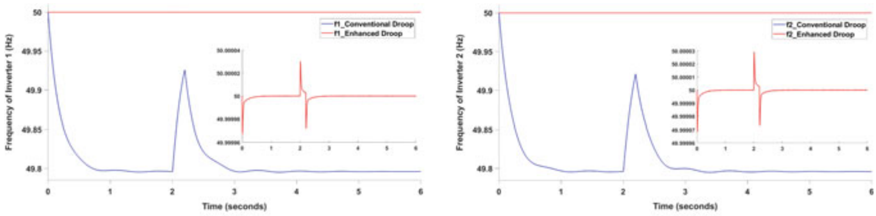


Fig. 5 Droop control-based VSI



(a) (b)

Fig. 6 Waveform of reference frequency for inverters given by droop controller

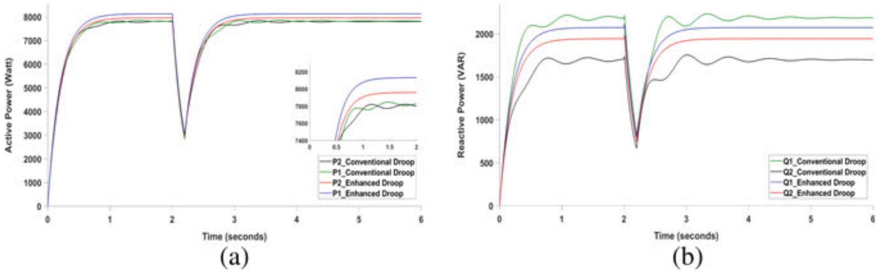


Fig. 7 Real and Reactive power flow from both DG units

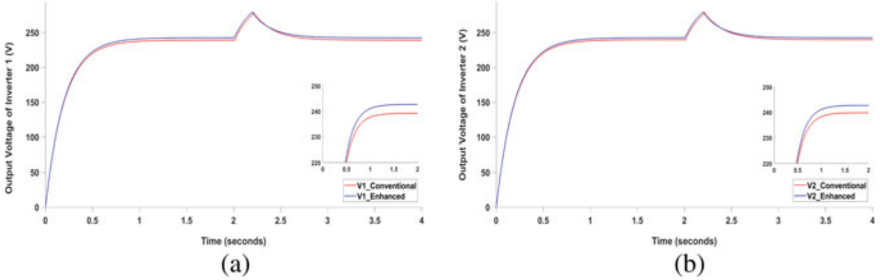


Fig. 8 RMS output voltage of both DG units

$t = 2$ s and removed at $t = 2.2$ s to see the robustness of the enhanced droop technique. It is also clear from the above waveforms that the proposed technique not only provides constant rated frequency but also adds virtual inertia to the system by minimizing the frequency deviations.

Figure 7a, b shows the active and reactive power sharing through the two DGs, respectively. The enhanced droop control improves the active and reactive power sharing remarkably with better steady-state response. The system gets stable faster after initial transient and after the fault disturbance due to the addition of derivative terms in proposed droop control strategy.

Figure 8a, b shows the comparison of the RMS value of phase voltage obtained at the inverter output side for the enhanced droop control and conventional droop control for the inverters 1 and 2, respectively. It can be observed from Fig. 8 that the proposed control supports to obtain the rated voltage at the load side after certain voltage drop through the lines.

6 Conclusion

This paper presents improved droop control technique for parallel connected DG-inverters in stand-alone mode. Simulation results show the restoration of the rated frequency of both inverters and improve the reactive power sharing between the inverters. The proposed droop control unlike the conventional droop control provides virtual inertia and damping properties in stand-alone mode during contingencies. Future work includes the testing of the proposed control in the real-time simulation platform to ensure the robustness of the controller during various contingencies.

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