A Multi-Agent Based Negotiation Support System for Cost Allocation of Cross-border Transmission

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Abstract: Regulation and protection have been the major issues to prevent the consumers from enjoying good quality of service (QoS) at reasonable prices, for example, electricity and long distance call service. Deregulation in such industries started in early 1970s and have achieved significant results in, for example, telecommunication industry. The deregulation in telecommunication was mainly focused on reducing the market power to add more competition to reduce the price and to improve QoS.

Similarly, the power industry in several countries also underwent regulation. The power industry used to be protected and regulated. Consumers were forced to buy electricity from particular suppliers and suffered high prices and low QoS. After deregulation, the original boundary lines have been removed and consumers have more alternatives. How to support optimal planning of cross-border electricity trade has become an important issue since then. Decentralization, or participants have the rights to participate in decision making, is one of the directions of deregulation.

In this paper a decentralized structure is suggested to solve the problem by using multi-agent technology to create autonomy for each participant. In such structure the centralization of information transmission or decision making is prevented. Each participant behaves rationally to search for best benefit or payoff through the information she or he owns or through information exchange with other participants. Although all the market participants make decisions to protect their own benefits, the optimal solution (total costs) of the whole system can be achieved finally. This structure is based on the method proposed in [5] and implementation, which a multi-agent system called Multi-Agent System for Cross-Border Trade (MASCBT), was done by using Java programming language. A demonstration on a 5-area test system shows that the suggested new approach is effective and promising.

Keywords: power market, cross-border trade plan, decentralized optimization, multi-agent technology

I.INTRODUCTION

Regulation and protection had created the opportunities for companies in several industries to generate high profits to keep them growing. However, in order to create such protection, the consumers had to pay the high price and suffer low quality of service (QoS). Electricity and long distance call service were the major targets of deregulation. Deregulation was introduced in early 1970s and had achieved significant results in telecommunication. After AT&T was forced to split and more competitors joined the market, consumers had more choices and the market power has significantly decreased.

Similarly, the power industry in several countries also underwent deregulation. The power industry used to be protected and regulated. Consumers were forced to buy electricity from particular suppliers at higher prices and with lower QoS. After deregulation, the original boundary lines have been removed and consumers have more alternatives. For example, the deregulation act in California allowed its consumers to purchase electricity from other states. How to support optimal planning of cross-border electricity trade has become an important issue. Decentralization, or participants, such as, owners of power generators, owners of transmission lines, and consumers, have the rights to participate in decision making, is one of the directions of deregulation. How to develop a negotiation support system to support such decentralized decision making is important.

Internet and related technologies also supported the shaping of the new market structure, where more and more information or decisions are transmitted through Internet. Which increase the transparency and efficiency of market operation. Such transparency or efficiency significantly decreased the market power and made consumers enjoyed more from what they paid.

Usually an interconnected power system consists of several regional networks that connected with tie-lines. Under transmission open access, the electricity trade inside a regional system can be handled locally. While the electricity trades among regional systems should pay for the usage of tie lines and the regional networks along the transaction paths. It is clear that wholesale cross-border trades should be considered together with the transmission cost in advance with the limits of the tie line capacities included. In this paper, we use the European network as an example to study the wholesale cross-border trade planning. But the considerations are equally applicable to all the interconnected networks world wide.

Electricity production in the European Union (EU) has, for decades, been based on monopoly production and 15 separate national markets. Community Directive 96/92/EC has brought about a change to develop the common electricity market in Europe [1]. However there were several considerations about how to develop the common rules of transmission open access: (1) In order to schedule such wholesale cross-border trade, a central transmission system operator (TSO) seemed to be necessary to collect all the information and to perform the needed calculations. Although for system security purposes it seemed to be necessary, the member TSOs may be opposed to this idea mostly for political reasons. (2) It is hard to ask for extreme equality when the national transmission systems facing native demands and foreign demands at the same time. How to obtain the optimum with the consideration of priority?

