An Agent-Based Test Bed for the Integrated Study of Retail and Wholesale Power System Operations*

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ABSTRACT

Our research team is developing an agent-based test bed for the integrated study of retail and wholesale power markets operating over transmission and distribution networks with smart-grid functionality. The test bed will seam together two existing test beds, the AMES Wholesale Power Market Test Bed developed by a group of researchers at Iowa State University and the GridLAB-D electric energy distribution platform developed by the U.S. Department of Energy at Pacific Northwest National Laboratory. This paper provides a brief overview of this challenging project.

Categories and Subject Descriptors

J.2 [**Physical Sciences and Engineering**]: Miscellaneous

General Terms

Experimentation, Performance

Keywords

Restructured power systems, smart grid functionality, agent-based test bed

1. INTRODUCTION

Modern power systems are extraordinarily complex, involving trade networks operating over physical transmission networks at both the wholesale and retail customer levels. Fortunately, spectacular advances in computational power are increasing our ability to study the performance of such systems, taking into account both the power engineer's concern with network reliability and the economist's concern with market efficiency.

One such advance is *agent-based modeling (ABM)*, the representation and study of interactive processes as dynamic systems of interacting agents. Based on object-oriented programming concepts, ABM is a "culture dish" modeling approach that can accommodate a variety of real-world structural conditions, institutional constraints, and behavioral modes with relative ease. Starting from initial conditions specified by the modeler, all subsequent system events are driven solely by agent interactions. Those interactions are determined dynamically in run-time by the internal structures, informational states, beliefs, motivations, and data-processing methods of cognitive agents as channeled and constrained by their external environments.

This paper briefly summarizes an ongoing project involving the integrated study of retail and wholesale power system operation with smart-grid functionality. This project is innovative in three key regards. First, the project team has extensive professional expertise in power engineering, economics, and ABM test bed development. Second, each team member is committed to the goal of transforming the study of power system operations through the development of open-source, extensible, micro-validated ABM test beds. Third, to our knowledge, no prior research has focused on enabling the open-source pre-testing of smart grid functionality for integrated retail/wholesale power system operations through controlled ABM test-bed experiments.

2. PROJECT DESCRIPTION

Retail and wholesale power market operations are intrinsically interdependent. Moreover, these market operations are constrained by transmission and distribution networks supporting underlying power flows. Power systems thus entail complicated dynamic couplings of market and physical system operations [13].

As explained at greater length in [1], the main goal of our project is to develop an agent-based test bed that permits the comprehensive study of power systems from both economic and engineering points of view. Our particular focus is the integrated study of retail and wholesale power markets operating over transmission and distribution grids with "smart-grid functionality."

By *smart-grid functionality* we mean service-oriented grid enhancements permitting more responsiveness to retail customer needs and preferences. An example of such an enhancement would be the installation of residential meters that can be read automatically and that support two-way communication between retail consumers and their suppliers, thus permitting a flexible array of contracts ranging from flat-rate to real-time pricing.

The specific context for the wholesale power market portion of our test bed is the design recommended in a 2003 White Paper [5] by the U.S. Federal Energy Regulatory Commission (FERC) for common adoption by North American wholesale power markets, referred to below as the *Wholesale Power Market Platform (WPMP)*. As depicted in Fig. 1,

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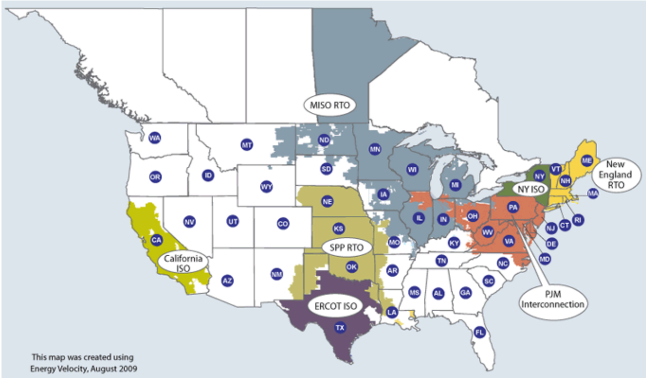

