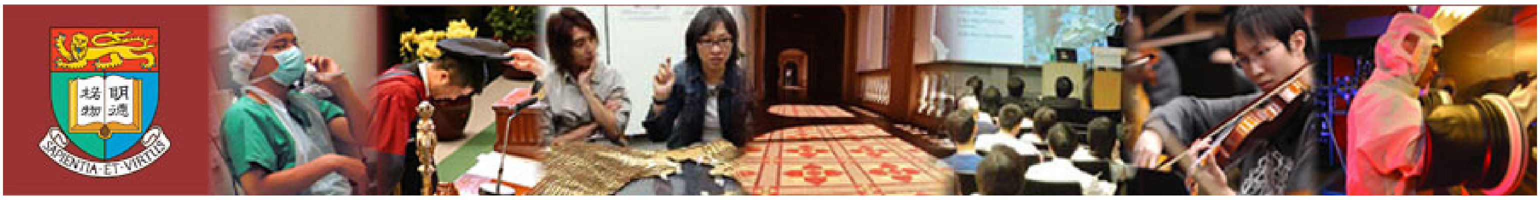

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Framework Design of a General-purpose Power Market Simulator Based on Multi-agent Technology

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Abstract: Power system deregulation has become a worldwide trend which introduces competition in power system in order to realize efficient electricity production and investment. In this regard, power market simulator will be a useful tool to study bidding strategies, market operation and market power and to train market operators. In this paper, the framework design of a novel power market simulator based on the state-of-the-art multi-agent technology is suggested and described in detail, which is the first phase in developing a general-purpose power market simulator.

Keywords: Power market, system deregulation, multi-agent technology, Internet, power market simulator

I. INTRODUCTION

Power system deregulation has become a worldwide trend to introduce competition into the traditionally monopolized industry in order to realize efficient electricity production and investment. Power markets have been established in UK, EU, Chile, Argentina, New Zealand, Australia, California of USA etc. [1], and more countries are going to establish power markets.

Under such a circumstance, power market simulator would be a useful tool to study bidding strategies, market operation and market power and to train market operators.

Prior to this paper, a few power market simulators have been developed. They can be generally grouped into two categories. One is mainly for the study of bidding strategies in order to find a way to maximize the economic benefits of a specified market participant. Usually only sellers and buyers are simulated. Other market participants, e.g. ISO and PX, are ignored because of the accentuation of simulation. MARKET by EPRI and Iowa University[2], PROSYM by Henwood Energy Services Inc.[3] and a power pool simulator drafted in [4] are within this group. Different algorithms are brought forward for price calculation and forecasting. Simulators of the other category are mainly for nenergy generation scheduling and investment planning based on bidding data. Examples can be found with PowerWeb by Cornell University[5], EOPS EMPS & SHOP by SINTEF Energy Research[6], MAPS by GE Company[7] and a simulator depicted in [8]. Algorithms for production cost and bidding prices, sometimes the amount of supplies or demands, are all preset or abstracted from historical databases for simulation. Gaming behavior of the participants is ignored.

In general, the existing power market simulators have reflected only part of a realistic model. The main limitation is that they cannot cover a wide-range of functions: bidding strategy test, market behavior, interaction of players, system operation, congestion mitigation, settlement, market power study and market operator training etc..

In this regard, we plan to apply the new state-of-the-art multi-agent technology to develop a general-purpose power market simulator to achieve the above goal. The simulator should be able to demo different types of power markets and study various bidding strategies and their interplay. The dominant features of the simulator are:

- A flexible framework is suggested to accommodate distinct market participants, their interactions and their communication. And different models of markets (single buyer, wholesale, retail competition) can be simulated with ease.
- A versatile wrapper mechanism is provided so that different decision-supporting applications for different participants can be embedded.
- The simulator can heterogeneously integrate and cooperate different computer systems and work in a distributed and open environment.

As the first phase of the development, an advanced and flexible framework using the state-of-the-art multi-agent technology is suggested and implemented, which is described in detail in this paper.

This paper is organized as follows: In part two, the participants and their functions in a power market are presented. Part three outlines the new technologies applied to the simulator. Part four describes the implementation and part 5 summarizes this paper with a brief introduction of future work.

