RETICULAR SYSTEMS INC.™

Using Intelligent Agents to Implement an Electronic Auction for Buying and Selling Electric Power

Revision 1.0

August 30, 1999

A Research Project Performed by:

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SECTION 1 *Executive Summary*

Background

The electric power industry is undergoing rapid and significant change with the advent of deregulation. Electric power marketers have emerged, and wholesale electric customers are learning to “shop around” for the best electric suppliers. At the same time, the industry is adopting Internet-based electronic reservations and trading systems that provide open access to all transmission services information for all market participants. With the advent of increased competition, the utilities are discovering that improved productivity in power generation and transmission takes on renewed importance. New tools and technologies are required to allow the industry to grow and thrive in this new era of deregulation.

Research Objectives

This white paper describes a research project conducted by Reticular Systems, Inc. and Alternative Energy Systems Consulting, Inc. (AESC) for the Electric Power Research Institute (EPRI) in Palo Alto, CA. This project focused on the development of intelligent agent technology and application of that technology to the electric power market. We have shown how networks of communicating and cooperating intelligent software agents can be used to implement complex distributed systems; distributed systems that implement electronic marketplaces. We investigated how collections of agents (agencies) can be used to buy and sell electricity and participate in the electronic marketplace. Agents can act as buyers or sellers, auctioneers or bidders and representatives for generators or consumers of electricity.

Research Results

Our research has shown that networks of intelligent agents provide a powerful problem-solving mechanism that is ideally suited for use in the electric power industry. Agents are ideally suited for use in network applications. The new restructured and unregulated power industry will utilize network communications and the Internet extensively. We have shown that agents provide an excellent mechanism for implementing information systems for buying, selling and scheduling electric power. We have shown how software agents can be used to represent the interest of various stakeholders involved in buying and selling electric power. Using our AgentBuilder Pro software product, we have implemented and tested a simple, agent-based electronic auction for buying and selling electric power.

Each agent can have its own goals, objectives, cost and profit objectives. Further, we have shown how agents can work together to form markets with agents buying and selling electric power and changing their role of buyer or seller as their electric power requirements change. This white paper describes the design of a prototypical electronic marketplace for buying and selling electric power. We also developed a simple demonstration system to show the operation of the agents and the marketplace. This demonstration system is available for download for further evaluation.

In summary this research has shown:

- Agents can be used to implement electronic marketplaces and electronic auctions.
- An individual agent can adopt the goals and intentions of its stakeholder.
- A central market authority is not necessary. Agents can dynamically form their own marketplaces meeting their individual needs.
- The distributed, multiple agent approach is significantly more useful than a central server, since individual agent behaviors are under the control of the stakeholder and not subject to the rules and constraints of a central authority.

Additional Information

Additional information concerning the work described in this paper can be found at a number of sources.

- Formal Report. This work is more fully documented in a detailed technical report WO8811-03 titled "Prototype Intelligent Software Agents for Trading Electricity: Competitive/Cooperative Power Scheduling in an Electronic Marketplace." Please contact EPRI directly for a copy of this document.
- AgentBuilder. The AgentBuilder Pro product developed and marketed by Reticular Systems, Inc. was used in development of the agents and agency described in this white paper. More information on AgentBuilder can be found at the AgentBuilder web site at `http://www.agentbuilder.com`.
- Related Work. Reticular Systems, Inc. has performed related research for other clients including the US Department of Energy. Information on these projects can be found on at `http://www.reticular.com.` AESC has also performed a significant amount of related work. Information about this work can be found at `http://www.aesc-inc.com`
- Downloads. The StandAlone Driver that shows the operation of the agency is available for download from the Reticular web site. The URL for the download is `http://www.agentbuilder.com/epri`.

SECTION 2 *Introduction*

Competition in the Electric Power Industry

With the advent of increased competition, the utilities are discovering that improved productivity in power generation and transmission takes on renewed importance. Since the utilities must compete they must find ways to reduce their costs and provide improved system reliability and better customer service. Moreover, the utilities are discovering that many of their old ways of doing business are no longer suitable for use in this new competitive environment. For example, many of their existing data systems were developed when the utilities were regulated, self-contained entities that did little buying and selling of power outside their own geographical areas. Now the utilities must have the capability of not only improving the processes in their own operations, but they must also work closely with other utilities, transmission companies, power marketers, and other organizations.

The electric power industry is becoming a large interconnected network of distributed resources. Buying and selling in this environment is made difficult because of the difficulty of obtaining information in a timely manner and making decisions using this information. Legacy systems are based on a centralized model where all information flows into a central site where decisions are made. This model is no longer valid for the new energy industry.

New methods for buying and selling energy, monitoring supply and demand, arbitrage, trading energy futures, system monitoring and maintenance, etc. are required. Electric power companies must have improved ways of conducting electronic commerce with their counterparts as well as energy transmission and distribution companies. Methods of automating many of these processes are also required. For true competition to flourish in the energy industry, new technology is required that will make it easy to buy and sell energy, monitor supply and demand, monitor the status of generation and transmission equipment, improve system reliability, communicate using open systems technology such as the Internet, and improve productivity. Intelligent software agents provide a promising mechanism for implementing these complex, high performance systems. The following paragraphs provide a brief introduction to intelligent agents. For a more detailed introduction to software agents see the AgentBuilder white paper at `http://www.agentbuilder.com`. This site contains extensive information about intelligent agents, agent applications and tools for constructing intelligent software agents.

Intelligent Agents in the Power Industry

Intelligent software agents are a new class of software that act on behalf of the user to find and filter information, negotiate for services, easily automate complex tasks, or collaborate with other software agents to solve complex problems. Software agents are a powerful *abstraction* for visualizing and structuring complex software. Procedures, functions, methods and objects are familiar software abstractions that software developers use every day. Software agents, however, are a fundamentally new paradigm unfamiliar to many software developers.

Intelligent Software Agents

Before defining the characteristics of an intelligent agent we first look at the general characteristics of a *software agent*. A software agent is viewed as an autonomous software construction; i.e., one that is capable of executing without user intervention. We place two additional constraints on the software before defining such a construct as a software agent: an agent must have the ability to communicate with other software or human agents and the ability to perceive and monitor the environment. The ability to communicate implies that the agent has the ability to cooperate with other agents (after all, cooperation is required in order to receive and acknowledge a communication). Cooperation is of paramount importance and is the primary reason for using multiple agents in a software architecture.

We define a software agent as a software component that:

- executes autonomously
- communicates with other agents or the user
- monitors the state of its execution environment

Having defined the general characteristics of a software agent, we can begin to address the question of what makes a software agent an *intelligent* software agent — this means that we must address the broader question of what is meant by the term *intelligent software*. For software to be considered intelligent it should possess (at least) the following capabilities or attributes:

- Able to exploit significant amounts of domain knowledge
- Tolerant of errorful, unexpected or wrong input
- Able to use symbols and abstractions
- Capable of adaptive goal-oriented behavior
- Able to learn from the environment
- Capable of operation in real-time
- Able to communicate using natural language

A strong argument can be made that an intelligent software agent need not have all of the capabilities and attributes described above. For example, many applications do not require a *real-time* response, merely a *timely response*. Other applications involve only agent-to-agent interaction and thus do not require the ability to communicate using natural language.

Truly intelligent agent software will thus possess the capabilities of agent software (autonomy, communicability, perception) and the capabilities of intelligent software (ability to exploit knowledge and tolerate errors, reason with symbols, learn and reason in real time, and communicate in an appropriate language). Thus it seems clear that intelligent agent software should not be viewed as being either “smart” or “dumb” but, rather, should be viewed as having intellectual capabilities lying along a continuum. Software with more intelligence will have greater capabilities. In certain applications, intelligent agents with limited capabilities will be all that is required.

Agents and Agency

While agents are useful and powerful computational entities and a single agent can be used to perform a wide variety of tasks, agents are most useful when multiple agents communicate, cooperate and collaborate to solve complex problems. A collection of agents that work together to provide some service is called an *agency*. The focus of this research project was on developing an agency that could be used to buy and sell electric power.

Each agent in an agency normally has some specialized task that it performs. In the agency defined in the following sections, we define buyer and seller agents that are delegated responsibilities by the various *stakeholders* involved in trading electricity. (A stakeholder might be a power generator, a power consumer or a power distributor). Each stakeholder has different goals, objectives and motivations. Some may value reliability over cost, others may view that managing costs is their primary objective. Each agent is designed to satisfy the goals, objectives, intentions, plans and schedules of its stakeholder.

These agents communicate and cooperate with each other to implement an electronic marketplace. In this marketplace, agents with excess electric power auction power to agents who need to purchase power. Likewise, an agent that needs to purchase power can initiate an auction to buy power from other agents who have excess capacity.

SECTION 3

An Agency for Trading Electric Power

The agency described in the following sections is a simplified version of the agency required in a real-world electric marketplace. However, the agency models the real world in sufficient detail to demonstrate the efficacy of the agent-based approach. The agency, as shown in Figure 1, consists primarily of agents representing energy suppliers and agents representing energy users (buyers) with TSO or (transmission system operator) or Regional Transmission Operator (RTO) agents providing support. For purposes of this research, these agents are self-contained entities having relatively unsophisticated capabilities. As the capabilities of the buyers and sellers increase (in future research efforts) it is likely that their activities will be disaggregated. Buyer and seller agencies would then replace the individual buyer and seller agents shown in Figure 1.

