Power Matching Method in Smart Grid Considering User Satisfaction by PIAX Platform

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Abstract—In Smart Grid, various kind of renewable energies have been rapidly introduced. Then, the structure of power grid has been shifting from the tree 1:N structure with centralized power plants to the M:N liked mesh structure with various kind of power resources. In this case, it is necessary that each power demand user determines to use a proper power source among a huge number of power supplies, and we call it as "Matching" in this paper. There are three issues to realize M:N matching control. The first issue is reducing calculation time. The second issue is the dynamic adjusting in spite of fluctuation of power demand and supply. The third issue is to control user satisfied matching such as power price or satisfaction to select renewable energy. In this paper, we propose the matching method that the demand and supply matching algorithm which solves above three issues by utilizing the P2P Interactive Agent eXtensions (PIAX) platform. The calculation time can be reduced by the autonomous distributed control by PIAX platform. The issues of dynamic adjusting of power demand and supply and to consider user satisfaction are solved by the proposed matching algorithm. Computer simulation results and evaluation results by PIAX platform show that the proposed method can reduce the matching calculation time, and maximize user satisfaction in power fluctuation of demand and supply.

Keywords—Smart Grid, Supply and Demand Matching, Peer to peer, Agent, Distributed control.

I. INTRODUCTION

In recent years, Smart Grid [1] has been attracting attention, because it realizes efficient power grid by ICT (Information and Communication Technology). In the Smart Grid, Home Gateway (HGW) is installed in each house and controls power demand and supply to realize balance of power supply and demand in power grid. In the Smart Grid, power generations and power storages are installed in each house for example photovoltaic power generators, fuel cells, electric vehicles and storage batteries.

Figure 1 shows a current power grid and a future power grid. The current power grid structure is 1:N tree structure by large-scale power generators for example thermal power generators, hydroelectric power generators, and nuclear power generators. On the other hands, the future power grid structure is M:N structure liked mesh by distributed power generators for example fuel cell, photovoltaic power generator, wind power generator, electric vehicle and storage battery. As above, the power grid will shift from the current structure to the future structure by introducing various kinds of power supply resources. In addition, power demand user will be able to choose a power company freely by the power liberalization of 2016 in Japan. Accordingly, it is necessary to control considering a user satisfaction between the power demand user and the power supply sources. For example, some power demand user wants to choose clean energy without care about the high power price. On the other hands, some power demand user wants to choose lower power price from any power generators. We call this control as “Demand and Supply Matching” in this paper.

Several studies [2][3] have reported that the centralized control server optimizes supply and demand matching. There are three main issues in the matching method by the conventional method. The first issue is calculation time. The calculation time of centralized optimization control increases corresponding to the increase of combination among supply resources and requested demands. Demand users need to assure the requested power immediately. The second issue is that the dynamic adjusting in spite of fluctuation of power demand and supply in during matching period. Renewable energies are unstable since the generated power amount of photovoltaic depends on weather. In addition, the demand power amount is also unstable because it changes by situation and time zone. In the centralized control optimization, it needs to optimize matching each time period when the power amount is changed. Therefore, the centralized control cannot optimize among many distributed power demands and supply nodes. The final issue is to consider user satisfied matching. The user satisfaction consists of power price, requested amount, and renewable energy selection and so on. The conventional centralized control optimization does not consider the user satisfaction. Therefore, the matching method considering the user satisfaction is necessary.

In this paper, we propose the demand and supply matching algorithm which resolves above three issues by utilizing the
P2P Interactive Agent eXtensions (PIAX) platform [4]. The calculation time issue is solved by the autonomous distributed control by PIAX. The issues of dynamic adjusting of power demand and supply fluctuation and to control user satisfaction matching are solved by the proposed matching algorithm. The proposed algorithm consists two phases, the first one is matching phase and the second one is exchanging phase. In case of occurring power fluctuation, a demand user starts to find new supply sources in matching phase in order to absorb dynamic change of power. Otherwise, each demand user starts to find more satisfied supply sources in exchanging phase in order to improve user satisfaction.

We show that the proposed method can reduce the matching calculation time, and maximize user satisfaction in spite of power fluctuation of demand and supply. The rest of this paper is organized as follows. In section II, related works are introduced. In section III, the proposed methods including demand and supply matching platform and algorithm utilizes the PIAX are described. In section IV, simulation results and evaluation results by PIAX platform are presented in order to evaluate the performance of the proposed method. Finally in section V, summary of this paper is presented.