II. POWER MARKET PARTICIPANTS AND THEIR FUNCTIONS

There are different types of power markets in the world [1,9]. A general-purpose spot market simulator should be able to simulate different types of power markets and their participants' behaviors with ease. Thus, to facilitate the simulation, participants of power markets should be modeled separately, but with links as shown in Figure 1. Their responsibilities and functions are summarized below:

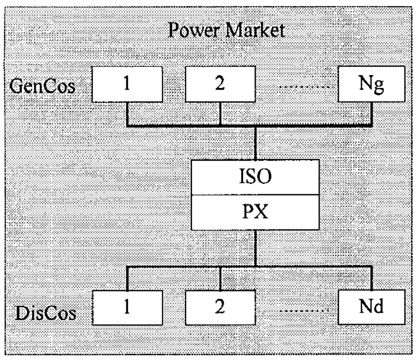

Fig. 1 Power market Participants

- Power Exchange (PX): It maintains a competitive market for all the suppliers and purchasers and determines the electricity market clearing price for day-ahead and hour-ahead markets according to the biddings. It also performs related settlement functions.
- Independent System Operator (ISO): ISO is responsible for system security and transmission system operation. It should also realize forward contracts and spot market transactions and take care of real-time power balances with security constraints considered. It should also provide and coordinate ancillary services and settle the bills related to real-time operation.
- Generation Company (GenCo): GenCo supplies electricity and part of ancillary services. It bids to the PX and provide supplies with agreement. Brokers and IPP can be regarded as GenCos. GenCos try their best to maximize their profit in the market via strategic bidding.
- Distribution Company (DisCo): DisCo bids to get the supply according to the forecast of energy demand. Utilities and large users can be regarded as DisCos. DisCos are aiming at purchasing electricity at lowest price from the market.

Except the participants mentioned above, an information board, called 'OASIS', is designed to let PX and ISO announce market information to the players.

III. NEW TECHNOLOGIES APPLIED TO THE SUGGESTED POWER MARKET SIMULATOR

A. Multi-agent Technology for the Overall System

Multi-agent technology is a new multi-disciplinary topic of distributed intelligence and computer science. [10,11,12] The features of this technology show its great potential to be applied to the general-purpose power market simulator we are going to develop. With different so-called *software agents* simulating different power market participants and the cooperation and coordination, a general-purpose power market simulator can be developed with high efficiency and quality. Such a simulator would be with high flexibility for practical market simulation.

Though there has not been a commonly agreed definition, a software agent is regarded as a software entity which is reactively located in an environment, autonomous, capable of self-contained problem solving, and with certain goals or objectives. Features of software agents are as follows:

- Autonomy: agents are able to make decisions about what to do based on the states encapsulated inside.
- Reactivity: agents are able to respond in a timely fashion to its environment changes.
- Proactiveness: agents are able to exhibit goal-oriented behavior by taking the initiative.
- Social ability: agents interact with other agents via agent communication language (ACL) to be engaged in social activities such as cooperative problem solving.

A multi-agent system is the assembly of agents and the environment in which agents reside. Such environment includes the communication and the interaction between agents, the intervention of human beings, and the supporting applications. Thus, relationships of cooperation or coordination as well as competition between the participants of a power market and the communication between them can be simulated in the environment of a multi-agent system with ease.

B. JATLite as the Platform

A multi-agent technology based platform is needed to develop the power market simulator. With regard to the requirements, the platform must have the following features to be adopted:

- Gives flexibility for the system to change the structure. Adding, removing or combination of agents should be allowed so that a system based on the platform can either expand or shrink.
- Supports full mobility of the agents. That means agents are free to be online, offline or migrate to other physical addresses with no affection to their functionality.
- Offers reliable message delivery and basic security to meet the critical communication requirement for market trading.

In this paper, JATLite [13] is selected to be the platform. JATLite, together with multi-agent system construction tools and APIs offered, is a heterogeneous multi-agent platform developed by the Center for Design Research of Stanford University. It is implemented in Java and has all the required features. Figure 2 is a schematic diagram of the platform.

