Electricity Grid Infrastructure

Hiroshi Asano

Abstract After experiencing the Great East Japan Earthquake and nuclear accident at Fukushima Daiichi Nuclear Power Plant in March 2011, Japan has been challenged to drastically change its energy policy toward more renewable energy sources (RES) and less dependence on nuclear energy. Substantial RES are promoted by feed-in tariffs for a low-carbon society. A smart grid aims at comprehensive optimization of power grids and consumers, with respect to power supply reliability, quality, CO_2 emission reduction, and cost. Active participation of distributed energy resources such as controllable loads and battery storage is expected to reduce costs of large penetration of energy generated from RES. Electricity reforms should fully utilize advanced technologies regarding not only conventional power plants and network technologies but also distributed energy resources and smarter energy management systems in the future grid.

Keywords Smart grid • Demand response • Renewable energy • Distributed energy resources

1 Introduction

Japan has few energy resources and is dependent on imports for 96 % of its primary energy supply. The country's energy-supply structure is extremely vulnerable. Following two oil crises in the 1970s, Japan diversified its energy sources through increased use of nuclear energy, natural gas and coal, as well as the promotion of energy efficiency and conservation. There has been an urgent need to implement global warming countermeasures, such as reducing carbon dioxide emissions from fossil fuel use. To ensure a stable electricity supply in Japan under these environmental constraints, it is crucial to establish an optimal combination of power

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sources that can concurrently deliver energy security, economic efficiency, and environmental conservation.

A low-carbon society is a political issue. Substantial renewable energy sources (RES) are promoted by a feed-in tariff (FIT). The Japanese power system is required to integrate large amounts of energy from RES. After the severe Fukushima nuclear plant accident in 2011, operations at most nuclear plants have been halted. The resulting substantial change of the generation mix has caused supply shortages and increases of electricity tariffs. In addition, the public need to choose the type of electricity and its supplier has increased. Thus, market reform will be required to (1) ensure a stable supply of electricity, (2) suppress electricity tariffs to the maximum extent possible, and (3) expand choices for consumers and business opportunities. This reform will be executed in three steps during 2013–2020.

After the Great East Japan Earthquake and nuclear accident at Fukushima Daiichi Nuclear Power Plant in March 2011, Japan has been challenged to drastically change its energy policy toward more renewable resources and less dependence on nuclear energy. The government has been addressing the best mix of energy sources, robust power supply systems, and nuclear power policy suited to the country.

Electricity supplies were tight in Japan until the 1950 Electricity Utility Industry Reorganization Order. This divided the country into nine service areas in May 1951, each served by a vertically integrated electric power company (EPCo) that generated, transmitted, and distributed power to end users. This resulted in nine regional monopolies, or investor-owned General Electricity Utilities (GEUs), Hokkaido, Tohoku, Tokyo, Chubu, Hokuriku, Kansai, Chugoku, Shikoku, and Kyushu EPCos, which remain the dominant players to this day. With the return of Okinawa to Japan in 1972, Okinawa Electric Power Co. became the tenth GEU in the country. Figure 1 shows the service areas of each regional power company.

Until the amendment of the Electricity Business Act in 1995, Japan's electric power industry was composed of the GEUs and the following wholesale electric utilities: Electric Power Development Co., Ltd., fully privatized in October 2004 and referred to below as J-POWER, Japan Atomic Power Co., and various wholesale electric utilities such as joint thermal power-generation companies. All of these have received investment from GEUs and publicly owned hydroelectric power generators.

This arrangement contributed to a reliable power supply in Japan. In the 1990s, prompted by restructuring developments in other parts of the world, the Japanese government decided to introduce competition in the electricity sector [1]. The intent of the 1995 Electricity Business Act, which was the first comprehensive amendment in 30 years, was to reduce electricity prices to internationally comparable levels through competition among stakeholders. The act introduced partial competition in the generation sector by allowing independent power producers (IPPs) to participate in the wholesale market. Since 1995, the electric power market in the country has been liberalized in stages, in 1999, 2003, and 2008 (Table 1). The ongoing regulatory reform since 2013 is described later.

