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Testing the Reliability of FERC's Wholesale Power Market Platform: An Agent-Based Computational Economics Approach

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Abstract: In April 2003 the U.S. Federal Energy Regulatory Commission proposed the Wholesale Power Market Platform (WPMP) for common adoption by U.S. wholesale power markets. The WPMP is a complicated market design encompassing real-time, day-ahead, ancillary, and financial transmission rights markets. Variants of the WPMP have been adopted in various parts of the U.S. (e.g., New England), but other regions (e.g., the Midwest) have resisted adoption on the grounds that the reliability of the design has not been sufficiently tested or demonstrated. This study reports on an ongoing collaborative project with the Los Alamos National Laboratory to develop an agent-based computational framework for testing the economic reliability of the WPMP. The key issue addressed is the extent to which the WPMP is capable of sustaining efficient, orderly, and fair market outcomes over time despite attempts by market participants to gain advantage through strategic pricing, capacity withholding, and/or induced transmission congestion.

1. Introduction

In recent years a whole new field has blossomed within economics, called *mechanism design*, in which the institutional rules governing trading are treated as variables subject to optimization. Indeed, a new journal (*Review of Economic Design*) has been established that is entirely devoted to this field. To date, however, much of this literature has focused on static mechanisms designed for essentially single trading periods in which sequential communication among participants is not permitted. The strategic possibilities open to the participants have thus been severely constrained.

In contrast, restructured wholesale power markets provide substantial scope for strategic behavior. These markets typically involve repeated price and quantity offers for the sale of large amounts of bulk electricity by small numbers of electricity generators, some with relatively large market shares. The generators can use their offers as signaling or punishment devices without the need for explicit communication. Moreover, they can create profitable price spikes either by withholding capacity from the market or by deliberately inducing congestion on transmission grid lines to prevent the import of power from outside their region. The recent meltdown in the California electricity market [Moore and Kiesling (2001), Borenstein (2002)] has forcefully brought home the dangers posed by these possibilities. Fears engendered by this disaster have led other regions of the country (e.g., the Midwest) to delay or even side-line their restructuring efforts.

For wholesale power markets, then, it is particularly important to determine *in advance of implementation* the extent to which market designs permit or even encourage socially undesirable market power and market efficiency outcomes. These outcomes could come about in two distinct ways: directly through the design of the market protocols; or indirectly through the strategic behavior permitted or even encouraged by these protocols. The exercise of strategic behavior is further complicated in these markets by the potential for transmission line congestion (either induced or inadvertent) and by the need to balance supplies and demands in real time. Wholesale power markets are thus extremely complex processes, rendering difficult the application of traditional analytical and statistical tools.

In June 2002, the U.S. Federal Energy Regulatory Commission (FERC) issued a Notice of Proposed Rulemaking (NOPR) in which it proposed a standard market design for common adoption by U.S. wholesale power markets [FERC (2002)]. After an extended period of discussion and criticism, FERC issued a White Paper in April 2003 [FERC (2003)] which put forward an amended wholesale power market design, termed the Wholesale Power Market Platform (WPMP).

The WPMP is a complicated market design. It encompasses real-time, day-ahead, ancillary, and financial transmission rights markets, all to be overseen either by a Regional Transmission Operator (RTO) or by an Independent System Operator (ISO). In its White Paper, FERC discusses four primary objectives for this market design. First, it should establish a customer-based competitive wholesale power market providing reliable service. Second, it should ensure fair and open access to the transmission grid at reasonable prices. Third, it should induce good price signals to encourage appropriate investment in new generation and new transmission. Fourth, it should provide effective procedures for market power oversight and mitigation.

The WPMP design has been adopted or submitted for adoption by wholesale power market operators in New England (ISO-NE), in New York (NY-ISO), in the Mid-Atlantic States (PJM-ISO), and in California (CAISO). On the other hand, the Midwest (MISO) filed to adopt a similar plan in July 2003 and then withdrew this filing in October 2003 on the grounds that the reliability of the WPMP has not been sufficiently demonstrated or tested. Strong opposition to the WPMP has also surfaced in other regions of the U.S. (e.g., states in the Southeast and the Northwest.).

This study reports on an ongoing collaborative project with the Los Alamos National Laboratory to test the economic reliability of the WPMP. The primary issue to be addressed is the extent to which the WPMP design reliably results in high market efficiency and socially acceptable market power outcomes despite attempts by market participants to gain market power advantages through strategic pricing, capacity withholding, and/or induced transmission grid congestion.

