Demand and Supply Matching Method in Smart Grid by Distributed P2P Communication

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Abstract—In Smart Grid, renewable energy such as photovoltaic power and wind power has been rapidly introducing. Then, the power grid has been shifting from the tree 1:N structure with centralized power plants to the N:M structure with various kind of power resources. In this case, to realize matching control among N supply resources including unstable renewable energy and M consumers, the scalable real time matching method is necessary. In this paper, we propose a novel scalable real time matching algorithm to reduce the transmission loss by distributed P2P communication that is the P2P Interactive Agent eXtensions (PIAX) platform. Then, we show that the proposed method utilizing PIAX enables the real time matching and can reduce the transmission loss similar as centralized control method.

Keywords—Smart Grid, PIAX, Peer-to-Peer, Real Time, Autonomous Distributed System

I. INTRODUCTION

In recent years, Smart Grid has been attracting attention, because it realizes efficient power grid by ICT[1][2][3]. 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 generation equipment and power storage equipment are installed in each house. They are photovoltaic power generator, fuel cells, electric vehicles and storage batteries. Therefore, the power grid shifts from the tree 1:N structure to the N:M structure by introducing various kind of power supply resources. Accordingly, it is necessary to control distributed power generations efficiently to reply to requested demand of each user. We call this control as “Demand and Supply Matching” in this paper. Moreover, the transmission loss corresponding to transmission distance is nearly 5% in Japan[4]. Therefore, it is necessary to control supply and demand matching by considering transmission distance. Several studies have reported that the centralized control server optimizes supply and demand matching[5]. However it is difficult to control many distributed generations including unstable renewable energy in real time. Because the calculation time of optimization matching between supply and demand increases corresponding to increase of combination by distributed supply resources and requested demands. Therefore, a scalable and real time method is necessary to reduce calculation time. In this paper, we propose a novel real time and scalable matching method that utilizes the P2P Interactive Agent eXtensions (PIAX) platform. We show that the proposed algorithm enables the real time matching, and can reduce the transmission loss similar as centralized control method.

This paper is divided as follows. In Section II, we explain Smart Grid. Then, in Section III, we point out the issues about demand and supply control in Smart Grid, and introduce PIAX. We propose demand and supply matching method utilizing PIAX in Section IV. In Sections V, we describe the evaluation results of proposed method. Finally we describe the conclusion in Section VI.

II. SMART GRID

Fig. 1 shows concept of Smart Grid. Smart Grid is a power system that the power grid is controlled by Information and Communication Technology (ICT). The smart grid aims to expand introduction of renewable energy, to control supply and demand balance, to realize high power efficiency, and to realize high reliability of power supply system. Then, HGW is installed in each house and collects power demand and supply information. Then, HGW collects the power demand request of home appliances and electricity price by electric power company, and controls power supply and requested demand to realize balance of power supply and demand in power grid. In the smart grid, there are the following two benefits. One is expansion in introduction of renewable energies, and other is operational efficiency of power generation equipment.

A. Expansion in introduction of renewable energies

With the serious problem of global warming, it is expected to reduce carbon dioxide by the expansion of introducing

Fig.1. Overview of the smart grid
renewable energies such as photovoltaic power and wind power. However, the power amount of renewable energies is unstable because of their high dependency on weather conditions. Therefore, it has become a major issue for the introduction of renewable energies. In Smart Grid, it would be possible to predict the generated power of renewable energies and to control them through HGW in real time. Then, it is possible to expand introduction of renewable energies, and to control the demand and requested supply adjustment by ICT.

B. Operational efficiency of power generation equipment

In Smart Grid, consumers are able to get the various kind of information through HGWs, such as current power consumption, electric charges, electric fee, and demand planning. Moreover, in real time pricing environments, electric fee varies depending on the amount of requested power demand. Therefore, consumers suppress the power consumption in case of high electric fee and increase consumption in case of low electric fee. Therefore, it is possible to suppress the fluctuations of total power demand in power grid, and to reduce peak power demand. Generally, Power Company installs power plant to meet the peak demand. Therefore, it is possible to reduce power plant by the suppression of peak demand, and to increase the operating rate of the power plant. Moreover, thermal power plants are operated to absorb peak demand, and Power Company can reduce carbon dioxide emission that is global warming by reducing the thermal power plant.

III. THE ISSUES OF DEMAND AND SUPPLY CONTROL IN SMART GRID AND PIAX

A. Issues in demand and supply control in Smart Grid

In Smart Grid, the demand and supply matching method having scalability and real time control is needed. The matching method must satisfy the four issuers described below.

(a) Power supply and demand matching algorithm

(b) Search function to find the supply nodes corresponding to the matching algorithms.

(c) Communication functions between the power supply node and demand node.

