Renewable and Sustainable Energy Reviews 80 (2017) 1043–1060

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

An overview of control approaches of inverter-based microgrids in islanding mode of operation

Mohammad Hadi Andishgar, Eskandar Gholipour*, Rahmat-allah Hooshmand

Department of Electrical Engineering, University of Isfahan, Isfahan, Iran

ARTICLE INFO

Keywords:
Microgrid
Hierarchical control
Droop control
Islanding mode
Future trends

ABSTRACT

Increased penetration of distributed generation (DG) into the power systems has created fundamental challenges from the viewpoints of control and reliable operation of systems. Microgrids (an aggregation of DG units, loads, and storage elements) with proper control strategies can be a good solution for removing or facilitating these challenges. The introduction of inverter-based microgrid in a distribution network has facilitated the utilization of renewable energy resources, distributed generations, and storage resources; furthermore, it has improved power quality and reduced losses, thus improving the efficiency and the reliability of the system. As most DG units are connected via a power electronic interface to the grid, special control strategies have been developed for inverter interfaces of DG units in islanded microgrids. This paper presents an overview of advanced control methods for microgrids, especially the islanded and inverter-based. Moreover, various control methods are compared and categorized in terms of their respective features. It also summarizes microgrid control objectives with their most problematic solutions as well as their potential advantages and/or disadvantages. Finally, some suggestions are put forward for the future research.

1. Introduction

Nowadays, due to the reduction of fossil fuel resources and particularly due to the economic and environmental issues, researchers have tended to use renewable energy resources [1]. The load on transmission networks is increasing unexpectedly due to an increase in demand for power energy. Since development of transmission networks is challenging from economic outlook, microgrids have been taken into consideration as economically viable alternative [2].

Improved reliability/efficiency of supplying energy in today's world where electricity demand is ever-growing, is much more needed. Microgrids (MG) incorporate different DG units into the utility grid and solve many problems of the existing power systems. It is also the vital building blocks of smart grids [3].

Due to the characteristics of DG units, connecting them to networks is not directly acceptable. Therefore, the use of power electronic interfaces is essential [4,5]. The main role of an interface inverter is to control the injected power. In addition, compensation of power quality problems such as voltage harmonics can be achieved through appropriate control strategies [6]. In order to successfully integrate DGs, many technical challenges must yet be overcome to ensure that the existing levels of reliability are not significantly affected and the potential benefits of DGs are fully achieved [7].

The use of DGs and microgrids is advantageous to the fields of environment, performance, investment, power quality, cost saving, and marketing [3]. Improving reliability and power quality of power system suppliers can reduce the network congestion and also decrease the need for bulk transmission systems [8,9]. Microgrids can operate in both grid-connected and islanded modes. In islanded microgrids, DG units are responsible for voltage control (amplitude and frequency) and also power sharing balancing. The duty of power sharing is to ensure that all modules share the load according to their rated capacity and availability of power from their energy sources [10]. Since most DG units are connected to the gird via a power electronic interface, islanded microgrids need special inverter control strategies whose overview is presented in this paper.

Microgrid should be able to operate intelligently whether connected or disconnected from the grid [11]. Interface inverters are usually connected in parallel [12]. Controlling parallel voltage source inverters forming a microgrid has been investigated in recent years [6]. Therefore, the main challenge is to ensure stability and voltage regulation to provide higher power quality for the customers. To avoid circulating current among inverters without using any communication links, droop control method is often used [13–15].

Microgrids have several characteristics that make them differ from the conventional power systems:

---

* Corresponding author.
E-mail addresses: andishgarhadi@yahoo.com (M.H. Andishgar), e.gholipour@eng.ui.ac.ir (E. Gholipour), Hooshmand_r@eng.ui.ac.ir (R.-a. Hooshmand).

http://dx.doi.org/10.1016/j.rser.2017.05.267
Received 1 October 2016; Received in revised form 24 February 2017; Accepted 29 May 2017

- Different dynamic and steady state characteristics of DGs.
- Significant imbalance due to single-phase loads or DGs.
- Significant portion of supplying energy from uncontrollable sources.

The reasons given cause the required control strategies to differ from those of conventional power systems. Microgrids should guarantee various functions such as the supply of electrical and/or heat energy, energy market participation, etc. The design of microgrid control systems is a complex task including various functions that can be solved in many different ways.

Different companies and institutes have developed many control systems to provide all functions expected from a microgrid and to solve the problems raised. Hence, various control systems have been proposed in the literature. Hierarchical control structure is the most reported control structure in the field of microgrid control. Many existing control structures can be examined within the framework of this control structure. A hierarchical control structure has three primary, secondary, and tertiary control levels. Each control level is dedicated for the control of one or more parameters of microgrid. The primary control is mostly used for controlling output voltage or power of DG sources. The secondary control is mostly used for the restoration of voltage and frequency and the tertiary control deals with microgrid import or export of energy. For an islanded microgrid, the first two control levels are used most.