Figure 1: North American energy regions that have adopted FERC's wholesale power market design. Source: www.ferc.gov/industries/electric/indus-act/rto/rto-map.asp

versions of the WPMP design have been implemented (or adopted for implementation) in energy regions encompassing over 50% of U.S. generating capacity. These energy regions include the Midwest (MISO), New England (ISONE), New York (NYISO), the Mid-Atlantic States (PJM), California (CAISO), the Southwest (SPP), and Texas (ERCOT).

The core design element of the WPMP is a two-settlement system to be managed by an *Independent System Operator (ISO)* or *Regional Transmission Organization (RTO)*. Roughly, a *two-settlement system* refers to the combined workings of a day-ahead energy market and a real-time energy market that are separately settled each day by means of *Locational Marginal Pricing (LMP)*. Under LMP, a separate price for power is determined at each point of the transmission grid at which power is injected or withdrawn.

As envisioned in the WPMP, and implemented in practice, the wholesale day-ahead market is structured as a double auction. *Load-Serving Entities (LSEs)* are permitted to submit hourly demand bids consisting of both fixed and price-sensitive hourly demands, and *Generation Companies (GenCos)* are permitted to submit hourly supply offers consisting of price-sensitive hourly supplies.

In actuality, however, the day-ahead market effectively functions as a single-sided seller auction because the bulk of the demand takes the form of fixed hourly loads (i.e., load profiles) implying essentially vertical hourly demand curves. As elaborated in [8], a key difficulty is that downstream retail power markets in the U.S. are still largely regulated with cost-based pricing, so that LSEs in fact have little incentive to submit price-sensitive demand bids.

Even in states that have nominally introduced retail competition, the use of extended default service contracts and long-term wholesale procurement contracts reduces market entry and contributes to the persistence of vertical demand curves in wholesale day-ahead markets. As experimentally shown in [9], under this scenario energy sellers are easily able to learn to implicitly collude on reported supply offers involving higher-than-true marginal costs that result in much higher market operating costs.

These adverse market performance characteristics suggest the need for an integrated restructuring of both retail and wholesale power markets. Rather than use actual systems as test beds, however, we are developing an agent-based test bed that seams together two previously developed agent-based test beds:

- AMES [2], an open-source software platform developed by a team of researchers at Iowa State University for the study of strategic trading in ISO-operated restructured wholesale power markets with congestion managed by LMP.
- GridLAB-D [12], an open-source software platform developed by the U.S. Department of Energy at Pacific Northwest National Laboratory (PNNL) for the study of power distribution systems for end-use customers with power loads arising from a variety of modeled appliances and equipment.

The resulting seamed test bed will permit us to pre-test, through intensive systematic experimentation, how an integrated restructuring of retail and wholesale power markets might best be implemented. Of particular interest will be the systematic experimental exploration of recent "smart grid" proposals for improving supply adequacy and the efficiency of overall power system operations, where "efficiency" refers to the non-wastage of current and future resources.

Specifically, four closely-related research topics will be pursued under this project by means of systematic experiments conducted within this seamed test bed, in combination with analytical and empirical studies. Refs. [3, 10, 4, 6, 7, 11] provide important background materials for these topics.

1. **Reliability and efficiency implications of retail contract choice:** Our first research topic concerns the potential effectiveness of bottom-up *demand response (DR)* initiatives supported by advanced metering or other technologies. What kinds of DR can be supported by existing or envisioned forms of advanced metering? What are the potential impacts of increased price-responsiveness of demand on supply adequacy and the efficiency of market operations? Also, what are the most appropriate designs for pricing contracts and financial risk-management tools under real-time, time-of-use, and flat-rate pricing? The ERCOT (Texas) energy region will serve as a key initial empirical case study for this first research topic, since ERCOT appears to have moved further than any other U.S. energy region towards the integrated restructuring of its retail and wholesale power market operations [7]; cf. Fig. 2.