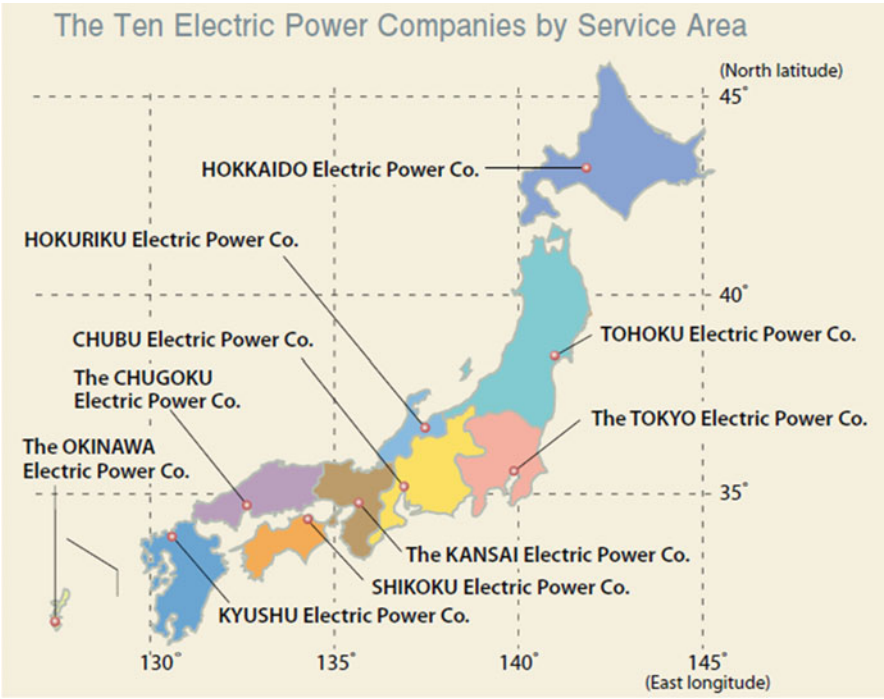


Fig. 1 Ten regional power companies in Japan (Source: Federation of Electric Power Companies of Japan)

Table 1 Historical development of regulatory reform in Japan

1st Institutional Reform: 1995
Introduction of competition into generation sector; auction of new power plant procurement
Foundation of new system that allows new entrants to supply electricity to customers in specified area
2nd Institutional Reform: 1999
Partial liberalization of retail electricity market for extra-high-voltage users with maximum demand of 2,000 kW
Shift from approval system to notification system of rate changes when the rate decreases
3rd Institutional Reform: 2003
Gradual extension of retail liberalization to high-voltage users with maximum demand of 50 kW
Establishment of neutral organization for monitoring of transmission; Electric Power System Council of Japan (ESCJ)
Establishment of wholesale power market; Japan Electric Power Exchange (JEPX)
4th Institutional Reform: 2008
Wholesale power market reform for activating power trading
Improvement of competition conditions on transmission usage for new entrants
No extension of retail market liberalization; reexamination after 5 years

The second institutional reform introduced in March 2000 partially liberalized the retail market by allowing power producers and suppliers (PPSs) to sell electricity to extra-high-voltage users with contracted demand with 2 MW or more. The scope of retail liberalization was subsequently expanded in April 2004 to users with contracted demand of 500 kW or more and then in April 2005 to customers with 50 kW or more, as a result of the third institutional reform.

2 Present Status

As shown in Fig. 2, there are currently ten investor-owned vertically integrated utilities responsible for supplying electricity to consumers in their respective service areas. GEUs must obtain approval from the Japanese government by providing supply conditions such as electricity rates as "general supply provisions" to consumers excluded from the retail liberalization. The regulated utilities are also responsible for supplying electricity to consumers subject to that liberalization, based on the "provisions for last resort service," if they cannot secure contracts with PPS (new retailers).

Although the share of electricity from PPSs has remained limited, just the potential threat of competition has gradually decreased retail tariffs for both residential and industrial consumers. Competitive pressures stemming from the market reforms have forced the incumbent utilities to increase their operational efficiencies while lowering electricity rates and offering a variety of pricing plans. These developments have resulted in a 15 % drop in system average prices over 1990–2011.

