Renewable and Sustainable Energy Reviews 76 (2017) 717–727

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A review of droop control techniques for microgrid

Usman Bashir Tayab[a,*], Mohd Azrik Bin Roslan[a], Leong Jenn Hwai[a], Muhammad Kashif[a,b]

[a] University Malaysia Perlis, Malaysia
[b] University Malaysia Sawarak, Malaysia

ARTICLE INFO

Keywords:
Distributed generation
Microgrid
Inverter
Droop control technique
Renewable resources

ABSTRACT

Coordination of different distributed generation (DG) units is essential to meet the increasing demand for electricity. Many control strategies, such as droop control, master-slave control, and average current-sharing control, have been extensively implemented worldwide to operate parallel-connected inverters for load sharing in DG network. Among these methods, the droop control technique has been widely accepted in the scientific community because of the absence of critical communication links among parallel-connected inverters to coordinate the DG units within a microgrid. Thus, this study highlights the state-of-the-art review of droop control techniques applied currently to coordinate the DG units within a microgrid.

1. Introduction

Non-renewable resources, such as diesel, coal, and gas, are major energy sources of electrical energy produced by traditional power generators worldwide. However, the increasing demand for electrical energy, depletion of reserves of non-renewable resources, and generation of electrical energy from non-renewable resources have resulted in environmental pollution [1–3]. Therefore, the development of a distributed generation (DG) system that utilizes renewable resources to generate electricity is necessary [4,5].

DG systems are suitable for providing highly reliable electric power [6]. Several types of energy resources, such as solar thermal panels, photovoltaic panels, fuel cells, and microturbines, are currently available [7,8]. These renewable resources are difficult to connect directly to a utility grid. A microgrid is an interface between distributed renewable resources and the utility grid. This interface is a low-voltage distribution system consisting of DG units, energy storage devices, and load. Furthermore, a microgrid can be operated separately or connected to a main distribution system [9–11]. Fig. 1 illustrates the general architecture of a microgrid [12]. In addition, compared with a single DG unit, a microgrid has high capacity and control flexibility to fulfill power-quality requirements [13].

By contrast, the electric power generated from several renewable resources is in direct current (DC) form and converted to alternating current (AC) by an inverter [14]. Thus, an inverter is a crucial component of a microgrid. Furthermore, an inverter acts as an interface between the DG unit, load, and grid [15]. Inverters are also used parallel to a microgrid to improve performance. Parallel operation of inverters often provides high reliability, because the remaining modules can still deliver the required power to the load in case an inverter fails [16]. Several control techniques have been proposed for proper operation of parallel-connected inverters in microgrid. Among these methods, voltage and frequency droop control has gained popularity and is considered as a well-established method [17–19]. Thus, this paper presents an overview of recent studies on the droop control technique.

Section 2 provides an overview of the conventional droop control technique. Section 3 presents the virtual impedance loop-based droop control technique. Thereafter, Section 4 discusses the working principle of the adaptive droop and robust droop control technique. Section 5 focuses on simulations to support the analysis. Section 6 provides a discussion on different methods and future work. Finally, Section 7 concludes this report.

2. Conventional droop control

The inverter output impedance in the conventional droop control [20–22] is assumed to be purely inductive because of its high inductive line impedance and large inductor filter. The equivalent circuit of two inverters connected in parallel to a point of common coupling bus is shown in Fig. 2(a), and the phasor diagram is shown in Fig. 2(b). In an inductive system, the active and reactive power drawn to a bus from each inverter can be expressed as follows [23,24]:

$$P = \frac{EV\ \sin\alpha}{X}, \tag{1}$$

* Corresponding author.
E-mail address: usman.tayab@yahoo.com (U.B. Tayab).

http://dx.doi.org/10.1016/j.rser.2017.03.028
Received 13 May 2016; Received in revised form 22 November 2016; Accepted 8 March 2017
1364-0321/

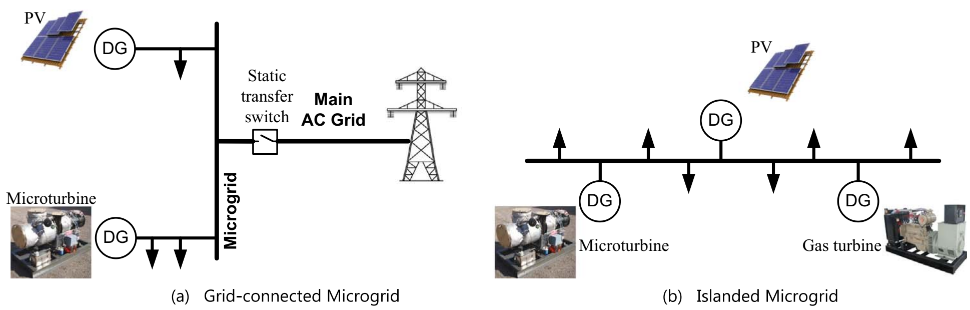

Fig. 1. General architecture of a microgrid. (a) Grid-connected microgrid (b) Islanded microgrid.

