Power Supply-and-Demand Balancing Solution Using Distributed Storage Batteries

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Abstract

The dissemination and expansion of renewable energy such as photovoltaic power generation are promoted by means of feed-in tariff (FIT) and other procedures. However, output fluctuations caused by weather events create concerns due to the unfavorable effects on the supply-and-demand balance of the electric power grid. A new mechanism for adjusting the supply-and-demand of electricity is called for in order to secure a stable electric power system.

This paper presents a new power supply-and-demand balancing solution proposed by NEC that is based on its virtual integration technology for distributed storage batteries using a hierarchical hybrid control system.

Keywords

virtual integration, hierarchical hybrid control system, demand response, load frequency control, governor-free, power supply-and-demand balancing, distributed storage batteries

1. Introduction

In order to resolve the issue of the power supply-and-demand balance that has been triggered by the increased use of renewable energies, the traditional supply-and-demand adjustment on the power supply side is already regarded as inadequate. The potential for a new supply-and-demand balancing mechanism considering the demand side is currently under active deliberation. The "demand response" (DR) being studied together with a new market framework to be introduced after the institutional reform of the complete electric power deregulation in 2016 is a typical example of these deliberations.

This paper presents the power supply-and-demand balancing solution proposed by NEC. We focus particularly on the "hierarchical hybrid control" system and "virtual integration technology" for active use with multiple storage batteries distributed over a wide area on the consumer side.

2. Hierarchical hybrid control System for Distributed Storage Battery Control

The power supply-and-demand adjustment using DR of the present solution is implemented by direct remote control of the electrical equipment of consumers. Therefore, it is vital not to spoil the convenience of use of consumers' equipment. From this viewpoint, the storage batteries of the consumers are a very promising type of control target equipment. This is because the storage batteries are regarded as not exerting direct influence on consumer convenience, unlike air conditioners.

On the other hand, to implement the power supply-and-demand adjustment capability for the renewable energies that are estimated to be generated over 50 million kW by using DR, the power control capability to be procured is expected to exceed some millions of kW. If this is to be done using consumer storage batteries with only a few kW of output per unit, it is required to control as many as more than million storage batteries over a widespread area.

- **Hierarchical hybrid control system (patented)**

  The hierarchical hybrid control system is a storage

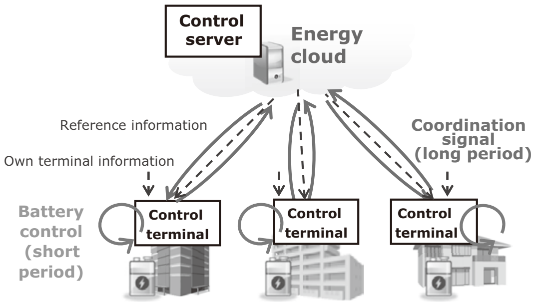

Fig. 1 Hierarchical hybrid control system.

battery control platform developed to control wide-spread storage batteries of the million unit class. **Fig. 1** shows the schematic structure of the system, which is composed of the cloud based control server and with the control terminals on the storage battery side.

The hierarchical hybrid control system controls storage batteries using long-period coordination signals from the control server together with the reference information. This includes the frequency measured by each battery on its own terminal, the reference information and the load frequency control (LFC) signal. With this control method, the system controls the batteries for a short period but optimizes the control of the whole group of storage batteries for a long period. While the control amount distribution of the whole storage battery group is optimized using the coordination signal, individual batteries are controlled for a short period independently from the cycle of the coordination signal so that a high control response can be achieved. The coordination signal containing the optimization information is delivered for a long period of more than ten minutes. For example, so that the possibility of reserving the time for calculations required for optimization makes it possible to increase the limit of the "number" of controllable storage batteries significantly.

In case a communication error happens during delivery of the coordination signal, the time availability for retransmitting the signal ensures high reliability control even when the communication system in use is a cheap one such as the Internet. Furthermore, the possibility of identifying the control status of each storage battery also contributes to improving the reliability of the control procedures.