Agency - Market Operation

The proposed energy market will consist of an agency of buyers and suppliers interacting directly to establish bilateral contracts for the sale and delivery of energy. Information is provided to all participants via a public forum, in this case shown as

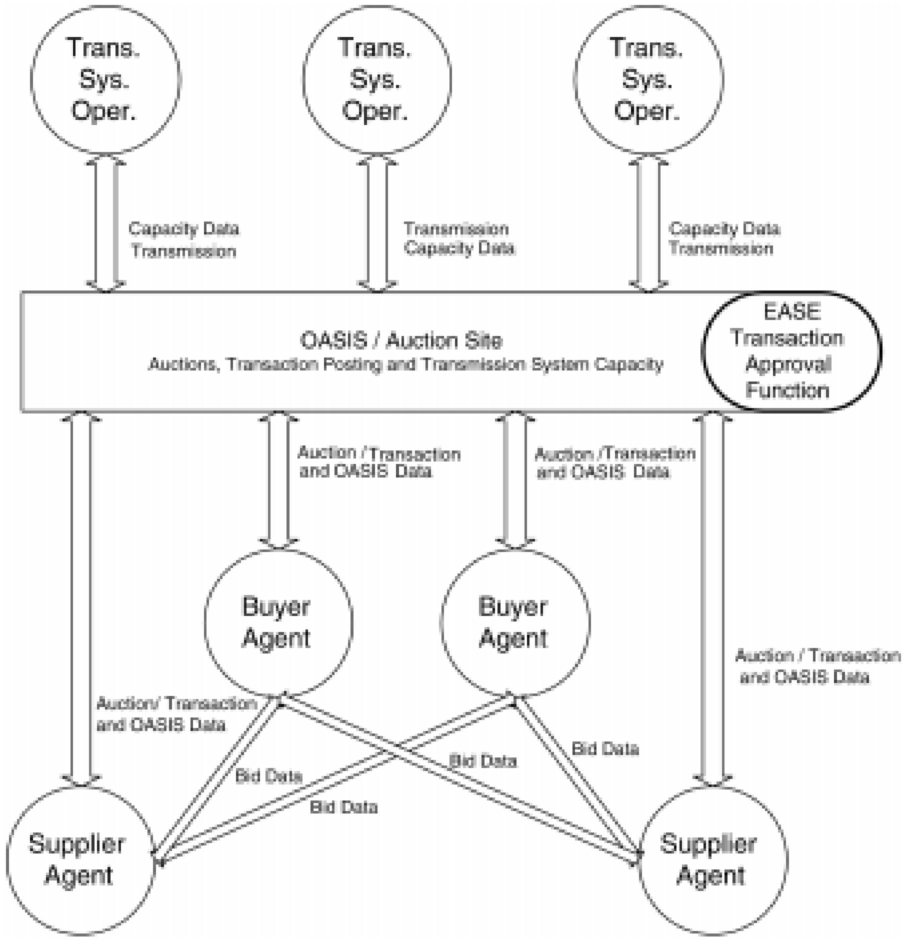

Figure 1. Energy Market Agency

the OASIS / Auction web site. The market will operate continuously under a process having three basic stages:

- Auction
- Transaction Definition
- Transaction Execution

Time and budget constraints during the research effort made it necessary to limit the scope of the market in a number of ways. The market is therefore:

- limited to energy (kWh) only (excluding ancillary services such as kVAR and spinning reserves).
- does not address specifics of metering, true-up, billing, financial and contracts.

Stage 1: Auction

Buyers and suppliers/sellers are matched using a modified Dutch auction format. In this format both buyers and sellers may conduct an auction session by posting buy/sell information in a public forum (e.g., OASIS /Auction web site). For purposes of demonstration, an Energy Agent Simulation Environment (EASE) is used to model the physical environment and the transaction approval functions.

Buyers and sellers conduct individual Dutch auction sessions using the public forum without the assistance or oversight of an auctioneer. The process begins when the auctioning party (buyer or seller) posts auction information (e.g., amount and timing of the capacity (for sale or purchase), price, auction session identifier, minimum acceptable contract quantity, etc.). The auctioning party is not responsible for calculating delivery costs (transmission) since this depends on the physical location of the bidder, which is not known to the auctioning party at the time of posting.

However, it is important to note that the posted price in a seller (supplier) auction excludes transmission costs while transmission costs are included in the buyer auction price. In the case of the seller auction, this is analogous to a supplier of wholesale fish that delivers the fish to the auction house. It is the responsibility of the bidder to determine if the final cost of the fish (after adding the cost of shipping to the buyer's location) is acceptable. Buyer's located near the auction house can afford to bid more while buyer's that incur higher shipping costs must bid less in order to achieve the same profit. In the case of a buyer auction the buyer is petitioning prospective suppliers (bidders) to supply energy at his location. This is analogous to a restaurant operator that offers to pay a specific price for fish delivered directly to his restaurant. The restaurant operator has no knowledge of how far the fish will be shipped. Wholesale fish suppliers (bidders) must determine if they can supply fish at the specified price and location and still make an acceptable profit. In either case, the bidding party must estimate the delivery costs prior to submitting a bid.

In accordance with the Dutch auction format, the price of the next posting during the auction session is modified using a known price modifier. However, the auctioning party may choose to discontinue the auction session (not proceed with next posting) if the next price falls below (seller) or above (buyer) the reserve price established by, and known only to, the auctioning party. The only difference between a buyer and seller auction is that the price modifier is negative for a seller auction (descending price) and positive for a buyer auction (ascending price). In both cases, the auctioning party receives less value the longer the session continues.

Under this auction format the auctioning party is compelled to accept bids and complete transactions before the next session or risk getting a lower price. The bidder, on the other hand, is under pressure to submit a bid before the capacity is purchased (or supplied) by another bidder or before the session is discontinued and the capacity is possibly withdrawn from the market altogether. Waiting for the next posting can result in a "better deal" for the bidder but at the risk of losing the transaction altogether (if the auction session is discontinued before a bid can be submitted).

The Dutch auction format has been shown to promote bidding strategies that result in equitable product valuations. Bidding parties have less fear of winner's curse (over-paying) since the bidding process does not involve a public competitive bidding process such as in the English Outcry (or Open Cry) auction. No information is available on bids from other prospective bidders prior to bidding so bids tend to approach the true valuation of the product (e.g., bids are not elevated by exuberant or misinformed bidding).

Stage 2: Transaction Definition

Prospective bidders access the public information and evaluate information on the various auction sessions relative to their needs. If a decision is made to bid then bids are electronically submitted directly to the auctioning party (see Appendix II for bid contents). Transaction information relative to the price and starting time of the energy delivery are set in the auction posting so only the quantity and duration of the delivery need to be identified in order to fully define the transaction.

For purposes of the research, this is further simplified by:

- Fixing the duration of all bids to one hour, and
- Fixing the start time to coincide with the beginning of the next hour of the day (e.g., only the next hour of service is in play).

Given these further simplifications, the auctioning party need only establish the quantity/capacity to be sold.

The auctioning party processes incoming bids as follows:

- Validate all incoming bids to insure that they have been directed to the appropriate auctioning party and that minimum requirements of the posting (i.e., bid exceeds minimum contract amount, correct delivery time, etc.) have been met.
- Identify bidders that are prevented from participating due to known transmission system problems/limitations (i.e., system outage or other known limitation, etc.).
- Identify and deal with “bidder collisions” where a bidder collision is defined as receipt of two or more bids for the same item. If for instance, a supplier posted 100 MW of capacity and receives two bids totaling 200 MW then a collision condition exists. If however, the bids had totaled 100 MW or less then the bids can be satisfied as received and a collision condition does not exist.

In a traditional Dutch auction, when a collision occurs the auctioneer announces that a collision has occurred and the bids are withdrawn. The auctioneer then increases the price and allows bidding to resume. This process is repeated until the collision condition no longer exists or until an impasse is reached (repeated collisions) and the lot is withdrawn. In the absence of an independent auctioneer, this response to bidder collisions is not practical. Without oversight, auctioning parties could falsely announce a collision as a means of forcing higher bids. In addition, repeated collisions can consume too much time and resources.

$$B'_i = C * \frac{B_i}{\sum_{1}^{n} B_i}$$

For these reasons, an alternate solution is proposed that equitably divides the available capacity among the bidding parties. The solution calls for adjustment of bid quantities as follows:

Where:

n	=	Number of bids received
C	=	Posted capacity

B' = Modified bid

B = Original bid

This solution will work in most cases but problems can arise if the number of bidders is large and/or there is a great disparity between the size of the bids. In either event, the modified bid(s) can drop below the minimum acceptable transaction amount (or may drop below the bidder's minimum acceptable amount). In that event the following additional heuristics are proposed:

1. Notify any bidder (not previously notified) whose modified bid falls below their stated minimum and allow them to withdraw their bid with no penalty. If they consent to a modification then proceed, if not then remove their bid and recalculate the distribution. Note that bidder's eliminated in this fashion may be allowed to reenter their bid if sufficient capacity becomes available (e.g., transmission capacity limitations, bidder defections, etc.) later in the session.
2. Set all modified bids, if any, that fall below the transaction minimum to the transaction minimum and distribute the remaining capacity amongst the remaining bidders in the same fashion as before.
3. Repeat this process until all bids are above the contract minimum or until it becomes impossible to reach an acceptable solution.

If this process does not yield acceptable bids (e.g., some bids remain below the contract minimum) then some bidders must be excluded. In that event, remaining bidders would be excluded based on the size of their original bid. Smaller bidders are eliminated first with the earlier bidder getting preference over later bidders in the event of a tie (i.e., last bid received is first to be eliminated in the event of equal size bids). The process is repeated until the capacity is distributed and no bid is below the transaction minimum.

1. Transmit the fully defined/modified transactions to the bidders for confirmation and acceptance. If a bidder refuses the transaction (defects) at this point then they forfeit a portion of their deposit. The amount forfeited will be equal to the loss in income that the auctioning party will experience if this capacity is held over to the next auction session (e.g., product of rate modifier and the refused/modified bid).
2. Offer the forfeited capacity to the remaining bidders. Offers would be made to larger bidders first (i.e., largest bidder would be offered the capacity up to their original bid size, etc.). Earlier bids would get preference over later bids if two or more bidders are tied based on size alone.

3. Offer any remaining capacity to bidders previously excluded (most recently excluded bidder gets first right of refusal) as long as the amount remaining exceeds the auctioning party's minimum transaction amount.

Stage 3: Transaction Execution

Transaction execution is a two step process. The first step requires that the auctioning party check the transaction for system feasibility. This is accomplished using the system power model and information on transactions already recorded (as read from the web site). If a transaction appears feasible then it is posted as a "pending' transaction on the Auction web site. The auctioning party checks and posts each transaction separately until all transactions have been entered. Larger transactions are checked and executed first (to maximize income).

If a transaction fails the system feasibility check (i.e., causes an overload condition in any part of the power system, etc.) then the transaction amount is reduced until:

- The overload condition is eliminated,
- The bidder's transaction minimum is reached (if they have not previously agreed to reduction below this point), or
- The auctioning party's transaction minimum is reached.

If it becomes necessary to notify and receive approval from a bidder for a reduction below their minimum transaction amount (if they haven't previously agreed) then this transaction is placed on hold while the bidder is notified. The auctioning party continues to work through all of the transactions until as many as possible are recorded as "pending".

The second step of the transaction execution process involves final system approval. As currently envisioned this function will be provided by the OASIS / Auction web site itself. Pending transactions will be evaluated for system feasibility in the order that they are received. Feasible transactions are approved and move from a "pending" to "recorded" status. This has the effect of reserving the capacity on the transmission grid since all parties must access the public site for information on new transactions. If a pending transaction is found to cause a system overload condition then the auctioning party is notified and given the opportunity to reduce the transaction (if possible). If the modified transaction is still not feasible then its status is changed from pending to "rejected".

