Development of a Demand- Response System and Its Application to a Virtual-Power- Plant Construction Demonstration Project

Mizu Nakamura
Building Systems Company
Azbil Corporation

Kana Mizutani
Building Systems Company
Azbil Corporation

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The demand response method of regulating demand in conformity to the available supply of electric power began to gain attention in the wake of the tight electric power supply situation after the Great East Japan Earthquake. Japan's Ministry of Economy, Trade and Industry initiated demonstration projects related to demand response, and Azbil has developed an automated demand response (herein after ADR) system.

This paper introduces the system and describes our virtual power plant construction demonstration project, which has been ongoing since 2016.

1. Introduction

After the Great East Japan Earthquake in 2011, power supply capacity in Japan decreased due to the shutdown of nuclear power plants.

At the time of the earthquake, several "smart city" projects were underway in Japan, including demonstrations in which demand was controlled in accordance with the supply of electricity, which is called "demand response." The major purpose of demand-response in Japan before the earthquake was reduction of CO_2 emissions.[1] However, with the reduced power supply capacity of the electric power companies, the necessity of adjusting demand to meet supply increased, and demand response became more focused than before.

As a result of this situation, Japan's Ministry of Economy, Trade and Industry started a Building Energy Management System (BEMS) Promotion Subsidy project in fiscal year 2012. Azbil Corporation was selected as an aggregator company in this project. It obtained visualizations of energy consumption through remote-controlled building management systems (BMSs) installed in multiple buildings, and implemented demand response according to the degree of constraint between the power supply and demand.

Thereafter, OpenADR, which is a communication protocol for demand response systems, was specified as a standard protocol by the OpenADR Alliance (URL: http://www.openadr.org) in the U.S., and has also been selected for use in Japan.[2] For demonstration projects related to demand response that are led by the Ministry of Economy, Trade and Industry, OpenADR has become the de facto standard for communication.

Azbil has developed an ADR system, which is a demand response system using OpenADR, and has participated in related demonstration projects since 2015.

2. Demand Response Terminology

Terms used in this paper are given for ease of understanding.

(1) Demand response

In demand response, consumers of electricity (the demand side of the equation) respond to requests from the power suppliers to reduce consumption in order to balance supply and demand.

In the past, suppliers generated electricity in accordance with the amount of electric power required by the customers (often used in the same sense as “buildings” in this paper). Demand response (DR) is the opposite idea to the above.

Demand response will be abbreviated as DR in this paper.

(2) Negawatt

This refers to the amount of power reduced. Customers can reduce energy costs by the negawatt. In addition, in negawatt trading, it is possible for customers to earn profits proportionate to their negawatts.

By using negawatt trading, power suppliers can avoid making investment to increase the capacity of power generation facilities.

(3) Aggregator

An aggregator is a company that collects many customers, requests them to reduce electric power consumption, and provides the negawatts to power suppliers, or buys and sells the negawatts.

(4) Virtual power plant

A virtual power plant (VPP) integrates energy facilities, such as renewable energy generation equipment and storage batteries, with negawatts gained from DR. Virtual power plant will be abbreviated as VPP in this paper.

(5) OpenADR

A standard communication protocol for DR. It was developed and is managed by the OpenADR Alliance in the U.S. It specifies a communication protocol between a virtual top node (VTN), which consists of power generation companies and other power suppliers, and a virtual end node (VEN), which consists of aggregators.

Communication between the VTN and VEN includes requests for DR (called DR events) from VTN to VEN, the transmission and reception of measurements, etc.

The latest version of the OpenADR specification is OpenADR 2.0b, which is the edition used as a standard in Japan.

3. Azbil's ADR System

The ADR system is used in Azbil's aggregator business.

This section gives an overview of the ADR system.

3.1 System configuration

Figure 1 shows the system configuration. The ADR system is installed in Azbil’s aggregation center. The ADR system and the building management system LAN in the customer’s building are connected by a dedicated network.

Through this network, ADR remotely controls the BMS to execute DR, etc.

