INL/CON-09-16467
PREPRINT

Accelerating the Customer-Driven Microgrid Through Real-Time Digital Simulation

IEEE PESGM 09

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July 2009

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***Abstract*—Comprehensive design and testing of realistic customer-driven microgrids requires a high performance simulation platform capable of incorporating power system and control models with external hardware systems. Traditional non real-time simulation is unable to fully capture the level of detail necessary to expose real-world implementation issues. With a real-time digital simulator as its foundation, a high-fidelity simulation environment that includes a robust electrical power system model, advanced control architecture, and a highly adaptable communication network is introduced. Hardware-in-the-loop implementation approaches for the hardware-based control and communication systems are included. An overview of the existing power system model and its suitability for investigation of autonomous island formation within the microgrid is additionally presented. Further test plans are also documented.**

***Index Terms*—distributed generation, hardware-in-the-loop, microgrid, real-time digital simulator**

I. Introduction

FROM a modeling and simulation perspective, the customer-driven microgrid (CDM) presents unique challenges. Extensive development and testing of an autonomous CDM in a highly accurate real-time simulation environment, with physical hardware-in-the-loop (HIL), requires specialized testing capabilities. In addition, to realistically depict CDM islanding scenarios and control system interaction, simulation of moderately large power systems comprised of many distributed generators and controllers is needed. To study such system-wide microgrid behavior, research was conducted using a Real-Time Digital Simulator (RTDS). This system is capable of handling large amounts of data, interfacing with communication and control hardware, and providing high levels of system detail.

The Center for Advanced Power Systems (CAPS) at Florida State University has previously established an advanced test facility with the capability of HIL, real-time, power system simulation [1]. The principle computational system used is the RTDS. This large-scale electromagnetic transient simulator, developed by RTDS Technologies Inc. is described in [2]. The RTDS is designed to simulate systems in real-time with time step sizes on the order of 50 µs. For power electronics, the RTDS provides a feature to simulate such subsystems with smaller time-steps (typically 2 µs) [3]. The simulator makes use of a large number of digital signal processors and RISC processors, operated in parallel, and provides digital and analog I/O ports for interfacing hardware to the simulation. The system is scalable, allowing subsystems of up to 54 electrically accessible nodes to be simulated on a single "rack." There are 14 RTDS racks installed at the real-time power systems simulation facility at CAPS [4].

Despite the highly specialized tools available at CAPS for CDM design and testing, there were a number of issues that required consideration. The communication layer between the simulated power system and the physical microcontrollers had to be thoroughly planned to facilitate data transfer between the RTDS and controller hardware. Several methods of interfacing were researched in an effort to achieve high-speed, accurate data transfer. Different controller topologies were also considered, and are briefly discussed.

Ultimately the central requirement of the simulation environment was that it be able to take a given set of control algorithms as inputs, and test their performance in the CDM. Implementing the control system on several microcontrollers and connecting them to the real-time power system simulation via a hardware-based communication network accomplished this objective. This also eliminated the need to model

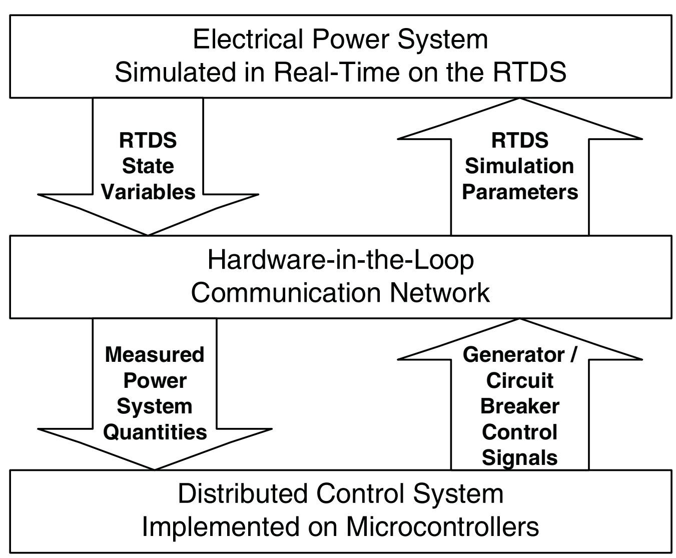

Fig. 1. Simplified block diagram of the HIL test setup.

