SIMULATING THE BEHAVIOR OF ELECTRICITY MARKETS WITH AN AGENT-BASED METHODOLOGY: THE ELECTRIC MARKET COMPLEX ADAPTIVE SYSTEMS (EMCAS) MODEL*

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ABSTRACT

Electricity markets that have pioneered the transition from a regulated monopolistic system to a decentralized open market have faced many challenges. As markets evolve, there is a need for new modeling approaches that simulate how electric power markets could evolve over time and how participants in these markets may act and react to the changing economic, financial, and regulatory environment in which they operate. To gain insights into the decentralized electric marketplace, Argonne National Laboratory developed the Electricity Market Complex Adaptive Systems (EMCAS) model. The EMCAS model is an electronic laboratory that probes the possible effects of market rules and conditions by simulating the strategic behavior of participants. It uses agent-based modeling techniques that represent market participants who operate with their own objectives and apply their own decision rules. The market participants with decision-making capabilities that are represented in EMCAS, called *agents*, include generation companies, demand aggregators, consumers, and independent system operators. The success of an agent is a function not only of its own decisions and actions, but also of the decisions and actions of other market participants. Since minimal amounts of local information are shared among participants, agent decisions in EMCAS are made without either perfect knowledge or certainty. Using the complex adaptive systems approach, agents in EMCAS learn from their previous experiences and modify their behavior. That is, as the simulation progresses, agents adapt their strategies on the basis of the success or failure of their previous actions. This paper presents an overview of the EMCAS model structure.

INTRODUCTION

Electric utility systems around the world are changing from regulated, vertically integrated monopoly structures to open markets intended to promote competition among suppliers and provide consumers with a choice. The unbundling of the generation, transmission, and distribution functions that is part of this restructuring creates opportunities for many new participants, or agents, to enter the market. Restructuring can introduce new types of business models, including power marketers and load aggregators. Each market participant has its own, unique business strategy, risk preference, and decision model. Decentralized decision making is one of the key features of the new deregulated markets. The goal is a fully functioning market with a sufficient number of participants to generate competition. Economic theory holds that competition will lead to increased economic efficiency, with the presumption that this efficiency will result in higher quality services and products at lower retail prices.

Many of the modeling tools for power systems analysis that were developed over the last two decades are based on the implicit assumption of a centralized decision-making process. Although these tools are very detailed and complex and will continue to provide many useful insights into power systems operation (Conzelmann et al., 1999; Koritarov et al., 1999; Harza, 2001), they are limited in

* Work supported by the U.S. Department of Energy, Assistant Secretary for Policy, Planning, and Program Evaluation, under Contract W-31-109-Eng-38.

their ability to adequately analyze the market forces prevalent in the new markets. Driven by these observations, Argonne National Laboratory's Center for Energy, Environmental, and Economic Systems Analysis (CEEESA) has started to develop a new deregulated market analysis tool, the Electricity Market Complex Adaptive Systems (EMCAS) model. Unlike conventional electric systems models, the EMCAS agent-based modeling techniques do not postulate a single decision maker with a single objective for the entire system. Rather, agents are allowed to establish their own objectives and apply their own decision rules. The complex adaptive systems (CAS) modeling approach simulates agents that learn from their previous experiences and change their behavior when future opportunities arise. That is, as the simulation progresses, agents can adapt their strategies on the basis of the success or failure of previous efforts. Genetic algorithms are used to provide a learning capability for certain agents. With its agent-based approach, EMCAS is specifically designed to analyze multiagent markets and allow testing of regulatory structures before they are applied to real systems; that is, EMCAS can be used as an electronic laboratory or "e-laboratory."

This paper first provides some brief background information on agent-based modeling. It then introduces EMCAS as a market simulation tool for the restructured electric markets. The paper describes the general methodology, including a description of market zones, locational market pricing, congestion charges, bilateral contracts, and pool and ancillary services markets, and then discusses agent risk preferences and the bid/market price expectations for individual agent learning. The paper closes with a discussion of current applications of EMCAS.

OVERVIEW OF THE AGENT-BASED MODELING CONCEPT

The complex interactions and interdependencies among electricity market participants are much like those studied in game theory (Picker, 1997). However, the strategies used by many electricity participants are often too complex to be conveniently modeled by standard game theoretic techniques. In particular, the ability of market participants to repeatedly probe markets and rapidly adapt their strategies adds additional complexity.