(d) Matching scalability of power supply and demand.

We describe the outline of PIAX platform which satisfies issue (b), (c) and (d).

B. PIAX: P2P Interactive Agent xTensions

Fig. 2 shows the overview of PIAX platform [5]. As shown in Fig. 2, API is defined to enable easy development of application programs. For example, the navigation application and the streaming application and the service composition application and content recommendation application in Fig. 2 are developed on PIAX platform. PIAX platform integrates the distributed agents and P2P overlay network, represents various kinds of object as an agent, and provides API that enables unified operations on the agents. Furthermore, the agents have powerful search functions, and we can search without considering communication functions. Therefore, we can easily implement a large-scale distributed system.

1) Powerful agent search function: Fig. 3 shows the hierarchical structure of PIAX platform. The Multi-Overlay layer provides search functions corresponding to P2P overlays, they are LL-Net (Location-based Logical P2P Network)[6][7], DHT (Distributed Hash Table) and ALM (Application Layer Multicast)[8]. It is possible to search in various parameters utilizing these overlay networks. For example, LL-Net provides geographic search, Multi-Skip Graph[9][10] 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 through 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 log₂N. Moreover, where the number of nodes in the Skip Graph is N, the average search number of times is O (logN). PIAX provides the fast search utilizing various kinds of overlays without depending on the number of nodes.
IV. THE PROPOSED METHOD

A. Matching control system using PIAX platform

We propose a power supply and demand matching control system that utilizes PIAX platform as shown in Fig. 4. The proposed matching system consists of various kinds of gateways (GWs) and Internet, and GWs communicate through Internet. There are many kinds of GWs, for example HGW, Building Gateway (BGW), Factory Gateway (FGW), and Management Gateway (MGW). PIAX platform and P2P matching software are installed in GWs except MGW, and PIAX platform is installed in MGW as shown in Fig. 4. By exchanging power supply and demand information via PIAX platform, GWs autonomously control power supply and demand matching by P2P matching software. Then, the scalability issue is solved by utilizing PIAX platform where the search number of times does not depend on the number of nodes, and the real time issue is solved by the flexible search mechanism in PIAX platform too.

Fig. 5 shows an example of attribute value search by combination of two overlay networks, one is LL-net which is used for the range search and other is DOLR which is used for the exact match search. For example in Fig. 5, an agent (HGW) has three attributes; the location attribute (latitude=135.50, longitude=34.00), the power generation type attribute (solar), and the generated power amount attribute (200). In Fig. 5, the GW which requests power supply can find the power supply GWs by the search query attribute combination of LL-net and DOLR. The search query for LL-net is “location inside circle (latitude =130, longitude=30, search radius =10), and the search query for DOLR is “type=Solar”. Then, this combination query searches the power supply GWs their power generation type is solar within radius 10 from its own location on the earth.

Next, we propose the demand and supply matching algorithm which is implemented in P2P matching control software installed in GWs to reduce the power transmission distance by LL-net and DOLR overlay networks which is implemented in P2P matching control software installed in GWs.
B. Proposed matching algolism to reduce transmission loss

Our target is to reduce the power transmission loss that depends on the transmission distance. Therefore, we propose the distributed optimization-matching algorithm that is a demand and supply matching algorithm to reduce the power transmission distance. The conventional centralized control method can minimize the whole transmission distance because the centralized controller knows the whole power transmission network topology. However, the centralized control method has a scalability issue. When various kinds of distributed energy resources based on renewable energy such as photovoltaic power and wind power are introduced, the calculation time becomes long by the centralized control method. On the other hands, the centralized control method is able to decide the ideal matching to minimize the transmission distance. Therefore, the proposed distributed optimization-matching algorithm aims to be closer to the matching accuracy by centralized control.

Fig. 6 shows the flow chart of the proposed matching algorithm that has two phases. First phase is the matching phase and the second phase is the exchange phase. In first matching phase, each node searches the nearer neighboring nodes to determine the first matching partner. However, matching opponent at first phase is preliminary, and it is not necessarily to find the nearest neighboring node to minimize the transmission distance. Furthermore, the overall optimization in whole power network is not necessarily. Then, in second exchange phase, each node exchanges the partner in order to reduce transmission distance. By repetition of exchange the matching partner, the whole transmission distance becomes closer to minimum transmission distance calculated by the centralized control.

