Simulation of Autonomous Electric Power Market

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ABSTRACT

Electric power market in Japan is now on the trend of deregulation and privatization just like in Europe and the United States. And various approaches for risk management have been investigated taking the electric power price fluctuation after the deregulation into account. The behavior of the investment in power generation plants has not, however, been studied in detail yet due to the complexity of the problem. The problem of the investment in the deregulated power market is that of autonomous decentralized decision-making system, which includes various kinds of decision-makers, that is, power producers called IPPs Each generator has its own criteria for plant investment. Therefore, the total behavior of the decentralized power market will be so complicated, and normative approach will not be applicable for this analysis. We have developed a simulation-based system for behavioral analysis and also the framework design of the decentralized power market.

1 INTRODUCTION

Electric power market in Japan is now on the trend of deregulation and privatization just like in Europe and the United States. Some IPPs (Independent Power Producer) can participate in the Japanese power market, and some big consumers can select the power producers. And various approaches for risk management have been investigated taking the electric power price fluctuation after the deregulation into account.

However, this risk management treats the fluctuations of shorter term than one year. The price fluctuation of longer term relates with the investment behavior of the power producers. The behavior of the investment in power generation plants is another serious problem when the stability of the market is discussed. It has not, however, been studied in detail yet due to the complexity of the problem. The problem of the investment in the deregulated power market is that of autonomous decentralized decision-making system, which includes various kinds of decision-makers, that is, power producers and consumers. Each power producer has its own criteria for the plant investment, and each consumer can select the power producers and/or the power market.. Therefore, the total behavior of the decentralized power market will become so complicated that the normative approach cannot be applied for this analysis.

We have developed a simulation-based system for behavioral analysis of the decentralized power market. In this paper the model is outlined and some simulation results are explained.

2 DEREGULATED ELECTRIC POWER MARKET CONSIDERED IN THIS STUDY

In this study the decentralized power market is supposed to be composed of a compulsory pool, multiple power producers and consumers for simplicity. Each power producer makes the decisions about plant investment every year based on the situations of the market, information about the other generators' decisions, expected gains through participation of the power market and its own criteria for investment, besides operating the power plants everyday.

The power producers give the information about the marginal cost functions to the pool based on the parameters of their own plants, and the consumers also inform the power pool of their demand curve. The pool operator decides the power price based on the marginal cost and the demand functions every hour. Therefore, the plant investment behaviors of the power producers have effects on the price fluctuations of the power market in short and/or long terms. The investment behavior would also depend on the returns from investment expected subjectively, the historical behavior of the power market and also the future investments activities of all the other power producers.

The causal relation about the investment is summarized in Fig.1. As is easily understood from this figure, the decision-makings has dynamic structure, that is, the previous decision-makings have effects on the current decision-makings.

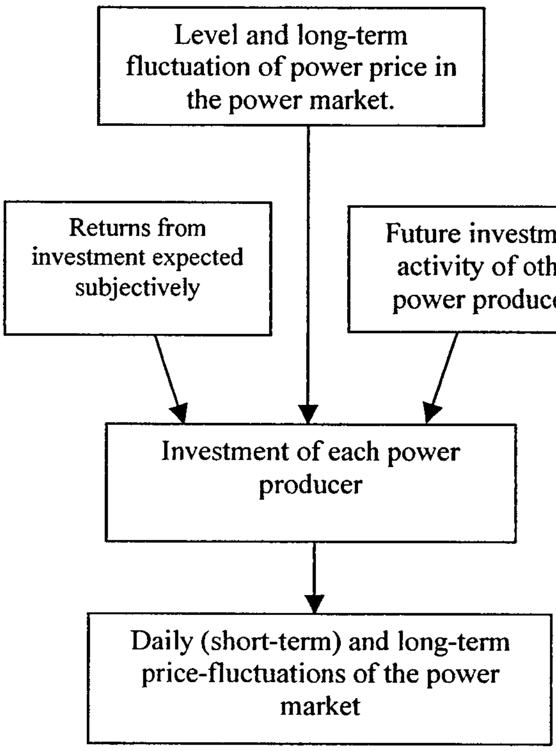

Fig.1 Causal relations as to the investment of power producers.

3 APPROACHES FOR THE ANALYSIS OF AUTONOMOUS DECENTRALIZED DECISION-MAKING SYSTEM

As is explained in the previous sections, the deregulated power-market is considered to be an autonomous decentralized decision-making system.

The most important feature of the autonomous decision-making system is that it includes a lot of decision-makers that differ one another in their criteria for decision-making. And all of the decision-makers in the system can make appropriate decisions based on their own criteria and also surrounding environment for decision-making, that is called a framework for decision-making in this study. The framework includes the procedures and information-structure for decision-making, the various kinds of economic incentives for investment, pricing mechanisms in the market, and so on. The ultimate target of this study is to synthesize the framework for autonomous decision-making system. However, the market simulation is indispensable for the design of the framework in a quantitative manner.