2. **Aggregated Models of Distributed Energy Resources for System Operators:** Our second research topic will focus on *distributed energy resources (DER)*, including both distributed generation and distributed storage facilities. Examples of consumer-owned DER are depicted in Fig. 3. Our emphasis will be on *photovoltaic (PV)* DER. Key issues to be explored include what kind of modeling methodology is required to capture the stochastic features of aggregated PV power generation that are important for power system operators? What are the imminent dangers of increased PV penetration? Given a smart-grid communications and control framework, what strategies will lead to maximum energy capture from the sun? What are the desirable types, sizes, and sitings of DER from

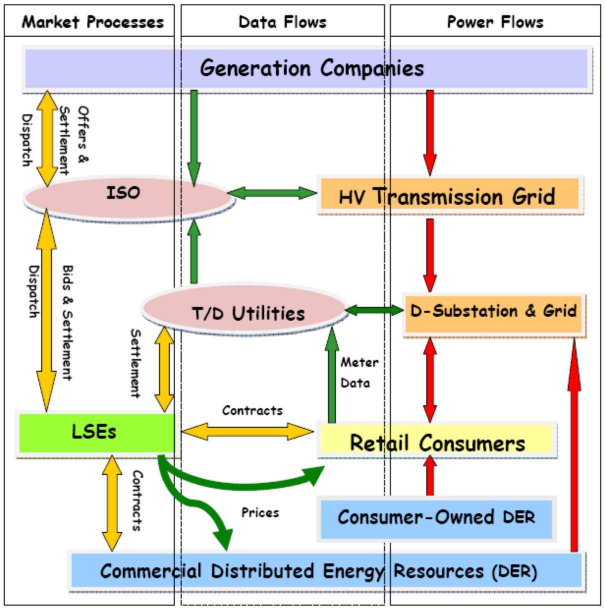

Figure 2: Integrated retail and wholesale market structure in ERCOT

a social efficiency viewpoint? A methodology to analyze, model, and simulate large-scale distributed photovoltaic (PV) installations will be provided. In particular, an aggregate type of model will be developed, suitable for use by system planners and operators. The model will be experimentally validated by way of a real PV panel installation at ISU.

3. **Distribution Networks with Embedded DER:** Our third research topic will focus on distribution grid architecture issues. Will proposed restructurings of the distribution and/or transmission networks to incorporate *microgrid*[1] and other transformations of grid architecture help to improve both supply adequacy and system efficiency? Could market operations be used to control local grids in "islanded" mode (under grid contingencies) with increased penetration of distributed generation? How can the market "sense" a disturbance (i.e., blackout), and re-dispatch itself to supply critical local load based on available generation?

4. **Agent-based Algorithms for Smart Device Implementation:** Our fourth research topic will focus on smart-grid devices and "agent intelligence." What kind of software should be preferably embedded in a smart device? How much computational complexity is required for implementation, and how does it affect cost? What learning algorithm(s) should the agents use? Do some algorithms outperform others, and in what ways? Which ones benefit the users more?

A schematic depiction of the intended co-simulation of the seamed AMES/GridLAB-D test bed is provided in Fig. 4.

[1]By a *microgrid* we mean an integrated electrical energy system composed of interconnected energy sinks and sources that can operate in parallel with the distribution grid or in an intentional island mode.

