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A generic microgrid controller: Concept, testing, and insights

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HIGHLIGHTS

- Specifications for a Generic Microgrid Controller (GMC) are developed.
- These specifications were incorporated in IEEE standard 2030.7.
- Implementation of a conforming controller is demonstrated in HIL.
- Master Microgrid Controller has two core functions: Transition and Dispatch.
- A generation/load mismatch threshold for seamless islanding is established.

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ABSTRACT

Microgrids have garnered attention in recent years as a way to increase the reliability of the grid, increase the reliability of electricity service to customers, adapt to an increasing percentage of intermittent renewable generation, and serve both customer critical loads and the needs of adjacent communities in the case of emergencies such as natural disasters. One barrier to microgrids is the historic cost and lack of standardization associated with microgrid controllers. To reduce this cost and address standardization, specifications for a Generic Microgrid Controller (GMC) were developed with the goal to facilitate the design and ease of adaptation of microgrid controllers to various microgrids of different sizes and with different resources. A GMC must address two core functions, Transition and Dispatch, as well as several optional higher level functions such as economic dispatch, and renewable and load forecasting.

The GMC specifications were demonstrated and evaluated using a commercial simulation platform for two different microgrids, a 20 MW-Class community microgrid and a 10 MW-Class medical center microgrid. For each microgrid, the GMC was tested in hardware-in-the-loop (HIL) using an OPAL-RT real-time digital simulator, and the two core functions were assessed. The results established that (1) the GMC is successful in seamlessly transitioning the microgrids to and from an islanded mode, (2) a load/generation mismatch at the time of separation depends on the microgrid configuration and must be lower than a specific value determined by simulation testing, and (3) the GMC Dispatch Function response is acceptable in maintaining, in the islanded mode, 60 Hz for a range of load changes.

1. Introduction

The grid is evolving rapidly as reflected by the worldwide investment in energy RD&D which includes energy efficiency, renewable energy, energy storage, hydrogen, fuel cells, and other cross-cutting technologies. Worldwide investment in smart grid technology reached 14.9 billion dollars in 2013. The United States' investment in smart grid technology experienced a substantial increase in the 2010–2012 time frame as a result of the stimulus funds initiative [1,2]. After superstorm Sandy in 2012, microgrids were recognized at the national level [3] as the key component in increasing reliability of the grid [4,5], building resilient communities, and facilitating public safety especially during unforeseen occurrences including natural disasters. Additional attributes include economic benefits [6–8] (especially benefits of self-generation, peak shaving [9]), integration and management of intermittent renewable resources [10,11], and environmental benefits [12] including reduced greenhouse gas [6,13] and criteria pollutant emissions.

A key aspect of microgrids is seamless disconnection from the grid in order to support, at a minimum, critical loads of the customer in the case of a grid outage. Under such circumstances, the grid reference is lost and local voltages and frequency become especially sensitive to generation and load fluctuations. As a result, a microgrid controller is

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Nomenclature

APEP	Advanced Power and Energy Program
GHG	Greenhouse Gas
GMC	Generic Microgrid Controller
HIL	Hardware in the Loop
MMC	Master Microgrid Controller
PCC	Point of Common Coupling
TEV	Testing, Evaluation, Verification
UCIMC	University of California Irvine Medical Center
UCIMG	University of California, Irvine Microgrid

required to not only transition the system to an islanded mode, but to also ensure system stability by balancing load and generation. When grid-connected, the controller is responsible for (1) economic dispatch [14,15], system optimization of efficiency [16,17], emissions [13,18], service to the customer, and (2) the provision of ancillary services [19,20] to support utility grid economy, reliability, and resiliency [21].

There are two major approaches to microgrid controller design: centralized, and distributed [22]. Centralized microgrid controllers incorporate a "master controller" which communicates with local devices via a network [23]. Local controllers rely on the autonomous operation of individual devices. Modern controllers of this type typically utilize frequency droop control for power sharing and reactive power droop control for voltage regulation [24]. This approach lends itself to a "plug and play" method of microgrid development and the omission of a single point of failure results in higher system reliability. However, coordinating the operation of the system as a whole becomes difficult due to the lack of a communications network. A hybrid approach incorporates distributed controllers to provide transient stability control, and a slower communications network to collect and set the overall system operating status. Control schemes of microgrids are well researched. Studies utilizing a centralized controller with a communications link to each distributed generation resource are presented in Refs. [25–28], and the associated modes of control in grid-connected and islanded modes are discussed in Refs. [29,30]. Recently, much interest has shifted to distributed control schemes with many proposed controllers based on some form of droop control [29,31,32]. It may be argued that these configurations are favored over centralized controllers since in large networks, it is not practical for individual microgrid elements to know the state of the entire system, and the installation of a communications network introduces additional points of failure and is often prohibitively expensive.