Computational social science offers appealing extensions to traditional game theory. Computational social science involves the use of agent-based models (ABMs) to study complex social systems (Epstein and Axtell, 1996). An ABM consists of a set of agents and a framework for simulating their decisions and interactions. ABMs are related to a variety of other simulation techniques, including discrete event simulation and distributed artificial intelligence or multiagent systems (Law and Kelton, 2000; Pritsker, 1986). Although many traits are shared, ABMs are differentiated from these approaches by their focus on achieving "clarity through simplicity," as opposed to deprecating "simplicity in favor of inferential and communicative depth and verisimilitude" (Sallach and Macal, 2001).

An agent is a software representation of a decision-making unit. Agents are self-directed objects with specific traits. Agents typically exhibit bounded rationality, meaning that they make decisions by using limited internal decision rules that depend only on imperfect local information. Emergent behavior is a key feature of ABMs. Emergent behavior occurs when the behavior of a system is more complicated than the simple sum of the behavior of its components (Bonabeau et al., 1999).

A wide variety of ABM implementation approaches exist. Live simulation where people play the role of individual agents is an approach that has been used successfully by economists studying complex market behavior. General-purpose tools such as spreadsheets, mathematics packages, or traditional programming languages can also be used. However, special-purpose tools such as Swarm, the Recursive Agent Simulation Toolkit, StarLogo, and Ascape are among the most widely used options (Burkhart et al., 2000; Collier and Sallach, 2001).

Several electricity market ABMs have been constructed, including those created by Bower and Bunn (2000), Petrov and Sheblé (2000), and North (2000a, 2000b, 2001). These models have hinted at the potential of ABMs to act as e-laboratories suitable for repeated experimentation under controlled conditions.

THE EMCAS CONCEPT

EMCAS is an electricity market model related to several earlier models (VanKuiken et al., 1994; Veselka et al., 1994). The underlying structure of EMCAS is that of a time continuum ranging from hours to decades. Modeling over this range of time scales is necessary to understand the complex operation of electricity marketplaces.

EMCAS includes a large number of different agents to model the full range of time scales (see Figure 1), including generation companies (GenCos), transmission companies (TransCos), distribution companies (DisCos), independent system operators (ISOs) or regional transmission organizations (RTOs), consumers, and regulators. The focus of agent rules in EMCAS varies to match the time continuum. Over longer time scales, human economic decisions dominate. Over shorter time scales, physical laws dominate. Many EMCAS agents are relatively complex or "thick," compared with typical agents. EMCAS agents are highly specialized to perform diverse tasks ranging from acting as generation companies to modeling transmission lines. To support specialization, EMCAS agents include

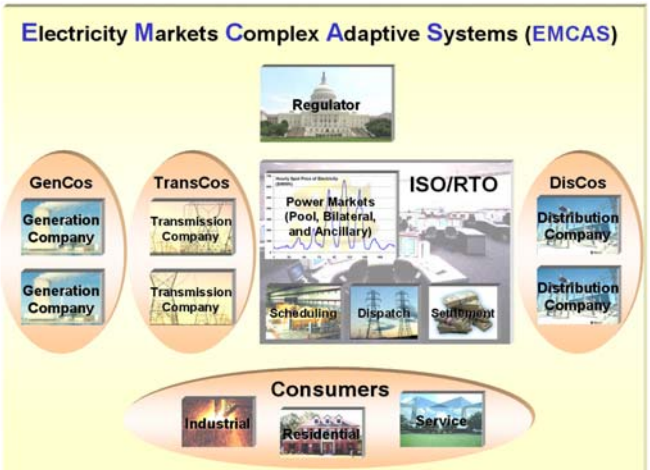

Figure 1: EMCAS Structure and Agents

large numbers of highly specific rules. EMCAS agent strategies are highly programmable. Users can easily define new strategies to be used for EMCAS agents and then examine the marketplace consequences of these strategies.

EMCAS MARKETS

The EMCAS modeling system operates at six time scales or decision levels that include an hourly dispatch as well as several forward markets, such as day-ahead, week-ahead, month-ahead, year-ahead, and multiyear (Figure 2). At each decision level, generation company agents make decisions regarding the operation of the generating resources they manage and formulate marketing strategies. Dependent on user-defined rules, different types of markets are available to players at each time scale. The types of markets available and the specific rules under which each operates will influence decisions made by market participants.

