Control of a Multiple Source Microgrid With Built-in Islanding Detection and Current Limiting

Jeffrey M. Bloemink, *Student Member, IEEE*, and M. Reza Iravani, *Fellow, IEEE*

***Abstract*—An approach for the control of a voltage-sourced converter-interfaced distributed energy resource microgrid environment with multiple energy sources is analyzed and experimentally validated. The control approach is designed to operate in grid-connected and islanded modes of operation, as well as provide a smooth transition between the two modes. Additional features including islanding detection with positive feedback and dynamic overcurrent limiting are also evaluated. Validation is achieved through the results obtained from a scaled down prototype system with further results from the time-domain simulation of a medium-voltage microgrid.**

***Index Terms*—Autonomous, control, inverter, islanding, microgrid, voltage-sourced converter (VSC).**

I. Introduction

As THE depth of penetration of distributed energy resources (DERs) increases to meet the rise in demand for electricity while reducing environmental impacts [1], microgrids will become more commonplace [2]. Sources which are part of a microgrid have unique requirements: each DER, whether a distributed generator (DG) source or a distributed storage (DS) unit, should be able to be added and removed without a significant impact on the microgrid. The microgrid should also be able to transition smoothly between grid-connected (GC) mode and islanded (IS) modes in both preplanned and emergency situations [2]–[4].

In most cases, a DER unit is interfaced to the host microgrid with a voltage-sourced converter (abbreviated as *converter* throughout this paper), creating the need for an effective method of controlling this interface converter to meet these microgrid operational requirements [5]. This paper further explores the converter control strategy introduced in [6]; a phase and magnitude variance-based controller which incorporates features necessary for operation in a microgrid environment (i.e., islanding detection, overcurrent protection, and droop control). This control strategy will be referred to throughout this paper as the voltage-controlled strategy (VCS). The intention of this paper is to further that of [6] by:

- demonstrating its use with multiple sources;
- compare and test its compatibility with sources utilizing other control methods;
- characterize the overcurrent limiting capabilities;
- discuss islanding detection tuning procedures;
- validate operation experimentally with hardware implementation.

A common approach to converter control is based on regulation of direct and quadrature (dq) current components [7] (i.e., the converter is operated as a current-controlled voltage source). This strategy will be referred to throughout this paper as the current-control strategy (CCS). It is neither necessary nor desirable that all DER units utilize the VCS in a microgrid setting, so configurations are investigated in which all units utilize the VCS; multiple VCS-based and multiple CCS-based units coexist; or a single unit utilizes the VCS, and the remaining units utilize the CCS. The CCS approach works well when the microgrid is grid-connected, with the grid supporting the voltage and frequency at the point of common coupling (PCC) bus; however, when the microgrid is disconnected from the utility (islanded), the converter cannot maintain the voltage and frequency at the PCC [7]. In a microgrid with multiple sources, this behavior can be corrected by ensuring at least one unit utilizing the VCS (master) is present. This is commonly referred to as a master-slave control scheme and has been discussed previously in [8]–[10]. This paper explores this concept with the use of the VCS control scheme of [6]. With a VCS unit present, the frequency and voltage are supported after the transition into islanded mode by the VCS-based source while the CCS units continue to exchange real and reactive power with the microgrid. A consequence is that it is not necessary for the sources utilizing the CCS to immediately detect the islanded state. This feature is important if the CCS units are designed without the intention of coordinating with other sources in the microgrid, such as an aggregate of a large number of photovoltaic interface inverters.

Overcurrent protection is achieved by applying static or dynamic limits to the commanded output voltage magnitude. Islanding detection is achieved through forced-destabilization of the microgrid upon islanding; exploiting the fact that the sources dominantly determine the PCC bus voltage in islanded mode [11]. This destabilization affects the converter terminal voltage and can therefore be detected locally. Hardware testing is done with two inverter-interfaced sources in order to verify controller features. Further insight into the performance and behavior of the proposed VCS is achieved through the time-domain simulation of a larger scale model with five inverter-interfaced sources.

Manuscript received November 27, 2011; revised February 23, 2012; accepted April 30, 2012. Date of publication August 24, 2012; date of current version September 19, 2012. Paper no. TPWRD-01011-2001.

J. Bloemink is with the Electrical Engineering Department, Imperial College, London, SW7 2AZ, U.K. (e-mail: j.bloemink@imperial.ac.uk).

M. R. Iravani is with the Electrical Engineering Department, University of Toronto, Toronto, ON M5S 3G4 Canada (e-mail: iravani@ecf.utoronto.ca).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TPWRD.2012.2198497

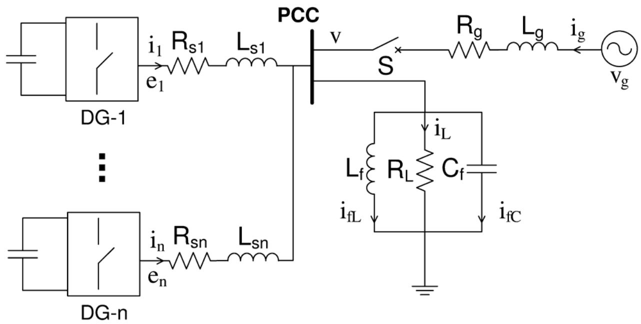

Fig. 1. Schematic circuit diagram of the test system.

