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전력시장 시뮬레이션을 위한 MAS 기반 GENCO 모델링

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Multi-agent System based GENCO model for an effective market simulation

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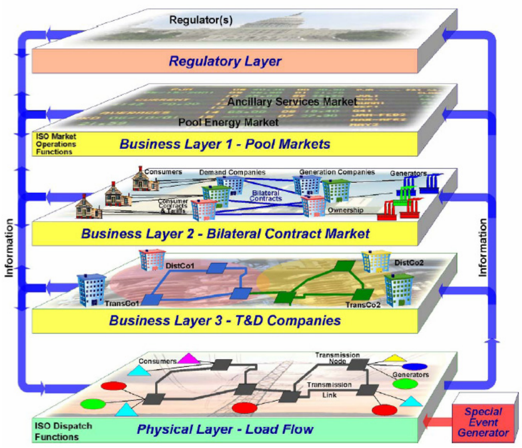
Abstract - Since the competitive market environment was introduced into the electric power industry, the structure of the industry has been changing from vertically integrated system to functionally unbundled and decentralized system composed of multiple (decision-making) market participants. So the market participants such as Gencos or LSE (load serving entity) need to forecast the market clearing price and thus build their offer or bidding strategies. Not just these market players but also a market operator is required to perform market analysis and ensure simulation capability to manage and monitor the competitive electricity market. For fulfilling the demand for market simulation, many global venders like GE, Henwood, Drayton Analytics, CRA, etc. have developed and provided electricity market simulators. Most of these simulators are based on the optimization formulation which has been used mainly for the least cost resource planning in the centralized power system planning and operation. From this standpoint, it seems somehow inevitable to face many challenges on modeling competitive market based on the method of traditional market simulators. In this paper, we propose a kind of new method, which is MAS based market simulation. The agent based model has already been introduced in EMCAS, one of commercial market simulators, but there may be various ways of modeling agent. This paper, in particular, seeks to introduce an model for MAS based market simulator.

1. Introduction

Electricity market is quite complicated to be analyzed and forecasted because there are too many complexities. One of the complexities is incurred by different layers not existing in a similar dimension like the relation between physical system and abstract market architecture as shown in Figure 1 [1]. The balance between supply and demand, system stability, load flow on transmission system are the primary requirements of physical dimension, while transactions in pool market and bilateral contract market are the secondary requirements in the facet of business area. Business contracts should be made only unless the contracts violate the constraints of the system to be stable and secure.



<Figure 1> Layers of Electricity Market

We intend to apply MAS (multi-agent system) based model to market simulation in this paper in lieu of traditional simulation method based on optimization formulation for modeling strategic interaction and dynamism of market participants, especially Gencos.

2. Two approaches for market simulators

There are two ways of modeling market simulators according to the approaches of handling the problem. One is the analytic method using the strict mathematical formulation with optimization techniques. The other is the empirical method based on trial and error concept using heuristic methods, for example genetic algorithm, tabu search, simulated annealing, and so on.
Analytic approach has been widely used in current market simulators, whose original formulation was made for the resource planning model based on production cost minimization or social welfare maximization in a vertically integrated power industry.
Empirical approach has been being introduced for making up the weak points of analytic model on formulating electricity market environment consisting of many decision makers, which is entirely different from traditional industry environment in which there is only one decision maker.
The characteristics of two methods are summarized in Table 1.

<Table 1> Characteristics of Two Simulation Models

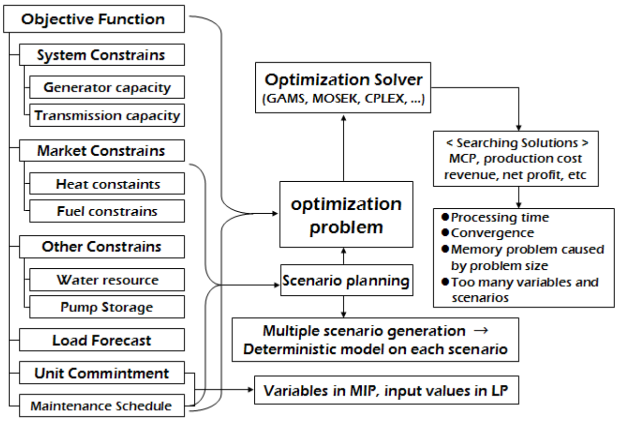
	Analytic model	Empirical model
Simulation method	Mathematical Optimization	Trial and error based on heuristic approach
Outcomes	Deterministic value on each scenario	Stochastic value having pdf1)
Commercial Simulators	PLEXOS, CeMOS	EMCAS

2.1 Structure of traditional simulators

Traditional simulators have applied the optimization formulation to market simulation. Linear programming has been preferred among many kinds of different optimization methods like linear programming, non-linear programming, combinatorial optimization, etc. because of its assurance on convergence and simplicity of modeling. Generally, generation cost minimization and social welfare maximization may be the objective functions of optimization problem. Physical capacities of generators and transmission lines are considered as the constraints of the optimization problem. Optimization was a good method for the centralized resource planning and operation scheduling problem of vertically integrated utility in the electric power industry since there is only one decision maker which is the best case in considering the simulation as an optimization problem.
But the formulation as one optimization problem of overall system or market tends to make the processing time longer and sometimes even shut down the computer by a critical memory problem due to the big problem size. Both PLEXOS of Drayton Analytics and CeMOS of CRA were created on the basis of the structure shown in Figure 2. Also, they adopt commercial optimization solvers like MOSEK and

1) pdf : probability density function

GAMS for solving the formulated optimization problem.



