# The Design and Implementation of Power Service Discovery System in Distributed Generation Environment

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***Abstract*—The present paper introduces a power service discovery system. The power service discovery system realizes new power services on a smart grid. The new power services are based on the selection of generations, which enables us to provide/receive electricity under specific conditions. We describe the design and implementation of the power service discovery system. Our implementation constructs a demonstration system. The demonstration system reveals that the power service discovery system realizes the new power services such as conditioned power supply.**

***Index Terms*—smart grid, service platform, service discovery, distributed system.**

## I. Introduction

In recent years, there has been an increasing interest in distributed generations such as photovoltaic systems, wind generations, micro gas turbines, and fuel cells. Many companies and factories are adopting such distributed generations. The distributed generations will represent large proportion of generations in the future power grid.

The penetration of the distributed generations causes the instability of the electric power grid. Each distributed generation operates on its own way, which results in a fluctuation of both grid frequency and voltage. These instabilities of the electric power grid may break grid facilities as well as electric appliances in our house.

In order to stabilize the electric power grid in a distributed generation environment, researches on new power grid called *smart grid* have been actively conducted [1–11]. On the smart grid, *smart meters* measure generation output and power consumed by electric appliances. The smart meters communicate each other and share the measured power information. Using the measured power information, each smart meter controls generations and electric appliances to stabilize the electric power grid. The control method of generations and electric appliances based on the shared power information on the smart meters is a key technology for providing reliable and efficient power delivery system.

Studies on the smart grid have primarily investigated control methods of generation and electric appliances [1–7] or communication schemes [8–11]. These studies assume that the smart grid is mainly used by electric power industries for reducing the cost of grid stabilization. However, the smart grid has a possibility to be profitable to the demand side since the smart grid can work as a platform for power market. We believe that developing a power market platform using the smart grid accelerates the spread of the smart grid.

In view of this, we propose new power services on the smart grid. To realize these power services, we present a power service discovery system working on the smart grid. The power service discovery system enables us to look for generations which satisfies our requirements such as the type of generation, price of the power, and the owner of the generation as well as power output. Since there will be a huge number of generations and electric appliances, we present a design of a distributed search system based on hierarchy of the electric power grid.

The present paper describes a design and an implementation of the power service discovery system. We make the following key contributions in the paper.

1) We show some examples of new power services on the smart grid. The new power services are based on the selection of generations, which enables us to provide/receive electricity under some conditions. For example, we can receive only when our own photovoltaic system provides enough electricity. We can realize such new power services by a power service discovery system.
2) We present a design of the power service discovery system for the new power services on the smart grid. Our service discovery system works with a huge number of distributed generations and electric appliances. The service discovery system can handle search query within a second while avoiding grid instability.
3) We show the implementation of the power service discovery system. We also show a demonstration system of the power service discovery on a pseudo smart grid, which reveals the feasibility of new power services as well as the search scheme.

The remainder of the present paper is organized as follows. Section II presents example scenarios of power services and describes the requirements of the power service discovery system. Section II also describes related works and clarify the standing point of our power service discovery system. Section III presents the design of our power service discovery system and show how our power service discovery system looks for the specified generation. In Section IV, we imple-


doi: 10.1109/ICRERA.2012.6477406

ment our power service discovery system. We also present a demonstration system and show that our power service discovery system can realize new power services. Finally, Section V concludes the paper.

## II. Distributed Generation Environment

In the future power grid, there will be a great number of distributed generations such as photovoltaic systems, wind generations, and micro gas turbines. In such a distributed generation environment, we want a power discovery scheme which finds generations satisfying specified conditions to effectively use the distributed generations. For example, we can find specific type of generations, generations providing low-price power, and generations which are owned by a specific owner. In this section, we propose new power services based on such power discovery scheme and show the requirements of the power discovery scheme.

### A. Scenario of Power Service

To clarify the requirements of a power discovery scheme for new power services in distributed generation environment, we consider three scenarios of power services.

