Featured Articles

Power System Stabilization Solutions in North America and Future Outlook

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OVERVIEW: In recent years the power industry in North America has been characterized by an aging infrastructure of electric power transmission and distribution, with incentives for the development of renewable energy. The electric power exchange market has also become revitalized, giving rise to a variety of challenges for power system operation. In response to these challenges, industry observers have called for system reforms to the electric power exchange market, with regulatory agencies imposing tougher measures on transmission operators to improve electric power system reliability. This article discusses the technologies needed for power system operation in an environment of system reform and stricter regulations. It describes the work being done on power system stabilization solutions technology in the form of electrical energy storage systems for ancillary services and protection and control systems of wide-area power systems. Also discussed is how the creation of these technologies will affect the unbundling of Japan's power generation and transmission businesses (scheduled for 2020), and changes to its energy mix.

INTRODUCTION

LARGE amounts of renewable energy from sources such as photovoltaic power generation and wind power generation are recently being introduced worldwide. Since renewable energy output varies with the weather conditions, it has a large impact on power system stability. Focusing on the leading-edge initiatives underway in North America, this article describes power system stabilization solutions technology and the results it has demonstrated as well as the future outlook for this technology.

POWER ENVIRONMENT AND CHALLENGES IN NORTH AMERICA

North America is ahead of Japan in unbundling its power generation and transmission businesses and introducing renewable energy, and the initiatives being undertaken there are leading the way for the rest of the world.

A report by the U.S. Department of Energy entitled Wind Vision[1] suggests that the penetration of wind power generation could account for 35% of all the energy generated in the US by 2050. However, California has a high rate of photovoltaic power generation, and the guidelines set forth in its Renewables Portfolio Standard[2] call for renewable energy to provide 33% of the state's power demand by 2020.

The large amount of photovoltaic power generation in California has been shown to result in a phenomenon called a 'duck curve,' which is characterized by a rise in photovoltaic power generation during the day, with an apparent decline in power demand. Since renewable energy output is prone to fluctuation, power system stabilization is a problem that needs to be addressed.

One approach to power system stabilization has been the creation of ancillary markets aimed at balancing power supply and demand.

Along with the rise in renewable energy, North America is also grappling with the problem of its aging infrastructure of electric power transmission and distribution. As seen in the example of Hurricane Sandy in 2012, large-scale damage from weather anomalies is also on the rise. In response to the increase in blackouts caused by the aging infrastructure of electric power transmission and distribution and weather anomalies, a growing number of stability control systems such as Remedial Action Schemes

(RAS) are being introduced to prevent large blackouts in wide-area power systems.

In this way, North America is undertaking many leading-edge initiatives with respect to its infrastructure of electric power transmission and distribution. The rest of this article discusses the work that Hitachi is doing on power system stabilization solutions in North America.

ANCILLARY MARKET TRENDS AND WORK ON ELECTRICAL ENERGY STORAGE SYSTEM

Ancillary Market Trends in North America

Power grids aim for frequency stabilization by balancing power supply and demand. A system has been created in North America for coordinating the balance of supply and demand in the form of ancillary services that enable regional system operators to engage in market transactions to procure power. In addition, regulations enacted in October 2010 create incentives by mandating high-priced purchases of power provided by service providers who respond precisely to the command values of system operators. The result has been a growing demand for electrical energy storage systems that enable high-speed response. Electrical energy storage systems with a total capacity numbering in the tens of megawatts were rapidly introduced in 2015.

CrystEna Electrical Energy Storage System and Pilot Project Results

Hitachi has developed an electrical energy storage system called CrystEna (a combination of the words ‘crystal’ and ‘energy’) designed to enable stable power use while maintaining the balance of power supply and demand. It is being introduced to markets in Japan and around the world as one of Hitachi’s solutions businesses.

Developed for the ancillary services market, CrystEna (a 1-MW shipping container-type electrical energy storage system) is a comprehensive package that includes components such as a power conditioning system (PCS), lithium ion battery, and control system mounted in a standard 40 ft-class shipping container (see Fig. 1). CrystEna has been designed to easily handle large-capacity systems by using a package mounting with a single shipping container system configuration along with standardized specifications enabling expansion to a large-capacity system configuration comprising multiple shipping containers(3).

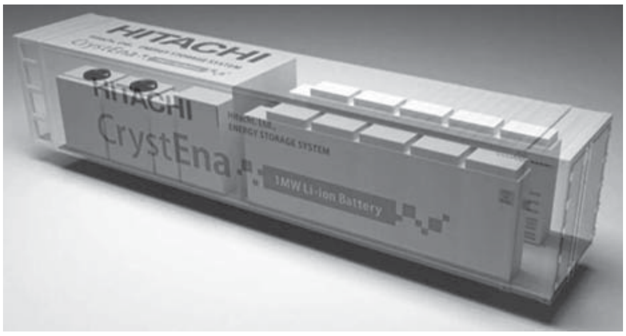

Fig. 1—External Appearance of Shipping Container-type Package.
Components such as a power conditioning system (PCS), lithium ion battery, and control equipment are mounted in a standard 40-ft-class shipping container.

