Electrical Power and Energy Systems 78 (2016) 390–400

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Cooperative control strategy of energy storage systems and micro sources for stabilizing microgrids in different operation modes

Mohammad H. Moradi, Mohsen Eskandari, S. Mahdi Hosseinian *

Faculty of Engineering, Bu-Ali Sina University, Hamedan, Iran

ARTICLE INFO

Article history:
Received 29 October 2014
Received in revised form 30 November 2015
Accepted 4 December 2015
Available online 22 December 2015

Keywords:
Microgrids
Energy storage systems (ESSs)
Power converters
Droop control
Cooperative control
Dynamic stability

ABSTRACT

The islanding capability of Microgrids (MGs), when a fault happens in the grid, is seen as one major driver in enhancing the reliable of MGs. However, the use of power electronic interfaces based-MGs faces some difficulties in maintaining stability in an islanding mode due to the low capacity of installed DGs as well as the low speed response of MGs to any load changes. In fact, the lack of availability of spinning reserves makes fast response to load changes, as well as balancing between power generation and load demand difficult. This leads to deviation in voltage and frequency from their (pre-determined) permitted values. In this paper, a new MG's topology along with a novel control strategy is proposed for stabilizing MGs in different operation modes. Battery storage is used to address the slow response problem of micro sources (MSs) to load changes, and to balance load demands and power generation in the islanding mode of MGs. A droop control idea is adopted in the lowest level of a hierarchy controller to enhance cooperation between power electronic inverters, and to improve load dispatch and voltage regulation. The voltage variation of the MG's main bus is considered as a load change criterion, instead of the output power of converters, to increase the response speed of the control system. The effectiveness of the proposed control strategy is assessed using MATLA/SIMULINK. It is shown that the proposed control strategy improves the operation of MGs in grid connected and islanding modes where soft transient between these two modes are achieved.

Introduction

In the near future, the use of distributed generation (DG) units, including renewable energy resources (RESs) [1,2], micro-sources (MSs), combined heat and power units (CHP) [3] and energy storage systems (ESSs) [4] are expected to increase in power system, though the use of low efficient traditional power plants are anticipated to decrease. In such arena, the development of digital technology and the emergence of intelligent measurement tools make collection of consumers' data possible. This enhances the management of power system and reduces electrical losses. In this light, a passive distribution network can be seen as an active smart grid linked to the upstream network while affecting its operation and stability.

A successful development of power system requires supplying electricity to consumers with high quality and reliability, low prices, and without any power interruption while encouraging privative companies to participate in the deregulated power system. As such, proper management and control of DGs, ESSs and loads within a small geographical area, forming a small grid, known as a microgrid (MG), are essential. The ability of operating in two different modes namely, an islanded mode (IM), isolated from the main grid, and a connected mode (CM) enables MGs to improve the reliability and quality of the delivered power particularly for sensitive loads [5,6].

In many cases, MG sources are connected to low or medium voltage networks through power electronic interfaces at small scales, from several kilowatts to few megawatts. The way of controlling MG sources generally differs from that of conventional power system due to the absent of any governor systems to deal with the voltage and frequency of MGs comprising renewable resources. So adjusting voltage and frequency is central in the development of an effective control strategy in power electronic interfaces based-MGs [7].

In conventional power system, including synchronous machines, due to inertia, a considerable kinetic energy, called spinning reserve, is available which is typically stored based on rotor mass. Such kinetic energy makes the system fast while it provides a proper response to disturbances (load variations). Conversely, in MGs, due to the limited capacity of installed resources and the lack of spinning reserve, energy storage systems (ESSs), like battery, are

* Corresponding author. Tel.: +98 81 38220954; fax: +98 81 32511176.
E-mail address: s.hosseinian@basu.ac.ir (S.M. Hosseinian).

http://dx.doi.org/10.1016/j.ijepes.2015.12.002
0142-0615/

needed in order to counterbalance MS's slow response to load variations and to compensate any unbalancing between production and consumption [8,9].

In the current literature, compared with conventional power system, MGs are treated in three major categories, namely: (a) control [10], (b) energy management [11], and (c) protection [12]. By contrast, this paper focuses solely on the control aspect of DGs.

A hierarchical control system might be adopted in practice to deal with power sharing and voltage regulation of MGs [13–15]. In such control system, at the lowest level, decentralized control can be used based on active power–frequency (*P*–*f*) and reactive power–voltage (*Q*–*V*) droop control to mimic synchronous generators' behavior. This allows power sharing and prevents circulating current among converters [16–26]. In such vision, despite a far distance between DGs, communication equipment, which increases MG's construction costs and reduces reliability, is not required and grid variables, like voltage's amplitude and frequency, are used as control signals [27]. Other reasons that justify the use of droop control in MGs rest on such factors as its plug and play capabilities, simplicity, low cost and high reliability [28–30].