To carry out this study, we are constructing an agent-based computational economics (ACE) model of a wholesale power market. This ACE model incorporates the salient aspects of the Standard Market Design (SMD), a wholesale power market design implemented by the Independent System Operator in New England (ISO-NE) in March 2003. The SMD is in conformity with the original standard market design proposal announced by FERC in its June 2002 NOPR [FERC (2002)] and is in close conformity with the WPMP, the amended version of this originally proposed design [FERC (2003)]. Training manuals, operation manuals, and weekly reports published by the ISO-NE are being used as guidelines in the construction of this ACE model.

In April 2003, the U.S. Department of Energy published a quantitative assessment of FERC's original standard market design proposal [U.S.DOE (2003)]. This study compares a projected continuation of existing conditions to an alternative case in which seamless U.S.-wide standard market design implementation is assumed. This careful study includes many cautions regarding modeling assumptions introduced for reasons of analytical and statistical tractability (e.g., continual market equilibrium, absence of strategic bidding, demand held constant across tested cases, etc.). The goal of the study was to produce an estimate of the average long-run consumer cost savings to be expected under FERC's standard market design. No attempt was made to assess overall market efficiency or market power impacts, the focus of the current project. In addition, Yang et al. (2003) propose the use of a simulation tool (GridView) for the study of FERC's originally proposed standard market design. The capabilities of the tool are illustrated using PJM case study data from 2002. Again, however, no attempt is made to address market efficiency or market power concerns.

Other than these two studies, we are unaware of any other attempts to provide a systematic overall assessment of FERC's SMD/WPMP proposals, particularly with regard to market efficiency and market power implications. However, ACE electricity modeling for various other purposes is currently being pursued by research groups at a number of different institutions. In addition to the Los Alamos National Laboratory, these institutions include the Argonne National Laboratory, CSIRO-Australia, Helsinki University, Iowa State University, London Business School, and the Pacific Northwest National Laboratory. See Tesfatsion (2004a) for annotated pointers to this work.

Section 2 provides a more careful discussion of ACE modeling and its potential usefulness for wholesale power market design. Section 3 outlines our ACE electricity model, and Section 4 outlines the experimental design for our project. Concluding remarks are given in Section 5.

2. The ACE Approach to Wholesale Power Market Design

Agent-based computational economics (ACE) is the experimental study of economies computationally modeled as evolving systems of autonomous interacting agents with learning capabilities. Extensive resources related to ACE can be accessed on-line; see Tesfatsion (2004b).

The key distinction between ACE modeling and other types of quantitative economic modeling is agent *autonomy*. Agents in ACE models are encapsulated software entities capable of reactivity, social communication, goal-directed learning, and - most important of all - self-activation and self-determinism on the basis of private internal processes. In short, ACE models permit distributed and privatized local control (personhood), not simply distributed local action, in an attempt to better represent and predict the performance of decentralized economic processes with human participants.

ACE modeling is a culture-dish approach to economic analysis. Ideally, the thumbprints of the modeler should not be visible after the initial period.

As in a culture-dish laboratory experiment, the ACE modeler starts by constructing an economic system with an initial population of agents. These agents include both economic agents and agents representing various other physical, social, and environmental phenomena (e.g., generators, load-serving entities, ISO, transmission grid, weather). Each agent is an encapsulated software entity that includes attributes together with methods that act on these attributes. Some of these attributes and methods are designated as publicly accessible to all other agents, some are designated as private and hence not accessible by any other agents, and some are designated as protected from access by all but a specified subset of other agents.

The ACE modeler specifies the initial state of the economic system by specifying the initial attributes and methods of each agent. The initial attributes of any particular agent might include type characteristics (e.g., trader, ISO), structural characteristics (e.g., cost function, operational scope), and initial information about other agents (e.g., locations and addresses). The initial methods might include internalized market protocols (e.g., bidding rules, market power mitigation rules), modes of information acquisition and storage (e.g., communication protocols, data compression methods), learning modes (e.g., reinforcement learning, anticipatory learning), trading rules (e.g., electricity bidding strategies, transmission investment strategies), and rules for changing rules (e.g., learning mode updating, strategy updating). The economic system then evolves over time without further intervention from the modeler. All events that subsequently occur must arise from the historical time-line of agent interactions. No external coordination devices are permitted. In particular, no resort can be made to the off-line determination and imposition of market-clearing prices.