1) Thank-you-shopping electricity
When users enjoy their shopping in a shopping mall, the shopping mall provides electricity to an electric vehicle at a parking lot from photovoltaic systems attached to the shopping mall. If the power output from the photovoltaic system decreases, the power shortages are compensated by other photovoltaic systems at the other shopping malls of the same group.
2) Powering company products
Some companies provide to their electrical appliances from the companies' EVs. If a user has an electric appliance from such a company, the electrical appliance automatically finds the company's EVs and receives electricity from the EVs.
3) TV program with electricity
Some broadcasting stations provide electricity for TVs as well as TV programs. When a user watches the TV program, the TV receives electricity from the generation of the broadcasting station.

### B. Requirements

Realization of these services requires a searching scheme for distributed generation. This scheme needs to satisfy three requirements below at the same time.

First, the scheme must be able to handle frequent advertisement from generation. The power output from renewable energy generation varies every moment. On the other hand, the imbalance between power supply and demand leads to the fluctuation of the power system frequency, which in turn causes dropouts of generation and loads, and a blackout in the worst case. To avoid these, frequent advertisements from generation would be required in order for the search results to reflect the changes in power supply quickly.

Second, the scheme should be able to deal with enormous search queries from loads simultaneously. Today, a lot of loads are connected to the electric power system. These loads are required to search for the power provided by distributed generation over and over again in order to balance power demand and supply. Thus, it is required that frequent searches from a good deal of loads should be processed at the same time to balance power supply and demand.

These two requirements above suggest that the practical service discovery system would be distributed one which comprise multiple computational nodes.

Last, the scheme should be able to support range queries in distributed environment. In the scenario, certain generation provide electricity for a certain load as a service. The status of electric transfers can be virtually arranged metering power generation and consumption. In this arrangement, the difference between generation and consumption is required to remain within the tolerance level, which is determined considering the stability of electric power system.

### C. Related Works

A searching scheme is distinguished by the method of disposing the information about "what is where," i.e. search index or advertisement, and the method of searching involved by that of disposing search indexes.

By the method of disposing indexes, existing searching schemes are classified into four groups: centralized, replicated, distributed, and hybrid between replicated and distributed [12]. Among these groups, Our approach is classified as hybrid case. In this case, the distributed system holds multiple copies of the indexes but not all indexes are assigned to one system node.

One of the example for this case is DNS [13]. In many cases, DNS contents servers are operated with redundant configuration. Through the delegation of zone by the upper level domain node to the lower level domain node, indexes are distributed in the hierarchical manner in order to reduce the load on the upper level DNS contents servers. Cache copies in DNS cache servers also play a secondary role in distributing indexes. Searching process in DNS is conducted recursively with a first query to the top level domain node. This type way of disposing indexes and searching assumes that mapping from host name to network address is relatively static [14], so it is not appropriate if the frequent advertisement and search is required in order to update information with current data repeatedly. The reason why it is unsuitable is because the disproportionate loads are put on the upper level domain nodes by processing search query or index update request.

Another example is the searching scheme using DHT [15–18]. DHT has the capability to efficiently distribute indexes, but the utilization of a hash function destroys magnitude relation of the original numerical data used to calculate hash values, and thus it is difficult for such system to handle search queries with range specification.

## III. Design

Toward the realization of power services on smart grid, we designed a power service discovery system. The power service discovery system searches for generations using search query, which includes users' preferences on generations. For example, we can search for renewable energy sources such as photovoltaic systems and wind generations by specifying the type of generations. The power service discovery system is capable of handling the huge number of generations and electric appliances, which vary in their status every moment.

Fig. 1 shows an overview of the power service discovery system. The power service discovery system consists of multiple *smart power flow controllers (SPFCs)*. We especially call SPFCs at the bottom level *terminal SPFCs (T-SPFCs)* in our explanation. The SPFCs are deployed in a hierarchical topology based on the hierarchy of the power grid as shown in Fig. 1.