This work is sponsored by the National Science Foundation, grant number 0757956, under subcontract 4-42854/16150 to FSU from CSM.

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978-1-4244-4241-6/09

controller hardware, thus reducing computational load in the simulation.

II. Distributed Microgrid Control System

A. Control System Interface

In traditional HIL simulations, the high-speed analog input and analog output ports of the RTDS are essential for synchronizing the software simulation with physical power system elements, such as protection relays, motor drive controllers, and sensors for voltages and currents. Previous co-simulations have been run with the RTDS, using analog signals for data interchange [5].

In the current study, analog I/O ports on the RTDS are used to transfer data between the RTDS and each of the microcontrollers in the distributed control system. The microcontrollers communicate with each other via digital I/O. Fig. 2 provides a graphical representation of this interfacing scheme. Custom Dynamic C software was developed at CAPS to support data transfer and communication between the distributed controllers and the real-time simulator.

The nature of this design allows for variable communication topology between the controllers. Such topologies could include complete interconnectivity, hierarchical communication, or an ad hoc scheme. Regardless of topology choice, feedback and control of the electrical simulation is made possible by this HIL controller interface.

B. Scalability

Another relevant issue when dealing with high-fidelity modeling is scalability. In order to simulate large CDMs, both the amount of physical hardware connected to the RTDS and the complexity of the power system increase. Three microcontrollers are currently available to implement the CDM control system. Each of these devices (SR9000 Smart Star) may actually represent one or more distributed controllers.

Although a single controller only represents one power system component, a microcontroller may represent the controller for several of these system components. This helps to resolve some of the system scaling problems, as the control implementation scheme would otherwise require large numbers of hardware controllers for increasingly large CDM simulations.

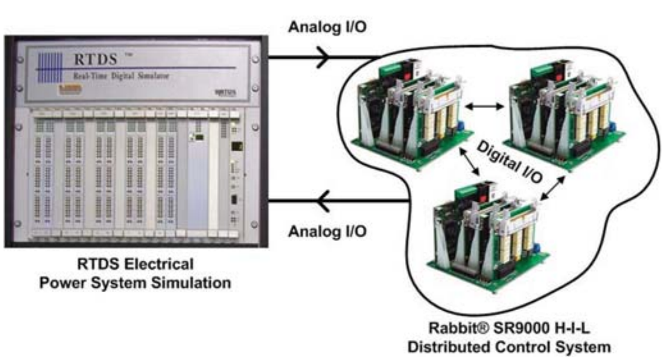

Fig. 2. HIL microgrid test setup.

III. Hardware-in-the-Loop Implementation

A. Thunderstone System

The Thunderstone system, developed and tested in [6], was chosen as a suitable candidate for CDM testing and evaluation. A summary of this electrical power system model that was implemented on a RTDS, is illustrated in Fig. 3. It employs four distributed generators, a transmission network, associated circuit breakers and transformers, various loads, and line-to-ground fault logic for stability testing. Multiple islanding scenarios and autonomous microgrid reorganization schemes can be tested using this real-time power system simulation.

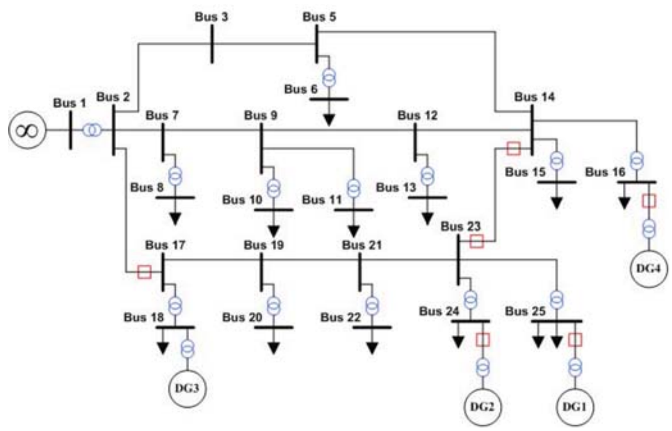

Fig. 3. One-line diagram of the Thunderstone power system.