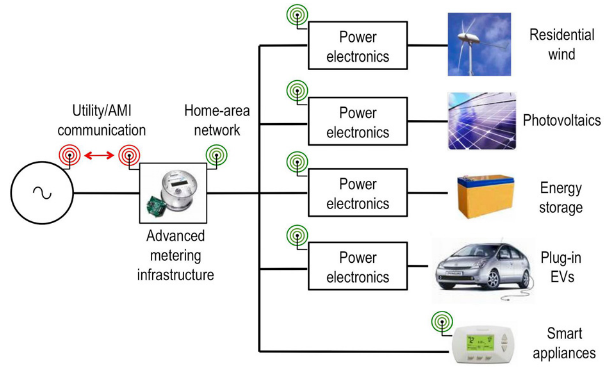

Figure 3: Consumer-owned distributed energy resource possibilities.

The AMES test bed simulates *generation companies (GenCos)*, *load-serving entities (LSEs)*, and an *Independent System Operator (ISO)* engaging in a wholesale power market operating over a high-voltage transmission network. The GridLAB-D test bed simulates a *transmission and distribution utility (TDU)* managing a lower-voltage distribution network servicing a region of retail customers. Seamed together, the resulting integrated test bed will permit a more comprehensive examination of the consequences, both intended and unintended, of various smart grid initiatives.

To implement the seaming depicted in Fig. 4, we are starting with the development of a relatively small proof-of-concept model in which AMES is seamed with a retail module supported by GridLAB-D at one of the AMES load buses. The retail module consists of a distribution network linking a collection of retail customers and DER (including PV). After thorough testing, other AMES load buses will be similarly extended with retail modules.

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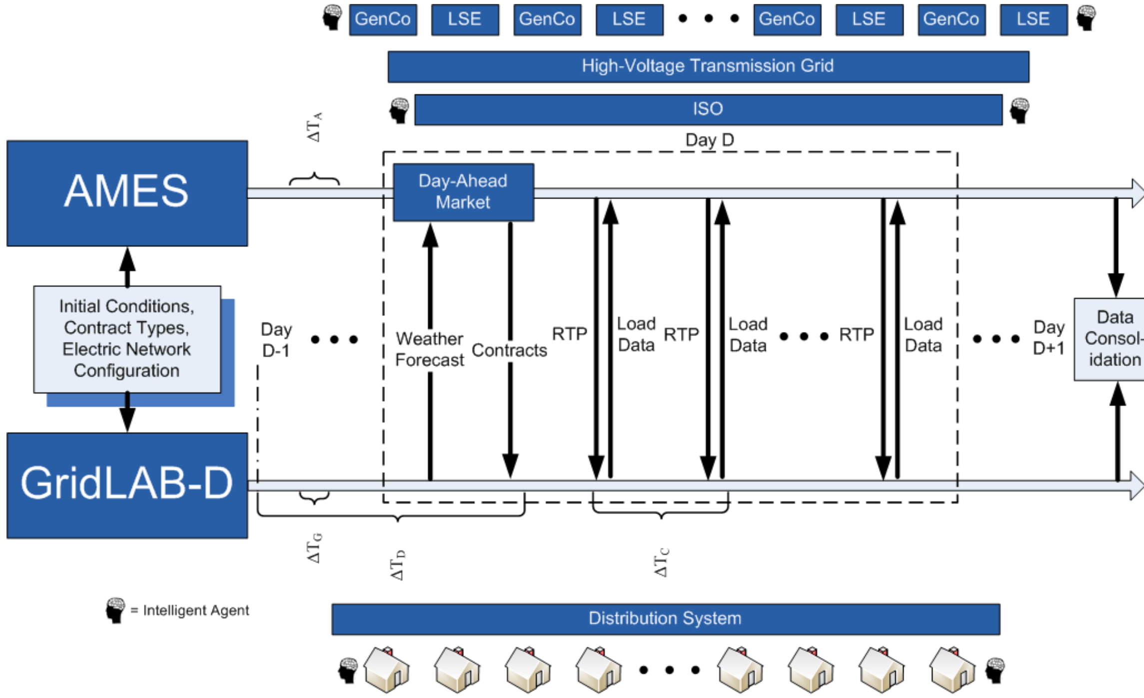

Figure 4: Seaming AMES with GridLAB-D: Co-simulation software data exchange

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