As this brief discussion indicates, ACE modeling offers a number of possible advantages for the quantitative modeling of wholesale power markets. Key market participants can be modeled as cognitive self-activated agents, strategically aware of both competitive and cooperative possibilities with other agents. Moreover, the learning representations used for these agents can be calibrated to empirical data and to human-subject experimental findings. Realistically detailed institutional and structural market features can be incorporated with relative ease into the virtual wholesale power market inhabited by the agents, and agent behaviors and interaction patterns within this market can evolve over time. Consequently, ACE modeling permits the comprehensive reliability testing of a market design in the face of repeated attempts by self-seeking participants to exploit the features of the market design for their own advantage. See Nicolaisen et al. (2001) for a more detailed discussion and demonstration of these points.

3. Our ACE Wholesale Power Market Model

To carry out an economic reliability study of FERC's WPMP, we are developing an ACE Wholesale Power Market (WPM) Model with Java/RePast implementation [RePast (2004)]. This model incorporates the salient aspects of the WPMP as actually implemented by the Independent System Operator in New England (ISO-NE).

Specifically, as indicated in Figure 1, our basic ACE WPM Model includes the following specific ISO-NE aspects taken directly from the ISO-NE Market Operations Manual M-11 [ISO-NE (2003)].

First, the modeled participants include generators, load-serving entities (LSEs), and an Independent System Operator (ISO). Second, the ISO undertakes the daily management of real-time (RT) and day-ahead (DA) markets (a "multi-settlement process") as well as a supply re-offer period. More precisely, the ISO establishes Locational Marginal Prices (LMPs) and financially binding positions in the DA market. Differences from DA cleared quantities are settled in the RT market at real-time LMPs calculated using security-constrained economic dispatch. Third, transmission grid congestion is managed via the inclusion of congestion components in LMPs. Fourth, throughout each operating day, the ISO undertakes periodic reserve assessments to ensure adequate supply. Fifth, an AC transmission grid subject to realistically modeled physical constraints (e.g., loop flow effects) supports these various market processes.

The ACE WPM Model is fully modular and extensible, hence capable of handling realistically dimensioned transmission grids. Initially, however, we are focusing on a particular small-scale demonstration model with a 5-bus transmission grid. A slice-in-time depiction of the particular 5-bus transmission grid to be used in our demonstration model, due to John Lally (2002), is depicted in Figure 2. As detailed in the training manuals and guides published by the ISO-NE and the Pennsylvania-New Jersey-Maryland Independent System Operator (PJM-ISO), the Lally depiction of a 5-bus transmission grid is now routinely used by these ISOs as a training model for the participants in their regional electricity markets.

A UML (Unified Modeling Language) visualization of the class hierarchy underlying the ACE WPM Model is depicted in Figure 3. As indicated in this figure, our plan is to incorporate a bilateral market and a point-to-point financial transmission rights market into the ACE WPM Model at a later stage of development.

The activities of the ISO during a typical operating day in the ACE WPM Model are depicted in Figure 4. Finally, the dynamic activity flow in the ACE WPM Model is depicted in Figure 5.

4. Experimental Design

The key issue to be experimentally addressed in this project is the economic reliability of FERC's WPMP design. Specifically, to what extent does the WPMP design result in high market efficiency and socially acceptable market power outcomes despite attempts by market participants to gain market power advantages through strategic pricing, capacity withholding, and/or induced transmission grid congestion?

Market efficiency will be defined conventionally to mean the ratio of actual total profits earned to the maximum possible total profits that could be earned under competitive conditions. Market power for sellers (or buyers) will be defined conventionally to mean the difference between the actual total profits earned by sellers (or buyers) and the maximum possible total profits this type of trader could have earned under competitive conditions. To distinguish between market power arising from protocols and microstructural aspects and market power arising through strategic learning, the conventional measure of market power will be decomposed into structural and strategic components. Following Nicolaisen et al. (2001), *structural* market power is defined to be the market power that would be attained by sellers and buyers in the absence of opportunistic asks and bids, i.e., under the presumption that sellers and buyers ask and bid their true reservation values. In contrast, *strategic* market power is defined to be the difference between the experimentally observed levels of market power for sellers and buyers and their analytically derivable structural market power levels.