3. Virtual Integration Technology

The virtual integration technology is packaged in the energy cloud (control server) as software (**Fig. 2**). The software collects information such as "the specifications including the rated output" of each of the various batteries, as well as the continuously varying information, including the "storage status" and "surrounding environment status including temperature." It then optimizes the charge-discharge distributions of all of the storage batteries after assessing the specifications and status variations.

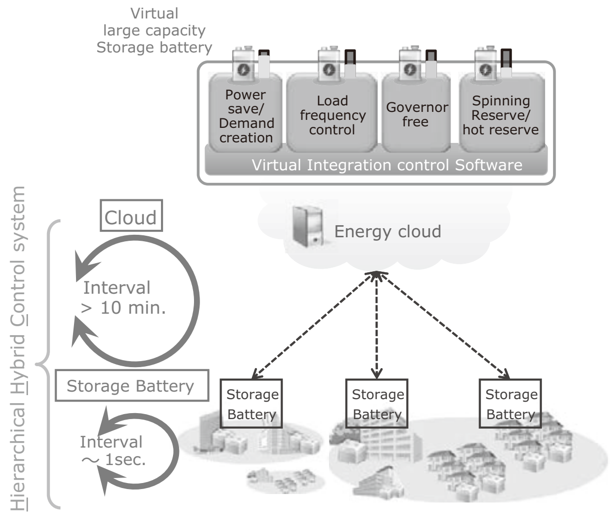

Fig. 2 Concept of virtual integration technology/hierarchical hybrid control system.

The charge-discharge distribution is delivered to each storage battery as a coordination signal from the cloud, and each storage battery controls the charge/discharge based on the coordination signal and the information measured on the battery such as the frequency. As the virtual integration can regulate a large number of wide-spread storage batteries in an ideally bundled manner (virtual integration). The multiple storage batteries can be handled in the same manner as a single storage battery (virtual large-capacity storage battery).

(1) Excessive charge/discharge avoidance of battery groups

One of the critical functions of virtual integration is the charge/discharge control algorithm for avoiding excessive charge/discharge of each storage battery[1). **Fig. 3** shows the fluctuations of Power system frequency of representative power supply-and-demand adjustment functions, the load frequency control (LFC) and the governor free (GF) functions.

Fig. 3 shows that the irregularity of the LFC and of the GF have different orders in the time axis and that the properties of fluctuations such as amplitudes are also different. Consequently, an attempt

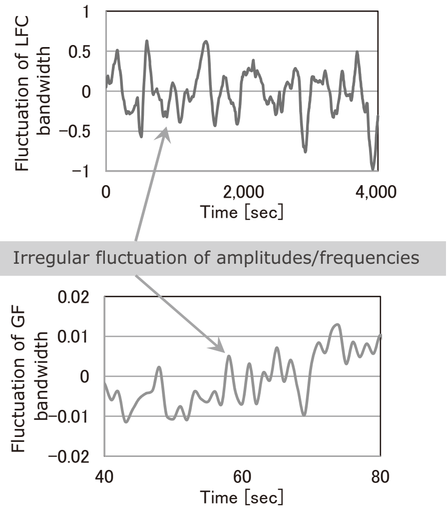

Fig. 3 Fluctuations of normalized frequencies in the LFC/GF bandwidths.

to reduce the fluctuations by means of the charge/discharge of the storage battery group could cause excessive charge or discharge due to the effects of such irregularities. The virtual integration identifies the irregularity of each supply-and-demand adjustment function by means of a unique mathematical treatment. This distributes the SoC (State of Charge) rate correction coefficient optimally to each function and each battery. The result is the possibility of the continual control of the charge/discharge of the whole battery group.

(2) Degradation suppression control of storage battery

Of importance in the DR such as for power supply and demand adjustment using the storage batteries of consumers from the viewpoint of improving convenience is to suppress the degradation of storage batteries following repeated charge and discharge. As the virtual integration can reflect the battery condition including the temperature and SoC to the control, it can distribute charge/discharge in a manner that minimizes degradation according to the conditions[2)]. **Fig. 4** shows a case of verifications of the degradation speed distribution when the batteries are controlled or not by using the degradation suppression algorithm.