If there is sufficient time prior to the next auction session then the auctioning party can continue to offer up any remaining capacity to the remaining bidders or to previously excluded bidders that aren't impacted by the transmission constraint (if any). Otherwise the remaining capacity can be offered in the next auction session at the modified price. The auctioning party also has the option of stopping the auction session and removing the remaining capacity from the market.

Note that each transmission system operator (TSO) is responsible for monitoring and reporting on the status of its transmission resources. Each TSO is continually monitoring the status of its assets and updating the status of these resources on the OASIS / Auction web site.

Agent Descriptions

The agency shown in Figure 1 contains three basic types of agents. *Buyer* and *supplier* agents engage in bilateral contracts for energy supply while the *TSO* agents provide physical layer support in the form of inputs to the OASIS / Auction web site. This research has focused on the overall market/auction and the buyer/seller interaction. Therefore, the following discussion is limited to the behavior of the buyer/seller agents.

Buyer/Supplier Agent Types

Under the proposed market format both buyers (energy users) and suppliers may conduct auction sessions. Therefore, market participants have the option to:

- Conduct an auction session and wait for bidders to approach them,
- Review and subsequently bid into the various auction sessions, or
- Both conduct an auction session and bid into the auctions of others.

The decision process involved in determining whether it is advantageous for a market participant to conduct an auction versus bidding (or both) was too complex to address adequately in this research effort. Therefore, in order to simplify the initial effort we will assume that all market participants fall into one of two classes: auctioning and bidding /non-auctioning. Furthermore, we will assume that an auctioning type market participant will always conduct an auction to meet their needs and a bidding type participant will never conduct an auction. In other words, we do not allow dynamic casting as part of the prototypical system design. This limitation allowed us to concentrate on conducting and observing the energy market and to gain insight about the benefits of conducting auctions in this market. Table 1 shows the possible agent configurations relative to the energy market buyers and sellers. As the table shows there are basically two types of buyer and seller agents: auctioning agents and bidding agents.

TABLE 1. Agent Configuration

Seller Agents	Buyer Agents
Auctioning Supplier	Bidding Supplier
Auctioning User	Bidding User

Auctioning Agent Description

An auctioning agent conducts auction sessions as needed to fulfill its energy requirements. Both buyers and sellers/suppliers may conduct auctions. The basic auction process is similar in both cases. A greatly simplified version of this process is shown Figure 2.

The auctioning process starts with a status evaluation that includes:

1. Establishing the buyer/seller capacity needs (whether it is the anticipated generation capacity or a user's expected load).
2. Checking the status of all potential transactions previously recorded by the buyer/seller that have yet to be transacted (e.g., energy delivery/acceptance is still in the future, etc.). Some transactions may have changed status due to transmission system problems and it may now be necessary to open a new auction session to accommodate the change.
3. Identifying any auctions that the buyer/seller is currently conducting.
4. Checking transmission system status (availability and cost).

Once status has been established the auctioning agent decides whether to continue an existing session, close an existing session and/or open a new session. For the research effort, auctions are defined for energy delivered in the next hour; therefore agents will only have a single auction underway at any time. It is conceivable that an agent may choose to close out an existing auction and immediately open up another. Ultimately, an agent could have multiple sessions underway for a variety of time periods in order to accommodate a variable time horizon.

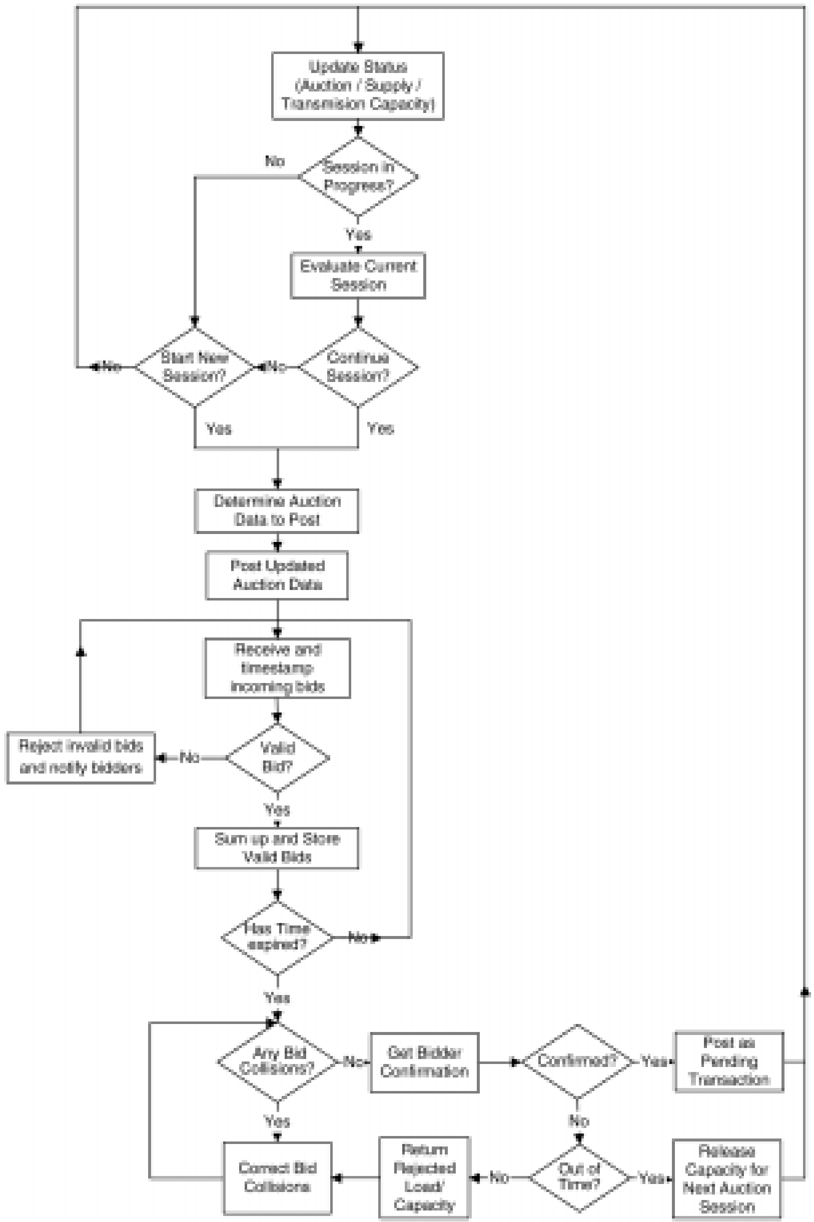

Figure 2. Auctioning Agent Decision Process

If a decision is made to open or continue an auction session, then the agent must determine the information that will be posted. Again this is an involved process that requires an evaluation of the market and the buyer/seller's constraints. Having determined what data to post, the agent sends the data to the web site and awaits responses from prospective bidders. Each bid is validated, recorded and given a timestamp as it is received. Invalid bids (i.e., bids that are below the contract minimum or are for the wrong auction session, etc.) are returned while all other bids are retained. When the time for bidding has expired the auctioning agent checks if the total of the bids exceeds the posted capacity/load. If so then a bid collision condition exists that the auctioning party must eliminate prior to proceeding.

The auctioning party can attempt to eliminate the bid collision problem by:

- equitably distributing the capacity amongst the bidders, or
- selecting bidders that are the most advantageous to the auctioning party (i.e., a single large transaction versus many smaller ones, etc.).

In this effort, we attempted to achieve an equitable solution as described in the previous section, Stage 2: Transaction Definition. Once the bid collisions are resolved the auctioning agent transmits the modified bid information to the bidding agents for confirmation. Capacity associated with bidders that reject the suggested modification(s) is put back into the capacity/demand "pool" and distributed amongst the bidders until the bid collisions are resolved and all capacity has been distributed or until the auctioning party runs out of time.

Bidding Agent Description

By definition, a bidding agent will always fulfill their energy needs by participating in the auctions of other agents. Both buyers and sellers/suppliers may bid into the auctions of others with the process being very similar in both cases. A greatly simplified version of this process is shown in Figure 3.

The bidding process begins with a status evaluation that includes:

1. Establishing the buyer/seller capacity needs (whether it is the anticipated generation capacity or a user's expected load).
2. Checking the status of all potential transactions previously recorded by the buyer/seller not yet transacted (e.g., energy delivery/acceptance is still in the future, etc.). Some transactions may have changed status due to transmission system problems and it may now be necessary fill this capacity from current auctions.

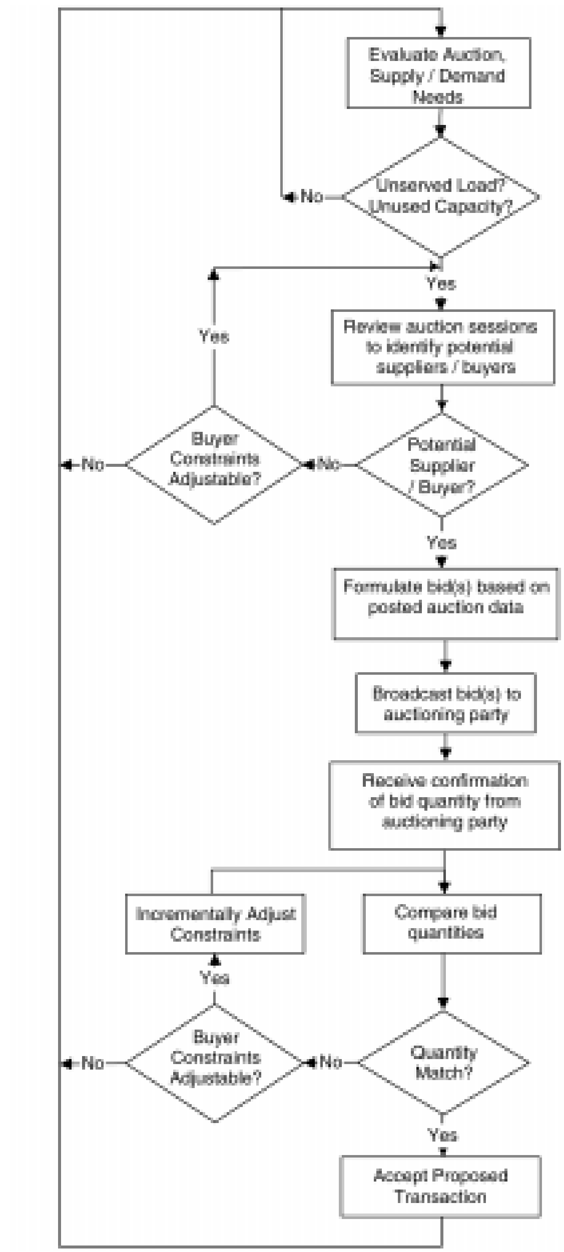

Figure 3. Buyer/Bidder Agent Decision Process

3. Checking transmission system status (availability and cost).

Once status has been established the bidding agent determines whether there is a need (unserved load or unused capacity) to participate in any auctions at this time. If there is a need to participate then the bidding agent reviews existing auction sessions relative to its needs and price constraints. If the bidding agent is unable to identify potential auction sessions meeting its requirements then it must decide if it can modify its needs/constraints (i.e., capacity, minimum transaction size, price and urgency). It may be possible for the bidding agent to wait for the next session, and a better value, if the urgency is low or it may require that the agent accept less value in order to lock up the transaction during this session. Note that for purposes of this research effort, we have assumed that sufficient capacity exists to supply the needs of all users. Therefore, our agents will never be faced with the scenario of not being able to purchase sufficient capacity (the lights go out).