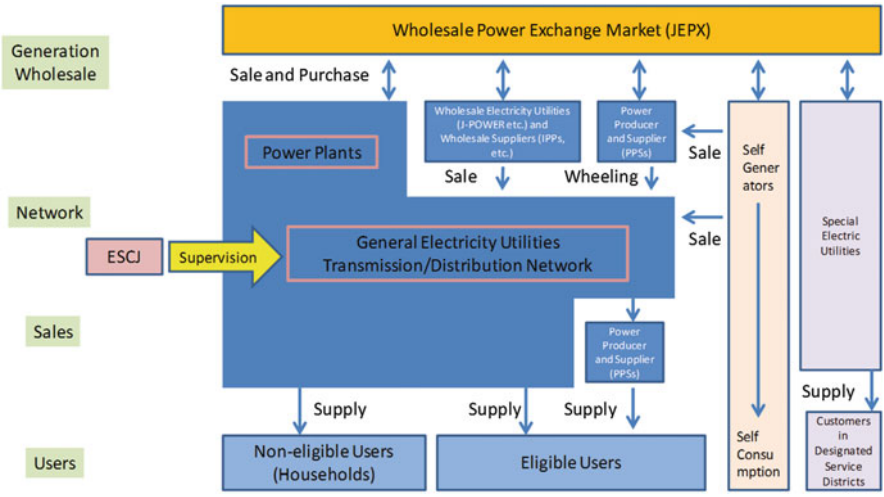


Fig. 2 Current electricity supply system in Japan as of August 2012 (Effective 1 April 2006)

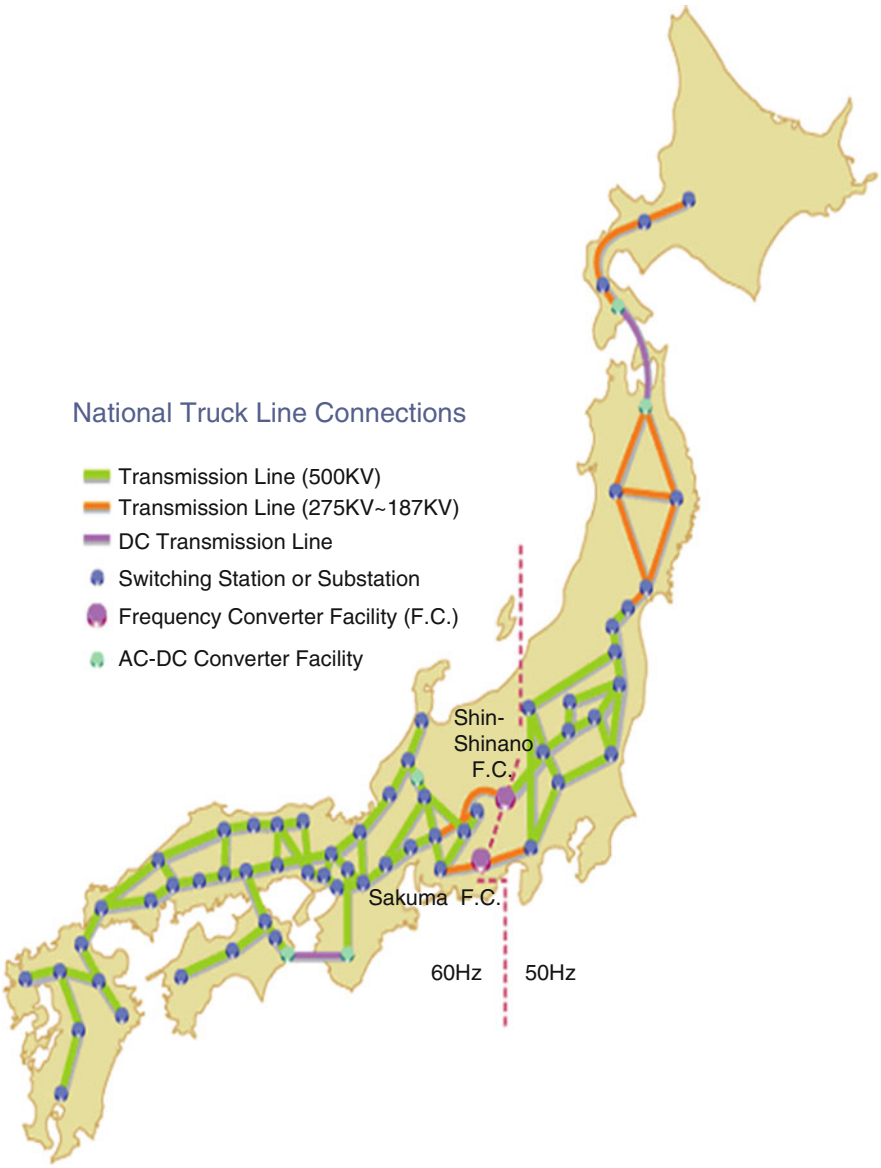


Fig. 3 National transmission grid in Japan (Source: JEPIC 2011)

After the Great East Japan Earthquake in March 2011, eastern Japan faced severe electricity shortages because power plants were damaged by the earthquake and tsunami. Figure 3 shows the national transmission grid, which has a limited capacity of frequency converters (FC) between the 50-Hz eastern grid and the 60-Hz western grid. FC capacity is currently under expansion, from 1.2 to 2.1 GW.