Generally there are two basic approaches to handle the wholesale cross-border trade schedule. One is the central schedule approach, where the market operator is responsible for working out an optimal cross-border transmission schedule at minimum transmission cost that considers the system operation constraints, and then allocates the cost to individual transactions. Centralized optimization methods can be used for the first task, such as Ref. [2] and [3]. Very often market participants might doubt the fairness of such centrally announced results. Besides the central optimization has to be re-calculated whenever a new transaction is added. The other approach is the decentralized schedule, which uses the invisible market hand to solve the problem by market participants themselves. One such implementation [4] uses the Bilateral Shapley Value to negotiate in multilateral trades via a multi-agent system. This approach avoids the centralized decision making of the market operator and is quite attractive to market participants. However the optimal social welfare is not guarantied. In Ref. [5], a decentralized method is suggested base on ‘first come, first serve’ rule to implement the cross-border trade planning with the help of multi-agent technology. However in order to keep the system security and improve the speed, a central sever is still required.

In this paper, we propose a decentralized structure based on the method discussed in [5]. In the new structure, the centralized information collection is prevented and each regional system acts rationally based on local information to search its own benefits. However the total transmission cost is minimized after such self-protective decisions. The significant advantage of this structure lies in that it is based on each participant’s rational behavior and any super controller can be avoided.

The paper is organized as follows: in next section, we shall first present the mathematical model of the problem in its centralized optimal format. Then the decentralized approach will be introduced. In section III, we provide the detailed model of multi-agent system. System implementations and complexities will be introduced in Section IV. In section V, a 5-area system will be used as an example to illustrate the negotiations among participants. Conclusions are made in the last section.

II. MATHEMATICAL MODEL

The basic assumptions used in our research are:

(a) The transmission price of each tie line is a constant and announced in $per unit power flow. The transmission limits of tie lines are known in per unit. For simplicity, the transmission loss is neglected (Its cost can be included approximately into the tie line transmission price) and the power flow of each tie line is controllable.

(b) An area is clarified as supply, demand or transit area if its net injection power P_i is greater than, less than or equal to zero. $P_{i,max}$ is the net injection capacity of area i when P_i>0. The net generation capacity $P_{i,max}$ for a supply area and the load demand of a demand area are all known.

(c) There are enough generation capacities to meet the load demands in the entire inter-connected system and the tie-line capacity is enough such that all the demands can be satisfied via proper schedule.

For the wholesale cross-border trades scheduling problem, the math model for the centralized optimal decision can be formulated as follows:

$$\begin{aligned} & \min \sum_{(i,j)\in A} c_{ij}\cdot f_{ij} + \sum_{i\in S}\Big(t_i \cdot \sum_{j:(i,j)\in A} f_{ij}\Big) + \sum_{i\in D,T}\Big(t_i \cdot \sum_{k:(k,i)\in A} f_{ki}\Big) \\ & s.t. \quad \sum_{j:(i,j)\in A} f_{ij} - \sum_{k:(k,i)\in A} f_{ki} = P_i \quad \text{for } i = 1,2,\dots,n \qquad (1) \\ & \qquad 0 \le f_{ij} \le f_{ij,max} \qquad \text{for all } (i,j)\in A \\ & \qquad 0 \le P_i \le P_{i,max} \qquad \text{for all } i \in S \end{aligned}$$

where

f_{ij} : power flow on the tie-line from region i to region j, and f_{ij}>0;

$f_{ij,max}$: capacity of the lie-line from region i to region j;

c_{ij} : price of per unit power flow for usage of tie-line (i,j);

t_i : price of per unit power flow for usage of network of area i;

S, D, T: denote supply, demand and transit area sets respectively;

A : entire tie line set with m directed tie-line flows;

n : total number of areas.

The three terms of the objective function in (1) are the total costs for tie-lines usage; the total fees for usage of all supply area networks; and the total fees for the usage of other area networks respectively. It should be noticed that the generation cost is not included in the objective function for simplicity. There is no difficulty to include generation cost of each supply area into the problem. This is realized through introducing a fictitious 'supply area - tie line' set with the tie line transmission price equal to the generation cost of the supply area and the original supply area becomes a 'transit' area in the new system.