If a need exists and potential auctions have been identified then the bidding agent must make an auction selection(s) and formulate bids. This could be a complex effort accounting for price as well as reliability of both the potential suppliers and the involved transmission capacity. For this research we have assumed that the bidding agent uses a relatively simple heuristic giving preference to price, transaction size and reduced transmission system usage.

The auction selection and bid formulation heuristic will undoubtedly evolve during the course of additional research as we observe the market in action and learn from observing agent behaviors and operations.

Initially, the bidding agent will use the following procedure to select auctions and formulate bids:

1. Select auctions with the best price first (lowest price for buyer, highest price for supplier). If two auctions have an equal price then the bidding agent will give preference to the auction providing the largest transaction size. If competing auctions have both the same price and transaction size then preference would be given to the auction involving the least amount of transmission system assets.
2. Select the maximum bid size that can be accommodated by the auctioning party up to the bidding agent’s total requirement (i.e., obtain all of the needed capacity from a single auction if possible).
3. Modify the bids to insure that no bid is below the minimum acceptable transaction size. This will be accomplished by reducing the size of other bids in the reverse order as noted in 1 above (least favorable bids are reduced first).

For this effort, the bidding agent will formulate and submit bids with a total capacity equal to it's estimated need. However, a more realistic approach would likely involve submitting bids in excess of the need (overbooking) to compensate for expected bid reductions by auctioning parties (to alleviate bid collisions). In addition, as the bidding party's sense of urgency increases (time of energy delivery/acceptance approaches) then it may be advantageous for the bidding party to submit bids in excess of their need in order to insure that sufficient capacity is obtained. The cost function associated with the bidder's urgency would therefore need to override the penalty associated with defecting[1] on these additional bids.

Agent Information

For this phase of the research, we have assumed "perfect knowledge." This means that all agents will have information of equal quality. For instance, there will is no uncertainty pertaining to a user's load requirements or a supplier's capacity.

Agent information can be classified into three basic types: predictions, status, and historical.

Predictions

Predictions are usually calculated or estimated by the agent in order to facilitate decision-making. For the agent-based energy market this would consist of predictions of energy pricing, user loads and generation capacities (for the agent and possibly for its competitors also). This type of information contains the most uncertainty since it requires estimation based on past and current indicators. For our effort, we have assumed that predictions of load and capacity are perfect and these values will be input as constants prior to using our demonstration system. Load and capacity profiles (future needs and capabilities) are entered for each agent that provides several hours or days worth of information. The market simulation is then initiated and allowed to run for successive hours.

Prediction of market pricing will be left open with only some of the agents given this capability. A relatively simplistic prediction algorithm will be used (still to be determined) by these "speculator" agents. In this context speculator means to anticipate the price and/or load as opposed to buying and selling in a speculative manner.

1. The term *decommiting* is also used in the literature.

Status Information

Agents participating in the agent-based market will access the OASIS /Auction web site to gather information on the status of auction sessions, relevant transactions and on the status of transmission assets. This information will be dynamic in that it will change as auction session's open/close and transactions are recorded.

Historic Information

In order to function in the proposed energy market agents will need knowledge of what has happened in the past (i.e., pricing information, transmission limitations, past transactions, etc.). As currently envisioned, this type of information will be accumulated by each agent during operation. When the system is first initialized each agent will have no historic and will keep an account of its actions during successive sessions. Historic Transaction Data Description summarizes the information that each agent type should store during normal operation. This information is a record of all transactions that each agent is party to whether it is a bidding or auctioning agent.

TABLE 2. Historic Transaction Data Description

Description	Units	Comment
Bid Identifier	na	A unique identifier for the bid that includes the auction and bidding party's identities and an additional number so that multiple bids to the same auction from a single bidder can be differentiated (future use).
Initial Energy Quantity	k W h	Amount to be bought (buyer) or sold (seller) as initially offered by the bidder. This amount may change if bid collisions occur.
Delivery Date / Time (see note 1)	Date/ Time	Delivery start date/time
Transaction Duration (see note 2)	Hour s	Desired duration of transaction
Price (see note 3)	$/ MWh	Price per unit (should correspond to posted value)
Bidder's Delivery Location	na	Bidder's supply or end use location for computation of transmission route / capacities. This could correspond to a grid location on the system map.
Auctioning Party's Delivery Location	na	Auctioning party's supply or end use location (metering) needed for bidder to estimate transmission route and costs. This could correspond to a grid location on the system map.
Final Transaction Amount	na	Energy quantity that will be delivered/accepted. This value may be different than the amount originally bid due to bid collisions.

Notes:

1. Transaction delivery date/time will correspond to the next hour of service for the research demonstration system.
2. Transaction duration and minimum transaction duration will be fixed at one hour.
3. Transaction price is set by the auctioning party.

Market Issues

The following sections briefly discuss some of the major issues that must be addressed in implementing agent-based market solutions. These issues all deserve additional research.

No Auctioneer

One of the objectives of the research project was to determine if multi-agent systems can be used to eliminate or reduce the role of independent third parties such as the PX or ISO in the energy marketplace. For this reason we have intentionally left out the role of central controller or central auctioneer in the proposed energy market. To compensate for the lack of any central control element we:

- Use the Dutch auction format since this is less vulnerable to auctioneer abuse than other auction formats.
- Post / record auction information in an open and public forum since this should help deter abuse by auctioning parties.

Transmission System Oversight/Control

Under the proposed agent-based market, TSO agents monitor the capacity (current and projected) of their own individual resources and update the posted web site capacity information accordingly. Actual approval of transactions and therefore commitment of transmission system resources is the responsibility of the entity/organization operating the auction web site. This organization, much like the ISO in the California marketplace, reviews all “pending” transactions to determine their feasibility. Individual transactions that overload the system or are otherwise unacceptable are changed from “pending” to “rejected” status while acceptable transactions are changed from “pending” to “recorded” status. Ultimately, a qualifier code that provides information on the reason for the status would also be included. As currently envisioned, the web site is used to indirectly notify the affected parties. This eliminates the need for direct communications between the approving organization and the bidding or auctioning parties.

Note that there are circumstances that could cause the approval organization to change the status of previously approved transactions from “recorded” back to “pending” or even to “rejected” status. Sudden loss of transmission system capacity (i.e., lightning strike, fire, etc.) is one such situation. Therefore, it is necessary for both bidding and auctioning parties to constantly review the status of their transactions. The intent is to allow the marketplace to respond to system events like these rather than a central agency. Whether this is a workable arrangement or will simply result in chaotic and unstable market behavior remains to be seen. It may be difficult in a real world scenario for the approval agency to evaluate the transactions quickly enough.

We are operating under the assumption that market participants will not knowingly try to overload the system. System calculations by both the bidder (prior to bidding) and the auctioning party (prior to recording) are required and should reduce the incidence of overloading. In the event the proposed arrangement is unworkable (unstable, chaotic, etc.) then we may need to:

1. Maintain or increase the amount of transmission capacity held in reserve.
2. Release transmission capacity or reduce the reserve capacity in steps as the hour of delivery gets closer. Transmission capacity is related to weather conditions, which can be unpredictable. Holding some capacity in reserve until the hour before (or possibly a few hours) would allow for some margin of error.
3. Require that auctioning parties contact each TSO that is affected by a proposed transaction and get clearance to proceed prior to posting the transaction.

These issues may not come into play during our research effort. During this effort, we have limited the transactions to a single hour beginning with the next hour. This limitation virtually eliminates variability due to weather. However, future research should investigate the issue of transaction loading. Increasing the number of market participants and the number of associated transactions will shed some light on this issue. However, large-scale experiments are needed to prove the value of this approach in a real-world environment.

Bidder Defections

Bidder defection is when a bidder backs out of a transaction prior to its execution. This can be disruptive to the marketplace since the auctioning party may not be able to move this capacity to other bidders (i.e., other bidders have pulled out, insufficient time remains before the next auction session, etc.) during this session. If this happens then the auctioning party will lose money when this capacity is posted (at a lower price) at the next session. If one assumes that this capacity will be sold at the next session then the loss is equal to the price difference between the two sessions.

Without a disincentive, there is little that prevents bidders from participating in multiple auctions and then defecting on transactions that either exceed their needs or are less advantageous. And in fact, it is to their advantage to defect as late as possible in the auction session in order to increase the likelihood that the capacity will become available in the next session at a more favorable price.

The remedy that has been proposed calls for payment of (or an agreement to pay) a deposit at the time the bid is placed. If the auctioning party is forced to exclude a bidder (due to a bid collision or transmission system problem) from the session there is no penalty. However, if a bidder chooses to defect then an amount equal to the auctioning party's potential loss is forfeited. Where the auctioning party's loss is equal to the amount of capacity that would have been transacted if the bidder had not defected multiplied by the price modifier that was posted in the auction session.

How to prevent bidder defection and the associated implications is an important issue that we will need to address during later research efforts.

Accumulating Bids vs. "First-Come First-Served"

The proposed energy market calls for auctioning parties to accumulate bids prior to processing as opposed to operating on a "first-come, first-served" basis. This is intended to provide more equitable access to bidders of varying levels of sophistication and also to eliminate communications advantages. However, in a system where transmission capacity is a limiting factor it may be advantageous for the auctioning party to evaluate bids and execute/record transactions as soon as possible so as to quickly lock up the available transmission capacity. Operating on a "first-come, first-served" basis has the added advantage of virtually eliminating bidder collisions. These negatives are balanced in part by the fact that accumulating bids allows the auctioning party to be more selective (i.e., give preference to larger bids, etc.).

This may be less of a concern in an asynchronous market (auctions open and close according to auctioning party's timing) since auction sessions will be closing and transactions recorded on a continuous basis.

Bid Modification due to Collisions

The proposed method for dealing with collisions attempts to provide an equitable solution. In an unregulated “real” world it is just as likely that an auctioning party would not go to the effort to achieve an equitable solution but instead would be more self-serving. We have chosen the equitable route based on the perception that the regulatory environment would not permit solutions that could unfairly exclude individuals from participating in the marketplace.