We can search for generations over the whole system by means of messaging between SPFCs. The SPFCs operate in two phases, an advertisement phase and a search phase. In the advertisement phase, the SPFCs share information about the connected generations. In the search phase, the SPFCs look for generations which satisfy the user requests based on the shared generation information. Details of the advertisement phase and the search phase are given in the following section. We describe the two phases separately, but the system works well under asynchronous operation of the two phases.

### *A. Advertisement*

In the advertisement phase, generations periodically send the generation information to T-SPFCs. Fig. 2 shows an example of the generation information. The generation information consists of a `DeviceID`, `Slack`, and a descriptions of the power service. The `DeviceID` and `Slack` are mandatory. The `DeviceID` is a unique ID in the whole system. The `Slack` is a capacity to provide electricity. We use the `Slack` as a controllable amount of power provision in the generation information. The description of the power service is a set of key-values. We can write any attribute here as long as we can describe the attribute by a combination of key-value pairs.

When the SPFC receives generation information, the SPFC writes down the information in a list. It is noted that here the SPFCs include T-SPFCs. The SPFC forwards the generation information to the upper level SPFC. Before forwarding, the SPFC aggregates generation information in terms of the description of the generation information. The message forwarding terminates at the top level SPFC.

Since some SPFCs are connected to multiple lower SPFCs, this aggregation reduces the number of forwarding messages. The number of receiving messages increases exponentially at the top level SPFC. The reduction of the number of forwarding messages helps to meet the requirement of handling enormous advertisements.

### *B. Search*

In the search phase, load devices periodically send search queries to T-SPFCs. Fig. 3 shows an example of a search query. The search query consists of a `DeviceID`, `PowerCons.`, `Slack`, and a condition for power services. The `DeviceID`, `PowerCons.`, and `Slack` are mandatory. Load devices also have unique IDs `DeviceID`. The `PowerCons.` is a current power consumption of the load device. The `Slack` is a capacity to reduce the power consumption [19]. The condition of power services is a set of key-values. We can write any AND conditions as a combination of key-value sets. If we want to search with OR conditions, we can generate two search queries.

When the SPFC receives a search query, the SPFC looks into its table of generation information and check if there is generation which corresponds to the search condition. When no generations found, the SPFC relays the search query to the lower SPFCs. If there are no more lower SPFCs, the SPFC finally relays the search query to the upper SPFC. The search sequence terminates when the generation found or when no generation found at the top level SPFC. The search result is relayed to the SPFC to which the load device send the search query.

Such search scheme performs a local-first search, which effectively handles a large number of search queries because the search query is not forwarded after the discovery. It is noted that our search system provides not optimal search results. There might be other generations outside of the local search space. We sacrifices the retrieval of optimal solutions to meet the requirement of handling enormous search queries.

## IV. Implementation

We implemented our power service discovery system to show that the power service discovery system can provide power service scenarios such as the ones described in Section II-A. Since we have no experimental smart grid, we also implemented a pseudo smart grid using off-the-shelf components.

Fig. 4 shows the power service discovery system on a pseudo smart grid. As stated in Section III, messaging between smart power flow controllers (SPFCs) realizes power service discovery. We implemented the SPFC as a ruby program on a laptop PC. We prepared seven SPFCs and connected them on an IP network. We assigned SPFC IDs to the SPFCs and configured the SPFCs to communicate in a tree structure as depicted in Fig. 4. When a T-SPFC receives a power provision data, the T-SPFC advertises the power provision data to the upper SPFC. When the T-SPFC receives a search query, the T-SPFC searches for a generation which satisfies the condition in the search query. After the search, the T-SPFC replies the search result to where the search query is sent from. SPFCs also have a function of message relaying to relay the search results.