Our ACE WPM Model is well suited for investigating how systematic changes in structural and behavioral market aspects might impact market efficiency and market power outcomes in both the short and long run when the market is operating under the WPMP protocols. Our initial experiments will specifically focus on three treatment factors, identified below as TF-1, TF-2, and TF-3.

TF-1. Potential Dynamic Error Accumulation Using DC vs. AC Approximations for LMP calculations

Conjecture:

Commonly used DC approximations that appear to provide satisfactory approximations in static single-period LMP calculations could lead to serious error accumulation over time in the type of dynamic LMP calculations that have been implemented by the ISO-NE and that are called for by FERC's proposed WPMP design.

Experimental Design Treatment Factor:

Compare ACE WPM Model performance under DC vs. AC implementations for the optimal power flow calculations underlying the calculation of LMPs, given that the true underlying transmission grid is AC and non-radial (hence subject to loop-flow effects).

TF-2. Passive Demand versus Active Demand-Side Bidding

Conjecture:

Active demand-side bidding in the DA electricity market results in higher market efficiency and a lower potential for the exercise of market power.

Experimental Design Treatment Factor:

Compare ACE WPM Model performance under two models of demand-side behavior:

(a) LSE demand is represented by given loads at designated load nodes and takes the form of given demand schedules with possibly differing elasticities (standard assumption in the electricity literature);
(b) LSEs at designated load nodes actively bid for electricity in the DA market for electricity in each trading period (recommended by the WPMP, and the actual situation in ISO-NE).

TF-3. The Effects of Trader Learning Representations

Conjecture:

Trader learning representations can significantly affect market performance. Market protocols should be designed to perform robustly under a wide range of possible learning behaviors.

Experimental Design Treatment Factor:

Compare ACE WPM Model performance under different trader learning representations:

(a) Simple derivative-follower reinforcement learning;
(b) Stochastic reinforcement learning (e.g., Roth-Erev);
(c) Genetic algorithm individual learning;
(d) Genetic algorithm individual and social learning.

Initial experiments with these three treatment factors will be conducted using the small-scale 5-bus AC transmission grid depicted in Figure 1. Subsequent experiments will be conducted using an AC transmission grid scaled up to more realistic dimensions (e.g., the ISO-NE 900+-bus transmission grid).

5. Concluding Remarks

The growing desire to move to market-based designs for the wholesale trading of electricity has prompted a surge in engineering research stressing security, technical implementation, and fraud protection concerns. Following the California restructuring disaster in summer 2000, however, it is now generally recognized that economic reliability concerns regarding market power and market efficiency must be considered on an equal par with these engineering concerns.

The wide range of computational experiments to be undertaken in this project should help to demonstrate the feasibility of undertaking comprehensive studies of electricity market designs that take into account both economic and engineering concerns. Using an ACE approach, researchers can study the possible impacts of strategic behavior on market efficiency and market power in electricity market models that incorporate realistic grid configurations, loop flow effects, and unforeseen power outages due to equipment failures. In addition, the ability to distinguish carefully between structural and strategic market power effects should have immediate practical ramifications for market design far beyond the directly envisioned application to wholesale power markets. This ability should be particularly valuable for public regulatory bodies responsible for ensuring that market processes remain orderly, fair, and efficient. Last but not least, ACE frameworks permit rigorous systematic testing of electricity market designs *prior* to their actual implementation.

Acknowledgement

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❖ **Traders**
- Sellers and buyers
- Follow market rules
- Learning abilities

❖ **ISO Roles**
- Assessment of system reliability
- Optimal power flow calculation
- Settlement procedures

❖ **Multi-Settlement Process**
- Day-ahead electricity market
- Real-time electricity market
- Supply re-offer period

❖ **AC Transmission Grid**
- Congestion managed via LMP
- 5-bus demo model (scalable to more complex grid)

