ARTICLE IN PRESS

Renewable and Sustainable Energy Reviews xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Review of primary voltage and frequency control methods for inverter-based islanded microgrids with distributed generation

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ARTICLE INFO

Keywords:
Distributed generation
Droop control
Hierarchical control
Microgrid
Primary control

ABSTRACT

Microgrid (MG) is a relatively new concept for the integration of distributed generation (DG) along with the loads in a distribution system. Islanded microgrid can be considered as a weak grid that has less inertia compared with the conventional power system. This reality makes the microgrid vulnerable to contingencies. Towards a flexible, safe and secure operation of an islanded MG, researchers have introduced a hierarchical control structure comprising tertiary, secondary and primary control. The primary control plays an important role in maintaining the voltage and frequency stability by sharing the loads among the DGs. This paper reviews and categorizes various primary control methods that have been introduced to control the voltage and frequency of inverter-based microgrids. Moreover, the reviewed methods in terms of their potential advantages and disadvantages are compared. Finally, the future trends are presented.

1. Introduction

The environmental issues besides the increasing concern for traditional energy resources lead to increasing concentrations on distributed generation based on renewables. Integration of the parallel DGs with a cluster of loads in the power system makes a novel concept “microgrid”. MGs are located in the distribution systems in both medium voltage (MV) and low voltage (LV) levels [1]. At first, the concept of microgrid introduced in [2,3]. An LV microgrid can operate in two different operating modes:

a) Connected Mode: in this case, the MG is connected to the main MV network and it is able to either inject power into the MV network or absorb the power from it.
b) Islanded Mode: when disconnection from upstream network occurs, the MG forms an island and according to a power management plan will supply the loads inside the island [4].

The islanded microgrids in comparison with the conventional power systems are weaker grids and with a smaller equivalent inertia. This reality makes MGs sensitive to the system contingencies and vulnerable to voltage and frequency deviation, especially when the penetration of intermittent renewable generation is high [5]. Safe, economic and stable operation of the MG in both operation condition depends on existence of a proper control system [6–9]. To enhance the controllability, flexibility and security of the distribution system, MG is controlled in a hierarchical approach [8]. The hierarchical control of MG has three level including: 1- primary control (first level) 2- secondary control (second level) 3- tertiary control (third level) [8–12]. These control levels differ in terms of time response and communication requirements [12].

Primary control of an inverter-based islanded microgrid can be divided into two general classification comprising: a) communication based methods b) without communication methods or droop-based methods [13]. The communication based methods include centralized control [14–16], distributed control [17,18], master-slave control [19–21], angle droop control [22,23].

Because of reliability issues and restriction on physical location of the DG units, it is preferred that there is no communication link between the DG units in microgrid [6]. So, researchers proposed the primary control without communication methods including P-F/Q-U droop control and its variants [24–30], P-U/Q-F droop control [31–33], virtual frame transformation [34–38].

Recently, some valuable reviews are carried out on different types of microgrid control methods with different objectives, especially hierarchical control of the microgrid [39–44]. Reference [39] provides the main control techniques proposed in the literature along with the information of research projects and experimental microgrids all around

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http://dx.doi.org/10.1016/j.rser.2017.10.022
Received 7 March 2017; Received in revised form 13 September 2017; Accepted 26 October 2017

Please cite this article as: Rokrok, E., Renewable and Sustainable Energy Reviews (2017), http://dx.doi.org/10.1016/j.rser.2017.10.022

Nomenclature

DG	Distributed Generation
LC	Load Controller
LV	Low Voltage
MG	MicroGrid
MC	Microsource Controller
MGCC	MicroGrid Central Controller
MV	Medium Voltage

the world. Reference [40] states that the next generation of microgrids might adopt the distributed techniques due to dividing the control tasks among the DG units. The extensive integrated communication infrastructures can be a challenge for the distributed control techniques. In [41], a new family of control and management system for microgrids based on play and plug concept and frequency dynamics is presented. In [42], the control techniques and their corresponding objectives from the point of frequency and voltage stability are discussed and the factors that affect the proper load sharing are presented. Reference [43], in addition to surveying the operation of MG in islanded mode, is investigated the possible control schemes of the MG in grid connected mode.

This paper aims to provide a more comprehensive classification, challenges and solutions of the primary control methods in an islanded MG. To this end, first the microgrid control structure in terms of hierarchical control system is briefly surveyed. Then, the primary control methods are introduced and the advantage and disadvantage of the methods are discussed and compared. Finally, the future trends are presented.