Life management is usually an important requirement for storage batteries since performance drops as the battery is charged and discharged. In conjunction with the development of the CrystEna system, Hitachi has therefore also developed an operational control simulator that estimates CrystEna’s operation performance. Fig. 2 shows how the simulator works. As storage batteries degrade, their performance in areas such as capacity and internal resistance is affected by the voltage, current, and temperature they are used with. For that reason, Hitachi has created a method of predicting battery life under various usage conditions with a high degree of precision, by applying multivariate analysis to the degradation factors for the lithium ion batteries used in containers. The operational control simulator comes with four functions, which are used to (1) set operation strategy by analyzing

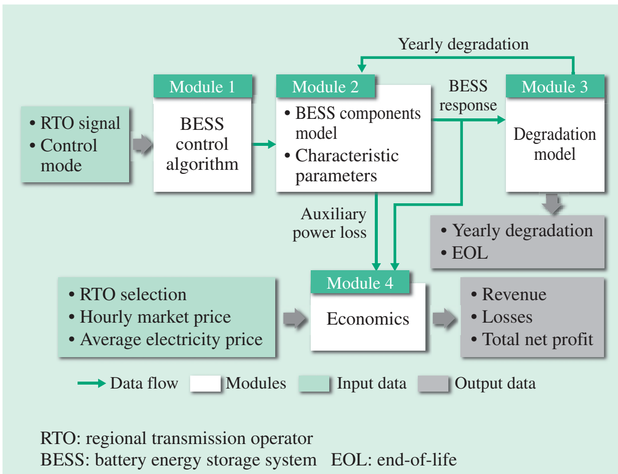

Fig. 2—Operational Control Simulator.
A lithium ion battery degradation model enables estimation of operating revenue when a battery reaches the end of its operating life.

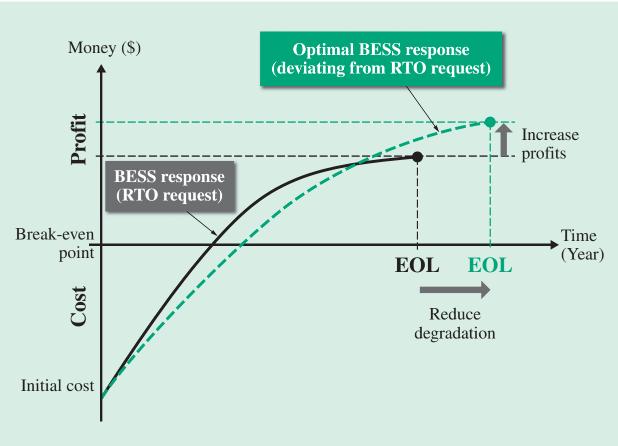

Fig. 3—Illustration of Revenue Maximization by Extending Battery Life.
Moderating storage battery operation can be expected to extend battery life and increase revenue over the lifetime of the battery.

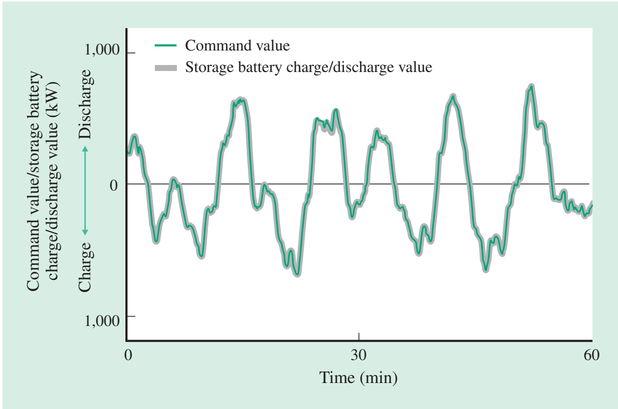

Fig. 4—Electrical Energy Storage System Response to Command Values.
The system responds to system operator commands without delays.

the command values sent from the system operator, (2) select PCS and storage battery combinations, (3) estimate degradation using lifetime prediction, and (4) calculate revenue using market parameters.

The operational control simulator's lifetime prediction function can evaluate operation in terms of the risk to revenue posed by time degradation. It can also suggest operation methods that can extend storage battery life while maintaining the tracking ability to conform to system operator command values, ensuring optimal system configuration proposals in line with the return on investment of various businesses.