II. RELATED WORKS

A. PIAX (P2P Interactive Agent eXtensions)

PIAX is an open source framework that incorporates the agent mechanism and structured P2P overlay network. PIAX integrates P2P overlay networks and mobile agents. Users, contents, services, devices, and sensor nodes are integrated as agents and act autonomously. Such agents are distributed in the P2P network. Each dispersed agents can communicate effectively on the overlay network. PIAX provides a unified operation for variety of objects. It is suitable for searching the abstract objects of large number of widely distributed agent. It has multi-overlay, and provides a variety of applications.

Figure 2 shows the overview of PIAX platform. API is defined to enable to develop application programs easily. We can develop various kinds of applications for example the navigation application, the streaming application, the service composition application, and content recommendation application. PIAX platform integrates the distributed agents and P2P overlay network, represents various kinds of object as agent, and provides API that enables unified operations on the agents. Furthermore PIAX has powerful search functions and communication functions between agents. Therefore, we can easily implement a large-scale distributed system.

1) Powerful agent search function : Figure 3 shows the hierarchical structure of PIAX platform. The Multi-Overlay layer provides search functions corresponding to P2P overlays, they are LL-Net[5] (Location-based Logical P2P Network), DHT (Distributed Hash Table) and ALM (Application Layer Multicast). It is possible to search in various parameters utilizing on these overlay networks. For example, LL-Net provides geographic search, Multi-Skip[6] Graph provides range search, and DOLR(Distributed object location and routing) provides exact match search. In PIAX, a powerful agent search function is realized by these overlays.

2) Communication function between agents : The overlay transport layer supports NAT traversal. PIAX users are possible to develop applications without considering communication functions such as socket communication using IP address and port number. Specifically, agents can communicate each other using agent IDs.

3) Scalability : PIAX provides the high scalability search. For example, where the number of area is N in case of LL-Net Level-1, the maximum search number of times is log_4 N. Moreover, where the number of nodes in the Skip Graph is N, the average search number of times is O(log N). PIAX provides the fast search utilizing various kinds of overlays without depending on the number of agents.

B. Demand and Supply Matching in Smart Grid

The power grid will shift to the future structure by introducing various kinds of power supply resources. Power demand users will be able to choose a power company freely by the power liberalization of 2016 in Japan. The future power grid is M:N structure by distributed power generators for example fuel cells, photovoltaic power generators, wind power generators, electric vehicles and storage batteries. In the future power grid, it is necessary to consider user satisfied matching between the power demand users and the power supply sources. The user satisfaction consists of some parameters they are power price, power amount, and power generator type. For example some power demand user wants to choose clean energy without care about the high price, and some power demand user want to choose low price from any power generators. We call this control as “Demand and Supply Matching”. The conventional centralized control method needs thirty minutes to optimize for demand and supply matching.
We must consider total four issues for realizing power demand and supply matching; they are above three issues and communication issue between agents.

The first issue is calculation time. These conventional methods optimize the matching by the centralized control using LP (linear programming). Therefore, the calculation time increases corresponding to increase of combination among distributed supply resources and requested demands. Demand users need to assure the necessary power amount immediately, and supply sources need to control the supply power in order to balance the amount of demand and supply power. The calculation time increases corresponding to increase of the number of supply sources and demand users.

The second issue is the dynamic adjusting in spite of fluctuation of demand power amount and supply power amount. Renewable energies are unstable, for example generated power amount of wind power generator depends on the weather. In addition, demand power amount also varies because it depends on demand user’s situation and time zone. These conventional methods optimize the matching by the centralized control. Therefore, it needs to optimize matching in every time when the power amount is changed. Then, centralized matching method cannot handle many distributed power demand and supply sources.

The third issue is to consider user satisfied matching. These conventional methods do not consider the user’s satisfaction. Therefore, the matching method considering the user’s satisfaction is necessary.

The final issue is how to communicate between demand user’s gateways and supply resources’ gateways. Each demand gateway needs to find supply gateways in order to control user satisfied matching. Therefore, it is necessary to implement NAT traversal function and search function.