However, achieving an equitable solution is only possible up to a point (i.e., too many bidders, etc.) at which time it becomes necessary to exclude some bidders. We have chosen to exclude smaller or slower bidders based on the idea that a free market would penalize entities that are slow to act or have less purchasing power.

Transmission / Distribution System Costs

Equitable allocation of transmission and distribution system costs is a key issue in a market-driven energy marketplace. Transmission costs can be fixed or dynamic in nature. Fixed costs price the first and last increment of transmission capacity the same while more dynamic pricing could allocate higher costs as remaining capacity decreases. In the first case, there is no deterrent against over use while the second allows market forces to drive transmission use.

However, our research effort has focused on answering the more fundamental question of whether an agent-based market can function at all. EPRI is addressing the issue of transmission cost allocation in other projects and we not therefore attempt to address this issue in our effort. We make the assumption that transmission costs are fixed and are allocated based on the transmission capacity in use (i.e., x $/kWh transmitted, etc.). To further simplify our efforts we also assumed that each agent has a “road map” of the system that allows them to easily establish a transmission route and associated cost for each potential energy transaction. For example, an energy delivery from point A to point B will always travel through transmission line C at cost D. This will eliminate the need to run the system simulation for all potential transactions and reduce the computational burden on the agents.

SECTION 4 *Agency Implementation*

Demonstration Overview

This section of the report describes the prototype demonstration of agent technology created by Reticular Systems, Inc. and AESC. The purpose of this demonstration is to illustrate the use of agent technology in an electronic commerce application. This application is designed to show how agents can be used to implement an electronic marketplace. This demonstration is not meant to be a prototype of an actual marketplace. Because of budget and schedule constraints, the scope of this demonstration is quite limited. The demonstration shows how intelligent software agents acting as buyers and sellers of electric power can be used to implement an electronic marketplace.

Demonstration Agents

The demonstration marketplace is shown in Figure 4. The market is comprised of three different kinds of agents. These are the Buyer/Seller Agents, the Facilitator Agent and the Facilitator/Grid Interface Agent (also called the Experiment Control

Agent). The following paragraphs provide a brief description of the function of each of these agents.

Figure 4. The Demonstration Agency for Electric Power Trading

Buyer/Seller Agent (BSA)

The Buyer/Seller agents (BSA) buy and sell electric power. They represent either electric power producers (generators) or electric power consumers (loads). These agents are the primary participants in the marketplace and do all of the buying and selling of electricity.

A BSA can take on a number of different roles. Agents can, at any instant in time, be either buyers or sellers of electricity; they can also either be conducting an auction (to buy or sell) or they can participate in an auction as a bidder (to buy or sell). Table 3 summarizes the roles a BSA can fill. Note that all roles are not currently implemented in the demonstration system.

TABLE 3. Roles and Functions of Buyer/Seller Agent (BSA)

Role	Function	Description
Buyer	Auctioneer	Buy power
Seller	Auctioneer	Supply power
Buyer	Bidder	Buy Power
Seller	Bidder	Supply Power

Each BSA exhibits unique and individual behavior determined by its own unique economic and behavioral model. There are three components of each agent's behavior. These are:

- buying/selling strategy
- market supply/demand characteristics
- operational power quantity requirements

Strategy. Each BSA has a unique buying and selling strategy. BSAs can exhibit anxious buying and selling behavior, cool-headed behavior or greedy behavior. See Figure 5 for an illustration of different buying and selling strategies.

Market Supply/Demand. Each BSA has its own unique supply or demand requirements and unique operating policies for satisfying supply/demand requirements. These policies dictate how much each BSA is willing to spend/charge for power.

Operational Requirements. Each BSA represents a supplier or consumer of electricity. Each supplier or consumer has it own unique power requirements that vary over time. While market price may dictate agent buying/selling behavior to some extent, agents must still ensure that adequate amounts of power are bought and sold to sustain operations.

These three factors are used to compute supply and demand curves that determine the amount of power that each agent will require based on the price of that power. As prices go up, agents will be willing to consume less power and be willing to supply more power. As prices fall, agents will be willing to consume more power or sell less power. A supply curve describes the desired selling price for a quantity of electricity to be delivered at a given date and time. A demand curve describes the required buying price for buying a given quantity of electricity at a given date and time.

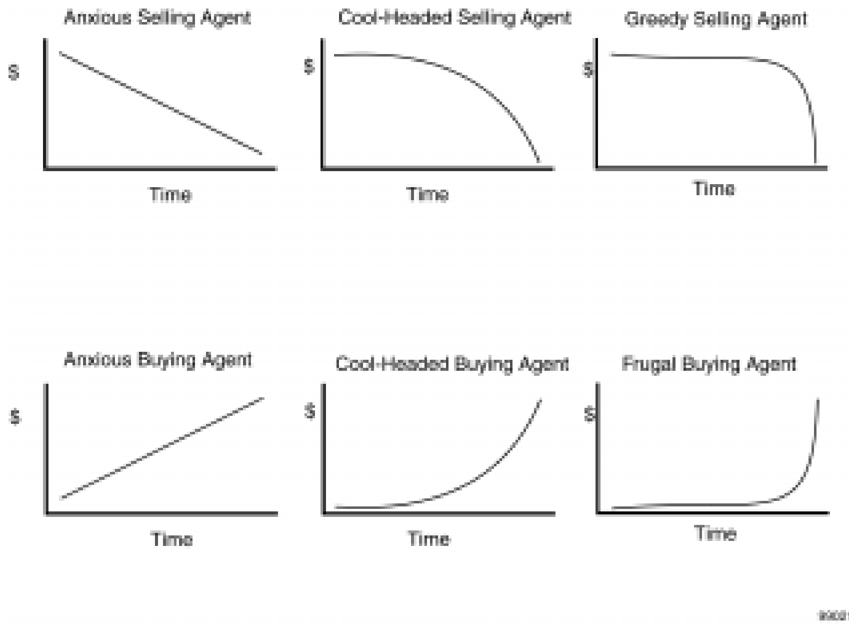

Figure 5. Buying and Selling Strategies

Facilitator/Grid Interface Agent (Experiment Control)

The facilitator agent provides a number of unique services to the electronic marketplace. The facilitator keeps tracks of all BSAs that are participating in the marketplace. Each BSA communicates with the Facilitator and indicates whether it wishes to buy or sell electricity and whether it wants to be a bidder or auctioneer in the marketplace. Thus, the Facilitator acts as a broker or matchmaker connecting buying agents with selling agents and auctioneering agents with bidder agents. Because of the small size of the demonstration system, a facilitator is not required and is not implemented.

The Grid Interface Agent (GIA) performs two major functions in the demonstration system. First, the GIA provides a mechanism for conveniently simulating the power industry infrastructure. In an operational system, this infrastructure (power supply and demand) will dictate the behavior of the BSAs. The GIA provides a convenient mechanism for setting up and controlling the operation of the individual BSAs.

In a production system, the GIA would be replaced by the institutional infrastructure that specifies the behavior of each BSA. That is, the buying and selling prices will normally be driven by economic and physical factors (e.g., how much power is available to sell and how much surplus generation capability is available for use). However, for the demonstration, we need a way of specifying the behavior of each of the BSAs. The GIA provides a convenient interface for doing this.

The GIA also provides a convenient way of setting up and controlling each BSA and examining the results of BSA activities (buying and selling). Thus, the GIA collects data from all market sessions and displays it in a convenient way (i.e., using the graphical user interface on the GIA).

The Market Place

The market consists of a combination of buyer and seller agents taking on roles as either bidders or auctioneers. The agents are each assigned a role (as buyer or seller and auctioneer or bidder) by the demonstration operator using the GIA. The agents then conduct an auction buying and selling electricity in accordance with the economic needs and buying and selling strategies of the individual agents. For purposes of demonstration, the initial scenario allows only suppliers to auction and buyers to bid.

Demonstration Scenario Description

An agent initiates an auction by advertising that it is going to conduct an auction and specifying the time of the auction. All bidders interested in participating in the auction can then join the auction and submit bids. Each auctioning agent can be viewed as conducting an auction that is selling/buying 24 items - power supply or demand for one specified hour on a given day in the future.

The auctioning agent will offer a quantity *Q* of electricity at an asking price *AP* for delivery at hour *H* on delivery day *D*. The agent will also specify when the next round of the auction will be held for selling the remaining power not sold in the current round as well as the price adjustment *PA* that will be applied to the remaining power asking price in the next round. Each auctioning agent will also maintain a reserve price *RP* that specifies the minimum/maximum price that the agent will accept before refusing any further transactions at a lower/higher price. The *RP* is known only to the auctioning agent and is not made available to bidding agents. Note that an auctioning agent may decide to reintroduce this block of capacity back into the marketplace at some later time.

Agents that want to buy/sell power from/to the auctioning agent specify the quantity that they are willing to buy/sell at the specified price. The auctioneer then forms a contract with the bidder to deliver that power (subject to collision constraints). Agents are encouraged to buy during a particular round because they cannot be sure that they can get the power they require in a later round if it is purchased in this round by some other agents. While bidder agents may wish to defer contracting with the auctioneer, they do so at the risk of being unable to acquire the amount of power that they require.

Figure 6 illustrates a typical auction. For the demonstration, the initial round is for delivery of power at the specified hour seven days in the future. The next round is for delivery of power at that same hour six days in the future. If bidding continues to the last round, then this round is for sale of power to be delivered on the next day. Note in this particular example that the price profile shows that the agent will reach its reserve price before all seven rounds of the auction is completed. Since bidders don't know when the reserve price will be reached and the remaining power withdrawn from the market, they are encouraged to bid early in the round.

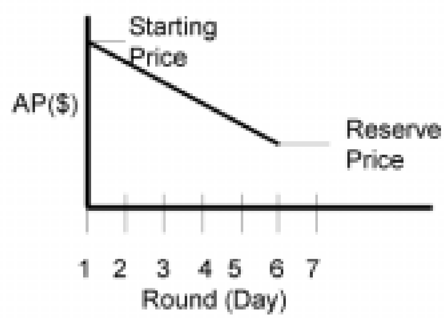

Figure 6. Market Operation

Note that the example auction is for one day intervals but the auction interval during a demo session can vary from as little as one hour to as long as one day. This interval is set prior to the start of a demo session and is fixed for a particular agent during the session. Thus, auction intervals will vary from one agent to the next.

Agent Communication

In order to perform their individual tasks, each agent must communicate with other agents in the agency. The following paragraphs provide an overview of the communication between the various agents in the auction agency.