Fig. 3 shows how revenue is maximized by increasing storage battery life, comparing the revenues resulting from two operation methods. The first method is a simple response method in which the batteries are charged and discharged in conformance with system operator commands without considering storage battery life. The second method is an output optimization method in which the charge/discharge output is adjusted to account for storage battery life, while still maintaining conformance to command values. By using the output optimization method, storage battery life is extended, and the electrical energy storage system can be operated for a longer period, which increases the amount of total revenue that is ultimately obtained.

In February 2015, Hitachi started a CrystEna pilot project in the US ancillary market. Actual power transactions were used to evaluate the storage system's performance, demonstrate its reliability and effectiveness, and verify its ability to respond well to command values (see Fig. 4).

PROTECTION AND CONTROL SYSTEM OF WIDE-AREA POWER SYSTEM (RAS) OVERVIEW AND FUTURE OUTLOOK

This chapter discusses the challenges facing the US power transmission industry and provides an overview of an R&D project undertaken by Hitachi and the Bonneville Power Administration (BPA) to find solutions for these challenges.

Challenges Facing Power Transmission Industry in North America and How RAS Addresses Them

With blackouts on the rise in North America due to problems such as the aging infrastructure of electric power transmission and distribution and natural disasters, there is a demand for the prevention of large blackouts. The increase of renewable energy is also causing imbalances between supply and demand and inducing voltage fluctuations, making transmission grid operation more complex. Investment in power system analysis is expanding and there is a need for technology to effectively maximize existing facility performance. Other problems facing the industry include operation restrictions that reduce the output of renewable energy. Fig. 5 illustrates the challenges facing the power transmission industry.

Work on grid stabilization technology is being done around the world, with advances in power electronics such as static var compensators (SVCs) and high-voltage direct current (HVDC) and the standardization of substation equipment such as phasor measurement units (PMUs) and intelligent electronic devices (IEDs). But development of technology that can

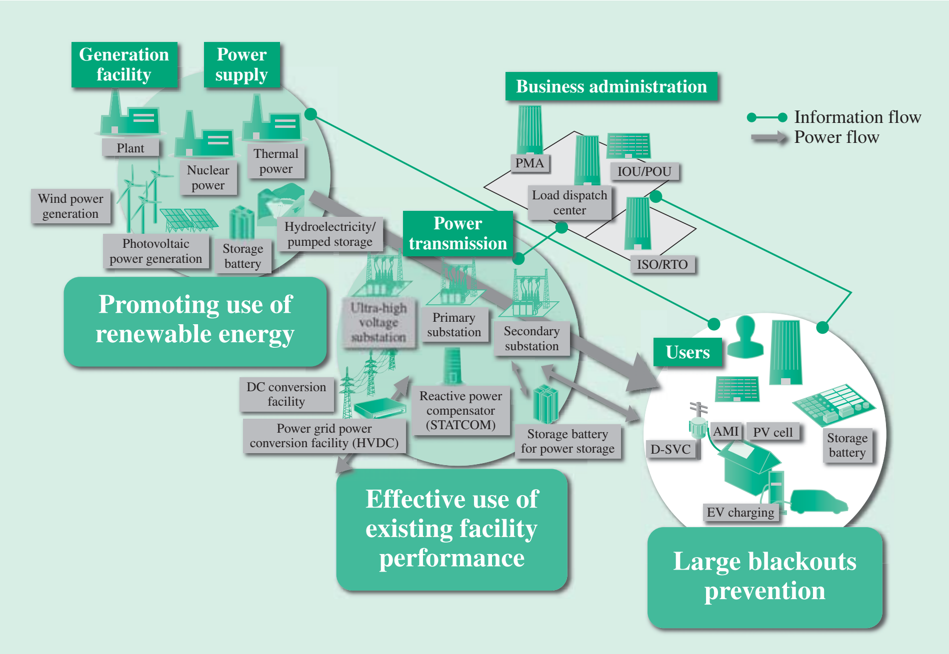

Fig. 5—Challenges Facing Power Transmission Industry.
Various challenges need to be resolved to provide a stable power supply.

provide comprehensive control of these components to enable optimal operation is lagging. Therefore the development of RAS that provide integrated stability control systems for wide-area grids is necessary. RAS is a scheme that automatically performs the correct operation (set beforehand) to maintain the operation standards of the North American Electric Reliability Corporation (NERC) when a predefined failure precursor is detected.

R&D Project with BPA in North America: Overview and Future Outlook

Headquartered in Portland, Oregon, BPA is a nonprofit power system operating body under the control of the U.S. Department of Energy (DOE). BPA currently uses an RAS for grid stabilization.

BPA currently employs an off-line RAS, which gathers offline data before grid faults occur. When the RAS is operated, power system analysis using offline data is performed and the generator shedding amount is calculated under preset conditions.