In general, there are three approaches for the analysis of the autonomous market composed of a lot of decision-makers. One is the normative model approach, e.g., optimization model, another is the experimental economics approach, and the other is the simulation-based experiment approach (See Fig.2).

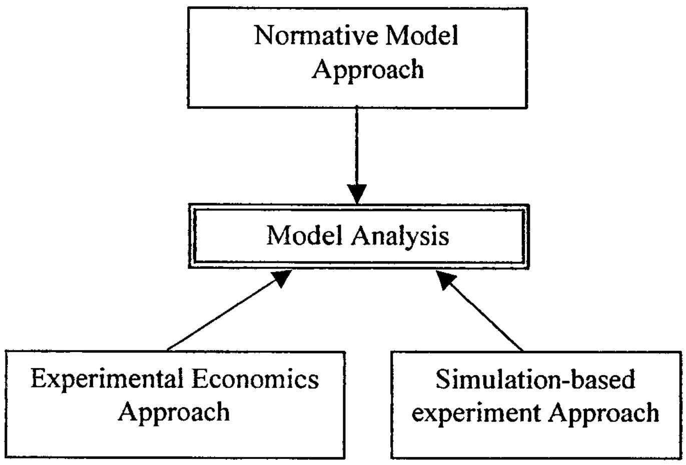

Fig.2 Three approaches for model analysis of autonomous market.

The normative (optimization) model approach is often used for model-based analysis, and is efficient to get useful information through the simulation if the appropriate model for optimization can be constructed. However, in the case of the autonomous decentralized decision-making system the complete set of decision-makers cannot be obtained. What we can do in this case is to use a model or a set of models that would be exist in some situations.

The experimental economics approach has been developed to overcome this problem. In this approach various subjects participate in a virtual market designed with deliberation, and the process of the experiment is recorded and analyzed with discretion. Usually computer terminals are used as interfaces between subjects and the market. This approach is sometimes effective in finding a new behavior of a subject in the market. However, the performance of the experiment depends on the abilities of the subjects and the same experiment results cannot be obtained again. And the number of objects is also limited due to the ability of the subjects in processing the information about the market.

The third approach taken in this study is based on the simulation model including various kinds of decision-making algorithms about plant-investment and power consumption. The decision-makers realized by using computer programs exchange the information related the market with one another and make the decisions based on their own criteria. This is considered to be complementary to the above two approach. Although it cannot obtain the an optimal solution for some situations of the market, nor find new behaviors of the participant in the market through the simulations, it can include a numerous decision-making rules and observe the total behavior of the market with a lot of participants. And what is most important compared with experimental economics approach in this study is that it can reproduce the same simulation results.

Another important point of taking this approach is that the purpose of this approach is not to forecast the future behavior of the market but to design the robust framework or rules for the market to behave without unacceptable fluctuation in power price. For the design of the market, the decision-making rules included in the model should not necessarily appear in future, but should be one of the rules that are considered to appear in some situations. The designed rules, if any, can be tested by using various sets of rules.

4 OUTLINE OF THE SIMULATION MODEL

The simulation model developed in this study is composed three parts: a power pool, power producers and consumers.

The role of the power pool in this study is to keep the balance between the power supply and demand. The power pool gathers the information of supply function of power production, that is the relationship between the price and the amount of produced power, and demand function, that shows the relationship between the power price and the power demand. The pool decides the equilibrium price based on the obtained information and announce the price and related information such as the amount of production to all of the participants in various manners. The process of the power pool is considered to be of short-term simulation and is summarized in Fig.3.

The behavior of the power producers comprises two decision-making. One is of the short-term and the other is of the long term. In the short-term decision-making the power producers decide the strategy about the amount of the power production as a function of power price. For this purpose they should evaluate the return of investment taking the other power producers' behavior about investments. In the long term decision-making, they decide on what condition they dispose and construct power plants. The long term simulation of power producers are shown in Fig. 4.

The consumers model is very simple in this study. The demand function is constructed by using the fixed price elasticity. It can be made more realistic one as the advance of the study.

Each decision-making process is constructed as an independent process on computers, and can exchange information with other decision-makers through the computer network. This simulation framework can be modified easily, and is considered to be suitable for the simulation of the autonomous decentralized decision-making process.