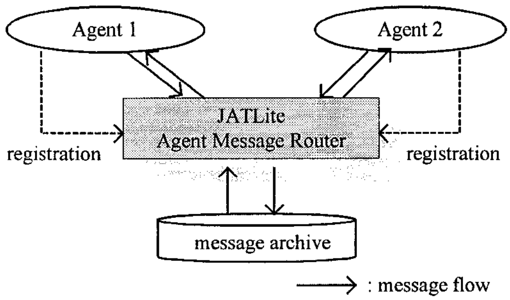

Fig. 2 Agents communication through the AMR of JATLite

The core of JATLite is the agent message router (AMR). Agents communicate through the AMR. AMR also provides agent name service (ANS). As soon as an agent is online, its location (IP address and the communication port) are refreshed in the storage managed by the ANS so that it can be located by the AMR easily for message forwarding. Thus, agents are with full mobility.

Agents register and connect to the AMR with a name and password. Agents collect messages sent to them from the AMR, and each agent can only know the information sent to it. This provides security for the market trading data.

The reliable message delivery is also guaranteed by the AMR. Messages sent to an agent would be directed to the AMR and saved in the message archive first before forwarded to the receiver. Messages are always saved in the archive maintained by the AMR until the instruction for deletion has been got from the receiver. This minimizes the chances of lost or damaged messages due to accidental failure of an agent or network malfunctioning. As soon as an agent is online, messages sent to it can be retrieved.

Agent modeling with JATLite is independent and agents can be added, removed or combined very easily. So systems based on JATLite are flexible.

C. *Java as the Programming Language*

Java is adopted as the programming language to offer heterogeneity and wrapper mechanism for the various agent simulation and system integration.

Developed by Sun Microsystems and having been submitted to the open standards process, Java is a complete object-oriented programming language that allows truly platform-independent application development [14]. It is simple, architecture-neutral, portable, distributed, multithreaded, robust, dynamic and secure.

There are three main forms of Java applications particularly for network based systems development, which are Java stand-alone application, Java applet and Java servlet. These three forms of application are all applied to the simulator. Agents are Java stand-alone applications, OASIS is based on Java servelets and the interaction between the viewer and the OASIS is assisted by Java applets.

Java stand-alone application is just like any application in other object-oriented languages. Agents in this form can interact freely with both the operating system and the hardware where it runs. Java applet is the most convenient for light-weighted objects construction and is widely used on the Internet. However, applets cannot interact with the operating system or the hardware on which it is executing without signature. That is due to the consideration of network security. All interactions and computational loads must be on the host side from which an applet is hatched. Such a limitation intends to make the server overloaded. Software packages of each agent are also out of control of the owner. Those are why the agents in the simulator are all in the form of Java stand-alone application. Java servlet used by the OASIS is to support dynamic webpage generation and client requested computation on the server side. Such feature is needed for dynamic data display as would be requested by the market participants.

The wrapper mechanism with Java is called Java native interface (JNI), by which a Java application can wrap in or interact with applications in other languages, e.g. C++ and Fortran. Thus, existing software or decision-supporting system can be plugged into agents without re-developing in Java. Under a properly designed agents structure, such decision-supporting systems can be changed and *plugged* back again without affecting other parts of the agent.

Another Java technique applied to the simulator is Java database connection (JDBC). JDBC offers a set of functions with which an agent can connect to and manipulate the data in its database.

All applied Java techniques in the simulator are summarized in Table 1.

Table 1 Featured Java technologies applied

Part Name	Featured Technologies
Agents	Java Standalone Application, JDBC
Wrapper in the agents	Java Native Interface (JNI)
OASIS	HTML, Java Applet, JDBC, Java Servlet

IV. IMPLEMENTATION OF THE SIMULATOR

A. *Structure Designed for Agents*

A common hierarchical structure is designed for each agent, as is illustrated in Figure 3.

