Electrical Power and Energy Systems 98 (2018) 36–47

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Active power management in a low-voltage islanded microgrid

M.A. Hossain[a,*], H.R. Pota[a], M.J. Hossain[b], A.M.O. Haruni[a]

[a] School of Engineering & Information Technology, The University of New South Wales, Canberra, ACT 2610, Australia
[b] Department of Engineering, Macquarie University, Sydney, NSW 2109, Australia

A R T I C L E I N F O

Keywords:
DC-link energy
Islanded microgrid
Balanced power
Stable voltage
Voltage-band

A B S T R A C T

Growing electricity demand and scarcity of energy sources are the driving force of exploration of renewable energy sources. However, uncertain energy production of these sources creates difficulties in their control and operation with or without a grid utility connection. This paper proposes a novel power control strategy which employs a voltage band in the DC-link voltage to maintain voltage stability and thereby improve the power quality during temporary disturbances in a network. It is applied to act as an inverter's inertia and obtain maximum benefit from the storage system, based on the features of a DC busbar to avoid a voltage limit violation. It also proposes a demand dispatch strategy based on a client's terminal voltage, which avoids the complexity of communication lines, to balance the network power during power shortages. The developed control algorithm is tested on an IEEE 16 bus test feeder with multiple DG units and from the results it is found that the proposed control methods provide effective control of the voltage and power quality during transient conditions and scarce power generation.

1. Introduction

Due to increased concern about energy crisis and environmental issues, the power industry is shifting their power production from conventional power sources to renewable energy sources (RESs). The power industry is incorporating RESs into the grid utility in the form of distributed generations (DGs). The application of DGs can enhance reliability and stability of the local network, and can provide benefit to the suppliers by reducing system losses and investment on a new transmission line due to increased power consumption [1–3]. Power generation in the form of DGs for local and grid utility can create issues as many as it may solve. Therefore, a microgrid concept is evolved to coordinate among sources, loads, and energy storage devices for maintaining a distribution network stability [4,5]. A microgrid can be considered as a controlled small-scale power network's system, consisting of small-scale emerging generators, loads, energy storage elements, and control units, built within a defined area for maintaining system stability, reliability, and facilitating improved power quality to the consumer's premises [6]. During autonomous operation, microgrid elements, such as voltage source converters (VSCs), are principally responsible for providing voltage and frequency set points within a distribution network.

In a microgrid, small-scale emerging generators, such as wind, solar, fuel cell, and small-scale gas turbine, are installed in proximity to the load side, and use inverters as interface devices to inject active and reactive power into the network [7,8]. Inverters are able to supply controlled voltage and frequency depending on the control algorithms [9]. The characteristics of inverters are significantly different from the conventional generators; therefore, specific control algorithms are required for a stable microgrid operation [10–13].

There are several literatures that propose droop-based control for facilitating high reliability and avoiding the complexity of communication lines [14–17]. Droop control is popular due to its capability to coordinate various power rating units as well as being flexible and reliable, and is valid for both high-voltage (HV) transmission lines and low-voltage (LV) distribution ones. In an LV distribution network, the well-known active power/frequency (P/f) droop control requires much more effort than the active power/voltage (P/V) one because a predominantly resistive network naturally connects active power to the grid voltage [18–23]. For this reason, to control the voltage magnitude and network frequency in an LV microgrid, both P/V and reactive power/frequency (Q/f) droop controls are adopted.

As the application of control algorithms instead of the straightforward employment of droop control in a microgrid needs to be reviewed due to the increasing penetration of intermittent RESs, considering the renewable energy features mentioned in [23], voltage-based droop (VBD) control is proposed. Such a control approach integrates intermittent RESs rather than dispatchable energy sources by applying delays in the power change points. In it, although the terminal voltage is changed proportionally to variations in the power demand, a terminal

* Corresponding author.
E-mail addresses: Md.Hossain6@student.adfa.edu.au, alamgir_duet@hotmail.com (M.A. Hossain).

https://doi.org/10.1016/j.ijepes.2017.11.019
Received 14 March 2017; Received in revised form 11 October 2017; Accepted 14 November 2017