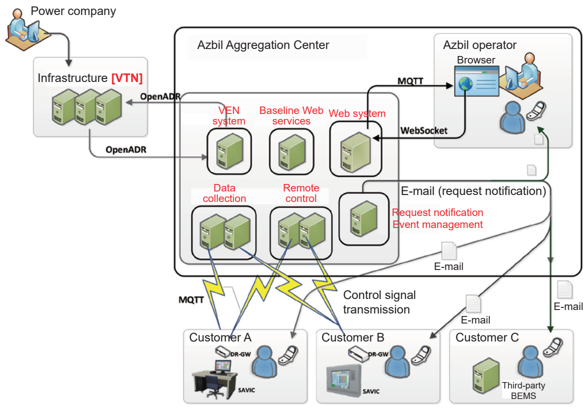

Fig. 1. ADR system configuration

The ADR system consists of the following 6 subsystems.

- VEN subsystem
- DR event management subsystem
- Data collection subsystem
- Baseline Web services
- Remote control subsystem
- Web-based monitoring system

In the following sections these subsystems are introduced.

3.1.1 Virtual end node (VEN) subsystem

This subsystem provides the VEN function defined in OpenADR. Together with the VTN operated by the power generation company, it implements DR. The VEN function of ADR is certified for OpenADR2.0b conformance[3] and can be connected to a VTN that supports OpenADR.

3.1.2 DR management subsystem

When the VEN subsystem receives a DR event, it notifies the relevant persons that DR has been requested.

There are three methods of notification.

(1) E-mail (for customers)

The request for DR is e-mailed to all relevant customers by the ADR system. When customers who do not automatically control their demand for power receive this e-mail, they manually control the demand for power by stopping equipment, etc. Developing the DR System and Applying It to the Virtual Power Plant Demonstration

(2) Alarm (for customers)

A request to reduce power demand is communicated to customers by generating an alarm on the BMS at the installation location.

The person who is notified is presumably the person in charge of building monitoring.

(3) Request management screen (for the aggregator)

This function allows the operator of the ADR system to monitor DR events in real time (see further in section 3.2.3).

The screen can display DR events in real time and generate an audible alarm.

3.1.3 Data collection subsystem

This subsystem collects measurements in order to record the actual power consumption, etc. It consists of the following two functions.

(1) DR gateway

A gateway installed in the customer's building. The measurements of electric power consumption are obtained from the BMS every minute and are transmitted in real time to the message queue telemetry transport (MQTT) broker on the central system.

(2) Accumulation of time series data

This function stores in a database the measurements received from the DR gateway via the MQTT broker.

3.1.4 Baseline Web services

It is necessary to calculate how much power was reduced by the control of power demand. To calculate the effectiveness, the amount of power consumption if control of the demand had not been applied must be estimated. The estimated value is called the baseline.

There are several methods of calculating the baseline 4 ADR uses two methods, a standard "high 4 of 5" baseline (can be adjusted on the day) and a pre-measurement, and calculates the baseline in real time on 5- or 30-minute cycles.

The baseline data is provided through the Web services and can be accessed by other subsystems.

3.1.5 Remote control of subsystems

This function provides remote control of the customer's facilities via the BMS installed at the customer's site. There are two control functions.

(1) Start/stop controls for the facilities

Facilities such as AHUs and lighting can be automatically started or stopped remotely. Facilities are stopped at the time specified by the DR event and restarted after the amount of time specified by the DR event.

(2) Setpoint controls (setting of analog values for indoor temperature, etc.)

This function can automatically lower or raise analog value settings for temperature, degree of valve opening, frequency, etc., by the desired amount from a remote location. In the same way as the start/stop controls, the settings are changed or the original setpoints are restored at the times specified by the DR event.

3.1.6 Web-based monitoring system

The user interface for the ADR system is provided by this subsystem.

By using technologies such as WebSocket and MQTT, real-time event monitoring through a web browser is provided.

Operators of the ADR system are the users of this subsystem. Details are given in section 3.2.

3.2 User interface

The user interface of the ADR system consists of the following four features.

3.2.1 Control settings

This function is used to configure the data (such as the provided services, e-mail address, power receiving point, and facility control point) related to power companies and customers. Screen examples are shown in figures 2–4.

On the control settings screen in figure 4, it is also possible to turn off control in the case of an emergency.