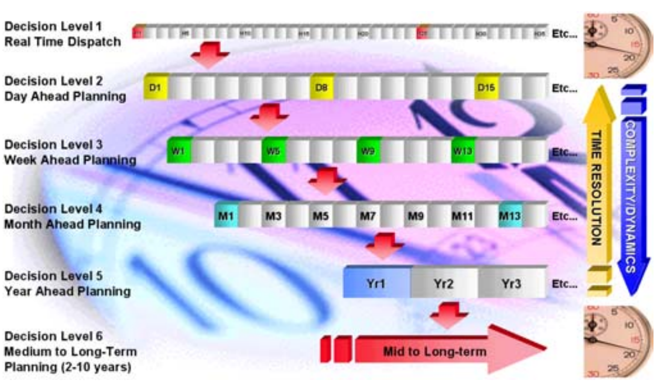

Figure 2: EMCAS Time Scales

Currently, EMCAS simulates three types of markets that include bilateral contract, pool, and ancillary services (Figure 3). Generally, bilateral contracts are agreements between a single generation company agent and a single demand agent. These contracts have time scales that range from hours to several years. In the pool market, EMCAS agents submit buy and sell bids to a power exchange or another entity that acts as a central clearinghouse. In some markets this function is conducted by the ISO. On the basis of bid prices, transmission constraints, and energy security considerations, the clearinghouse determines which bids are accepted and rejected and calculates the price of electricity. Pool markets are typically conducted at the day-ahead and hour-ahead time scales. Ancillary service markets, such as spinning and non-spinning reserves, automatic generation control (AGC), and replacement reserves, maintain electric quality and reliability. The ancillary services markets are usually conducted at the day-ahead and hour-ahead time scales in most markets.

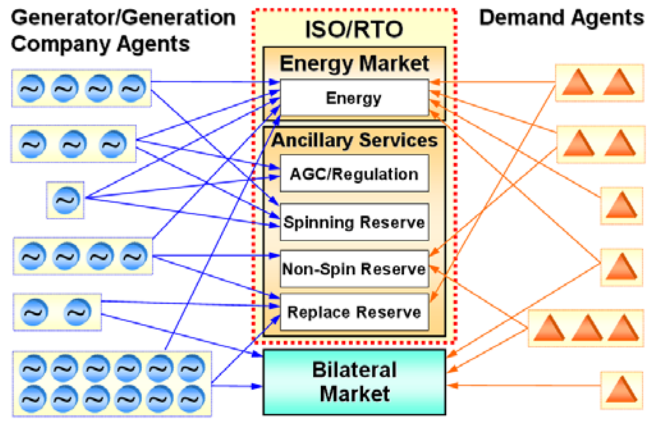

Figure 3: EMCAS Markets

EMCAS BILATERAL CONTRACT MARKETS

EMCAS simulates bilateral contracts among generation company and demand agents through a series of requests for proposals (RFPs) that are initiated by the demand agents. A demand agent formulates an RFP for capacity and energy on the basis of the anticipated needs of its customers and its risk tolerance for exposure to pool market price volatility. If a demand agent chooses to participate in the bilateral market, one or more RFPs are sent to select generation company agents. As shown in Figure 4, generation company agents analyze RFPs, formulate responses, and send these responses to demand company agents. The response includes prices for all or some portion of the requested capacity and energy. Demand agents evaluate the responses that they receive and either accept or reject the offers. On the basis of the bilateral agreements forged among market players and lessons learned from previous bid rounds, both demand and generation company agents revise their marketing strategies for the next round. The user controls the number of bidding rounds simulated by EMCAS.

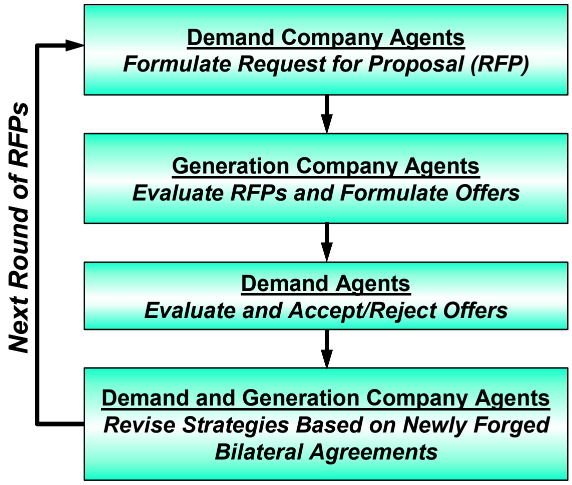

Figure 4: Sequence of Events for Modeling Bilateral Agreements

As described in more detail below, an agent's behavior is a function of its risk preference. For example, a generation company agent that is risk-averse may choose to forgo some potential profits on the pool market and sell its capability and production via bilateral agreements with a guaranteed stream of income. On the other hand, a purely profit-maximizing generation company may choose to enter solely into pool and ancillary services markets despite high market price volatility if it foresees that it can potentially make more money.