To assess the effect of droop gain on MGs operation and to perform a sensitivity analysis for stability of MGs a dynamic model might be established based on assuming frequency and voltage magnitude deviation as proportional to active and reactive power deviation, respectively. However, the accuracy of these assumptions depends on grid parameters, such as line impedance [23,31]. To address this, the study of [19] proposes a rotational matrix for transforming active and reactive power to a virtual frame. Later such matrix was adopted by [32] for transforming voltage and frequency to an orthogonal virtual frame to provide a means to decouple active and reactive power's control, though lack of sharing nonlinear and asymmetric loads is a drawback of this method. The studies of [33–36] suggest the use of virtual impedance to cope with such drawback. Compromising between power sharing and voltage regulation is seen as another drawback associated with the use of droop control. This is largely because power sharing, using droop control, requires voltage variables (amplitude and frequency) adjustment to deviate them from their steady state (nominal) values. Also, voltage regulation requires alteration of active and reactive power from their determined set points. In order to deal with this variable adjustment problem the use of a secondary controller is suggested [37].

A number of studies have looked at power flow in the islanding mode (IM), utilizing droop control; however, few studies have focused on the transient state. For example, in [38], a connecting procedure, for MG's (equipping droop control) resynchronization with the main grid is presented. In practice, maintaining MG's stability both during the MG's transition time, from CM to IM, and during MG's operation time in IM is problematic. Because MG exchanges power with the upstream network during the islanding

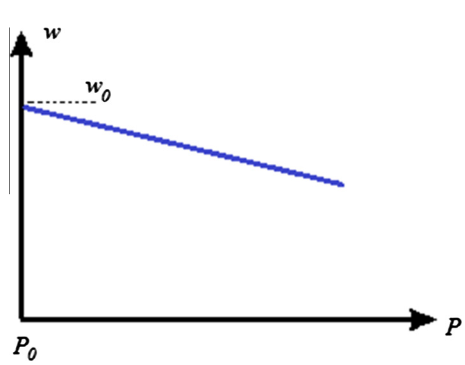

Fig. 1. Frequency-active power droop curve.

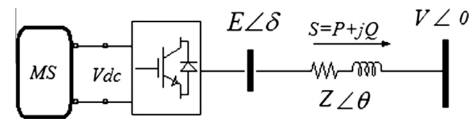

Fig. 2. Model of converter connected to MG bus.

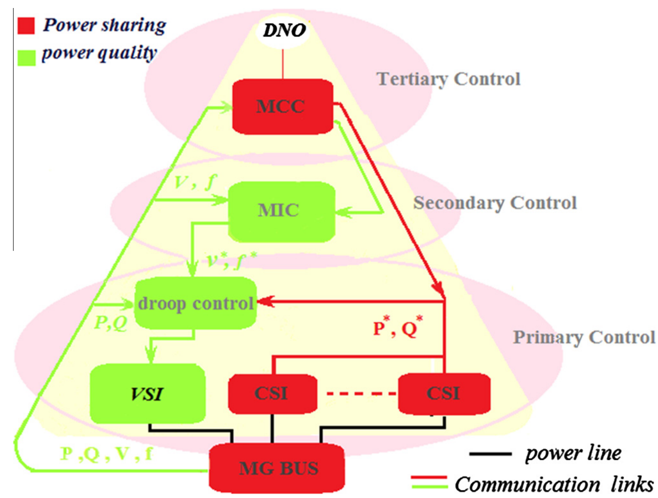

Fig. 3. MG control system pyramid.

moment, the exchanged power should become zero and a balance should rapidly be established between production and consumption rates. MG resources are responsible for power exchange compensation, but they often fail to be fast in response. This leads to an unbalance between production and consumption causing deviation of voltage variables (amplitude and frequency) from their permitted values, and this makes MG unstable. To cope with this problem the use of ESSs, like battery, and an appropriate control strategy with quick response become essential [39,40]. This is the main focus of the current paper. In [40] a method for stabilizing the voltage source converter-based MG via adopting battery and droop control is proposed. In this method, droop gains (in MSs and battery converters) cooperate with each other and they dynamically change so that the battery with fast response gives MSs enough time to respond to load variations. Despite the seminal work of [40] there are a number of issues associated with its assumptions as outlined below:

(1) The impedance of MG is considered inductive without considering any virtual impedance; however, this impedance is generally resistive (not inductive). Using physical inductive may increase the cost and size of DGs. Also adopting virtual impedance may reduce the accuracy and it may also impose some limits on the maximum and minimum of the power delivered by sources while there is possibility of having some stability issues.
(2) Droop controllers are used to dispatch power between power sources based on their gain variations and the load demand. This makes the trade-off between power sharing and voltage regulation problematic as power sharing based droop control depends on deviations of voltage amplitude and frequency from their specified steady state (nominal) values.
(3) All power sources and batteries are considered as voltage source inverters (VSIs) connected to the grid. Maintaining synchronization of such VSIs with the main grid and supplying the specified power (power set points) via adopting