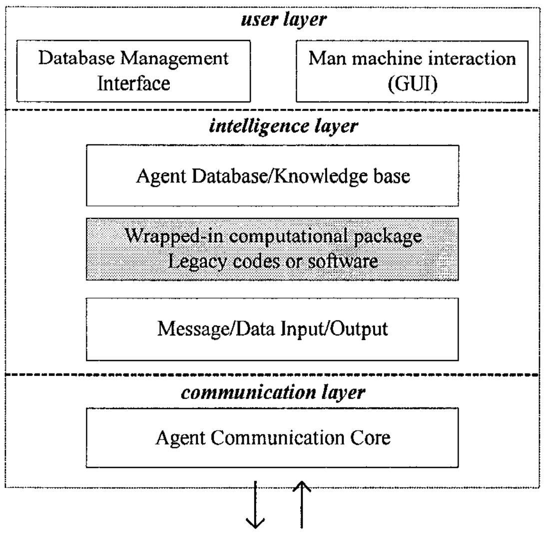

Fig. 3 Hierarchical structure of each agent

In order to enhance the flexibility and the modularity of the agents and the ease of further development, there are three main layers in the common structure and each part is developed separately. : the user layer, which includes the database/knowledgebase management tools and GUI to enable the interaction between the user and the agent; the intelligence layer, which includes the back-stage database/knowledgebase, the wrapped-in software for computing/reasoning and the module for data input/output; the communication layer, which contains the agent communication core.

Decision-supporting system is plugged into the intelligence layer. The *plug* or so-called wrapping mechanism is affiliated by JNI. Result from analysis is stored in the database/knowledgebase. Whenever new decision-supporting software is desired, it can simply plug to the port in the intelligence layer without affecting other parts of an agent. The agent can blind the change to other agents without sending a notification too. Thus, the marketing strategy of a participant can be changed at its own will. This fits to the gaming behavior of participants in a power market.

Agents can communicate to each other in a power market through the AMR of JATLite. User is informed of if required or necessary. A common language, known as knowledge query and manipulation language (KQML) [15], is used for the communication. Messages are parsed by the communication core to see if they obey the KQML syntax before sending to others.

B. *Infrastructure Integrated for the Simulator*

The developed simulator infrastructure is shown in Figure 4 together with their databases and the data flows.

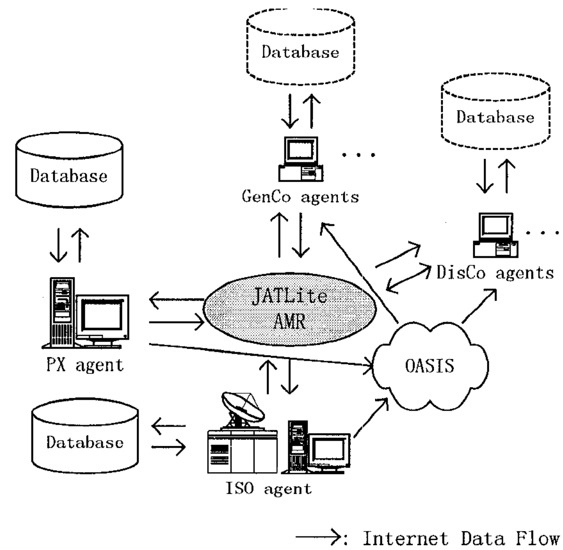

Fig. 4 Infrastructure of the simulator

The agents in the infrastructure are: GenCo agents, DisCo agents, PX agent and ISO agent. The system is flexible to expand or shrink, as required by a practical simulator.

The agents are distributed in the computer network, supported by their own *plugged-in* or *wrapped-in* decision-supporting software and free to use any computer platform. It is obvious that by using all the new technology mentioned above, different power markets, bidding strategies and scheduling rules can be simulated and studied flexibly. E.g., if the UK model is desired, the PXAgent and the ISOAgent can be combined to form the NGCAgent, who executes all the duties of PX and ISO. The corresponding decision-supporting software can also be plugged into the new agent's intelligence layer. The data flows can be changed by setting the new receiver's name in the messages. All this flexibility is brought by the application of the state-of-the-art technology with JATLite and Java.

V. SUMMARY AND FUTURE WORK

In this paper an advanced and versatile power market simulator framework is designed as the first phase in developing a general-purpose power market simulator based on multi-agent technology. With the application of JATLite as the platform and Java as the programming language, this framework meet all the requirements of this flexible simulator.

Future work will be the implementation of full functions of the agents and their decision-supporting systems through the plugged-in mechanism. The finalized power market simulator will act as a very useful tool in power market study and operator training.

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