In EMCAS, demand agents formulate two types of RFPs: energy deliveries that are constant over all hours of the contract term and energy deliveries that vary over time. The first RFP type, referred to as a base-load contract, is typically less expensive because a significant portion of the energy is delivered during off-peak load periods. The demand agent's request is based on projections of its customers' future energy requirements. These projections are made independently by each demand agent and are subject to uncertainty. This uncertainty stems from such factors as weather forecast errors, inaccurate projections of the type and number of future customers, and unpredictable variability in customers' electricity consumption patterns. To reflect this uncertainty, demand agents make several forecasts that span a reasonable range of future customer demands. Each possible future is assigned a probability level such that the sum of the probability of all futures equals 1.0. If the demand agent's corporate utility is heavily weighted toward ensuring that all of its customers' demands are reliably satisfied, the agent tends to forecast relatively high demand levels; for example, demands that are only exceeded 5 percent of the time. Decisions regarding the formulation of an RFP made by demand agents also reflect anticipated future prices of short-term markets and associated volatility.

Generation company responses to an RFP are based largely on projected pool market and bilateral contract prices (i.e., a demand agent's willingness to pay). These price projections are made independently by each generation company agent and are a function of historical information that acts as a collection of past experiences. A generation company then weighs the costs and benefits (i.e., net profits) of entering into bilateral contracts versus selling its energy production on the pool and ancillary services markets. Anticipated net profits are based on projected prices in each of the markets and the costs associated with power production. EMCAS production costs are a function of variable operating and maintenance (O&M) costs, fuel costs, heat rate curves that are represented as fuel consumption for blocks of production, and unit startup and shutdown costs. In addition to considering net profits, the generation company agent factors other components into its final pricing response to an RFP. These factors, such as risk of rejection and power plant costs, are reflected in the corporate utility and influence the demand agent's RFP price response. Therefore, price responses may be either higher or lower than the generation company's anticipated willingness to pay.

A generation company's power plant capabilities and previous commitments may limit its ability to respond to all RFPs; that is, it cannot bid to sell more power plant capability than it can deliver. Power plant capability limitations may also require that the generation company offers to deliver energy that is less than the amount specified in the RFP. Therefore, generation company agents must prioritize RFPs and respond to those RFPs that maximize their corporate utility.

A demand agent will accept offers (if any) that it determines will maximize its corporate utility. This determination is based on an analysis of the offers it receives and projected pool market prices. Trade-offs among prices and other corporate goals must be made. Differences in corporate objectives among demand agents can result in very different behaviors by agents that have similar customer profiles. For example, a demand agent that has a low tolerance for price variability may decide to serve most or all of its projected loads via long-term firm contracts. Another demand agent in a similar situation may decide to buy power on the pool market if it anticipates that prices will be lower.

In EMCAS, an agent learns about market behavior and the actions of other agents. This learning process is based on an exploration process. Agents explore various marketing and bidding strategies and observe the results of its actions. Once a strategy is found that performs well, it is exercised and fine-tuned as subtle changes occur in the marketplace. When more dramatic market changes take place and a strategy begins to fail, an agent more frequently explores new strategies in an attempt to adapt to the dynamic and evolving supply and demand forces in the marketplace. Even when a strategy continues to perform well, agents periodically explore and evaluate other strategies in their search for one that performs better. Through this process, agents engage in a price discovery process and learn how they may potentially influence the market through their own actions to increase their corporate utility.

EMCAS POOL MARKETS

In the pool market, EMCAS agents submit buy and sell bids to a power exchange or other entity that acts as a central clearinghouse. In some markets, this clearinghouse function is conducted by the ISO. Pool markets are typically conducted at the day-ahead and hour-ahead time scales. As shown in Figure 5, the clearinghouse is also responsible for posting information that is available to all agents. This information includes unit outages, historical pool clearing prices and system-level loads, weather forecasts, and load projections. Each agent in the market submits bids independently, without any information regarding the bids placed by its competitors. Instead, agents make bidding decisions on the basis of bulletin board information, the historical behavior of the market under different conditions, and market trends. In the current version of EMCAS, there is no collusion among agents.

EMCAS has two pool market options. The first is the locational marginal price (LMP) option in which all agents get paid the marginal bid to serve loads at a specific location. The LMP is paid to all generation companies that sell power (accepted bid) at a specific location regardless of the agent's bid price. The second pool market option is referred to as "Pay-as-Bid" in which each generation company agent that is accepted gets paid the price that it bids. In this type of market, generation companies may be paid different amounts for providing the same service at the same location.