<Figure 2> Structure of traditional market simulator

2.2 MAS based Market Simulator

2.2.1 Multi-agent system

The concept of "agent" has been introduced in artificial intelligence when we describe the program which performs some tasks specialized in some field or very complicated jobs to be done instead of a human. Multi-agent is a collection of more than one agent and has common characteristics like autonomy, social ability, intelligence, etc.

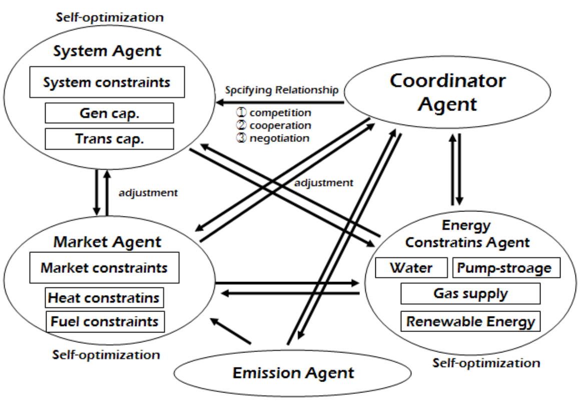
Autonomy means that agent can judge by itself and performs some tasks based on the judgement without the orders from humans or other programs. For example, if we apply agent technology to information search engine, then agents are able to collect, analyze, and arrange the information by itself even when there is no commands for searching from humans, while traditional information search engines do their job simply when they get orders.

Social ability means the agent's capability to cooperate with other agents to perform some tasks or accomplish some objects. Agent is not a stand-alone program but a member of society composed of a number of agents who cooperate with each other for the objective or a common good of the society. Each agent has its own unique role, and some agent has the role of coordinating the agent.

Intelligence means that agents perform tasks or accomplish objective according to their own reasoning and judging process not just based on codes or program already made by human, implying that agent can have the creativity or evolution on problem solving process.

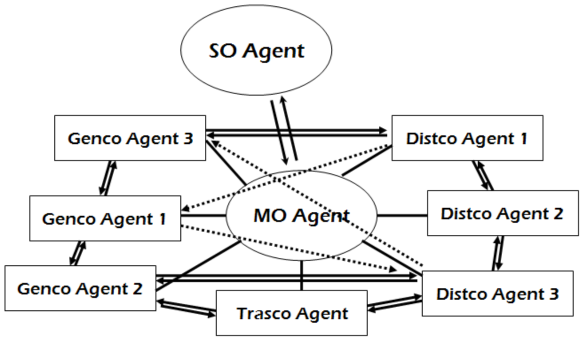
2.2.2 Application of MAS to electricity market simulator

The MAS based market simulator could have multiple agents each of which is in charge of their unique roles for the operation of power system and electricity market. For instance, we can establish a society composed of multiple agents and define their relationships using the game theory.



<Figure 3> Functional multi-agent composition

System agent is normally responsible for power system operation related to load flow and voltage stability subject to the generator installed capacity and transmission line capacity. Market agent tries to perform the market operation for the cost minimization and social welfare maximization under the heat constraints and fuel constraints. Energy constraint agent is obligated to manage limited energy resources like water flow, pump-storage, renewable energy sources.

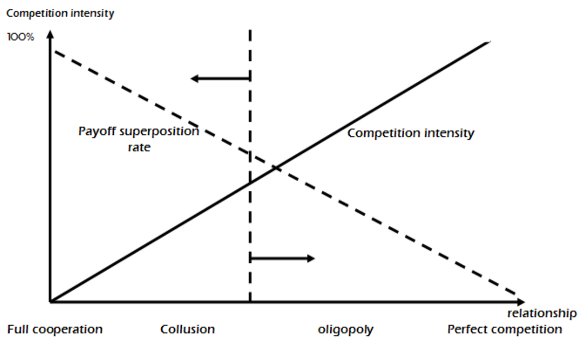


<Figure 4> Agent representing market participant

Agent may be also regarded as individual market participant like Genco, Transco, Distco, etc., which is the different aspect from the traditional market simulator having only one decision-making entity. Each agent represents each market participant having its own utility function and pursues the maximization of the utility function. Profit maximization can be another objective function of Gencos and Distco. Social welfare maximization may be the objective function of MO (market operator).

2.2.3 Relationship establishment in MAS using game theory

Relationship between agents is duly defined using game theory. Game theory provides us with three different kinds of gaming situation classified as cooperative game, non-cooperative game, and negotiation (or bargaining) game. In the same fashion, each game situation has a few sub-models like Cournot model, Bertrand model, Stackelberg game, Nash bargaining game, etc.