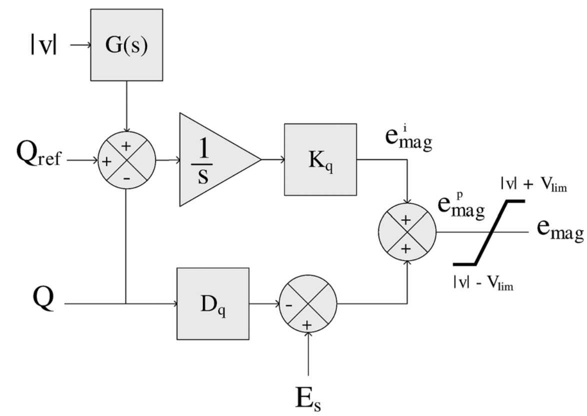

Fig. 2. VCS reactive power/voltage-controller block diagram.

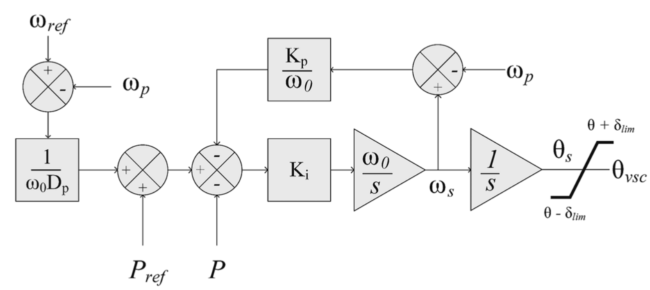

Fig. 3. VCS real power/frequency-controller block diagram.

II. System Description

A three-phase ac microgrid with n sources (Fig. 1) is considered, with the hardware implementation containing two units ($n = 2$) and the simulated system five ($n = 5$). Each source consists of an interface converter in series with an inductor that represents the aggregate of a series filter, coupling transformer, and short line. A representative load is formed with a parallel RLC branch at the PCC.

III. Controller Description

Each source utilizes one of the two aforementioned control strategies: VCS or CCS. The CCS will only be briefly described here, since it is a well-established approach [5].

A. Voltage-Control Strategy (VCS)

The VCS control approach is designed to operate in grid-connected and islanded modes of operation, as well as the transition between the two. The VCS fixes voltage and frequency, operating the converter as a voltage-controlled voltage source. Once in islanded mode, the power flow is determined passively according to the load impedance.

1) Voltage/Reactive Power Control: A block diagram of the converter voltage/reactive power controller is given in Fig. 2. Inputs Q and $|v|$ are the measured reactive power delivered by the source and the PCC voltage magnitude, respectively. Fig. 2 reveals the integral control strategy used to achieve regulation, with controller speed dominantly determined by the gain parameter K_q. e^i_{mag} represents the change in terminal voltage to regulate to Q_{ref}, e^p_{mag} the output terminal voltage required to reach desired operation, and e_{mag} the commanded output terminal voltage magnitude after limits are applied. D_q determines droop operation. More information about how droop constants are determined for power sharing can be found in [12]. The controller is designed based on the assumption that the reactive power flow is dominantly determined by the magnitude of the voltages at the converter terminals and PCC bus. Inspection of the controller block diagram yields

$$e^p_{mag} = Es - D_q Q + \frac{K_q}{s}(Q_{ref} - Q) + \frac{K_q}{s}G(s)|v|. \quad (1)$$

When in islanded mode, it is necessary to disable reactive power control and allow the flow of reactive power to be determined by the load. This is done by setting $K_q = 0$ upon islanding detection and confirmation [6]. E_s, the voltage setpoint, is determined depending on network parameters to allow the system to operate within the allowable limits once the system has islanded and the reactive power controller has been disabled. Further information regarding integral control of reactive power in microgrids can be found in [13] and [14].

Voltage Droop Control: The droop term of (1), $D_q Q$ is used to minimize interaction among sources in a multiple source configuration and enable reactive power sharing [12]. It ensures that the control scheme meets performance requirements regardless of the number of sources present [2].

2) Frequency/Real Power Control: A block diagram of the frequency/real power controller is given in Fig. 3. ω_p, ω_s, and ω_0 are the PCC bus, converter terminal, and system nominal frequencies, respectively. The gain term K_p is used to control power regulation speed. D_p represents the real power droop constant. The term K_i can also affect the controller regulation speed but is generally used to refine second-order transient behavior of the controller. Finally, the controller outputs a frequency ω_s that is integrated to θ_s, and limited appropriately to form the converter terminal voltage phase angle θ_{vsc}.

Proper operation of this controller is dependent on three factors:

- the real power flow and frequency are dominantly determined by the relative phase of the converter terminal voltage e;
- when in grid-connected mode, the utility dominantly determines the system frequency ω_p;
- when in islanded mode, the source must determine the system frequency ω_p .