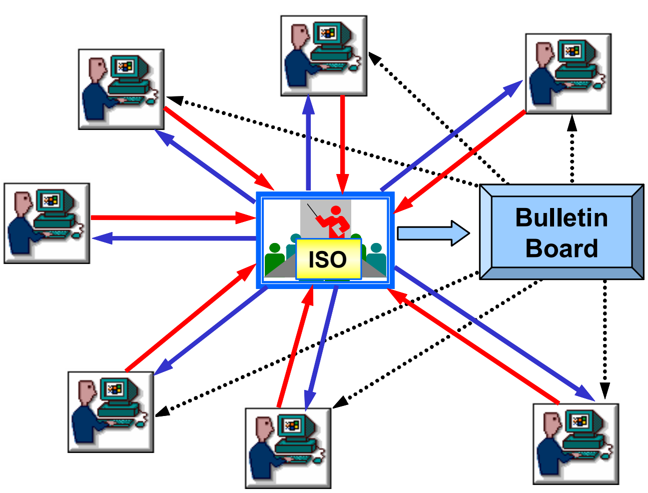

Figure 5: Pool Market Structure

Some agents may strive to exploit the physical limitations of the power system and the market rules under which they operate as a means to increase profit. For example, under the LMP market rule, if a generation company learns that under certain conditions it can frequently influence market prices, then it may decide to increase its bid prices. However, this higher bid price will increase the risk that it will be rejected. A company that has learned that it has little influence over the market or is risk-averse may decide not to increase bid prices.

In the day-ahead pool market, generation companies' bidding strategies are formulated for the entire day – not for individual hours. EMCAS generation companies use their projection of hourly LMPs, technical generation minimums, production costs, shutdown and startup costs, and minimum downtimes to formulate their bidding strategies. Companies may be willing to lose money during some hours of the day in order to make profits during other hours or avoid startup and shutdown costs.

On the basis of bid prices, transmission constraints, and energy security considerations, the clearinghouse determines which bids are accepted and rejected and computes the LMPs. The clearinghouse then separately notifies each company if its bids were accepted or rejected. On the basis of clearinghouse decisions, generation companies develop unit commitment schedules and formulate plans for the ancillary services markets.

EMCAS MARKETS: ANCILLARY SERVICES MARKETS

EMCAS models three ancillary services markets after the pool market closes. Spinning reserve markets are simulated first, followed by the AGC and replacement reserves markets. The amount of these services that is purchased by the ISO is a function of system reliability and security parameters that are entered into EMCAS by the user.

The ISO selects ancillary service bids based solely on price – not on location. The lowest-priced bids are accepted such that all ancillary services requirements are fulfilled. Total transfer capabilities on transmission lines include security constraints. Therefore, it is assumed that the transmission system can reliably accommodate ancillary services functions under all but the most severe situations.

Spinning reserve services are called upon by EMCAS when scheduled generation cannot meet load because of an unplanned event, such as a generator failure or a line outage. One or more units on spinning reserve duty are ordered to generate power to fill the supply shortfall. Spinning units that were previously called into generation service are eventually put back into a spin state, and, if required, generation from replacement reserve units fulfills the shortfalls.

Since ancillary services markets are cleared last, generation company agents must anticipate the costs, benefits, and risks associated with these markets in their overall marketing strategy. If all of a generation agent's resources are committed in other markets, then the opportunity to participate in ancillary services markets is lost. On the other hand, if generating capabilities are reserved for these markets and ancillary services bids are not accepted, potential profits that could have been made in other markets are lost. When making spinning and ancillary services marketing decisions, generation company agents must also consider the probability that they will be called upon and the profits or losses associated with generating power from the unit.

EMCAS has several user-specified settlement options for paying generation companies. Settlement rules impact a generation company's risk and hence company decisions. For example, if spinning reserve units are placed into service when LMPs are significantly lower than production costs, the generation company will lose money if the settlement rule states that the company will receive payments based on the LMP. The generation company agent has a much lower risk if there is a settlement rule that pays the higher of the LMP or marginal production cost

EMCAS MARKETS: LOCATIONAL MARGINAL PRICES

In EMCAS, the market clearinghouse or ISO determines the price of energy at all grid withdrawal and injection points. Under an LMP market rule where there is no transmission congestion, there is a single clearing price for all buyers and sellers. This is determined by the supply (i.e., price bids) and demand intersection point as illustrated in Figure 6. Essentially, power is sold up to the point where buyers are willing to pay for it. Because both supply and demand bids in EMCAS are specified in discrete quantities or blocks, the curves depicted on the figure are in the form of step functions.