<Figure 5> Relationship establishment between agents

A game is specified as n players, their strategies and payoff matrix. If two payoff matrices of two players are the same or proportional, the game of two players is a fully cooperative game. If the payoff matrix are completely different from each other, the game would be a non-cooperative game.

A's action

A's payoff

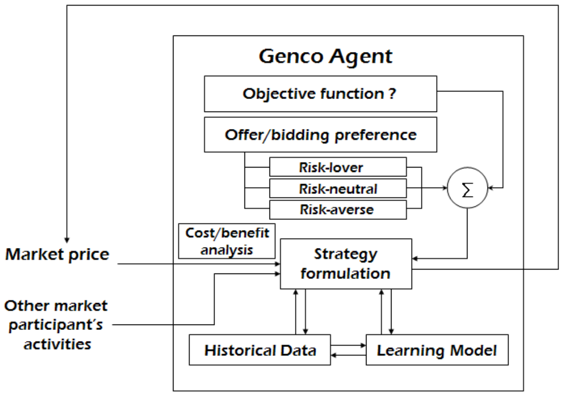
	R	P	S
R	0	−1	+1
P	+1	0	−1
S	−1	+1	0

B's payoff

	R	P	S
R	0	+1	−1
P	−1	0	+1
S	+1	−1	0

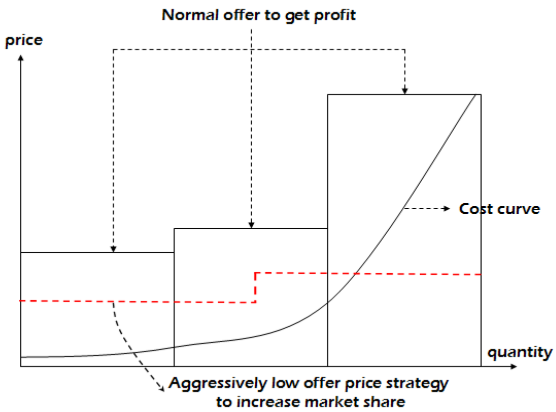
<Figure 6> Example for payoff matrices of two players

The strategic choice for the relationship between two agents is wholly determined by the judgement of agents. The choices of agents may be different from each other even in same situation dependent on the objective function or the strategic preference of each agent.



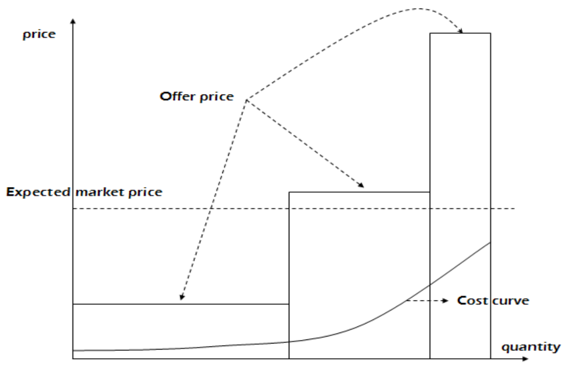
<Figure 7> Agent based Genco model

Each Genco has its own offer stack differentiated by its objective function and strategic preference. Genco more interested in market share than net profit will offer the lower price than expected marginal price, since it's priority lies in the increase of generation quantity supplied to the pool. Figure 8 shows the strategy to lower the offer price to raise the market share.



<Figure 8> Offer strategy change by objective function

Genco can choose the offer strategy as seen in Figure 9 if it prefers the risky strategy to pay back higher returns. If the Genco has the marginal generator, it will offer its generation with higher price than expected market price to raise the market clearing price. This is a typical phase of economic withholding in exercising market power.



<Figure 9> High offer price strategy expecting higher return

Nevertheless the Genco should take a risk of being cut in its offer quantity partly or entirely, leading to the decreased net profit. Accordingly, the offer strategies of Gencos are influenced by their objective functions and strategic preference on offer or bid. The MAS based market simulator reflects these kinds of different tendencies and strategic evolutions based on intelligence or learning ability. And it makes the model more realistic in the fact that each Genco has its own decision making independency.

3. Conclusions

This paper has presented a basic concept of MAS based electricity market simulator and the theoretical framework for building it. Traditional market simulators focused on the mathematical formulation of an optimization problem and the algorithm for searching the solution. For mathematical formulation, the problem model was required to have a deterministic objective function and related constraints, which leads the model too deterministic and static. It has been of the highest importance to find out an optimal solution for investment on generators and transmission lines under vertically integrated environment since there is only one decision maker for the investment. Under the competitive market the equilibrium replaces the concept of an optimal point in the steady-state. And the dynamism of market also gets importance in that the market players always try to unbalance the equilibrium for increasing their profit while the market operator try to maintain it. Even if we find out the equilibrium of the market at a specific moment, it would be negligible by the reactions of market players within a short time-horizon and require a new equilibrium to be found. Capturing these characteristics of market environment, the emphasis of the MAS based simulator is on making the problem model itself more realistic as close as possible to the real situation rather than solving the problem and finding out the optimal solution. Although there is no obvious evidence which method is better for competitive market simulation, the MAS based market simulator is expected to overcome several weak points of traditional market simulators.

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