III. THE PROPOSE METHOD

This section describes the proposed matching method that the demand and supply matching algorithm which solves above four issues by utilizing the PIAX platform. The PIAX platform solves the calculation time issue and the communication issue between home gateways. The demand and supply matching algorithm solves the issue of dynamic adjusting in spite of fluctuation of power demand and supply, and solves the issue to control user satisfied matching.

A. Demand and supply matching platform using PIAX

Figure 4 shows the power supply and demand matching control platform that utilizes PIAX platform. The matching platform consists of various kinds of gateways (GWs) that communicate through Internet. There are many kinds of GWs for example HGW, Building Gateway (BGW), Factory Gateway (FGW), and Management Gateway (MGW). These GWs participate in this platform, and trade the amount of power supply and demand. By exchanging power supply and demand information via this platform, GWs autonomously control power supply and demand matching. Then, the
calculation time issue is solved by the scalable search function in PIAX. The communication issue is solved by the flexible search mechanism in PIAX platform.

Figure 5 shows the actual structure of the matching platform. This platform consists of the physical network and the virtual network slice. The main function of the physical network is communication about actual power information between GWs. The main function of the virtual network is demand and supply matching using PIAX platform. The physical network consists of many kinds of GWs for example HGW, BGW, FGW, and MGW. First, a GW connects to Virtual grid Server then a virtual agent is created in the Virtual Network as shown in Fig. 5. Second, proposed matching algorithm is run among the virtual agents in the Virtual Network. Finally, a GW trades power supply and demand with other GWs based on the matching information from the virtual agent.

Figure 6 shows GWs search method using PIAX. An agent means a GW of demand user or supply source and some attributes are added in each agent in order to search other agents for example location information, power price, power amount and generation type. In this case a supply agent has these attributes; the location attribute (latitude=135.50, longitude=34.00), the power price attribute (30yen), the generated power amount attribute (200 w) and the power generation type attribute (Renewable energy). A demand agent can find this supply agent by the search query attribute combination of Skip Graph overlay and DOLR overlay. The search query for SkipGraph is “price within 25yen and 35yen”, and the search query for DOLR is “type = Renewable”. Then, this combination query searches the power supply agents with their power generation type which is renewable energy within price 25yen and 35yen.

B. Demand and supply matching algorithm

We propose the demand and supply matching algorithm in order to solve the issue of dynamic adjusting in spite of fluctuation of power demand and supply, and solves the issue to control user satisfied matching. The proposed matching algorithm is implemented in the Virtual grid Server in Fig. 5, and maximizes user satisfaction matching by considering the situation and fluctuation of power demand/supply.

Figure 7 shows the flowchart of the proposed matching algorithm. The proposed matching algorithm consists of matching phase and exchanging phase, and iterates these two phases. Then, each demand agent starts matching, and the matching phase is carried out. The matching phase aims to matching optimization on each agent. Each demand agent searches neighbor supply agent, and chooses the initial supply agent. If a requested power amount of demand agent is filled in the matching phase, then the exchanging phase is carried out. The exchanging phase aims to matching optimization in the overall agents. Due to exchange matching supply partner between demand agents, the total users’ matching satisfaction increases. If supply power fluctuation is occurred and it is difficult to provide the requested amount of demand power, then the matching phase is carried out again. This algorithm solves the issue of dynamic adjusting of power demand and supply fluctuations, and solves to maximize users’ satisfaction by dynamic iteration of two phases and by exchanging matching supply partner on each demand agent.

In the matching phase, each demand agent chooses initial matching supply partner in best effort. At this stage, it is not always necessary to user satisfaction because it is necessary to find a matching supply partner as soon as possible. If a demand agent cannot find any supply agents within a certain range, then demand agent searches with expand in stages. Moreover, if demand power or supply power fluctuation is occurred, then the demand agent searches new matching partner immediately in order to minimize the fluctuation and to prevent decreasing of user satisfaction because of the lack of requested demand amount.

Figure 8 shows an example of the matching phase. In this case, there are 10 demand agents and 10 supply agents in 1km² square areas. No.6 demand agent finds No.0, No.8 and No.9 supply agents and matches No.0 and No.9 supply agent.