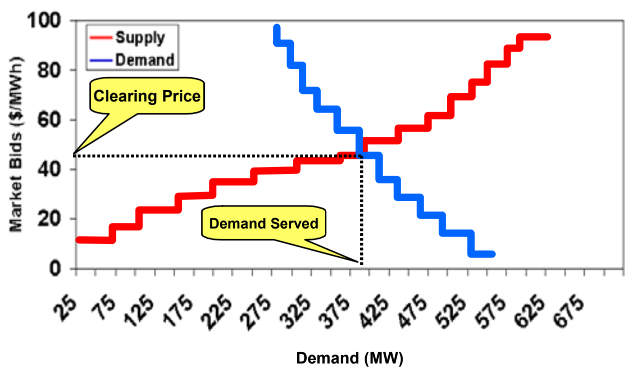

Figure 6: Market Price and Demand

When a transmission line reaches its limits but it would otherwise be economical to transfer power over it, congestion occurs and LMPs differ as a function of location. That is, the marginal accepted bid to supply a location differs from another because the transmission system does not have enough capability to transport the less expensive power to all locations in the grid. Therefore, expensive bids are sometimes accepted in order to meet electricity demands in some locations while some less expensive bids are rejected.

As shown in Figure 7, LMPs can vary significantly among nodes in the network (i.e., buses). As a simplification, EMCAS uses market zones instead of all buses in the power grid. These zones aggregate all market activities in a given geographical area to a single point. Market zones are assumed to have no intra-zonal congestion, and their geographical boundaries are based on bus-level load flow model simulations, such as the ones provided by the Argonne Load Flow (ALF) model or PowerWorld™. If agent behavior results in significant intra-zonal congestion, it is necessary to disaggregate a market zone into two or more uncongested zones.

Locational price differences in EMCAS are typically collected through transmission congestion charges. In EMCAS, these congestion charges can be based on energy delivery points whereby some demand agents pay a higher rate than others or congestion charges can be spread evenly among all demand agents (socialized).

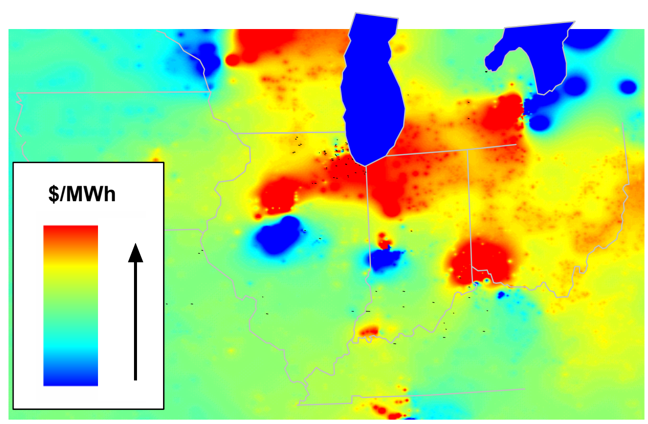

Figure 7: Illustration of LMPs (Source: Overbye, 2002)

AGENT RISK CHARACTERIZATION

In EMCAS, an agent's risk preference is broadly classified into risk-averse, risk-neutral, and risk-seeking. The risk preference is modeled by using a von Neumann-Morgenstern expected multiobjective utility function. Each agent can have a set of objectives (e.g., maximizing profits, maximizing market share, maximizing capacity utilization, and minimizing un-served energy). Different types of agents have different types of objectives. For example, generation company agents have different objectives than RTO agents. An individual agent's objectives may conflict with each other in that the achievement of one objective may negate the achievement of other objectives. For example, if a generation company agent tries to maximize the capacity factor of a unit at times of low market clearing prices, then profits may be compromised. Each objective of an agent is represented by a minimum expected value (X_{min}), a maximum expected value (X_{max}), and a risk preference (RP). A scaling factor (k) for each objective is used to compute the overall expected utility (OEU) as the sum of all single-objective expected utilities (EU) weighted by k.

A single-objective increasing utility function is defined by equations (1) and (2).

$$EU = \frac{1-\exp\left(RP*\frac{(X-X_{min})}{(X_{max}-X_{min})}\right)}{1-\exp(RP)} \quad for\ RP \neq 0 \qquad (1)$$

and

$$EU = \frac{(X-X_{min})}{(X_{max}-X_{min})} \quad for\ RP = 0 \qquad (2)$$

Similarly, a single-objective decreasing utility function is defined by equations (3) and (4).

$$EU = \frac{1-\exp\left(RP*\frac{(X_{max}-X)}{(X_{max}-X_{min})}\right)}{1-\exp(RP)} \quad for\ RP \neq 0 \qquad (3)$$

and

$$EU = \frac{(X_{max}-X)}{(X_{max}-X_{min})} \quad for\ RP = 0 \qquad (4)$$

Following is an example to illustrate these concepts. Consider a demand agent purchasing power either through bilateral contracts or from the day-ahead pool market. One of the objectives of the agent is to maximize its profits. The utility increases for increasing values of profit. For a given profit X, the utility of a risk-averse agent is higher than that of a risk-seeking agent (Figure 8). Hence, under similar circumstances, the risk-averse agent may not change its strategy of buying energy from bilateral or pool markets, while a risk-seeking agent may not be satisfied with the low utility and may try to increase its utility by shifting the energy purchases from bilateral markets to the pool market.