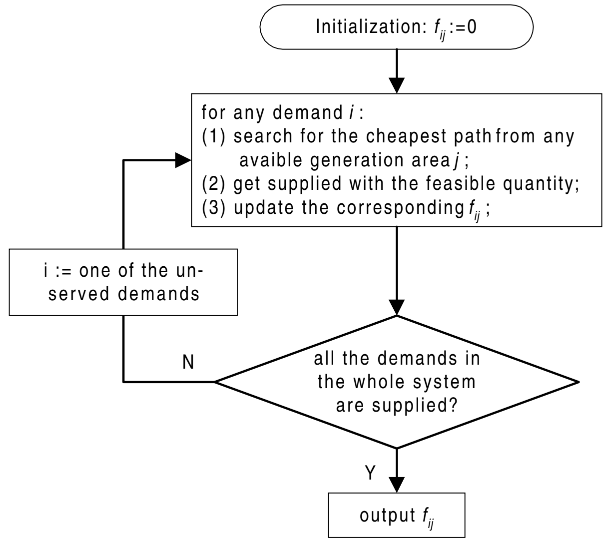


Figure1: flow chart of the decentralized approach

A decentralized approach is proposed in Ref. [5] to solve the linear optimization problem (1). The basic idea is that within each round of iteration, one demand i searches for the cheapest path to get supplied from any available generation area j. The quantity of the supply is the minimal value of following three parameters: the un-served demand of area i, the available generating capacity of area j, and the available transmission capacity of path from area j to area i. This process is repeated again and again all the loads in the whole system are totally satisfied. The flow chart is shown in figure 1. Using the inductive method, we proved that the final flow of the network from the decentralized approach above is the same as that from the centralized optimization defined in (1). Detailed algorithm and proof can be found in [5].

The advantages of the new approach are apparent:

(a) There is no need for a central coordinator. Each demand area searches for the cheapest path to satisfy its own need.

(b) Every demand area is satisfied with its choice based on the available cheapest path and doesn't need to worry about the bias from central processing.

(c) The minimal total transmission cost can still be guaranteed at the end with system constraints satisfied.

(d) When a new trade is added, previous trade schedules will not change. This is extremely attractive as compared with centralized optimization approaches.

(e) The new approach does not need transmission cost allocation calculation since it can obtain transmission cost of each trade during the process.

(f) The area power generation cost can also be included easily by introducing a fictitious 'supply area - tie line' set as mentioned before.

III. MULTI-AGENT SYSTEM MODELING

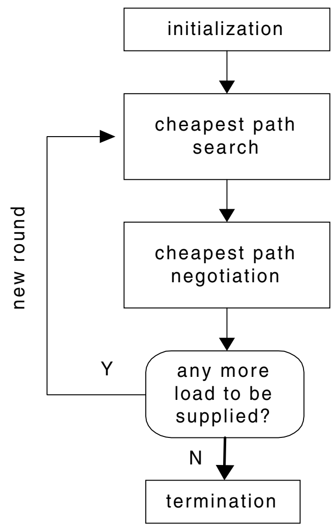


Figure 2: Functional Framework of the Multi-agent System

In our model each regional network is assumed to be a rational agent, who only has partial information, including the identity numbers of itself and the immediate neighbors, and the data of the tie-lines incident to itself, such as prices, capacities, and the existing flows. Each agent is responsible for updating related local information. We also assume that the communicate channels are perfect.

There are two major functions in the system by the communication of the agents. One is the cheapest path searching, the other is the cheapest path negotiation. The functional framework of this multi-agent system is shown in figure 2.

Initialization:

Each agent collects the local information and sends the synchronizing message.