Our pseudo smart grid consists of seven devices which substitute for generations as well as electric appliances and a power sensor which substitute for a smart meter. A mapping table between implemented devices and devices in scenarios is depicted at the bottom of Fig. 4. We use an Arduino utilizing Ethernet Shield as a power sensor. The power provision/consumption of each device is calculated by measuring the voltage drop across small resistors which are serially

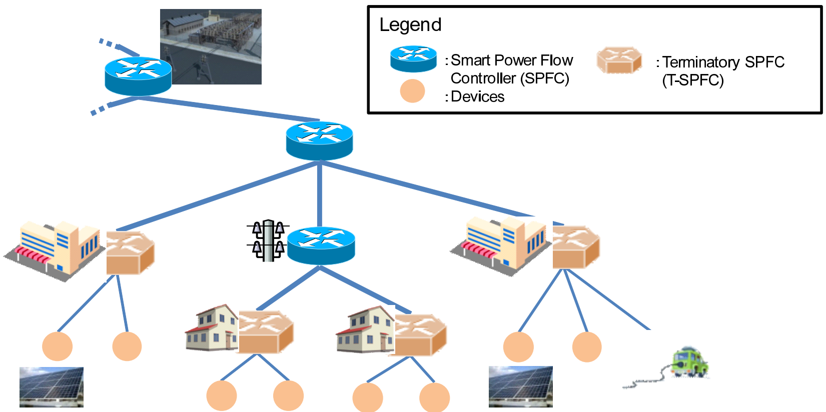


Fig. 1. Overview of a power service discovery system.

```
[ServiceProvision =
  [DeviceID = 67890]
  [Slack = +1367.9W]

  [Price = ¥25.4/kWh]
  [Gen.Type = PV]
  [Provider = Shopping Mall Nakajima]
]
```

Fig. 2. Example of generation information.

```
[ServiceRequest =
  [DeviceID = 12345]
  [PowerCons. = −507.8W]
  [Slack = +60.0W]

  [Price < ¥26.0/kWh]
  [Gen.Type = PV]
]
```

Fig. 3. Example of a search query.

connected to each device. The Arduino periodically reports the power provision data to the SPFC to which each device is connected. Since devices substituting for electric appliances have no ability to transmit search queries, we also implemented query transmission on the Arduino. The Arduino generates search queries including some conditions such as a type of generation and price of the power. The generated search queries are sent to the SPFC to which each device is connected.

In order to see the search results, we also implemented a power flow viewer. The power flow viewer shows power flows based on the results of search queries in a quasi-realtime manner. Fig. 5 shows our power flow viewer. We implemented the power flow viewer as a Java program. The power flow viewer collects search results as well as power provision/consumption data from power sensors. The power flow viewer draws arrows depicting power flows based on the search results. The width of the arrows varies according to the amount of the power flow.

Our implementation constructs a demonstration system. Fig. 6 shows the overall demonstration system of our power service discovery system. Seven SPFCs are connected in a tree topology which is the same topology as depicted in Fig. 4. The SPFCs change their screen color when they receive an advertisement, a search query and a search result as shown in Fig. 6. The blue, red, and green screen mean that the SPFC receives an advertisement, a search query, and a result of search query, respectively. We can see power provision of each generation as the width of arrows in a power flow viewer. We note that the light is not a device but a substitute for the sunshine.

Using this demonstration system, we confirmed that we can realize the "thank-you-shopping electricity" scenario described in Section II-A. We first connect a pseudo EV which requests the PV of a shopping mall to the pseudo smart grid. An Arduino detects the connection of the EV and transmits search query to a SPFC. The SPFC searches for generations which satisfy the condition, i.e. the PV of a shopping mall. When the SPFC finds the PV, the SPFC replies search result to the Arduino. A power flow viewer periodically retrieves the search results and draws an arrow between the EV and the PV at the shopping mall. We next cover the PV by hand, which results in the decrease of the PV output. The SPFC detects power shortage and searches for the other generations. The SPFC finds another PV and replies the search result.

## V. Conclusion

In the present paper, we proposed new power services on a smart grid based on the selection of generations, which enables us to provide/receive electricity under specific conditions. To realize the new power service, we designed and implemented a power service discovery system. Our implementation constructs a demonstration system on a pseudo smart grid, which realizes the new services such as conditioned power supply. We are currently working on the detailed considerations of the service discovery system such as the pricing scheme.