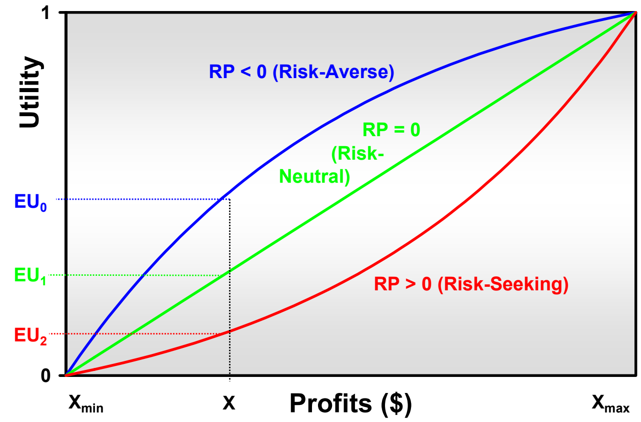

Figure 8: Example of Increasing Utility Function for Risk-Averse, Risk-Neutral, and Risk-Seeking Agents

Another objective of the demand agent could be minimizing the unserved energy to its customers. That objective could be achieved either by buying energy through bilateral contracts or by bidding into the pool market at a higher price. The utility increases for a decreasing value of this objective. For a given value of unserved energy X, the risk-seeking agent has a higher utility than a risk-averse agent (Figure 9). Hence, under similar circumstances, a risk-averse agent may either enter into bilateral contracts or bid at a higher price into the pool market, while a risk-seeking agent may just do the opposite.

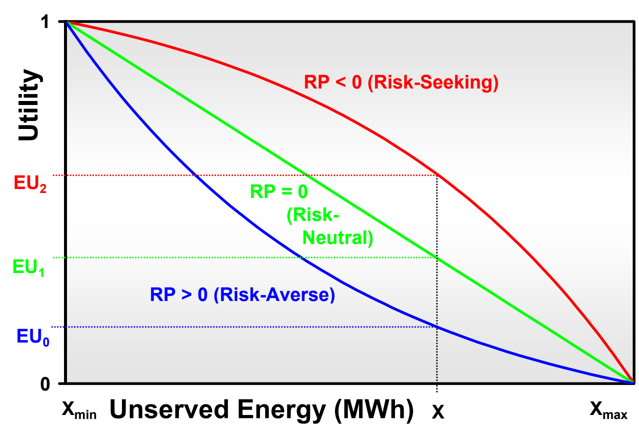

Figure 9: Example of Decreasing Utility Function for Risk-Averse, Risk-Neutral, and Risk-Seeking Agents

AGENT LEARNING

Agents involved in either the bilateral or pool markets develop price expectations to support their internal decision models. These expectations are based on a combination of public information (available to all market participants) and private information (available only to the specific agent). The differing private information available to the agents results in agents developing different price expectations. Initially, the agents have prior price expectations based only on public information (e.g., information on pool prices, system load, and reserve margin). We assume that agents *do not* have differing skills for forecasting the day-ahead market, the ISO forecast for load and reserves is taken as given. However, agents do have differing historical information regarding the acceptance and rejection of their own bids. On the basis of results from the EMCAS simulation, the agents update their price expectations using private information on bids that are accepted and rejected. This private information on bids is even more important for the bilateral market, because the results of the bilateral transactions are not public information, only the agents that execute a contract know the terms.

Consider the pool market first. The expected pool price may follow the simple relationship

$$P^{Pool} = a + b\,L + c\,RM \quad (5)$$

Where L and RM are the day-ahead forecast load and reserve margin, respectively. This framework can apply to each hour of the day and marketing zone. In the absence of congestion, we know that a bid is accepted if $P^{Pool} - Bid > 0$ and rejected if $P^{Pool} - Bid < 0$. If we subtract the bid from both sides of the simple price expectation model then we can interpret this as an index function for a binary variable model for acceptance and rejection based on the agent's private data on accepted and rejected bids and public data on forecast system characteristics. To generalize the specification, we estimate a quadratic response for the bid price as well, so the model is

$$y^{*} = a + b\,L + c\,RM + d\,Bid + e\,Bid^{2} \quad (6)$$

$$y = 1 \quad if \quad y^{*} > 0 \quad and \quad y = 0 \quad if \quad y^{*} < 0 \quad (7)$$

This binary variable index function may be used in either the probit model, where the underlying probability distribution is standard normal, or the logit function, where the underlying probability is logistic.