Fig. 7 shows an example of first matching phase. In this case, there are 10 demand nodes and 10 supply nodes in 1km² square areas. Each demand node searches neighbor supply nodes by location-based search. This search range is increased in stages when there is no supply node in the search range. In this case, No.6 demand node finds No.0, No.8 and No.9 supply nodes and matches No.0 and No.9 supply nodes. Fig. 8 shows the example of second exchanging phase. Each demand node searches neighbor demand nodes by location-based search, compares the searched transmission distance to previous matching distance, and selects shorter distance node. If the searched node is selected, each demand node exchanges the matching partner. In Fig. 8, No.4 demand node finds No.2 supply node and calculate the previous transmission distance and the searched transmission distance. The previous transmission distance is 100m and the searched transmission distance is 70m, then their matching partner is exchanged.

V. SIMULATION AND EVALUATION

In this section, we show the simulation conditions and the evaluation results compared to the central controlled matching algorism with ILP and the proposed matching algorism with PIAX platform.

Table1 shows the simulation and evaluation conditions. We evaluate the centralized control method by ILP utilizing CPLEX, and evaluate the proposed matching algorism by PIAX platform. Specifically, we developed ILP program to realize the matching algorism to minimize the transmission distance, and developed P2P matching control software to realize the proposed algorithm as shown in Fig. 6 utilizing PIAX agent library.
TABLE I. SIMULATION AND EVALUATION CONDITIONS

<table>
<thead>
<tr>
<th></th>
<th>Central control</th>
<th>Distributed control</th>
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<tbody>
<tr>
<td>Placement area</td>
<td>1km²</td>
<td></td>
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<tr>
<td>Number of supply / demand nodes</td>
<td>10, 20, 30, 40, 50, 60</td>
<td></td>
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<tr>
<td>Amount power of supply and demand</td>
<td>Normal distribution (Mean: 500W, Variance 500W)</td>
<td></td>
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<tr>
<td>Distance</td>
<td>Uniform distribution (0m ~ 1000m)</td>
<td></td>
</tr>
<tr>
<td>Machine spec</td>
<td>Dell PowerEdge R620 Intel Xeon 2.00GHz × 6CPUs Memory 13GB</td>
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</table>

A. Evaluation of the average transmission distance

The centralized control method is possible to get optimal transmission distance that is the minimum transmission distance. On the other hands, the proposed matching algorithm is a heuristic distributed algorithm to get the quasi-optimal transmission distance. Therefore, the evaluation point is that how close the transmission distance of the proposed algorithm to optimal value. We compared the central control matching method and the proposed matching algorithm in terms of the average transmission distance.

Fig. 9 shows the average transmission distance. The average transmission distance of the proposed algorithm is close to the optimal value independent to the number of nodes. The difference between the proposed algorithm and optimal value is within 5%. Therefore, the proposed algorithm is effective to reduce transmission distance in Smart Grid.

B. Evaluation of the calculation time

The calculation time of matching is a big issue of scalability and real time. Fig.10 shows the calculation time of the first matching phase as shown in Fig. 6. The calculation time of centralized control method exponentially increases correspond to the increase of number of nods. On the other hand, the calculation time of the proposed algorithm slightly increases correspond to the increase of number of nods.

From the above results, we confirm that the proposed method has scalability and realize real time calculation.

C. Evaluation of PIAX platforms

We tried to expand the large number of nodes exceed 60 nodes. However, we could not evaluate exceed 60 nodes. Then, we evaluated PIAX platform version 2 by the PIAX test bed in JGN-X [11]. We used 100 nodes consisted by three places (Otemachi; 10 nodes, Sapporo; 20 nodes, Keihanna; 70 nodes), and installed 2,000 agents. We evaluated the search scalability using 2,000 agents by Multi Skip Graph as shown in Fig.3. Fig. 11 shows the search latency time distribution by Multi Skip Graph. The average of search latency time is nearly 150ms, and Search latency time is within the range from 50ms to 240ms. Therefore, we confirm the search scalability by Multi Skip Graph. However, we cannot find the number of more than 1,000 peers in Fig. 11 because of the lack of robustness. This is why we cannot evaluate more than 60 nodes as shown in Fig. 10. Then, PIAX version 3.0 is released in June 2015. We will similarly evaluate the search scalability by Multi Skip Graph, confirm the robustness, and try to expand the large number of nodes exceed 60 nodes.
VI. CONCLUSION

In Smart Grid, various kinds of distributed energy resources based on renewable energy such as photovoltaic power and wind power and electric vehicles and storage device are introduced. Then, the power grid shifts from the tree 1:N structure with centralized power plants to the N:M structure with distributed various kinds of power supply resources. With the introduction of distributed power supply resources, it is required to control the demand and supply matching in real time. Several studies have reported that the centralized control server optimizes supply and demand matching. However it is difficult to control many distributed power resources including unstable renewable energy in real time. Because the calculation time of optimization matching between supply and demand increases corresponding to increase of combination by distributed supply resources and requested demands. Therefore, a scalable and real time method is necessary to reduce calculation time.

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