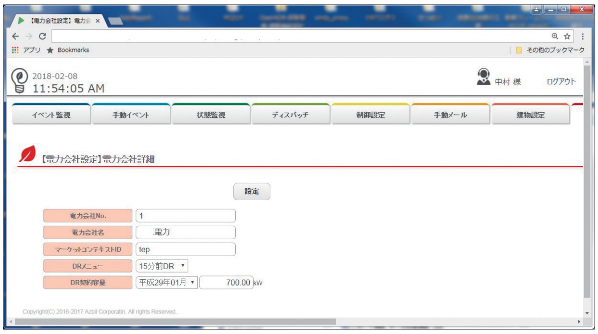

Fig. 2. Data settings screen for the power company

Fig. 3. Data settings screen for the customer

Fig. 4. Control settings screen

3.2.2 Dispatch settings

"Dispatch" refers to selection of the customers to whom demand control is applied when DR is desired. On the dispatch settings screen shown in figure 5, depending on the conditions specified by the DR event, the customers to whom demand control is applied are selected.

The following two dispatch methods are available.

Fig. 5. Dispatch settings screen

(1) Manual dispatch

Control is applied to all predetermined customers.

(2) Auto dispatch

In auto dispatch, the system automatically selects the buildings where demand will be controlled according to conditions such as the time period for DR and the amount of power reduction requested.

The ADR system is also compatible with relay dispatch. Relay dispatch is a DR method in which the demand for power is reduced by dividing the requested DR time period into multiple time periods which are assigned to multiple customers. Relay dispatch can be used for both manual and auto dispatch.

Figure 6 shows the relay dispatch settings screen.

Fig. 6. Relay dispatch settings screen

3.2.3 Event monitoring screen

The event monitoring screen (fig. 7) monitors and displays the various event data necessary for executing DR in real time, such as the DR events, alarms from customer facilities, control failures, and missing data.

Fig. 7. Event monitoring screen

On the event monitoring screen, real-time monitoring is carried out by obtaining, from the MQTT broker, events that are generated by subsystems such as VEN and remote control devices. The MQTT broker is connected to the web browser using WebSocket.

Figure 8 shows the flow of data for displaying the DR events from the VTN on the event monitoring screen.

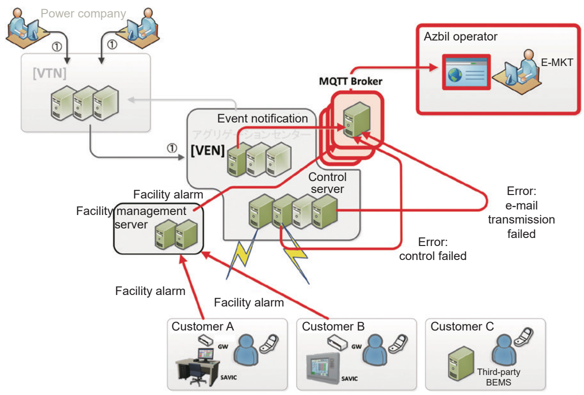

Fig. 8. Data flow for event monitoring

3.2.4 State monitoring screen

The state monitoring screen consists of the following two screens.

(1) Point monitoring screen

The point monitoring screen shown in figure 9 displays changes in the settings of control target points in the last 4 hours.

This screen is used to check if the settings of control target points have been changed by other control programs, etc.

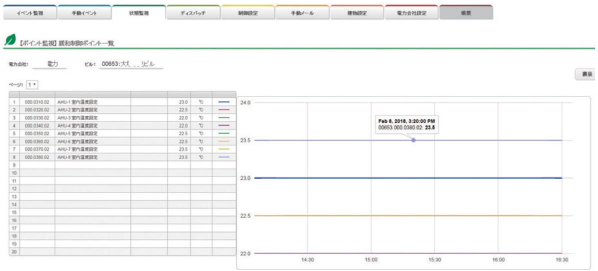

Fig. 9. Point monitoring screen

(2) Reduction monitoring screen

Figure 10 shows the reduction monitoring screen, which displays the amount of reduction every 5 minutes while demand control is being executed according to a DR request.

Since the target value and the actual value (amount of reduction) are shown, it is possible to learn at an early stage if achievement of the target is unlikely.

Fig. 10. Reduction monitoring screen

3.3 Flow of demand response

This section describes the process of DR in the system.

3.3.1 DR event received from VTN

The ADR system receives DR events using the OpenADR protocol. If the DR request is accepted, “OptIn” is returned to the VTN.