The bilateral market is similarly motivated, but the reservation price of the buyer is never observed. In the bilateral market, the price expectations of the seller may be specific to a demand agent, if there is enough experience, or represent all bilateral transactions.

EMCAS APPLICATION

In its most recent application, EMCAS is used to simulate the Midwest power markets for the state of Illinois. The focus of the analysis is whether the existing transmission system can support a competitive market to keep prices in check and allow for new market participants to compete for market share. EMCAS will also be used to investigate whether conditions can occur that will enable a company to exercise market power in some regions, thereby creating undue price pressures.

REFERENCES

Bonabeau, E., M. Dorigo, and G. Theraulaz, *Swarm Intelligence: From Natural to Artificial Systems*, Oxford University Press, Oxford, U.K.: 1999.

Bower, J., and Bunn, D.W. "A Model-based Comparison of Pool and Bilateral Market Mechanisms for Electricity Trading," *Energy Journal*, Volume 21, No. 3: July 2000.

Burkhart, R., M. Askenazi, and N. Minar, *Swarm Release Documentation.* Available at http://www.santafe.edu/projects/swarm/swarmdocs/set/set.html: 2000.

Collier, N., and D. Sallach, *RePast*. Available at http://repast.sourceforge.net/: 2001.

Conzelmann, G., V.S. Koritarov, K. Guziel, and T.D. Veselka, *Final Audit Report – New Generating Capacity Tenders 97/1 and 97/2*, report submitted to the Hungarian Power Companies Ltd., Budapest, Hungary: February 1999.

Epstein, J.M., and R. Axtell, *Growing Artificial Societies: Social Science from the Bottom Up*, Brookings Institution Press, Massachusetts: 1996.

Harza Engineering Company in association with Argonne National Laboratory, *Trans-Balkan Power Line Project*, Final Report: May 2001.

Koritarov V., G. Conzelmann, T. Veselka, W. Buehring, and R. Cirillo, "Incorporating Environmental Concerns into Electric System Expansion Planning Using a Multi-Criteria Decision Support System," *Int. Journal of Global Energy Issues,* Vol. 12, No. 1-6, pp. 60-67: 1999.

Law, A.M., and W.D. Kelton, *Simulation Modeling and Analysis*, 3rd ed. McGraw-Hill: New York, New York: 2000.

North, M.J., "SMART II+: The Spot Market Agent Research Tool Version 2.0 Plus Natural Gas," *Proceedings of the Computational Analysis of Social and Organizational Science Conference*, Carnegie Mellon University, Pittsburgh, Pennsylvania: 2000a.

North, M.J., "SMART II: The Spot Market Agent Research Tool Version 2.0," *Proceedings of SwarmFest 2000*, Swarm Development Group, Logan, Utah: 2000b.

North, M.J., "Agent-Based Infrastructure Modeling," *Social Science Computer Review*, Sage Publications, Thousand Oaks, California: Fall 2001.

Overbye, T.J., *Illustration of LMPs*, map used with permission of T.J. Overbye, University of Illinois, Urbana-Champaign, Illinois: July 2002.

Petrov V., and G.B. Sheblé, "Power Auctions Bid Generation with Adaptive Agents Using Genetic Programming," *Proceedings of the 2000 North American Power Symposium*, Institute of Electrical and Electronic Engineers, Waterloo-Ontario, Canada: Oct. 2000.

Picker R.C., Simple Games in a Complex World: A Generative Approach to the Adoption of Norms," *University of Chicago Law Review*, University of Chicago, Chicago, Illinois: 1997.

Sallach, D.L., and C.M. Macal, Introduction: The Simulation of Social Agents, *Social Science Computer Review*, Sage Publications, Thousand Oaks, California: Fall 2001.

VanKuiken, J.C., T.D. Veselka, K.A. Guziel, D.W. Blodgett, S. Hamilton, J.A. Kavicky, V.S. Koritarov, M.J. North, A.A. Novickas, K.R. Paprockas, E.C. Portante, and D.L. Willing, *APEX User's Guide (Argonne Production, Expansion, and Exchange Model for Electrical Systems) Version 3.0*, Argonne National Laboratory, Argonne, Illinois: 1994.

Veselka, T.D., E.C. Portante, V.S. Koritarov, S. Hamilton, J.C. VanKuiken, K.R. Paprockas, M.J. North, J.A. Kavicky, K.A. Guziel, L.A. Poch, S. Folga, M.M. Tompkins, and A.A. Novickas, *Impacts of Western Area Power Administration's Power Marketing Alternatives on Electric Utility Systems*, Argonne National Laboratory, Argonne, Illinois: 1994.