Figure 1. The ACE Wholesale Power Market Model

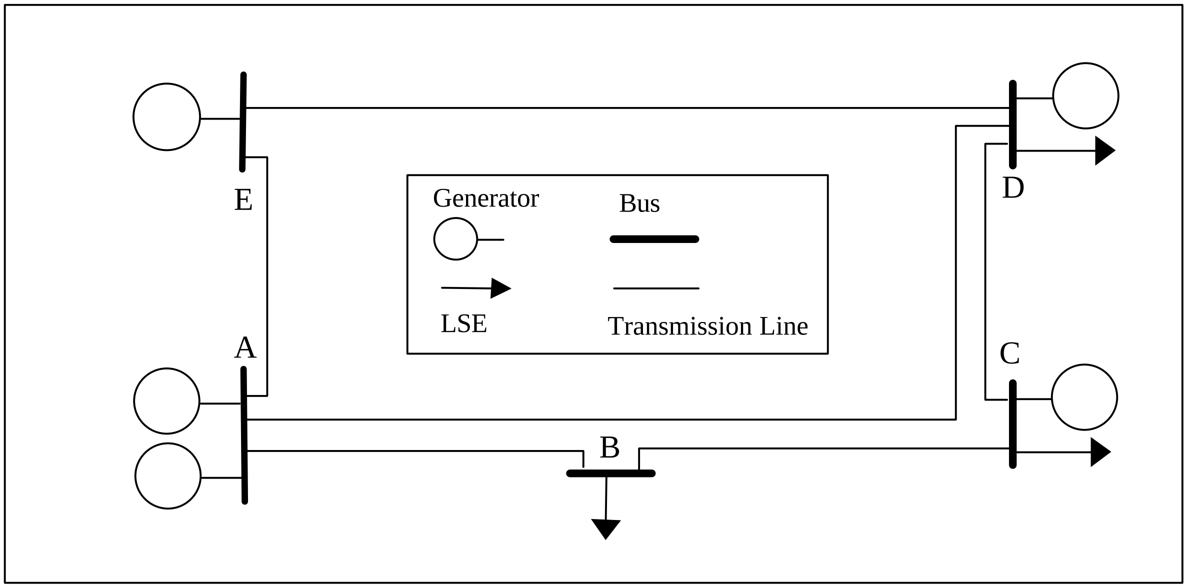

Figure 2. 5-Bus AC Transmission Grid (Initial Demo Model)