Most of the microgrid controllers developed are specific to the microgrid controlled. In contrast, the Generic Microgrid Controller (GMC), described in this paper, includes generic modules designed for adaptation to microgrids of various sizes and comprised of various resources in order to reduce upfront engineering costs and barriers to microgrids. The GMC development was conducted in two phases: (1) Research, Development, and Design (Design), and (2) Testing, Evaluation, and Verification (TEV). In Phase I, GMC specifications were developed which can be followed by a microgrid controller supplier for a wide range of facilities. In Phase II, specific implementation of the GMC was demonstrated both in Hardware in the Loop (HIL) simulation and in a physical demonstration on 20 MW-class University of California Irvine Microgrid (UCIMG) using a conforming controller provided by ETAP. To demonstrate the generic nature of the design, the GMC was also evaluated with HIL testing for the 10 MW-class University of California Irvine Medical Center (UCIMC) microgrid located 30 miles from the UCIMG. In the following sections, the GMC specifications developed are described, and the implementation of the GMC on both the UCIMG and UCIMC is summarized by describing the configuration, the modeling, the test plan, the HIL test set up, and the simulation results for the two microgrids.

2. GMC specifications

The GMC specifications were developed by the Advanced Power and Energy Program (APEP) under a major U.S Department of Energy (DOE) project [33] and integrated into the IEEE 2030.7 microgrid controller working group. APEP served as the co-chair of the working group and the interaction (timing and synergism) between the development of the GMC specifications and the working group assured a robust IEEE standard.

The GMC modular architecture is shown in Fig. 1. For each dispatchable element, an asset level control module is provided. Each module has a "fill-in the blanks" form to describe the asset to the Master Microgrid Controller (MMC). The functionality of these modules correspond to the lower level functions. The idea behind these specifications is to encourage a common framework for microgrid controllers across the industry. Controllers developed in accordance with this specification will provide the following benefits:

1. The controllable assets of the microgrid can be specified by adding "fill-in the blanks" forms which:
   a. Reduces the engineering effort required to implement a microgrid control system.
   b. Allows the MMC to be the same for most microgrids.
2. The MMC presents the microgrid as a single controllable entity which:
   a. Facilitates nesting of MMCs.
   b. Helps standardize the interconnection of microgrids to utility grids.
   c. Allows interoperability of higher level functions from different manufacturers.

These benefits are intended to (1) lower the barriers to more widespread deployment of microgrids, (2) improve electric power system resilience and (3) increase deployment of distributed renewable resources by adding the value of power supply assurance. The benefits also provide an upgrade-friendly architecture where improved higher level functions can rely on a standard interface to the core functions. In practice, the GMC specifications will serve as the core of a particular purchase with additional requirements added for customer-specified higher level functionality.

To constitute a microgrid, the MMC is required to have two main/core functions: Transition (Connect/Disconnect) and Dispatch which are considered the minimum additional functionality above the device or asset level. The core functions and various levels of control are

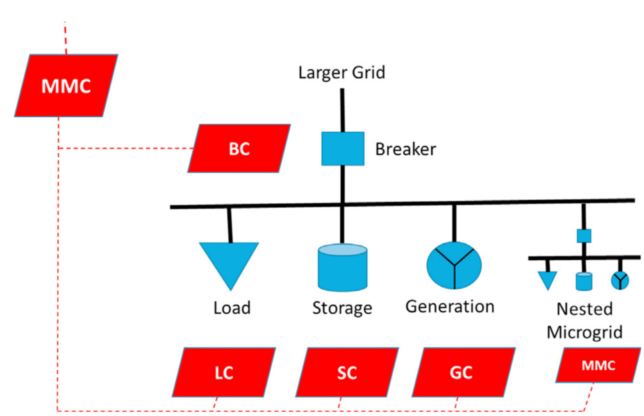

Fig. 1. GMC modular architecture.