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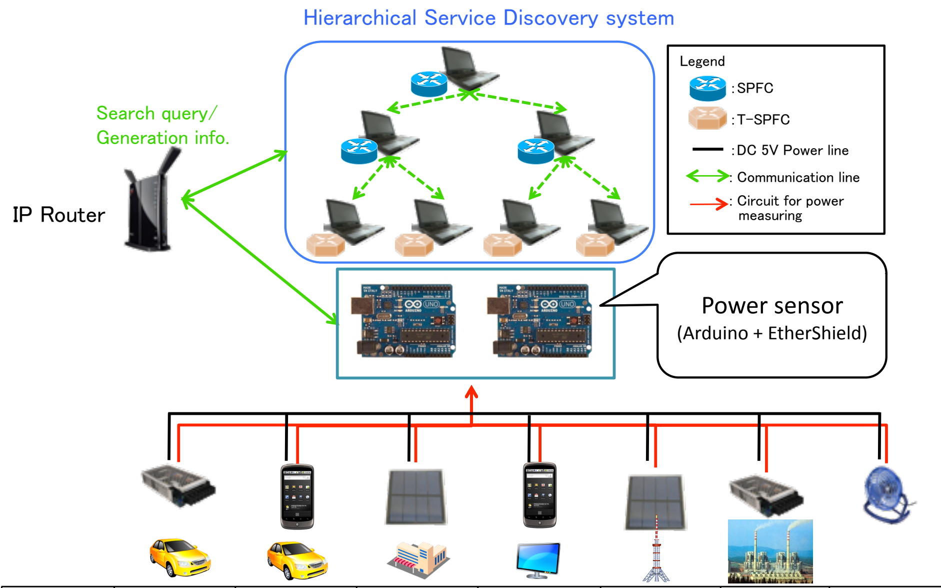


| Implemented Device | Regulated power supply | Smartphone | Small PV | Smartphone | Small PV | Regulated power supply | Fan |
|---|---|---|---|---|---|---|---|
| Device in scenario | Mr. A's EV (Discharging) | Mr. A's EV (Charging) | PV in Shopping mall | TV of A's friend | PV of a sponsor | Bulk generator | Other loads |

Fig. 4. Power service discovery system on a pseudo smart grid.

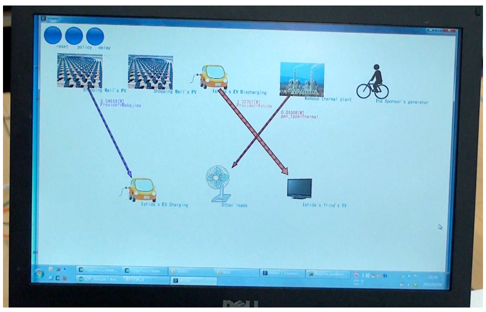

Fig. 5. Power flow viewer.

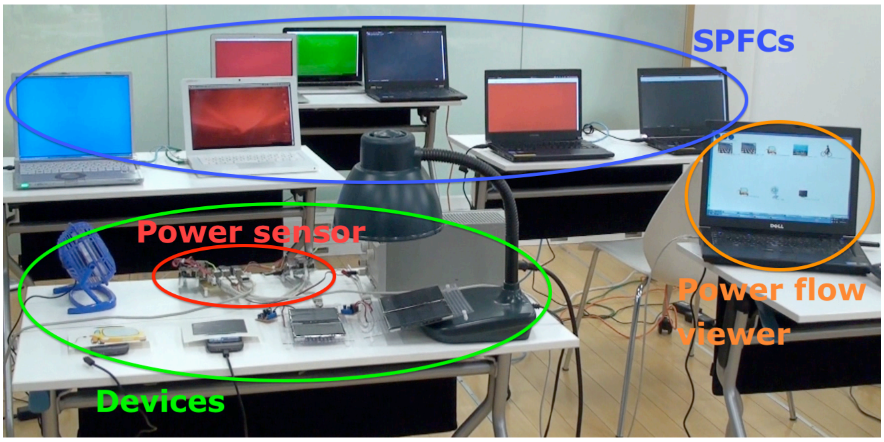


Fig. 6. Demonstration system.


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