The future target of this simulation-based experiment is shown in Fig. 5. This approach can also include human subjects as participants in the market, and by observing his/her behavior the

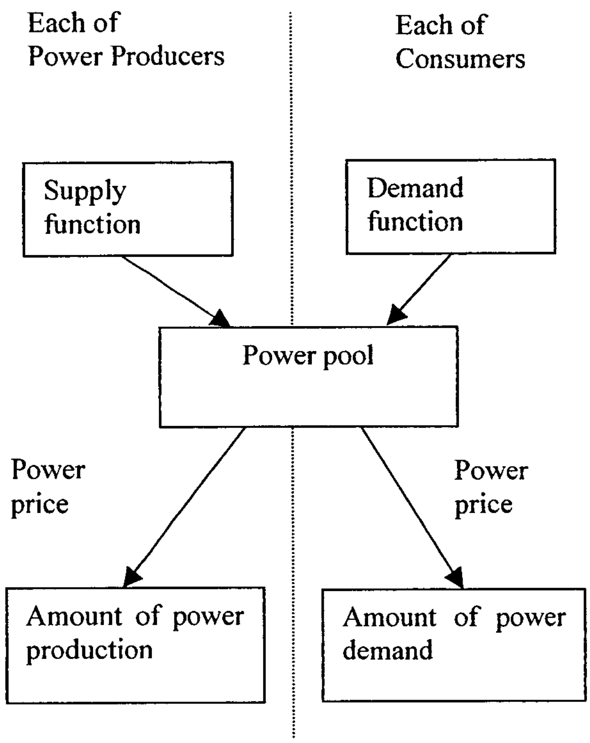

Fig.3 Sort-term simulation of market.

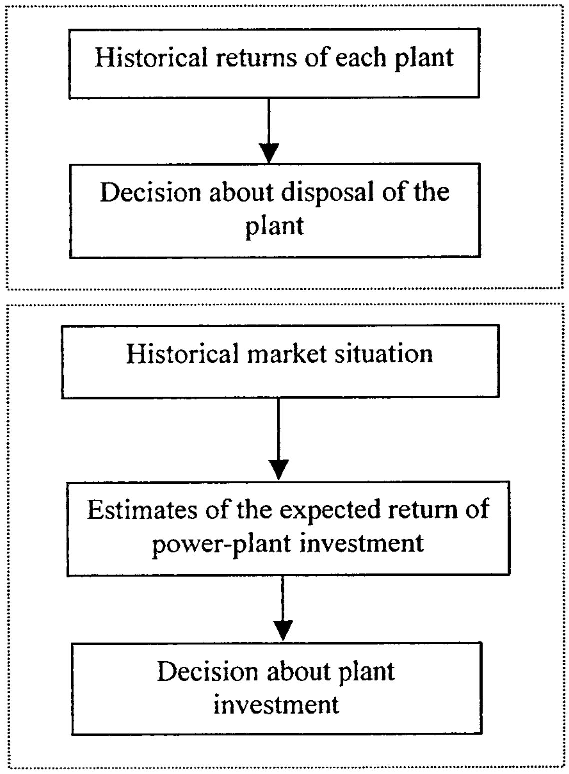

Fig.4 Long-term simulation of market (Plant disposal and investment)

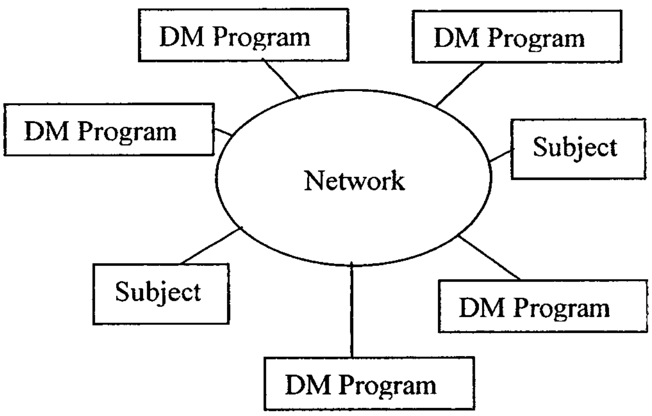

Fig.5 Simulation-based experimental environment of the virtual market. (DM: Decision-maker)

simulation algorithms can be modified so that the algorithms can represent more realistic decision-making process. This simulation environment can be expected as an open environment for the various social systems framework design.

5 SIMULATION CONDITIONS IN THIS STUDY

As the target of this paper, is not the detailed analysis of the simulation results but the total behavior of the model, the assumptions set for power producers and consumers are assumed very simple as follows:

The number and characteristics of power producers is 20, and their decision-making structures are also the same with that of each other. They can decide every year the capacity of each of four types of power generation plants, that is called as peak, middle1, middle2 and base in the following. "Peak" means the power plant for peak-demand hour, and so on.

The number and characteristics of consumers is only one. It is because the analysis of this paper is mainly on the behavior of supply side.

The power load is divided into 24 periods a day, and 4 seasons are considered in the model, that is, 96 time-periods correspond to one year. The power load has its peak at the daytime of summer and has the second peak in winter mainly due to air-conditioners' power demand.