Some review papers in this field are available in [1,2,7,10,16–24]. By reviewing state-of-the-art literature in each level of the control hierarchy, this paper tries to reach a more comprehensive classification of different challenges, solutions, and respective advantages and/or disadvantages of the microgrid control system in each control level. Different control approaches are reviewed and compared and then some suggestions for future works are presented.

The rest of the paper is organized as follows: Section 2 discusses the concept and the structures of microgrid. Section 3 illustrates the microgrid control structure and its various approaches; an overview of hierarchical control systems applied to microgrids; discussing the classification of control features in different hierarchical levels; and reviewing state-of-the-art in microgrid's control levels are presented in this Section. Future trends in microgrid control are stated in Section 4. Finally Section 5 concludes the paper.

2. Microgrid structures

In the past, power was generated in a centralized manner in power systems due to the benefits of mass generation. With increasing concerns about environmental pollution caused by centralized power plants and revealing shortcomings and deficiencies of traditional electrical distribution systems such as low efficiency and high energy losses, the need to revise the existing structure became clear. The efforts made by power industry experts to eliminate the existing deficiencies and modernize the network, resulted in introducing smart electricity grids. The main goal of this type of network is to supply reliable power and meet the growing needs of customers with the least damage to the environment [3].

Smart electrical energy grids benefit from different DGs in an appropriate way. DGs in different types and sizes in smart grids can reduce the need to get energy from the main grid by supplying energy at sites near the consumers. If generation is in excess of local consumption, the surplus can be sold to the grid [25].

In addition to many advantages, DGs have created challenges including complexity, changing rules of protection, and maintenance for power systems. To overcome these problems, all these DGs and local loads are needed to be considered collectively. Furthermore, new standards are needed for DGs and large units involved in power generation. Accordingly, the microgrid concept was introduced into the new power systems. Microgrids consist of small power sources such as diesel generators, wind turbines, fuel cells, solar cells as well as local loads and controllers. Microgrid concept was introduced in 1998 by the CERTS[1] which considers a microgrid as a community of small sources and loads that work as an independent system to produce both heat and power [26].

Smart microgrids are the basic components and building blocks of smart grids. A microgrid is composed of a variety of sources such as DGs, energy storage systems (ESS), and local loads. Microgrids along with the use of DGs promise many benefits for the electricity industry. A DG can reduce electrical and physical distance between supply and demand and thus improving voltage profile; saving costs; reducing congestion of transmission and distribution feeders; and reducing transmission and distribution losses. It can also reduce greenhouse gas emissions due to the use of clean energies and decentralize resources; it also improves power quality and reliability; reduces outage time; and reduces the effect of large outages. The ability of remote controlling; postponing the need for new transmission lines and large generating plants; and finally postponing the need for those related to electricity markets are of its benefits [27,28].

Some of the microgrid benefits are as follows [16]:

1. Utilizing DGs without interrupting the main network performance [29].

   Ability to operate whether connected to or disconnected from the network according to economic necessity or planned outage or power quality recovery when their values are placed below specific standards [30–32].
2. Improved reliability and flexibility due to the various benefits of DGs [29,33].
3. Use of DGs waste heat to improve generation efficiency [29,34].

Advantages like those mentioned above have made microgrids be used more than before and increasingly gain more attention every day. General schematic of a typical microgrid is shown in Fig. 1.

The concept of microgrid was first introduced in [35,36] as a solution for the reliable connection of DG units including ESSs and controllable loads. Microgrids can be described as a set of loads, DGs, and ESS which operate coordinately to deliver reliable electricity. It can be connected to the main grid at a point called PCC (Point of Common Coupling) [7].

A microgrid is able to operate in both connected to and islanded from the network and when transferred between these two modes as well. In the case of grid-connected, power shortage can be provided from the main grid and excess power can be sold to the grid or participate in ancillary service markets [7].

In islanded mode, the active and reactive powers generated inside microgrid should be in balance with the demanded power. IEEE standard 1547 determines the policies for interconnecting DG units. In grid connected mode, the main purpose is the energy management; while in the islanding mode, the main goal is voltage and frequency control [37,38].

Islanding, i.e. disconnecting the microgrid from the main power grid can be either intentional (planned) or unintentional. Intentional isolation occurs when there are scheduled repairs or when the reliability reduction of the main grid endangers microgrid operation. Non-scheduled islanding occurs in the case of faults or any unplanned events unknown to the microgrid [7]. Examples of practical microgrid implemented in Europe are presented in Table 1.

It can be concluded that about 59% of these microgrids are real; 67% are centralized; and 94% are the AC system.

3. Microgrid control

One of the main features and benefits of a microgrid is its islanding

---

[1] Consortium for Electric Reliability Technology Solutions.