If the request is rejected, “OptOut” is returned to the VTN.

3.3.2 Scheduling control based on the DR event

After the details of the received DR event (such as the start time of control, amount of active control time, amount of reduction) have been checked, the system selects the customers subject to control (who have been specified in advance for “dispatch,” and calculates the time period of control based on information about the customers. According to the calculated values, specific periods of time for control are scheduled.

3.3.3 Sending advance notice to customers

When the customers subject to control are selected, an advance notice of the start of control is sent to customers’ registered e-mail address. In the case of customers who do not remotely control their facilities, operators manually shut down equipment, etc., as specified in the notice.

3.3.4 During control

The customer’s facilities are remotely controlled according to the schedule determined according to 3.3.2. During the control period, the status of control can be checked on the monitoring system screen of the ADR system.

If requested by VTN, measurements, etc., can be transmitted using the OpenADR’s reporting service.

3.3.5 After control has ended

After control has ended, a report is sent to the VTN in response to its request. For example, the power consumption for 1 minute cycles and the baseline value in the DR period can be transmitted.

4. The FY 2016 VPP Construction Demonstration Project

In fiscal year 2016 Azbil participated in the Advanced Control Demand-Response Demonstration Project portion of a Virtual Power Plant Construction Demonstration Project sponsored by the Ministry of Economy, Trade and Industry.

The main features of the 2016 demonstration project were as follows.

(1) The amount of reduction was specified by a DR event

In the demonstration project in the preceding 2015 fiscal year, the amount of power consumption reduction by DR was contracted with each customer in advance. In 2016, a different amount of reduction was specified for each DR event.

(2) The criteria for DR success were more strict

In 2015, DR was deemed successful if the contracted amount of reduction or more was attained.

In 2016, the condition for success was an amount of reduction within ± 10 % of the value specified by the DR event. Moreover, instead of judging success or failure for each customer, aggregator success or failure was determined.

We will describe how the ADR system handled the above-mentioned features.

The system allows specification of the amount of reduction for each DR event as described in (1) above. Therefore, as shown in figure 11, multiple groups of customers’ buildings which were subject to control could be registered on the dispatch settings screen.

Additionally, it was possible to automatically select which groups were subject to dispatch by referring to the DR time slot and the requested amount of demand reduction so that the reduction would be close to the target.

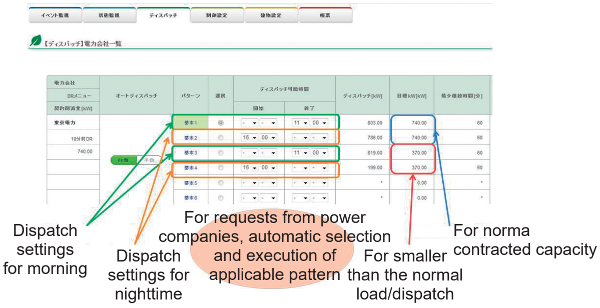

Fig. 11. Example of dispatch settings

As described in (2) above, the power reduction had to be accurate to within ± 10 % of the requested value. However, reduced power consumption may not take place as planned at customers' buildings because there are many related variable factors, because of unexpected events such as the sudden failure of a generator, etc. Therefore, the ADR system was made so that its operators are alerted to deviation from planned values and abnormalities in the facilities at an early stage on the reduction monitoring screen (fig. 10) or on the event monitoring screen (fig. 7).

If a deviation from the planned value is observed, the operators can separately stop the equipment in addition using the remote control system for the facilities.5

Details of the demonstration results by Azbil are given in the reference 5.

5. Conclusions

Azbil participated in the VPP construction demonstration project in fiscal year 2017. For the demonstration project, the following two functions were added.

- Transmission of the various measurements to the VTN using the OpenADR reporting services
- Relay dispatch (see section 3.2.2)

In the future, we intend to continue improving the system, for example by increasing the accuracy of the dispatch algorithm for matching the amount of reduction with the target amount, and improving user-friendliness for ADR's operators.

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Authors

Mizu Nakamura, Development Department 3, Development Headquarters, Building Systems Company

Kana Mizutani, Environmental Marketing Department, Marketing Headquarters, Building Systems Company