The case above shows the results of numerical calculations of the charge/discharge situation of a day when variations of SoC according to the individual usage situations of consumers are applied to 100 storage batteries with different ratings of kWh capacity and kW output. The graph shows the difference in degradation speed distribution depending on whether or not the degradation suppression control is applied. It is understood that the degradation suppression algorithm can control the degradation rate at around 40% on average.

(3) Multipurpose simultaneous control of storage batteries

Of importance for improving the storage battery utilization efficiency is to provide functions that are implementable by charge/discharge with a multiple purpose and simultaneous execution capability. This process is referred to as multipurpose simultaneous control. The virtual integration technology is capable not only of controlling multiple storage batteries as a single group all at once, but it also incorporates an algorithm enabling simultaneous control of multiple purposes[2)]. **Fig. 5** shows the control error when the DR operations of LFC and GF are executed simultaneously to control a group of 100 storage batteries. With this control method, the power supply and demand adjustments of the LFC and GF frequen-

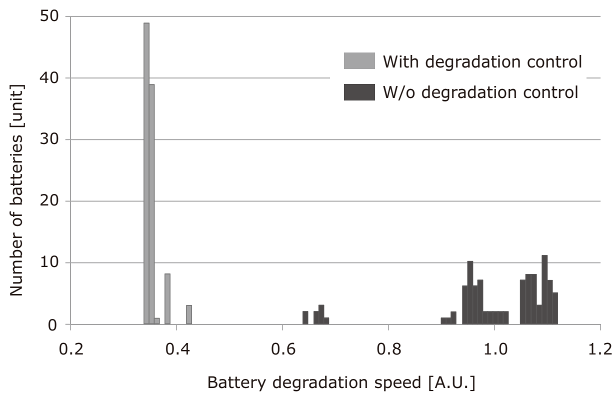

Fig. 4 Storage battery degradation speed distribution.

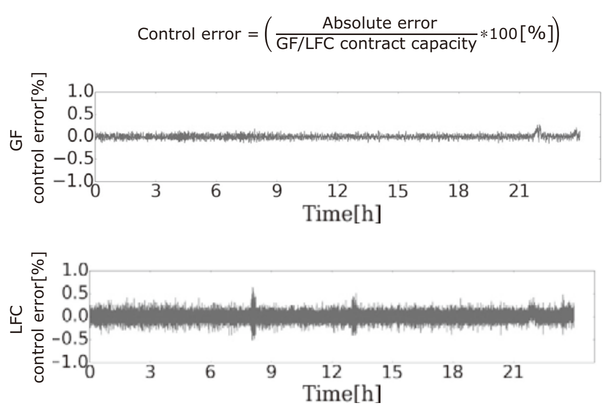

Fig. 5 LFC control error (top) and GF control error (bottom) of a whole storage battery group.

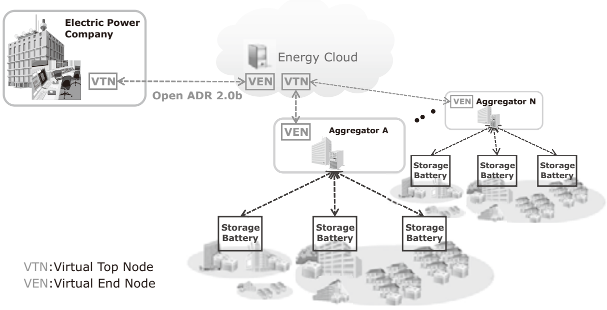

Fig. 6 Image of utilization of OpenADR 2.0b.

cies belong to different bands are performed as DR operations while executing the degradation suppression control shown in Fig. 4. The control error is evaluated by dividing the difference between the theoretical charge/discharge quantity of the "drooping characteristic" contracted with the power company and the actual charge/discharge quantity of the storage battery group by the contract capacity of each application. The graph shows that the control makes the LFC and GF compatible and executes each of them for 24 hours with an error below 1%. In this way, the virtual integration can simultaneously control multiple purposes including the control of degradation suppression resulting from charge/discharge and the LFC and GF adjustments.