Auction Setup

The Experiment Control agent sends a setup message to the Buyer/Seller agents. The setup message contains information about the Buyer/Seller agent's role, capacity and behavior curves, and it's trading partners. The Buyer/Seller agents return an acknowledgment when they are ready to begin the auction. The setup and ready messages sent between the Experiment Control agent and the Buyer/Seller agents are illustrated in Figure 7.

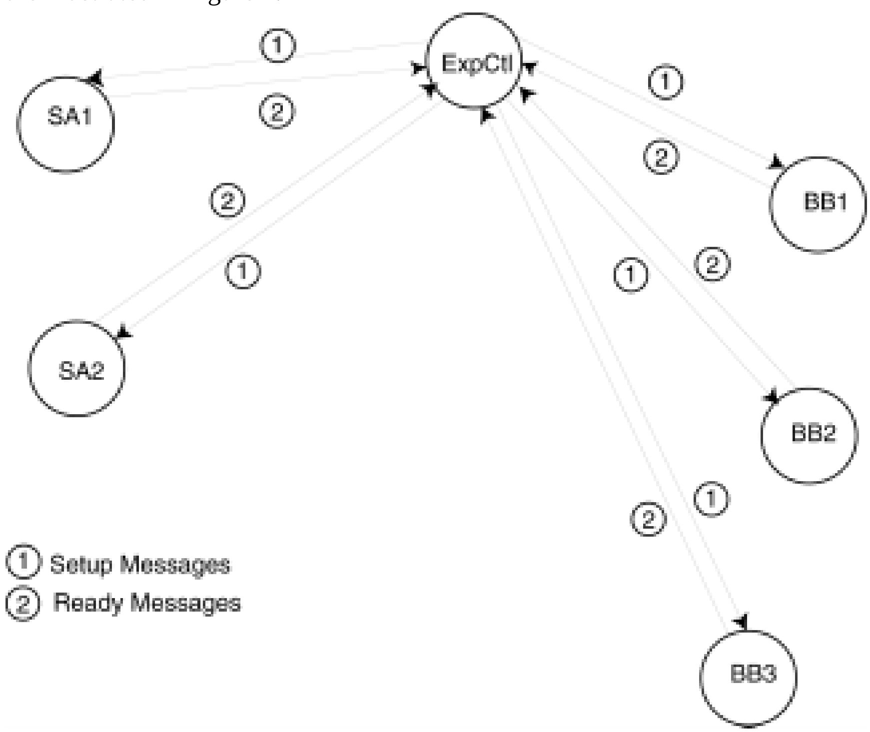

Figure 7. Agency Setup Protocol

Auction Sessions

Once the Buyer/Seller Agents are properly set up and ready to begin execution, the auction session cycle begins. The Experiment Control agent sends a time update to each of the Buyer/Seller agents. The Buyer/Seller agents send an acknowledgement back to the Experiment Control agent. The Experiment Control agent sends a message to the Buyer/Seller agents telling them it is okay to proceed with the auction session. The message protocol for sending a time update is in Figure 8.

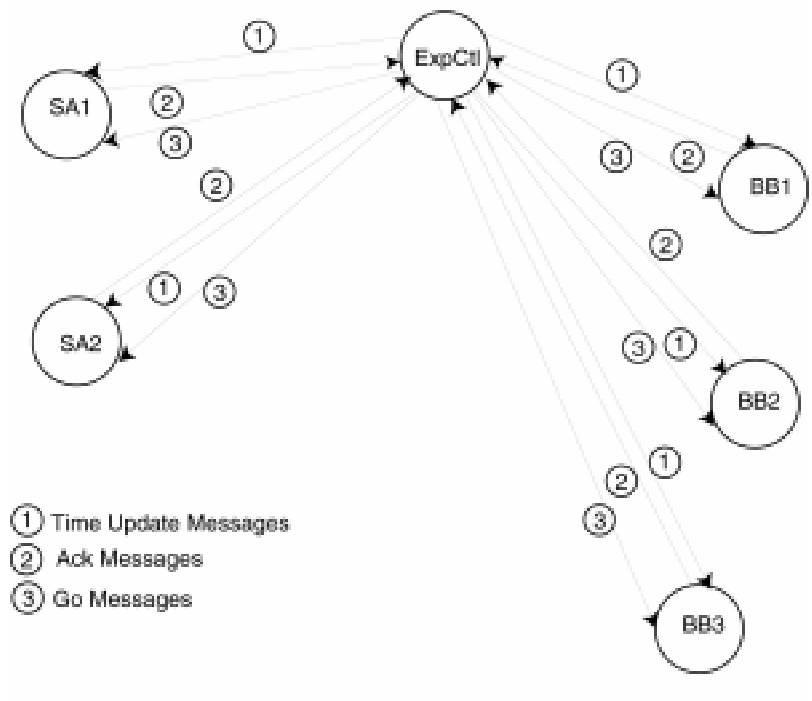

Figure 8. Agency Time Update Protocol

The Seller agents generate offers to sell one-hour blocks of electric power. The offers are based on their individual capacity and behavior curves. The offers are sent to each of the Buyer agents. This is illustrated as message “4” in Figure 9.

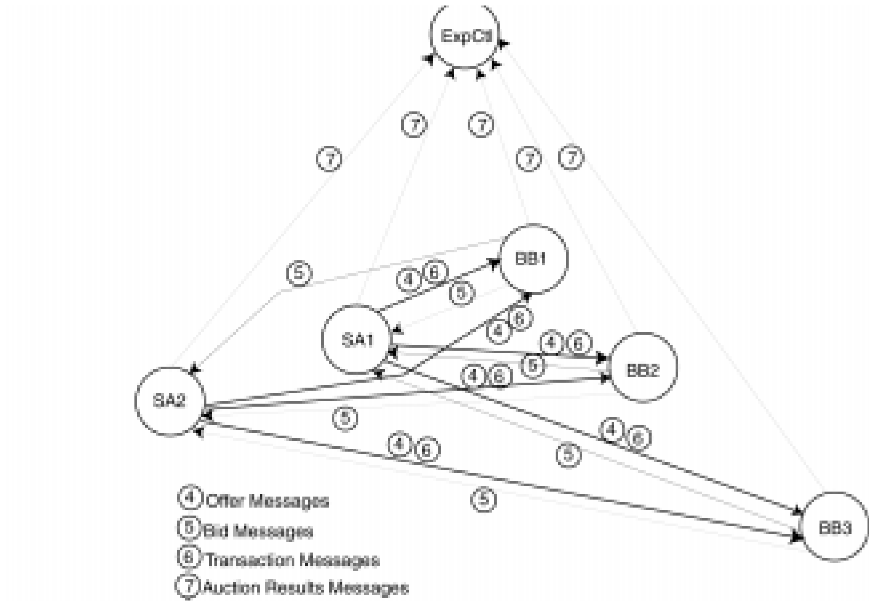

Figure 9. Auction Session Protocol

The Buyer agents generate bids for the blocks of power based on their capacity curves, behavior curves, and the prices in the offers. Bids are sent in messages that are delivered to the appropriate Seller agents. The offer messages are illustrated as message “5” in Figure 9.

The Seller agent receives all the bid messages from the Buyer agents. The Seller agent generates transactions, or commitments, based on the bids it received from the Buyer agents. Since the price for each bid for an item matches the offer, the bids with the greatest capacity are taken first. The transactions are sent to the appropriate Buyer agents. The bid messages are illustrated as message “6” in Figure 9.

Once transactions have been sent to the Buyer agents, the commitments are used to update the amount of electric power which still needs to be sold to meet its capacity curve requirements. The Seller agents then send their individual view of the auction to the Experiment Control agent. This view of the auction includes the number of offers, number of bids, and a complete transaction record for each of the 24 hours covering the power delivery date. The auction results message is illustrated as message “7” in Figure 9.

The Buyer agents receive the transactions from the Seller agents. The transactions are used to update the amount of electric power that still needs to be purchased to meet its capacity curve requirements. The Buyer agents then send their individual view of the auction to the Experiment Control agent. The auction results message is illustrated as message "7" in Figure 9.

The auction session cycle ends when the Experiment Control agent receives auction results from each of the Buyer/Seller agents.

Interface Description

The Experiment Control Agent provides a graphical user interface to control the simulated auction session and view the results as they are generated. Figure 10 illustrates the user interface.

The major sections of the interface are described in the paragraphs below.

Control Panel Buttons

The Control Panel contains five buttons that are used to control the operation of the software. Any of the buttons may be pressed at any time during the auction. The software checks for button presses at the end of each auction session. The last button pressed in an auction session is the button press that is used for subsequent processing. If more than one button is pressed or a button is pressed multiple times during an auction session, all but the last press will be ignored.

The **Initialize** button initializes the experiment control agent and causes it to send an initialize message to all the agents. The **Initialize** button must be pressed at least once in order for the software to run. To restart a auction, press **Initialize** at any time during the auction. The software will complete execution of the current auction session and then begin the initialization process.

The **Step** button is used to execute a single auction session; the system then waits for another command.

The **Run** button executes multiple auction sessions until the end of the auction. The end of the auction is reached when the simulated time reaches the delivery date. If another button (such as the **Step** button) is pressed during an auction session, the software will halt multiple auction sessions.

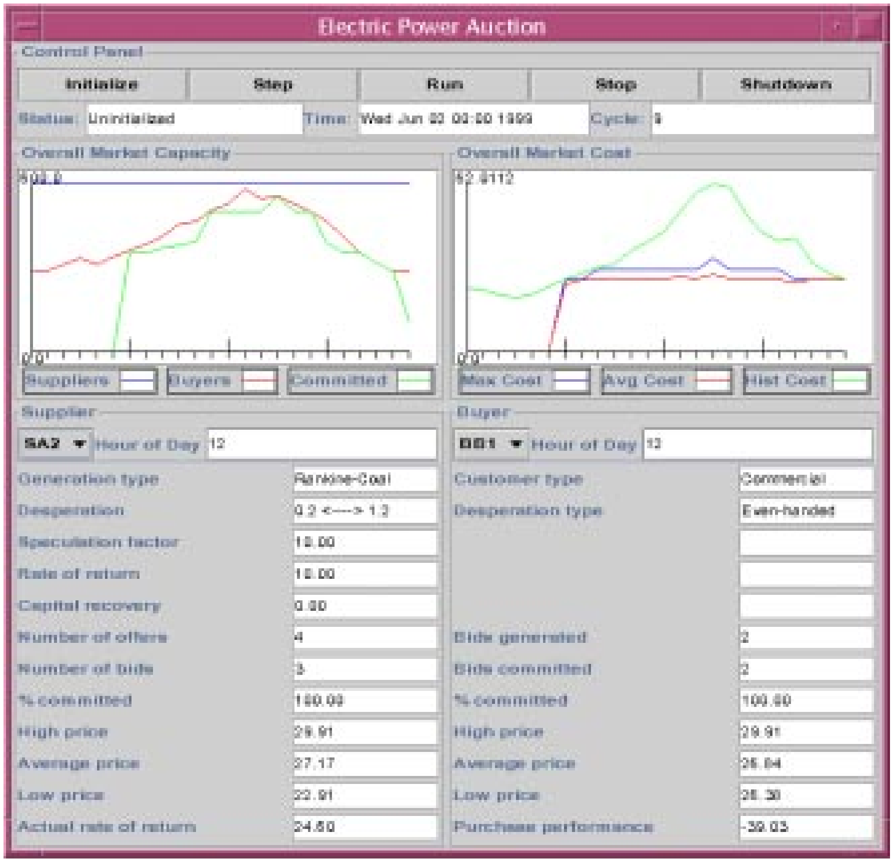

Figure 10. Experiment Control Panel

The **Stop** button stops executing auction sessions and causes the system to wait for another command. Continue the auction using either the **Step** or **Run** buttons after the auction has been stopped with the **Stop** button.