In the exchanging phase, each demand agent exchanges matching partner in order to increase the overall user satisfaction of matching. Each demand agent decides to perform exchange or not exchange. The exchanging phase aims to optimize the matching to maximize the overall user satisfaction.

Figure 9 shows an example of the exchanging phase. In this case, No.4 demand agent finds No.2 demand agent and
We define user satisfaction evaluation function as (1).

\[ \text{Satisfaction} = \sum_{n=1}^{N} \alpha_n \left(1 - \frac{|\text{Expect}_n - \text{Trade}_n|}{\text{Expect}_n}\right) \]  

There are many evaluation items in the matching control such as power price and power amount. For example, focus on only power price, a demand user expects to buy the power by 20 yen, however trades the power by 25 yen. In this case user satisfaction value of this demand user is 0.75. By changing the weights to each evaluation item, it is possible to deal with various users. Evaluation items to be emphasized in each user are different. In the exchanging phase user satisfaction is calculated by these equations, and the purpose of the exchanging phase is to maximize total satisfaction of all users.

IV. PERFORMANCE EVALUATION

There are two evaluation contents. The first evaluation content is calculation time of matching, and the second one is the average of user satisfaction. We evaluated calculation time in the matching phase as shown in Fig.7 in case of ILP which is the centralized method and the proposed method. Because, centralized matching method by ILP cannot calculate user satisfaction problem with nonlinear characteristics.

In order to show the results of dynamic adjusting in spite of fluctuation of power demand and supply, we evaluated the average of user satisfaction value and compared the average of user satisfaction value of without iteration matching with the average of user satisfaction value of proposed method. The average of user satisfaction is calculated by equation (1), which is represented by three valuables. The valuables are requested power amount, user expected power price and the percentage of renewable energy. Table 1 shows simulation and evaluation conditions and parameters.

Figure 8 shows the matching calculation time of centralized control method and proposed method. The x-axis shows the number of GWs and the y-axis shows the matching calculation time. The calculation time of centralized control method exponentially increases correspond to the increase of the number of agents. On the other hands, the calculation time of the proposed method slightly increases correspond to the increase of the number of agents. These results indicate that each agent optimizes matching autonomously and depressively in the proposed method. From these results, we confirm that the proposed method can reduce the calculation time, and can assure to provide requested amount of demand power immediately.

Figure 9 shows the average of user satisfaction value of without iteration matching and proposed matching method. The
Figure 10: The matching calculation time of centralized control method and proposed method

Figure 11: The average of user satisfaction value without iteration matching and proposed matching method

x-axis shows the time-step and the y-axis shows the average of user satisfaction value. The average of user satisfaction value of without iteration matching decreases at every time-step in spite of demand and supply power fluctuations. On the other hand, the average of user satisfaction value of the proposed method increases at every time-step in situations occurring demand and supply power fluctuations. Hence, each agent iterates the matching phase and the exchanging phase, and optimizes to maximize user satisfaction in every time-step. From the above results, we confirm that the proposed method realizes dynamic adjusting in spite of the fluctuation of power demand and supply, and realizes user satisfied matching. Using the proposed method, the user can obtain the power in real-time with maximized satisfaction.

V. CONCLUSIONS

We propose the matching method that the demand and supply matching algorithm by utilizing the P2P Interactive Agent eXtensions (PIAX) platform. The calculation time can be reduced by the autonomous distributed control by PIAX platform. The PIAX platform also solves the communication issue between GWs. The issues of dynamic adjusting of power demand and supply and the maximizing user satisfaction by demand supply matching are solved by the proposed matching algorithm. The proposed matching algorithm consists of the matching phase and the exchange phase. The matching phase aims to optimize matching satisfaction on each agent, and the exchanging phase aims to optimize matching satisfaction on overall users. By the matching phase, demand agents can find new matching supply partners when power fluctuation is occurred. By the exchanging phase, demand agents can obtain supply power with maximized satisfaction. Many kinds of GWs participate in this platform, and trade the amount of power supply and demand. By using the scalable search function and autonomous distributed structure of PIAX, GWs can trade power in real time.

The evaluation results show that the proposed method can reduce the calculation time drastically compared to the centralized method which is ILP, and can maximize the average of user satisfaction value in spite of fluctuation of power demand and supply compared to the centralized method. Therefore, we confirmed that the proposed method is very effective for demand and supply matching.

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REFERENCES