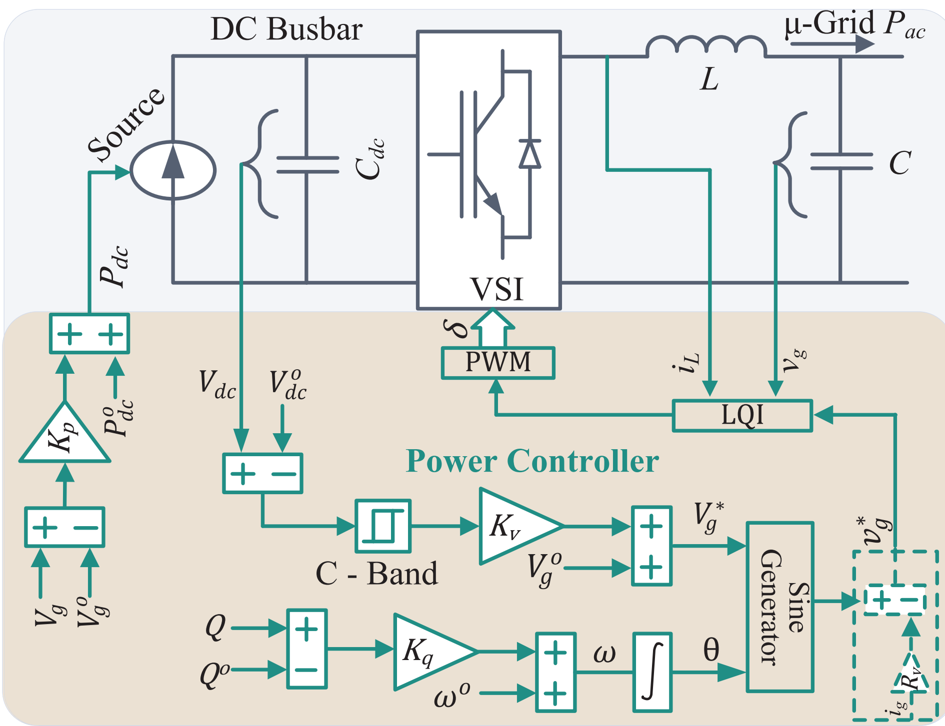

Fig. 1. Microgrid's power control strategy.

voltage deviation is not expected from a consumer perspective. Moreover, the active power control in [23] is postponed up to a certain limit of the terminal voltage considering the features of RESs. However, recently, RESs have been using energy storage elements [24], such as batteries, that can deliver power, as a dispatchable generator, into the network during a power mismanagement. Therefore, the VBD method needs to be modified for application in microgrids.

This paper proposes a control algorithm to minimise changes in consumers terminal voltage while facilitating steady-state power consumption during any small transient event. This strategy enables any unpredictable supply and demand to be balanced within tolerable DC-link voltages (V_{dc}) considering random power/load fluctuations.

To control the power supply and demand in a network, generally, the central energy management system (EMS) [25–29] needs to access each DG and load point for power measurements through communication lines. The design and modelling of these communication lines can be found in [30,31]. The communication modules create a complicated network. This is because, if any DG or load point is out of the communication range, the EMS may produce an unexpected signal sufficient to incur an undesirable situation. Therefore, using communication lines as a primary control strategy reduces the reliability of a microgrid [32]. However, it is always desirable to use the communication links for an optimal decision process in a tertiary control layer considering the electricity market and fuel cost [33].

The influence due to malfunctioning communication on demand response is analysed, and an optimal resource allocation scheme depending on features of the both power demand and monitoring data transmissions is presented to minimise the influence in [34]. In [35], an adaptive dynamic model is proposed to regulate voltage based on demand response strategy for reducing voltage fluctuation at customer premises in an LV distribution feeder. To prevent voltage and current limit violation in a distribution network considering fair consumer participation, a proactive centralised control for one hour ahead load and a reactive decentralised control for regulating consumption are presented in [36]. However, in the existing literatures, the concept of primary centralised load control for microgrids without communication is not found.

To improve the reliability of a microgrid, this paper also proposes a demand-side management system without communication lines that depend on the terminal voltage of a consumer's premises which assists in providing greater microgrid reliability along with a secondary controller.

The major contributions of this paper are summarised as follows.

1. A voltage band, which acts as inertia for an inverter's DC-link voltage controller to exploit the stored energy during disturbances and thereby minimise network voltage variations, is proposed. As it improves the quality of the network's voltage, the power quality of a microgrid is enhanced.
2. A voltage controller of an inverter, avoiding cascaded PI controller tuning while minimising the cost function of the system, is designed to track the instantaneous reference grid voltage with nullifying steady state error during disturbances. The application of the proposed voltage controller in a natural (*abc*) frame avoids the complexity of the Clarke and Park transformation.
3. A novel and simple demand-side management system based on the terminal voltages of end-users without communication lines is proposed. The proposed strategy uses relay-based load curtailment at the connection points of controlled loads in the case of a power deficiency of DG units in a microgrid.

The rest of this paper is structured as follows. In Section 2, an overall control approach for inverters in a microgrid configuration is briefly discussed. Section 3 describes microgrid control algorithms for a predominantly resistive line and develops a voltage control strategy to track the reference grid voltage. In Section 4, the simulation results demonstrate the effectiveness of the proposed controller compared with that of the VBD controller in a simple network. Section 5 presents the proposed control strategies in advanced networks to evaluate their performance in balancing the power supply and demand in a distribution network.

2. System overview

The proposed overall VBD control strategy for a microgrid is shown in Fig. 1. The power supplied from an energy source is considered a