The **Shutdown** button halts all software execution. The Experiment Control Agent sends a `quit` message to the buyer and seller agents. Once the buyer and seller agents have been successfully halted, the Experiment Control Agent and the interface software stop execution.

Control Panel Information Display

The status of the agency is displayed in the **Status** text field. The software is initially not initialized. The **Initialize** button must be pressed at least once to place the software into a *Ready* state. During the execution of an auction session a *Running* status is displayed. The software can also be in a *Stopped* state.

The current simulated date and time is displayed in the **Time** field. The date and time information includes the year, month, day of the month, day of the week, hours based on a 24 hour clock, and the minutes past the hour.

The number of auction sessions that have been executed is displayed in the **Cycle** text field.

Overall Market Capacity

The **Overall Market Capacity** panel provides a color-coded display of the *total capacity for suppliers* (blue), *total capacity for buyers* (red), and *total capacity committed* (green). The information is displayed as a line graph with three curves covering the 24-hour delivery date.

The total capacity for suppliers is the sum of the capacities for each of the seller agents. The supplier capacity is the capacity that may be generated at the delivery date. The total capacity for buyers is the sum of capacities for each of the buyer agents. The buyer capacity is the capacity needed at the delivery date. The total capacity committed is a running total for each of the 24 hours in the delivery date. The curve is a summation of all commitments for all buyers for each of the hours.

Overall Market Cost

The **Overall Market Cost** panel displays the total cost for buyers for each of the 24 hours in the delivery day. The information is displayed as a color-coded line graph with three curves – *maximum cost* (blue), *average cost* (red), and *historic cost* (green). The maximum cost is the highest cost paid by any of the buyers for each of the 24 hours in the delivery date. The average cost is the mean of the cost paid by all the buyers for each of the 24 hours in the delivery date. The historic cost is the price paid in the past for each of the 24 hours in the delivery date.

Supplier Status Information

The **Supplier** text panel provides information about one supplier for a specific hour. The panel provides a combo box that allows the user to choose any of the suppliers in the agency for status display. The panel also includes a text field that allows the user to specify the delivery hour of the day. The delivery hour must be an integer between zero and 23.

The next five fields in this panel provide static information about the chosen supplier. The **Generation Type** field identifies the method used by the supplier to generate power. The **Desperation** field is a range of desperation values that are used to set prices. **The Speculation Factor**, **Rate of Return**, and **Capital Recovery** fields specify values that are also used to set prices.

The bottom seven fields in this panel provide dynamic information that changes during a particular auction session. The **Number of Offers** is the number of auction sessions in which an offer has been generated for the chosen delivery time. The **Number of Bids** is the number of bids that have been received over all auction sessions for the item. The **Percent Committed** is the ratio of committed capacity to the total capacity that the supplier desires to sell for the chosen delivery time. The **High price**, **Average price**, and **Low price** fields show the highest, lowest, and mean prices for commitments made in the auction sessions for the item. The **Actual rate of return** is computed using the actual price information found in the commitments for the item.

Buyer Status Information

The **Buyer** text panel contains information for one buyer and a specific hour. The panel contains a combo box that allows the user to select any of the buyers in the agency. The panel also contains a text field that allows the user to specify the delivery hour of the day. The delivery hour is an integer between zero and 23.

The first two fields provide static information about the selected buyer. The **Customer type** identifies the type of buyer. Example types include *industrial* or *retail*. The **Desperation type** is an indication of the urgency of the desired capacity for the buyer. The **Desperation type** field defines the degree or level of desperation of a buyer to buy power. A buyer can be *greedy*, *even-handed*, or *desperate*.

The final seven fields provide dynamic information that changes in any particular auction session. The **Bids generated** field specifies the number of bids that have been generated for the item. The **Bids committed** field shows the number of bids that have been committed. The **% committed** field shows a comparison between the capacity committed and the desired capacity for the delivery time. The **High price**, **Average price**, and **Low price** fields show the highest, lowest, and mean prices for commitments made in the auction sessions for the item. The **Purchase performance** field shows a comparison of the actual price paid for the item with the historic price paid for the item. This value is displayed as a percentage.

Log File Description

The software generates a log file to capture the results of the auction. The log file can easily be read into a spreadsheet. The log file contains a block of agent information that includes the static information about each of the agents participating in the electric power auction. This block of agent information is followed by repeating blocks of auction session information and overall market information. There is a block of auction session and overall market information for each auction session.

Agent Information

A block of static agent information is the first information written to the log file. There is a one-line header for the block containing the “Agent Information” label. This is followed by smaller blocks of text for each of the Buyer/Seller Agents. Each of the smaller blocks contains eight lines of text. An example is shown in Table 4.

TABLE 4. Sample Agent Information Block

Agent Name	SA3
Customer Type	N/A
Desperation Type	N/A
Generation Type	Combine Cycle-Coal
Desperation	0.00 <----> 1.00
Speculation Factor	10.00
Rate of Return	10.00
Capital Recovery	0.00

The *Agent Name* applies to both buyers and sellers. We have established a convention that buyers use names in the form BBx, where BB represents buyer bidder and x is a number. Also, by convention, the sellers have names in the form SAx, where SA represents seller auctioneer and x is a number. The *Customer Type* and *Desperation Type* apply to buyers only. The values for Customer Type and Desperation

Type are text that provide general information about the buyer. The remaining five parameters have values of N/A because they do not apply to buyers.

The *Speculation Factor* specifies the additional that you are willing to forego as desperation increases. *Rate of Return* defines the amount of operating profit you hope to receive. *Capital Recovery* is the amount of the capital costs that are added to offers. The *Generation Type*, *Desperation*, Speculation Factor, Rate of Return, and Capital Recovery apply to suppliers only. The Generation Type is a text description identifying the method used to generate power. The Desperation is a range of values used to set prices. The Speculation Factor, Rate of Return, and Capital Recovery are single values that are also used for setting prices. The Customer Type and Desperation Type have values of N/A because they do not apply to suppliers.

Session Information

A block of session information is written to the log file at the end of each auction session. The information in this block represents activity in only the auction session identified and is not a running total across multiple sessions.

There are four lines of header information preceding a block of session information. The first line contains the “Session Information” label. The second line contains the simulated current date/time and the delivery date/time. The third line contains an “Agent” label followed by a comma-delimited list of buyer and seller agents. Since there is nine data items for each Buyer/Seller Agent, the name of each agent is repeated nine times. This places the name of the agent at the top of each column of data that applies to the agent. The fourth line contains an “hour” label followed by a comma-delimited list of labels for each of the nine data items. The labels are “#offer, #bid, #comm, %comm, high$, avg$, low$, ror, perf,” and are repeated for each of the Buyer/Seller Agents. The “#offer” label is the number of offers made for the item. The “#bid” label is the number of bids made or received for the item. The “#comm” label is the number of commitments made for the item. The “%comm” label is the percent committed. The “high$” label is the highest price paid for the item. The “avg$” label is the mean price paid for the item. The “low$” label is the lowest price paid for the item. The “ror” label is the actual rate of return for the item. The “perf” label is the purchase performance for the item.

The header information is followed by 24 lines of comma delimited values. The lines mirror the fourth line of header information except instead of labels, the values matching the labels are used. The line begins with a number representing the hour of the day. The hour ranges from zero to 23. The remainder of each line contains sets of nine values each.

Overall Market Information

A block of overall market information is written to the log file at the end of each auction session. The information in this block represents a running total of overall market activity. There are three lines of header information for a block of overall market information. The first line contains the “Overall Market Information” label. The second line contains the simulated current date/time and the delivery date/time. The third line contains an “hour” label followed by a comma delimited list of six labels. The six labels are “cap_sellers, cap_buyers, cap_committed, max_cost, avg_cost, hist_cost”. The “cap_sellers” label is the total capacity for the suppliers. The “cap_buyers” label is the total capacity for the buyers. The “cap_committed” label is the total capacity committed. The “max_cost” label is the maximum cost paid for the item. The “avg_cost” is the mean cost paid for the item. The “hist_cost” is the historic cost paid for the item. The header information is followed by 24 lines of comma delimited values. The lines mirror the third line of header information except that instead of labels, the values matching the labels are used. A line begins with a number representing the hour of the day. The hour ranges from zero to 23. The remainder of each line is a set of three capacity and three cost comma-delimited values.

SECTION 5

Running the Electric Power Market Agency Demonstration

Starting the System

There are three ways to run the system. You can run the system in “standalone” mode with no agents (i.e., simulate the agents), using just the agents or using the agents and the AgentBuilder AgencyViewer to inspect the communications flowing between agents.

Running Standalone

The first methods allows execution without requiring actual agents. This is accomplished using the `standaloneDriver`. To start the system double-click the `standaloneDriver.bat` file (using Windows Explorer program) and an auction Control Panel frame will be displayed. At this point, you can control the entire run using the control panel. The system behaves exactly like a system running with agents, but only simulates the agent behavior. This method uses the same set of resource files and creates the same logs as the other two techniques. This technique is useful for demonstrating the operation of the system without having to deploy and control multiple agents.

Running Agents Only

The second technique executes the agents but without a capability for examining the message communication between agents. To run the system using this method, double-click the `startAuctionAgentsNonAgencyMode.bat` file and the agents will be started. You will see the console windows of each agent appear. After the auction control panel is displayed, you can start the auction. You should see output in the console window of each agent as the auctions proceed. If any errors are generated and displayed, then there is likely a configuration problem in the system setup.

Running Agents and Viewing Communication

The third technique executes the agents and uses the AgentBuilder AgencyViewer. This is the most complicated technique but provides much more visibility into what is happening in the system. The AgencyViewer tool is a graphical tool to allow you to view communication messages flowing between the agents. An icon represents each agent and lines are drawn between the icons to represent each communication message sent between agents.