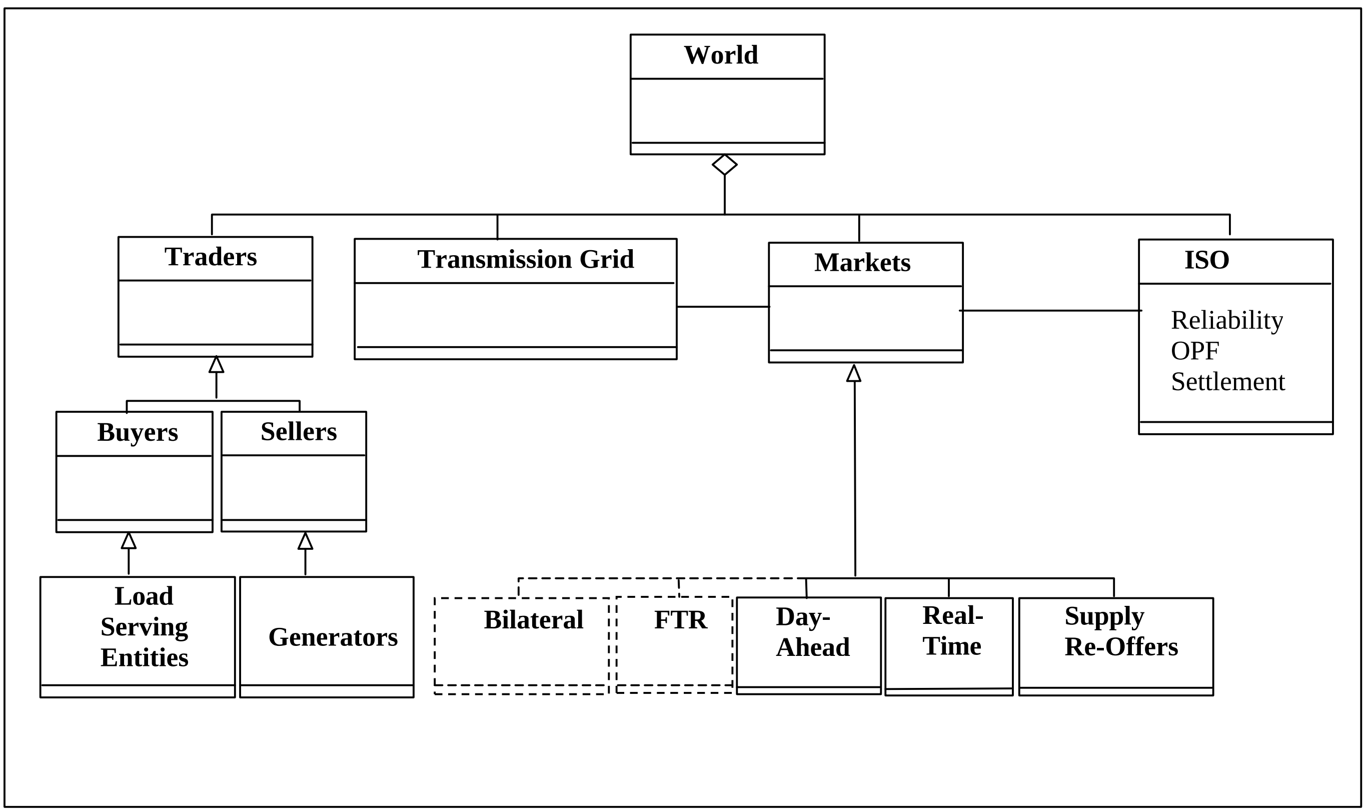

Figure 3. Class Hierarchy for the ACE Wholesale Power Market Model

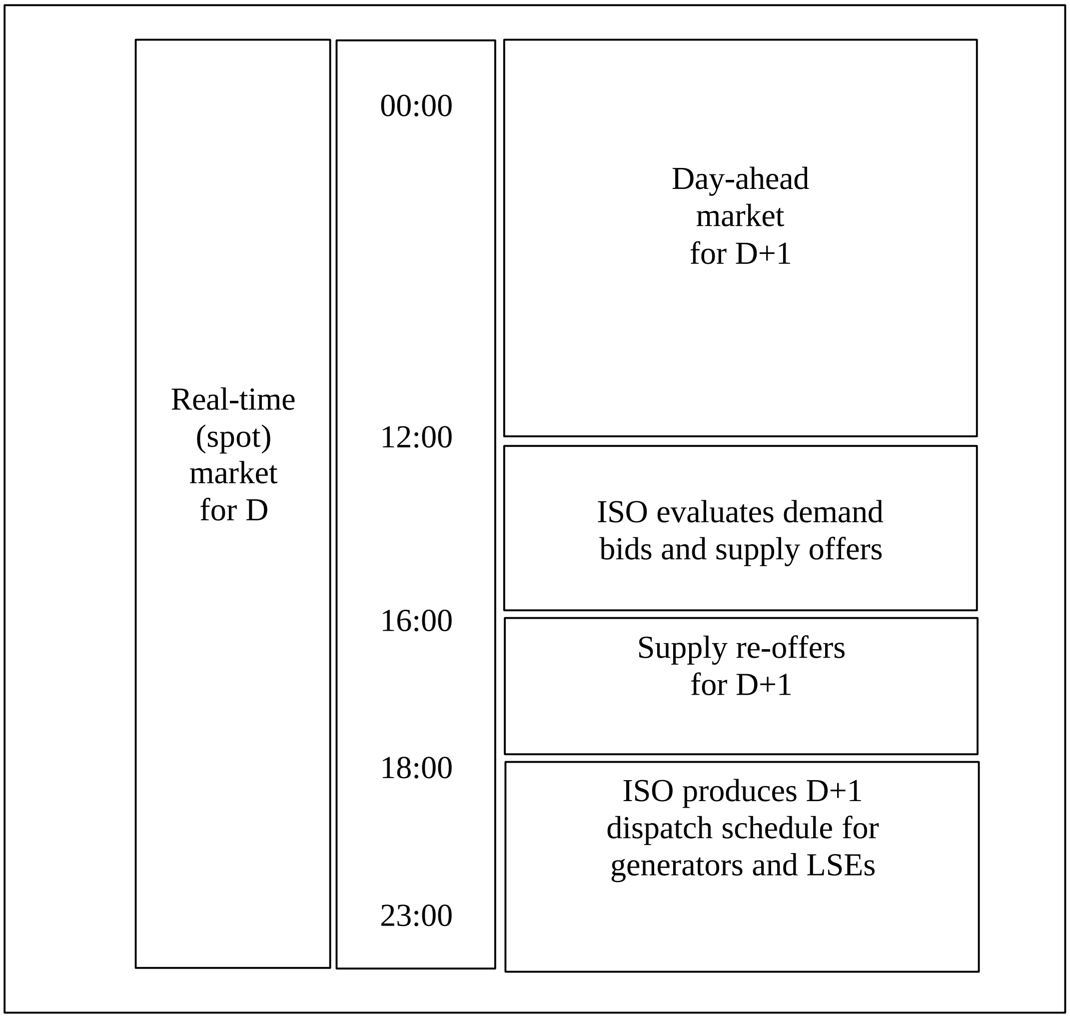