The country faces many challenges on multiple fronts, including the need for institutional reforms to further encourage competition in both wholesale and retail markets, address limited inter-utility transfer capacity, and formulate policies promoting renewable energy integration and demand-side participation.

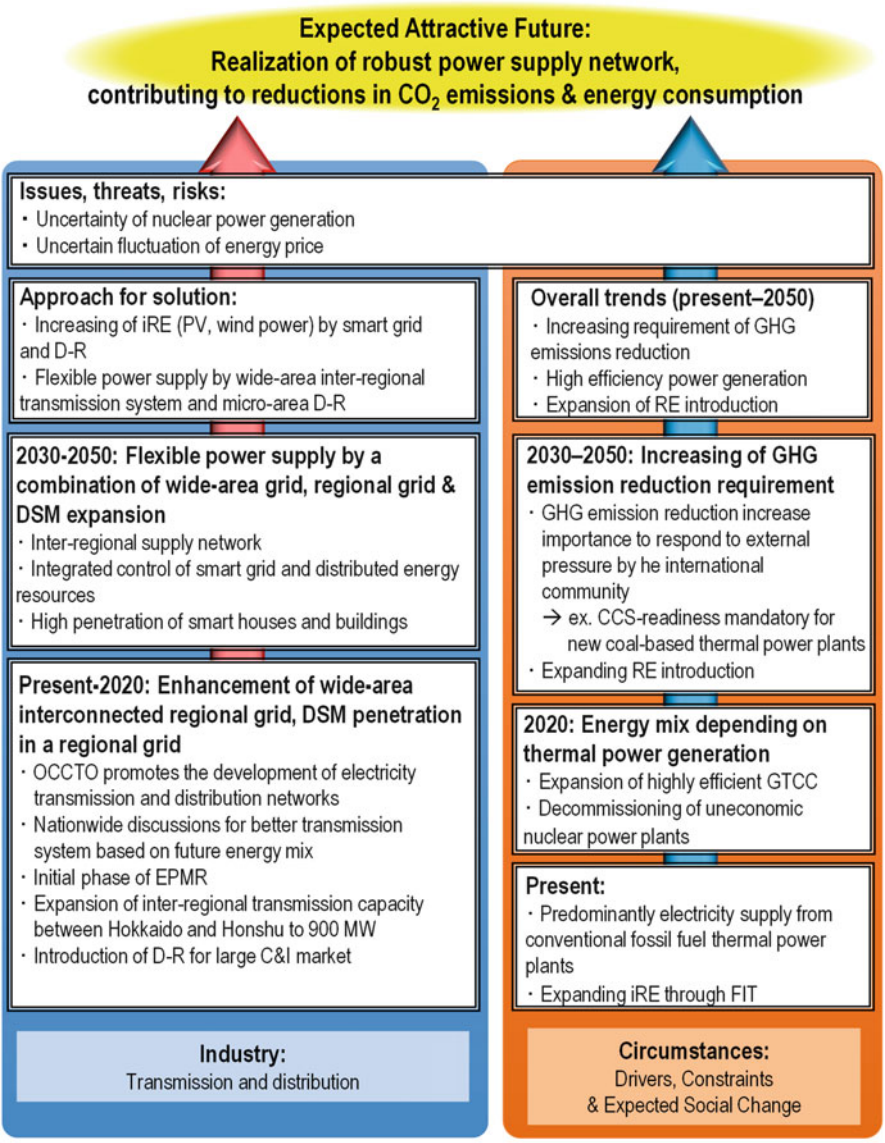
Large amounts of RES energy are promoted by the FIT. The Japanese power system is required to integrate such amounts. Moreover, the public need to choose the type of electricity and its supplier has increased. Market reform has been discussed to resolve the aforementioned problems in a government committee during 2012.

3 Technology Roadmap

3.1 Smart Grid

To realize the future grid, related technologies such as smart meters have already been demonstrated in the field. A smart grid was discussed before the Fukushima disaster, to integrate renewable energies and activate demand. These meters are being installed by Japanese electric power utilities to improve customer service and enhance operational efficiency.