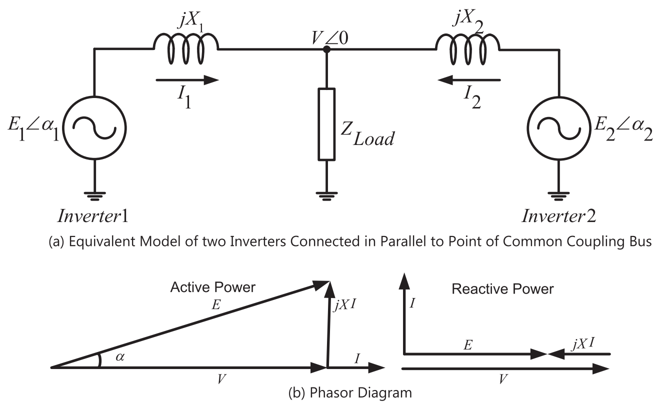

Fig. 2. (a) Equivalent model of two inverters connected in parallel to point of common coupling bus. 2 (b) Phasor diagram.

$$Q = \frac{EV\cos\alpha - V^2}{X}, \tag{2}$$

where E and V are the amplitudes of the inverter output voltage and the common bus voltage, respectively, α is the power angle, and X is the output reactance of the inverter.

Based on Eqs. (1)–(2) and small power angle $\alpha(\sin\alpha \approx \alpha$ and $\cos\alpha = 1)$, the active power injected from the inverter to the common bus is predominantly influenced by the power angle. By contrast, the reactive power is strongly dependent on the amplitude difference between E and V. In addition, the inverter output voltage phase can be changed by altering the inverter output voltage frequency. Consequently, the wireless control of the parallel-connected inverters primarily uses the frequency droop and output voltage droop to control the output power of the inverter.

A block diagram of the conventional droop control is shown in Fig. 3. Moreover, the equations of the droop characteristics of $P - \omega$ and $Q - E$ in Fig. 4(a) and (b) can be written as follows:

$$\omega_K = \omega^{\bullet} - m_K P_K, \tag{3}$$

$$E_K = E^{\bullet} - n_K Q_K, \tag{4}$$

where P_K, Q_K, m_K, and n_K are the real active power output, real reactive power output, frequency droop coefficient, and voltage droop coefficient of the K^{th} inverter, respectively. Furthermore, $\omega^{\bullet}$ is the rated frequency, and $E^{\bullet}$ is the rate voltage amplitude. The frequency and voltage droop coefficient are designed from Eqs. (3) and (4), as follows:

$$m_K = \frac{\Delta\omega}{P_{K\,\max}}, \tag{5}$$

$$n_K = \frac{\Delta E}{Q_{K\,\max}}, \tag{6}$$

where $\Delta\omega$ and ΔE are the maximum allowed deviation of frequency and voltage, respectively. P_{Kmax} and Q_{Kmax} are the nominal active and reactive power supplied by the system, respectively.

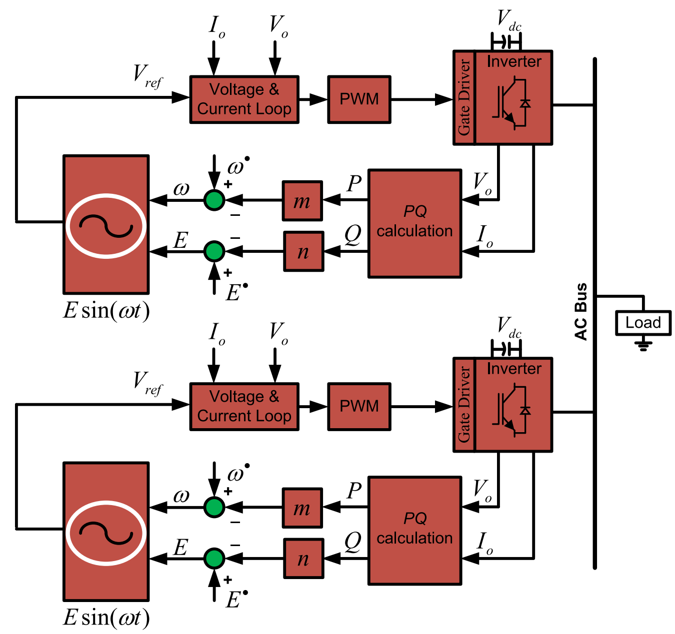

Fig. 3. Block diagram of conventional droop control.

Increasing the droop coefficients results in good power sharing but degraded voltage regulation [25]. The inherent trade-off of this controller is the selection of the droop coefficient value. The main advantage of the droop control technique is its avoidance of critical communication links among parallel-connected inverters. The absence of communication links between parallel-connected inverters provides significant flexibility and high reliability [26]. However, the conventional droop technique has several drawbacks [27–30], such as slow transient response, inherent trade-off between voltage regulation and load sharing, poor harmonic load sharing between parallel-connected inverters in the case of non-linear loads, line impedance mismatch between parallel-connected inverters that affect active and reactive power sharing, and poor performance with renewable energy resources.

3. Virtual impedance loop-based droop control

The conventional droop control cannot provide a balanced reactive power sharing among parallel-connected inverters under line impedance mismatch. Therefore, the imbalance in reactive power sharing is a serious problem in an AC microgrid. Several studies have achieved balanced reactive power sharing implementing virtual output impedance in droop control method through a fast control loop which emulates the line impedance (Fig. 6) [31,32]. Thus, the reference voltage from each inverter can be modified, as follows:

$$V_{ref} = V_o^* - Z_v I_o, \tag{7}$$