Cheapest path search:

A generic label-correcting algorithm [6] is modified to compute the cheapest path by successively updating the cost labels. Each agent maintains a set of cost labels *p(.)* at every stage. The label *p(j)* is either $\propto$, indicating that it has yet to discover a directed path from the source to agent *j*, or it is the cost of some directed path from the source to agent *j*. For each agent *j* a predecessor index, *pred(j)*, is also maintained which records the agent prior to agent *j* in the current directed path of cost *p(j)*. At termination, predecessor indices allow each agent to trace the cheapest path from the source node back to agent *j*. Detailed algorithm can be found in Ref. [6].

Cheapest path negotiation:

After each agent knows the identity number of its preceding agent along the cheapest path, it will send the message to the preceding agent for the usage of that regional network. There are three actions for a rational agent when receiving such request: (1) selfish plan when the receiver is a deficit agent, i.e., to decline the requests and refuse other agents to use its own regional networks until its own loads are fully supplied; (2) modest plan when the receiver is a balanced agent, i.e., to pass on the received requests to the preceding agent on the cheapest path and allow other agents to use its own regional networks by charging transit fees. (3) ego-centric plan when the receiver is a excess agent, i.e., to accept the requests based on the rule of "first come and first serve" and allow other agents to use its own networks.

Termination:

When no agent sends request to other agents, that means all the loads are supplied, then the system terminates.

The advantages of this model lie in that:

(a) There is no centralized owner or controller of the global information about the network. Therefore, any agent does not depend on the centralized information to make decisions.

(b) Each agent only has local information. Therefore it knows neither the global structure of the network, nor the numbers of agents in the network. This structure is quite attractive to develop a competitive market.

(c) The minimum transmission cost could be achieved by communication and cooperation among all agents.

(d) Each agent is satisfied with its choice since all the trades are resulted from rational behavior.

IV. SYSTEM IMPLEMENTATION

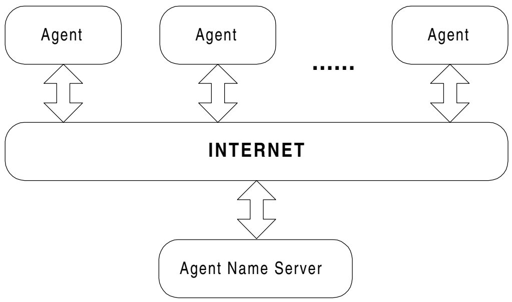


Figure 3 infrastructure of MASCBT

We have implemented a multi-agent system on the Internet — Multi-Agent System for Cross-Border Trade (MASCBT). Fig. 3 shows the infrastructure of MASCBT. Agent communication is done via the Internet. The agent name server provides agent registration service and the Internet connections for all agents. Fig. 4 shows a java applet and represents the agent E of the test system in Section V. The agent name and password are used to register the agent into the agent name server.

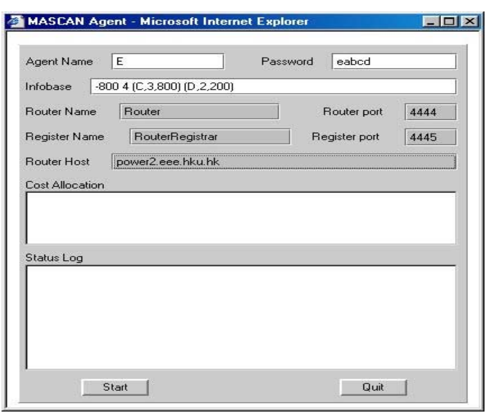


Figure 4 Applet of agent E

The execution time to process a message is always *O(1)* in MASCBT. The worst case of execution in MASCBT is that each agent processes a message sequentially. Therefore, the time complexity of MASCBT equals to that of the message complexity. Hence we only need to analyze the message complexity.

The cheapest path computation needs to be executed one time within a round of negotiations. The message complexity of the cheapest path computation is $O(m^2n)$. There are at most $O(nD_{max})$ rounds of negotiation in MASCBT, where D_{max} is the largest demand of a given network. Finally, we can conclude that the message complexity and time complexity of MASCBT is $O(m^2n^2D_{max})$. (The time complexity will be much better in practice because all the agents may execute concurrently). Therefore the performance of the system is satisfactory.