Reinforcement of interconnection lines has been studied for secure integration of supply and renewable energies. The electricity reforms should fully utilize advanced technologies, not only conventional power plants and network technologies but also distributed energy resources and smarter energy management systems. From the perspective of new technology, R&D in energy and the environment is increasingly important for ensuring a future sustainable society. It may be more effective to increase R&D expenditures on energy and environment for boosting new generation technologies, rather than supporting installation of uncompetitive generation technologies by FIT and emerging technologies for integrated grid control. One example of a roadmap to future technologies is shown in Fig. 4. GHG reduction rates by 2030 were under discussion by the government panel in March 2015. The future grid should utilize demand-side resources such as electric vehicles (EVs) and plug-in hybrid EVs to reduce the additional cost of substantial RES integration through a more integrated approach. R&D for supply-side resources including clean coal technologies and carbon capture and storage are described in other chapters of this book. Day-ahead, intraday, and balancing electricity markets with the participation of producers, resource aggregators, and consumers are significant.



Abbreviations:
CCS: Carbon Capture and Storage, C&I: Commercial and Industry sectors, DSM : Demand Side Management, D-R: Demand-Response, EPMR: Electric Power system Market Reformation, FIT: Feed-In Tariff, GHG: Green House Gases, GTCC: Gas Turbine Combined Cycle, IGCC: Integrated coal Gasification Combined Cycle, iRE: intermittent Renewable Electricity, OCCTO: Organization for Cross-regional Coordination of Transmission Operators, Japan, PV: Photovoltaics, RE: Renewable Electricity

Fig. 4 Technology roadmap for electric power grid

3.2 *Regulatory Reform*

The regulatory reform will be performed in three steps (Fig. 5) [2]. "Organization for Cross-regional Coordination of TSOs (OCCTO)" will be established in step 1 during 2015. Retail will be fully liberalized in step 2 during 2016. Present utility companies will be legally unbundled in step 3, around 2020. After the reform, OCCTO will optimize nationwide balancing between TSOs. The main roles are (1) formulation of a supply-demand plan and an electrical grid plan, advancing the development of an infrastructure for transmission, such as interties between control areas and nationwide system operations beyond individual areas; (2) under normal situations, addressing coordination from the standpoint of wide-area operation, regarding the supply-demand balancing and frequency adjustment by transmission and distribution sectors in each area; (3) under a tight supply-demand situation caused by problems such as disasters, balancing supply and demand by ordering reinforcement of thermal power sources and power interchange.

Regulatory reform of the gas industry is also under discussion, including unbundling of gas pipelines. The Agency for Natural Resources and Energy (METI) endeavors to treat both this and the electric industries fairly, to transition into an integrated energy industry that can provide more consumer benefits through one-stop energy solutions.

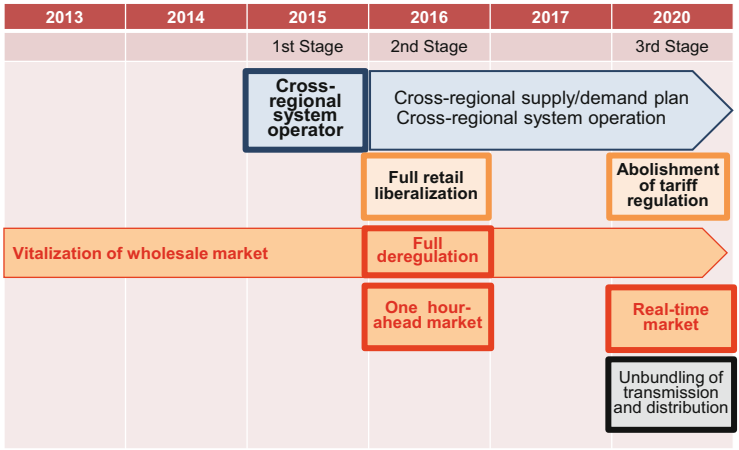


Fig. 5 Roadmap of reform in three steps

3.3 Integration of Renewable Energy Generation

Figure 6 shows challenges and solutions for PV integration. Operational challenges to RES integration are uncertainty, variability of output, and interconnection. Figure 7 shows a diagram of PV over-generation. Some electric utilities have already suspended responses to tremendous numbers of applications for connecting solar PV facilities, owing to a favorable FIT. Because the issue of restriction on grid connection is emerging, it is essential for Japan to introduce a more effective and meticulous output-control scheme to introduce renewable energy to the maximum extent possible. The METI decided to shift from the current system for introducing renewable energy to one with a new output-control scheme and revision of the current operation system for the FIT scheme.