The AgencyViewer tools is part of the Reticular's AgentBuilder product. When the AgencyViewer is started a window with eleven agent icons will appear. The are five bidder/buyers (BB1 - BB5), five sellers/auctioneers (SA1 - SA5) and one experiment control agent (ExpCtl). The AgencyViewer is shown in Figure 11.

Running the System

There are 5 basic operations performed with the Control Panel: Initializing, Stepping, Running, Stopping and Exiting. When the auction Control Panel appears, the user can run the auction. Figure 12 shows operation of the complete system.

The Auction Control Panel contains five buttons that are used to control the operation of the software. Any of the buttons can be pressed at any time during the auction with certain restrictions as noted below.

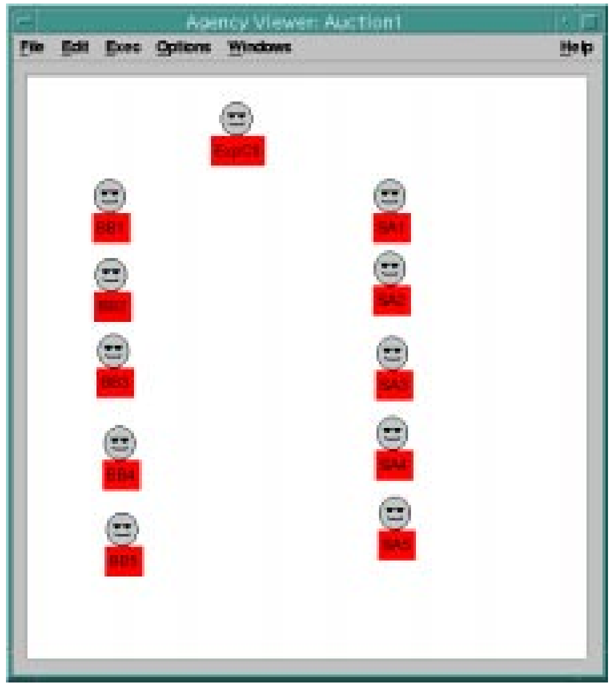

Figure 11. The AgentBuilder Used to View the Market Agency

The **Initialize** button initializes (or re initializes) the Experiment Control agent and causes it to send a setup message to all the agents. The Initialize button must be pressed at least once in order for the software to run. If the user wants to restart an auction, the initialize button can be pressed at any time during the auction. The software will complete the current auction session and then begin the initialization process. The **Step** button executes one auction session and then waits for another command. The **Run** button causes the software to run through multiple auction sessions until the end of the auction is reached. The end of the auction is reached when the simulated time reaches the delivery date. If the **Stop** button is pressed during an auction session, the software will stop multiple auction sessions. The **Stop** button will cause the software to stop executing auction sessions and place the system into *Ready* mode. It is possible to continue the auction using the **Step** or **Run** buttons after the auction has been stopped. The **Shutdown** button causes a shutdown of the software. The experiment control agent sends a quit message to the

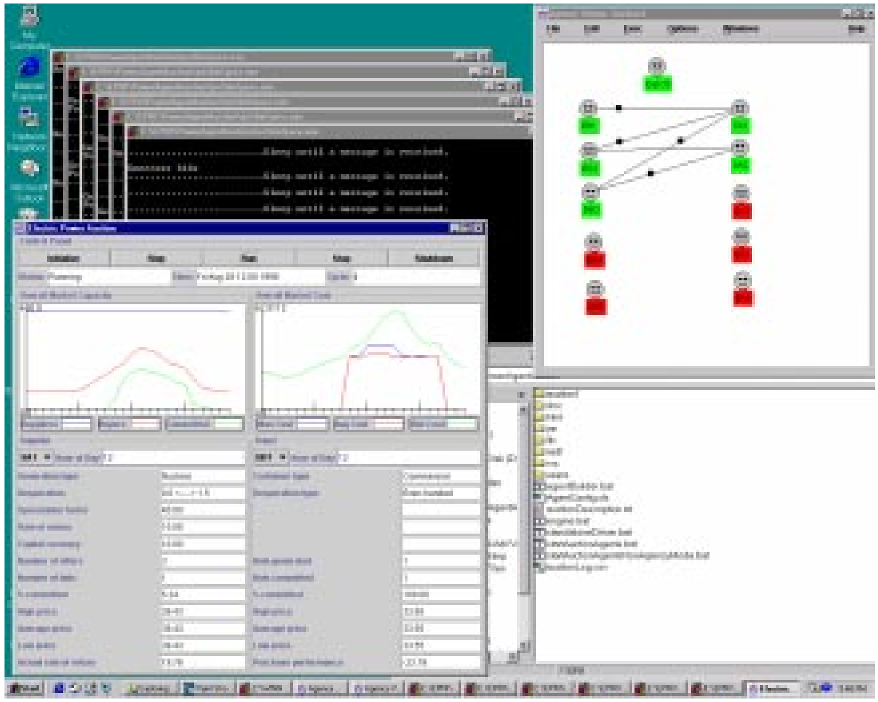

Figure 12. Executing the Agency By Running Multiple Agents

buyer and seller agents. Once the buyer and seller agents have been successfully shut down, the experiment control agent and the interface software shuts down.

Control Panel Text

The software continuously checks for button activations but the action is only performed if it is a legal operation at the time the button is pressed. The **Step** and **Run** buttons can only be selected when the system is ready. The system is in the Ready state only after initialization, i.e., after the **Stop** or **Step** buttons have been actuated. The **Stop** button is enabled only while the system is running (after the **Run** button has been clicked). The **Shutdown** button can be actuated at anytime.

Modifying the System

There are two ways to modify the auction: (1) modify the number of agents and their behavior (through the AgentConfig.xls spreadsheet) or (2) distribute the agents over several computers.

Capacity and Behavior Curve Descriptions

Excel Configuration Workbook

This section describes the steps required to configure an auction session using an Microsoft Excel spreadsheet/workbook. These spreadsheets provide a convenient mechanism for creating configuration files that define the auction and the buyer and seller agents participating in the auction. This workbook has been designed to simplify the process of setting up an auction session. There are four steps to the configuration process; these are accomplished by completing the worksheets/tabs in this workbook. The four basic steps are:

1. Auction Setup (session type, number of suppliers and buyers, and their energy requirements/capacities).
2. Supplier Agent Setup (generation type, profit goal, and auction strategy).
3. Buyer Agent Setup (business type and bidding strategy).
4. Save Setup.

Note that cells requiring user input are shown in blue.

Step 1: Auction Setup

To configure the auction, fill in a session type (summer or winter) along with the desired number of supplier and buyer agents. The up and down arrows may be used to increase or decrease the number of agents or a number can be entered directly. Once you have decided on the number of agents, you will need to specify the agent's capacity (for supplier agents) or peak load requirement (for buyer agents), along with an auction interval for each supplier agent. The auction interval represents the time interval between auction sessions (auction session interval). To facilitate auction setup the spreadsheet automatically calculates and displays the "market" position (% of market) of the supplier and buyer agents. The number of agents that have been configured via the supplier and buyer configuration worksheets is also displayed.

Step 2: Supplier Setup

To configure a supplier agent, start by selecting the name of an agent from the provided drop-down list. This agent must be one for which you have already entered a capacity and auction interval on the Auction Configuration page. The spreadsheet will automatically fill in the maximum and minimum capacity fields based on your previous inputs for this agent. Next, select the unit and fuel types from the drop-down lists provided.

The next seven fields all determine the amount of profit the agent will try to attain as well as the minimum profit the agent will accept. The desperation factor is a linear function that determines how low the supplier is willing to reduce the asking price as the auction progresses.

Desperation(0) gives the supplier's desperation at the end of the auction, while desperation(168) is the desperation at the start of the auction. The higher the desperation, the lower the asking price can become as the auction progresses. Refer to comments attached to various input fields for information specific to that field (i.e., suggested input ranges, limitations, etc.).

Once the agent is configured, click the update summary button to copy the agent information to the agent summary sheet. Repeat the above steps for all of the supplier agents in the auction.

Step 3: Buyer Setup

Buyer agent setup only needs three pieces of information. The first is the agent name. As with the supplier configuration, this must be the name of an agent for which you have already entered a peak demand requirement on the Auction Configuration page. Next, select a customer type - commercial, industrial, or retail, which determines the characteristic load shape.

Finally, select a desperation type. Unlike the supplier where you entered a starting and ending desperation factor, you select one of the three non-linear desperation characteristic curves - desperate, even-handed, or greedy. A plot of the non-linear desperation characteristic that was selected is displayed in the lower right portion of the Buyer Configuration worksheet/tab along with the load profile and historic MCP's that the buyer will use to formulate bids.

Once the agent is configured, click the update summary button to copy the agent information to the agent summary sheet. Repeat the above steps for all of the buyer agents in the auction.

Step 4: Save Setup

Once you have configured the various supplier and buyer agents, click the save configuration button on the auction configuration sheet. This will cause the configuration files to be generated for use by the agent software.

You will be prompted for the name of a directory in which to save the configuration files. This directory will be created below the directory containing this Excel workbook. For example, if this Excel workbook is in `C:\Demo`, and you enter *Config1* to the prompt, the configuration files will be saved in `C:\Demo\Config1`. If the directory you specify already exists, any existing configuration files will be replaced.

Note that the number of supplier and buyer agents that have been configured is displayed on the auction configuration worksheet adjacent to the input fields for the desired number of agents. These values should match prior to saving your configuration.

Note that if you modify the number of buyers or sellers, the `startAuctionAgents.bat` and `startAuctionAgentsNonAgencyMode.bat` files need to be altered to stop the correct number of agents. Simply copy a line and alter the name to start a new agent, or delete one if the number is being decreased.

Distributing the Agents

Each agent runs in its own Java virtual machine, so it may be necessary when running the system in multi-agent mode to distribute the agents across multiple machines. Several steps must be completed in order to distribute the agents. The AgentBuilder manuals are included in the distribution and should be referenced for more details about the distribution process. The steps for distribution include:

- Modify the properties of the agent to meet the requirements of the machine each agent runs on.

- Modify the agency properties to meet the requirements of the machine the AgencyViewer is running on.

- Generate the RADL files for each agent.

- Copy the modified system to all of the machines that are hosting the agents. Do not install the default system; rather install the version you have modified.

- Modify the startAuctionAgents script on each machine to start only the agents for that specific machine. Currently, this script starts all agents so the lines in the script starting the other agents (which run on different platforms) must be deleted.

- Start the AgencyViewer (if desired) and start all agents on the various machines. You should now be able to run the system in distributed mode.