As a real-time HIL based test setup, the Thunderstone system provides a wide variety of controller testing opportunities. The list of possible test cases using this real-time platform is also vastly increased due to the ability to investigate 'what-if scenarios' and reveal 'true-life' CDM implementation issues. Additionally, due to the parallel processing capabilities of the RTDS, system-wide response of the entire distribution system can be studied over extended periods of time. Non real-time modeling would simply be unable to provide the same level of detail.

Common practice in electromagnetic transient simulations is to split such a large-scale system into smaller subsystems, solving each network separately. In the present case, this can be accomplished by dividing the power system model into several pieces and solving each portion on a separate RTDS rack. Currently the complete setup uses two RTDS racks, both for simulation of the electrical power system and for communicating with associated external controller hardware.

B. Initial Results

Even without the final control algorithms implemented on the distributed control system, several preliminary tests were completed using the HIL testbed. Control signals from one of the microcontrollers were successfully input to the RTDS and used to modify generator set points. Electrical measurements from the power system simulation were then fed back into the controller and output to an LCD displays. Working only under open-loop conditions, distributed generators 1 and 2 were brought online to begin serving loads. Droop controls incorporated into the governor and turbine models attached to the distributed generators prevent complete closed-loop control by the hardware controllers at this time.

Having established the communication structure and demonstrated basic open-loop control of the power system, more advanced microgrid test plans can be formulated.

IV. Future Work

The next round of tests will incorporate more control signals from the microcontrollers, and then begin to evaluate the islanding capabilities of the Thunderstone system. As control algorithms become available in the near future, a viable testbed will already be in place to begin experimentation.

Future testing could include other relevant distribution systems with varying types and numbers of distributed generators. By introducing an array of distributed energy resources into the simulation environment, the real-world behavior of these complex microgrids becomes much clearer. Benefits of further dynamic CDM research include greater distribution network reliability and drastically reduced energy costs. These subjects are of critical importance for the self-sustaining energy distribution systems of tomorrow. Viable customer-driven solutions may prompt significant changes in conventional power systems and high penetration rates of CDM technology.

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VI. Biographies

I. Leonard received his B.S. in electrical engineering from the Florida State University in 2008. He is currently pursuing a Master of Science degree in Electrical Engineering at the FAMU-FSU College of Engineering in Tallahassee, FL USA. As a graduate research assistant at the FSU Center for Advanced Power Systems his research is principally focused on hardware-in-the-loop simulation as it applies to customer-driven microgrids.

T. Baldwin (S'86–M'92–SM'01–F'08) received the B.S.E.E. and M.S.E.E. degrees from Clemson University, Clemson, SC, in 1987 and 1989, respectively, and the Ph.D. degree in electrical engineering from Virginia Polytechnic Institute and State University, Blacksburg, in 1993.

In 1992, he was with the M. B. Haynes Corporation as a Design Engineer. Then, he was a Senior Engineer with ABB Electric Systems Technology Institute, Raleigh, NC, in 1994. He is currently an Associate Professor with the Florida A&M University–Florida State University College of Engineering, Florida State University, Tallahassee, where he is a Research Engineer at the Center for Advanced Power Systems. His research interests are in power distribution system design, industrial power systems, grounding issues, transformers, and the analysis of power quality problems.

M. Sloderbeck (M'88) received his M.S. in computer science from the Florida State University in 1990. He is currently employed at the Center for Advanced Power Systems at Florida State University, where he works on hardware-in-the-loop simulations for electric-ship systems.