(4) Compatibility with OpenADR 2.0b

The traditional DR is executed by means of human control of electric equipment (for example by stopping usage for power saving). At present, the automated demand response (ADR) for automating the traditional DR is increasingly used. The OpenADR Alliance, the international organization dealing with the communication protocols for use in the ADR, announced an international standard called "OpenADR 2.0b" in July 2013.

OpenADR presupposes a mechanism in which the VEN (Virtual End Node) playing the role of the client receives a request from the VTN (Virtual Top Node) playing the role of the server and responds to it (demand response). The hierarchical hybrid control system is compatible with OpenADR 2.0b so it can be linked with various energy management systems. This enables the power supply-and-demand balancing of various storage battery groups managed by several different aggregators (**Fig. 6**).

4. Deployment in Community Grids

Fig. 7 shows the control panel of distributed storage batteries by the virtual integration technology/hierarchical hybrid control system.

In the future, the power supply-and-demand balancing solution employing the virtual integration technology/hierarchical hybrid control system is expected to be used in applications such as the community grid, with which a power grid is formed on a per-community basis (**Fig. 8**).

The community grid indicates a potential of new, low-carbon and resilient towns where local generation and consumption of energy are possible by using renewable energies and storage batteries. Even in the case of an emergency after a power outage, the community grid is capable of supplying power using the storage batteries distributed in each housing or building and the batteries installed in electric vehicles. The individual management and status check of each storage battery enables a stable power supply to the community with an optimum power supply-and-demand balancing. For example sending the power from an area, house or building with excess power to those where power is insufficient. The virtual integration/hierarchical hybrid control system is an effective solution technology for the power

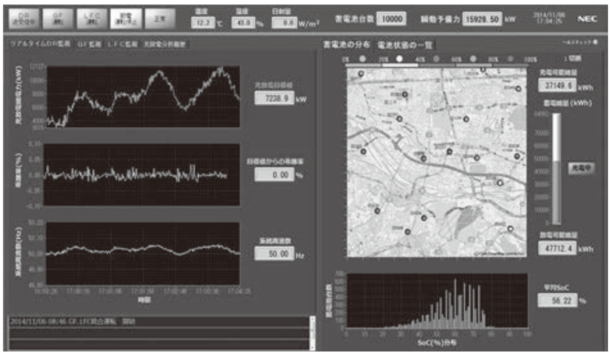

Fig. 7 Monitor/control panel of distributed storage battery control server.

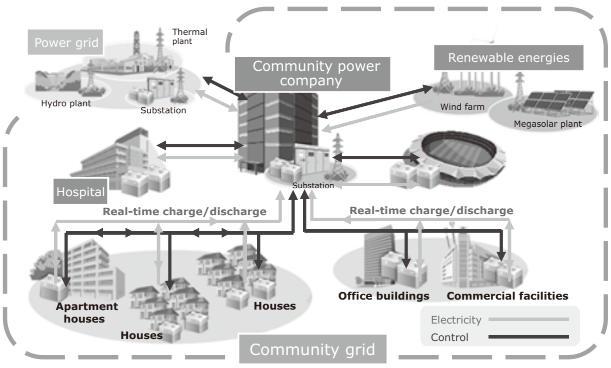

Fig. 8 Concept of community grid.

supply-and-demand adjustment of a community grid.

5. Conclusion

In this paper, we describe a virtual integration technology and hierarchical hybrid control system that is capable of providing power supply-and-demand balancing using multiple storage batteries distributed on the consumer side. The preset technology enables real-time synchronous control with high efficiency and high stability of grouped storage batteries, the number of which can be increased or decreased flexibly as required. It is our intention to contribute to an expansion of the introduction of renewable energies and to stabilize the power supply system via the provision of a new means of power supply-and-demand adjustment such as the one presented above.

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Vol.10 No.1 Special Issue on NEC's Smart Energy Solutions Led by ICT
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Vol.10 No.2
April 2016

Special Issue TOP