V. COMPUTER RESULTS

A 5-area test system [7] (see Fig. 5) is used for computer test and to show how our method works based on multi-agent technology.

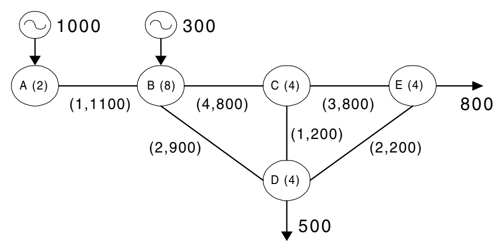


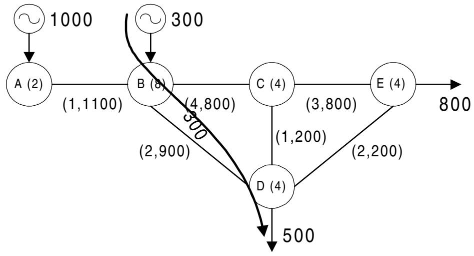
Figure 5 the test system schematic diagram

In Fig. 5 each bigger circle represents a regional network connected by tie lines to other networks. The number inside a circle represents the assumed transmission cost of per unit flow for transit through the regional systems. Each tie line has two parameters put in a parenthesis. The first number represents the transmission cost for per unit flow and the second number the transmission capacity of the tie line. The number by the side of a generator (or a demand) means the available generation capability (or the amount of load demand).

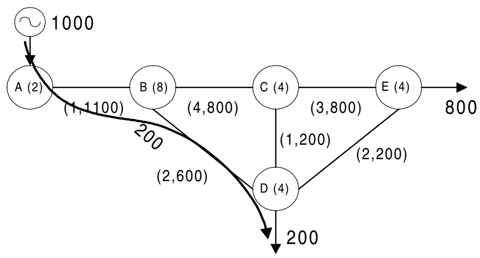
Region A and B are net exporters, they will execute the egocentric plan. Region D and E are net importers, so we assume they will execute the selfish plan when they are deficit, and then execute the modest plan when they become balanced. Region C is a transmit region with no net import/export, so it executes the modest plan.

<u>1st round</u>

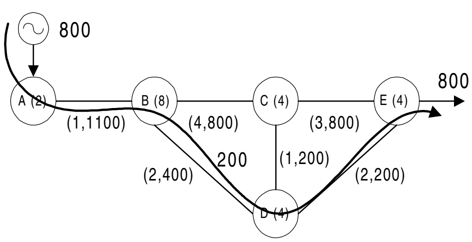
The cheapest path from an excess agent (i.e., agent B) to agent D is the path B-D and the cheapest path from agent B to agent E is the path B-D-E. E sends a request to D to augment a flow of 800 units, and D sends a request to B to augment a flow of 500 units. Because agent D is deficit area executing a selfish plan, it will reject the request from agent E to augment a flow via agent D. While agent B is an excess agent who executes the egocentric plan. So B will accept the request by augmenting available 300 units through networks of B to agent D, as illustrated by figure 6(a).



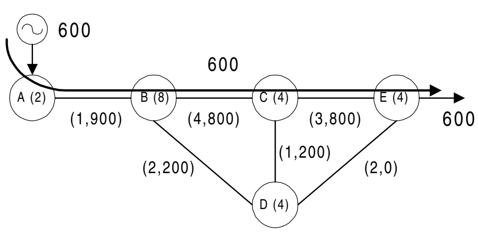
(a) Cost of trade B-D: (8+2+4)×300=4200



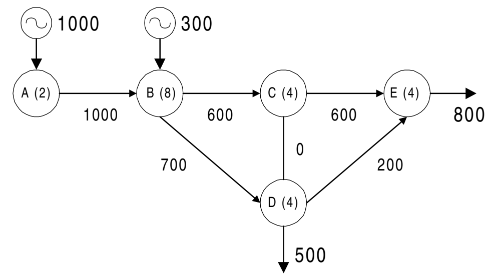
(b) Cost of trade A-B-D: (2+1+8+2+4)×200=3400