Figure 4. ISO Market Operation (Day D) in the ACE Wholesale Power Market Model

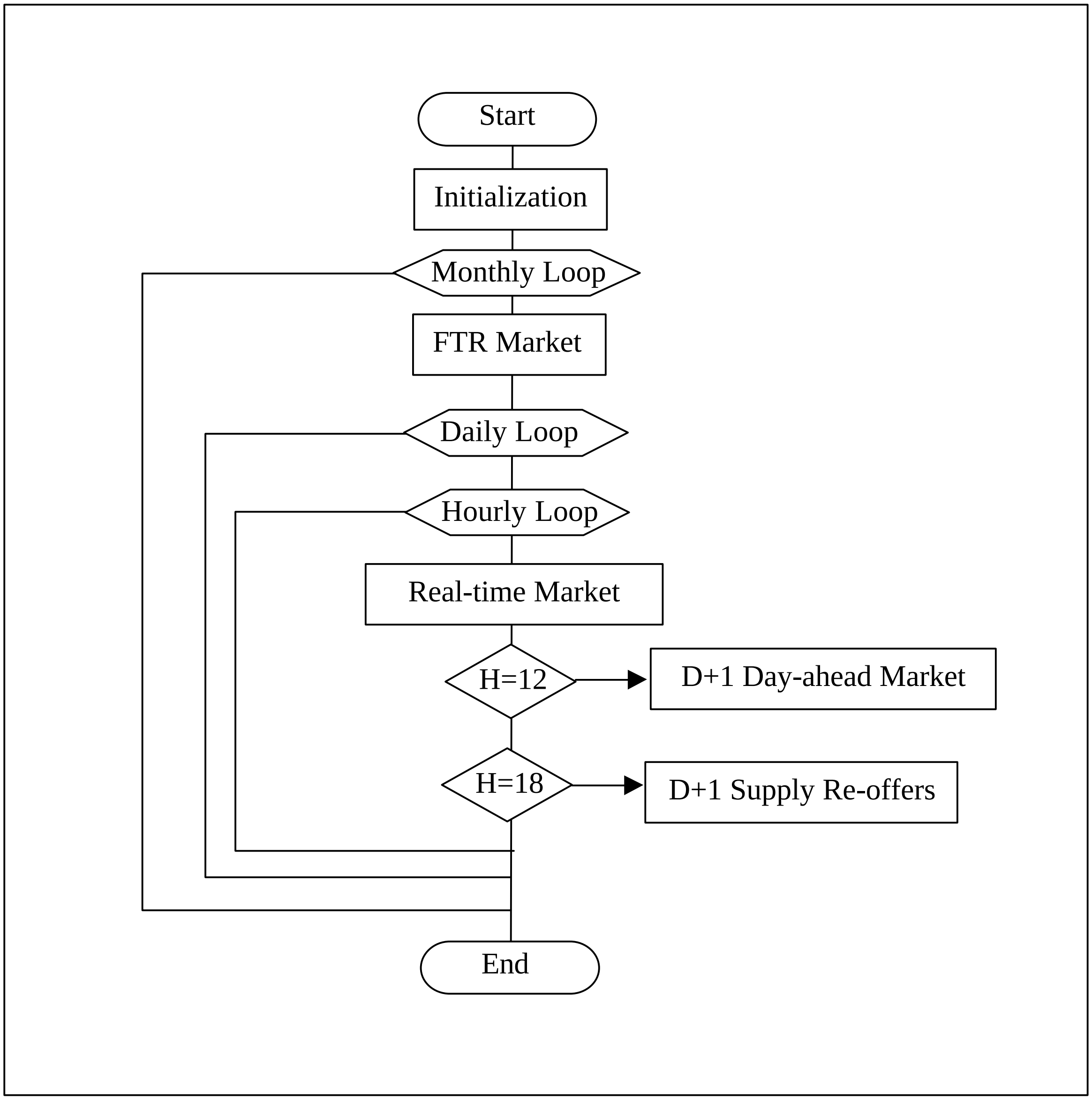

Figure 5: Dynamic Activity Flow in the ACE Wholesale Power Market Model