The key point of the model simulation is the estimates of the expected return of power-plant investment. The power producer estimate the future operation time of the plant under consideration based on the current market situation and future forecast of power demand. As is easily considered, the error in this estimation has a serious effects on the market behavior.

6 SIMULATION RESULTS

Two simulation results are shown in Figures 6-9. One is with decreasing power demand and the other is with increasing power demand. The price fluctuations are caused by the gap between estimated demand and the actual demand and also by the delay of the plant investments and disposals. Therefore, the coordination among decision-makers and also the information structure for decision-making.

The following basic characteristics have been obtained through simulations.

- The investment strategy of the plants for the base-load of the electric power is important, and excessive or insufficient investment of the base-load plant can cause large fluctuations in the pool power price.
- If the investment risk is taken into account the capacity of the plants with longer lead-time for construction is apt to get smaller. Longer lead-time means more risks.
- The uncertainty in demand forecast prevents the generators from installing the plants actively, which causes the rise in power price. Bilateral market is one option to decrease this risk, and the measure to manage this risk is to develop a new market for the risk. And the simulation experiment framework can be easily utilized for investigating the performance of the new market mechanisms.

7 CONCLUDING REMARKS

This paper introduced the new framework for the analysis of Autonomous Decentralized Decision-making System, that is called as Simulation-based Experiment Approach. The deregulated power market was taken as an example of the autonomous system. And through simulations the effectiveness was demonstrated. Furthermore, proposed is the future possibility of this approach as the large-scaled simulation environment. We are now developing the basic software framework for this environment.

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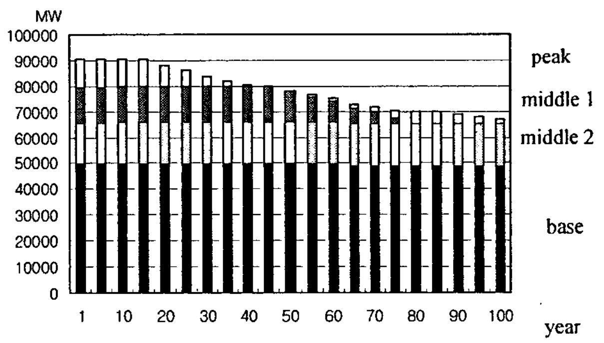

Fig.6 Output of four types of power plants of the case with decreasing power demand.

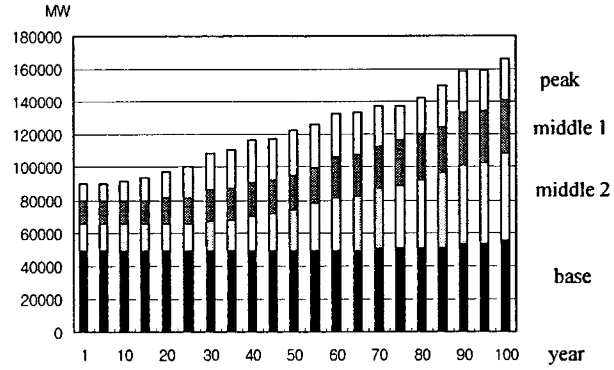

Fig.8 Output of four types of power plants of the case with increasing power demand.

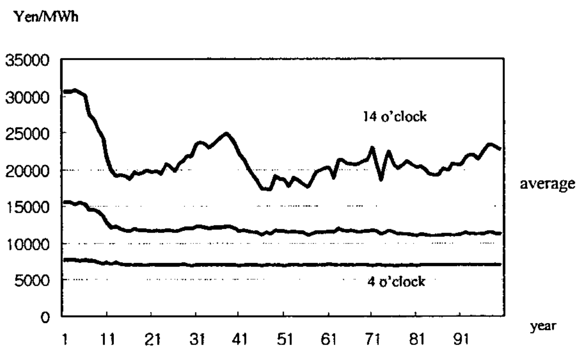

Fig.7 Price fluctuation of the case with decreasing power demand.

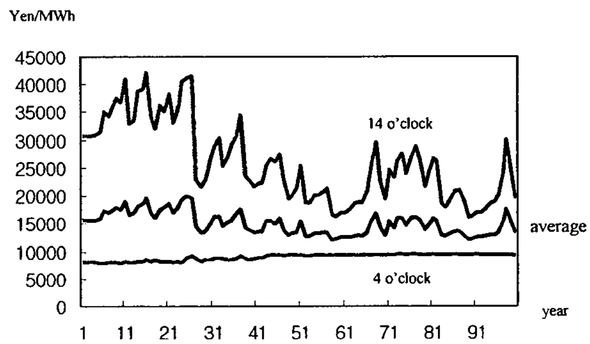

Fig.9 Price fluctuation of the case with increasing power demand.