Enhancing interregional operation for wind integration from Hokkaido to Tohoku and Tokyo is one of the solutions.

Ancillary services ensure system reliability. Some ISO/RTOs in the USA, e.g., ERCOT, allow demand-side resources to provide regulation and reserve services by demand-response programs. High penetration of variable generation such as wind power requires more flexible resource capacity.

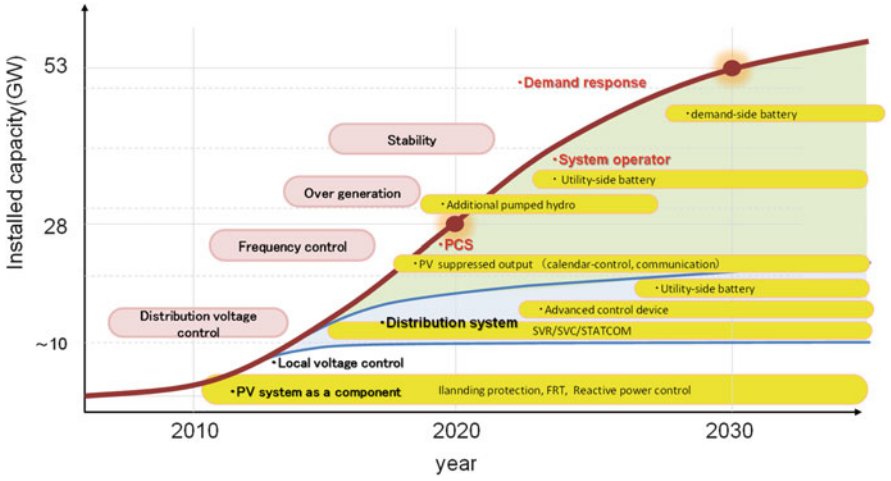


Fig. 6 Challenges and solutions for integration of PV

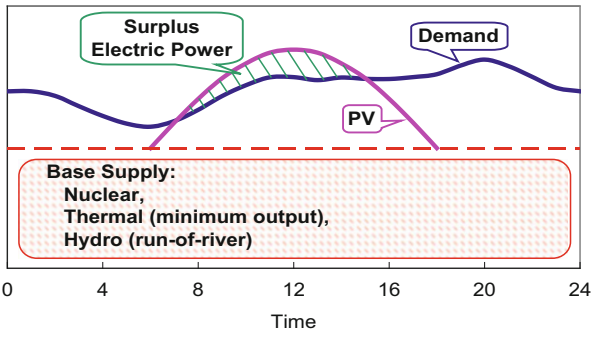


Fig. 7 Over-generation of PV

3.4 Integration of Demand Response

In the present environment, the majority of consumers are fully insulated from the dynamic wholesale electricity markets and actual real-time cost of electricity supply. Another opportunity is the use of distributed energy resources.

In the future grid, customers will be an integral part of the power system. They will help balance supply and demand and ensure system reliability by modifying the way they use and purchase electricity through various demand-response programs. These modifications come as a result of consumers having choices in full retail competitive markets and appear as a capability for load adjustment within the market. These choices involve new technologies, dynamic pricing, new forms of incentives based on market prices, and new information that transform consumer behavior. Advanced end-use technologies include smart appliances, advanced battery storage, EV, efficient CHP, and various energy management systems.

4 Benefits and Attractive Future Vision

The smart grid will be significant in maintaining system reliability, even under substantial integration of variable generation, and realize environmental benefits. Demand response will be critical in the operation of power grids after regulatory reform. Demand-side resources reduce the need for new generation resources and improve system reliability by providing ancillary services in the long run. As more intermittent RES such as PV and wind power are connected to the grid, the need for demand-response resources and balancing capabilities of power grid operators will increase.

It is important to seriously consider new energy policy that is suitable to Japan, paying attention to its unique conditions, i.e., the paucity of fossil fuels. Maintaining a stable power supply is essential for the public and industries that have supported Japanese economic prosperity. It is time to establish this new energy policy by sharing the powerful concept of future energy security across

the nation. This is particularly important from a global perspective. Japan must reconsider the role of nuclear power as an option to maintain security of supply and GHG reduction. Furthermore, it is necessary to establish a desirable energy-supply structure for ensuring a stable and robust supply under the restrictive energy conditions in the country. Energy utilities with a reinforced business base contribute to building such a new structure.

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