(c) Cost of trade A-B-D-E:
(2+1+8+2+4+2+4)×200=4600



(d) Cost of trade A-B-C-E:
(2+1+8+4+4+3+4)×600=15600



(e) Final solution of flows

Figure 6 Illustration of negotiation process

2nd round

After the 1st round, the cheapest path from an excess agent (i.e., agent A) to agent D is the path A-B-D and the cheapest path from agent A to agent E is the path A-B-D-E. Because agent D still is a deficit agent who is executing the selfish plan, it rejects the request from agent E to augment a flow via agent D. While agent B is a balanced agent who is executing the modest plan. It then passes agent D's request to A. Owing to the egocentric plan, agent A then approves the request to augment a flow of 200 units from agent A to agent D, as illustrated by figure 6(b).

3rd round

After the 2nd round, the cheapest path from the excess agent A to agent E is the path A-B-D-E. Since agent D becomes balanced, now all the agents (except A) along the path are the balanced agents who will execute modest plans. So the request sent by E is passed on until it reaches A. Furthermore, all the regional networks along the path could be used at a transit fee. Because of the congestion of tie-line D-E, only 200 units are augmented from agent A to agent E, as illustrated by figure 6(c).

4th round

After the 3rd round, since the tie-line D-E has been fully used, the cheapest path from the excess agent A to agent E now is the path A-B-C-E. The balanced agents along the path (except A) merely pass on the requests received to their predecessors until agent A gets the request. As the excess agent executing egocentric plan, A then approves the request to augment 600 units from agent A to agent D, as illustrated by figure 6(d).

Table 1: Cost Allocation (in money units)

Cost flow		Payment for service	Income from service
Area Network	A	0	2000
	B	0	10400
	C	0	2400
	D	7600	2800
	E	20200	3200
Tie line	A-B	0	1000
	B-C	0	2400
	C-E	0	1800
	B-D	0	1400
	C-D	0	0
	E-D	0	400
Total		27800	27800

When negotiations end, the wholesale cross-border trades are finalized, and so is the cost of the trades. The final flow of trades for the whole system is shown in Fig. 6(e), and it is easy to check that the optimal cost of 27800 for the problem (1) is also achieved. A summary of the trade costs is listed in Table 1. Totally agent D needs to pay 3400+4200=7600 by receiving 300-units power from agent B and 200-units power from agent A, while agent E needs to pay 4600+15600=20200 by receiving 800-units power from agent A going through two different paths. It is easy to prove the cost allocation result is the equilibrium point of the non-cooperative game for these five players [8].

VI. CONCLUSIONS

In this paper, we have proposed a decentralized structure to support negotiation of cross-border trade planning and cost allocation by using multi-agent technology. The major difference between this system and our earlier research is in the rule base that owned by each agent and the communication protocol.

In this system, each agent represents a regional network, which acts rationally to protect its own benefit by contacting and negotiation with neighboring agents to search for the best or cheapest path to transmit electricity. Although each agent does not receive any centralized information to guarantee the autonomous behavior, the minimum cost of the whole system is achieved finally. This structure provides a theoretical basis to support the solving of similar problems. For example, after China and Taiwan join World Trade Organization (WTO), the border should be open to support cross-border trading. How to allocate the cost of building new transmission or delivery channel as well as how to schedule the trade. Such system will be helpful to support such negotiation or even to semi-automate the negotiation process.

The other problem that can be solved by such system is the transmission of video-on-demand (VOD) across borders of different VOD service provider. VOD and power transmission, to some extend, have several characteristics in common, for example, congestion management. It is very difficult to set up buffer to store such signals once the transmission started. Therefore, negotiation for cross-border transmission and how to allocate the cost to guarantee the needed bandwidth is important.

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