With the support of BPA, Hitachi is developing an on-line RAS in an R&D project that implements a control function with online data, aiming to optimize the generator shedding amount. Through this project, Hitachi is planning to develop an on-line RAS prototype system that uses actual online grid data to calculate grid protection countermeasures in realtime and to demonstrate its feasibility and benefits in the future. Specifically, by performing parallel computing processing using multiple computers, Hitachi plans to propose and evaluate optimal countermeasures for phenomena such as transmission line overloading, abnormal bus voltages, and generator step-out that occurs when grid faults take place, covering the entire grid area from Canada to the western US. Table 1 lists

TABLE 1. Challenges Facing Power Transmission Industry and How Hitachi's On-line RAS Addresses Them

Hitachi's on-line RAS is solving challenges, to help stabilize power grids.

No.	Challenge	Response
1	Preventing large blackouts	• Detect signs of abnormalities, provide decision support for countermeasures using knowledge gathered in the past and prevent faults • Create wide-area protection and control schemes to localize effects of accidents
2	Making effective use of existing facility performance	• Maximize the performance of existing facilities by operating them at the total transfer capability of the power grid system in its present state instead of at a predefined total transfer capability • Support system operator decision-making that achieves both system stability and cost-effective operation
3	Promoting use of renewable energy	• Precisely identify and reduce operational risks associated with increase of renewable energy interconnection • Address the output fluctuations of renewable energy by making effective use of spinning reserve other than renewable energy

RAS: remedial action scheme

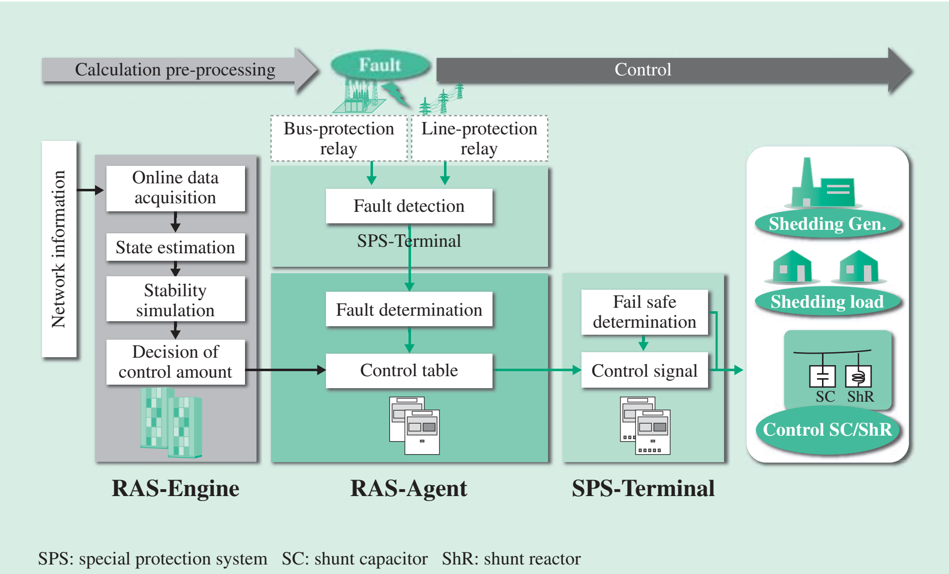

Fig. 6—On-line RAS Control Flow.
Hitachi's on-line RAS has a three-stage configuration for pre-event calculation and post-event control.

the challenges facing the power transmission industry and how Hitachi's on-line RAS addresses them. Fig. 6 illustrates the control flow of the on-line RAS.

CONTRIBUTIONS TO JAPAN'S ELECTRIC POWER INDUSTRY AND FUTURE OUTLOOK

With an increasing share of renewable energy and the upcoming unbundling of the power generation and transmission businesses, Japan's electric power industry is facing a changing environment. The US is ahead of Japan in the use of renewable energy and unbundling, and the work being done by Hitachi as described in this article could be applied to Japan in the future. For example, if wide-area coordination of power grids advances in the future, the knowledge gained from Hitachi's experience supported by BPA could be used to provide solutions that will help stabilize Japan's power grids. Similarly, knowledge gained from projects using electrical energy storage system in the North American ancillary market could be applied to solutions driven by electrical energy storage system designed to reduce sudden output fluctuations from the growing use of renewable energy in Japan.

CONCLUSIONS

This article discussed the work Hitachi is doing on grid stabilization in North America. These efforts will be expanded from North America to Japan and other countries in the future as it works on activities designed to help power system stabilization on a global scale.

REFERENCES

(1) U.S. Department of Energy, "Wind Vision: A New Era for Wind Power in the United States" (Mar. 2015), http://energy.gov/eere/wind/downloads/wind-vision-new-era-wind-power-united-states
(2) California Energy Commission Renewables Portfolio Standard (RPS), http://www.energy.ca.gov/portfolio/
(3) A. Honzawa et al., "Container-type Energy Storage System with Grid Stabilization Capability," Hitachi Review **63**, pp. 432–437 (Sep. 2014).

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