The rest of the paper is organized as follows. In Section 2, the hierarchical control structure of the microgrids is briefly explained. In Section 3, the primary control methods for an islanded MG are introduced and categorized. After that, the communication-based methods and the droop-based methods are discussed in Section 4 and Section 5, respectively. Section 6 gives the comparison of reviewed methods in terms of their potential advantages and disadvantages. Likewise, the future trends in control strategies for microgrids are stated in this section. Finally, Section 7 concludes the paper.

2. Microgrid control structure

Fig. 1 shows the structure of a typical low voltage MG along with the relation among MG controllers [4]. Generally, the MG comprises LV feeders, loads, microsources (like photovoltaic (PV), wind energy conversion system (WECS), fuel cell, microturbine,…) and storage devices (like battery energy storage system (BESS) and flywheel). The MicroGrid Central Controller (MGCC) that is installed at the LV side of MV/LV substation controls MG centrally. Load Controller (LC) and Microsource Controller (MC) are local controllers to control the loads and microsources, respectively and exchange the required information (like set-points, load/consumption situation,…) with the MGCC through a communication link. LC is used to control loads through the local load shedding schemes in emergency conditions and MC controls the active and reactive power of microsources [4].

Primary control or local control is the first level of hierarchical control system that has the fastest response and is used to stabilize the voltage and frequency of MG through the proper load sharing among the DG units [45–48]. MCs and LCs are responsible for the primary control in MG. Secondary control performs corrective action to remove the frequency and voltage deviations that exists in primary level. According to [4,49–51], secondary control may be employed in both centralized and decentralized approach (i.e. either MGCC can carry out the secondary control centrally or MCs do this locally).

Tertiary control manages the flow of power between the MG and the grid in the normal connected mode. Also, it has key function such as economic managing function and control functionalities that provides optimal scheduling of DG units [8].

3. Primary control methods for an islanded microgrid

There are two general classifications for primary control including communication-based methods and without communication methods. The communication-based methods have some advantages such as accurate power sharing, high power quality, good transient response and circulating current elimination. However, these methods have more cost and complexity and require to high-bandwidth communication link control loops. Without communication methods are based on droop control that uses the local measurement to control the DG units. These methods have many desirable features such as flexibility, expandability, redundancy, simple implementation [10,52]. However, droop-based methods have some drawbacks such as inaccurate power sharing, slow transient response and circulating current among inverters. To overcome these drawbacks, some variations on the conventional droop characteristics have been presented. Fig. 2 shows the classification of the primary control categories for an islanded MG. Primary control schemes are discussed in the following sections.

4. Communication-based primary control methods

Communication-based primary control methods give an excellent voltage regulation and appropriate power sharing. Moreover, in

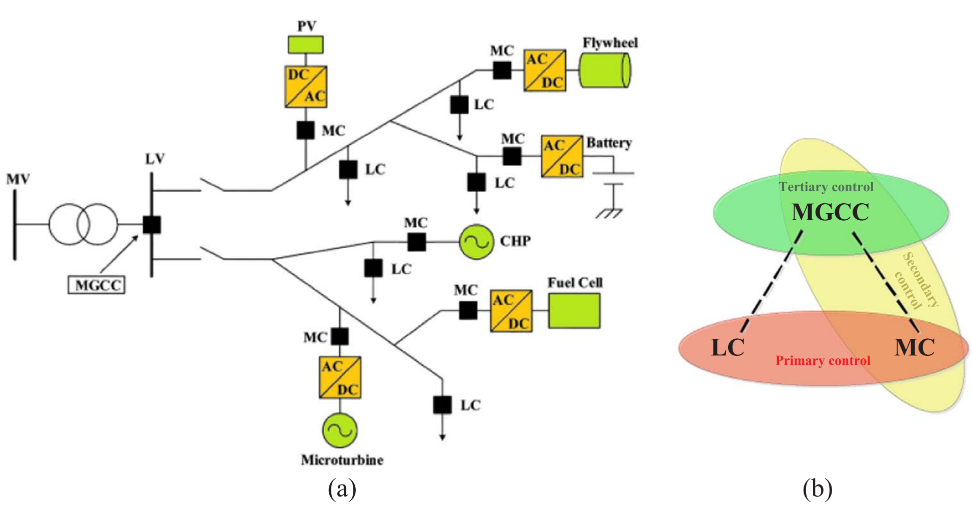

Fig. 1. a) typical low voltage MG [4], b) relation among the MG controllers.