INITIATIVES TOWARD BOLSTERING ELECTRIC POWER SYSTEM RESILIENCE

— STEPPING UP DISTRIBUTION VOLTAGE FROM 100V TO 230V IN JAPAN —

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SUMMARY

- As the electric power systems stretched across Japan need to be improved from multiple perspectives, various measures are being considered, including those for: (1) reviewing technical standards for transmission towers and utility poles, (2) promoting the elimination of aboveground utility poles, and (3) strengthening transmission and distribution networks by enhancing resilience and further incorporating smart technologies.

- Stepping up distribution voltage can also be an effective means of strengthening the resiliency and efficiency of electric power systems. Stepping up (increasing) the distribution voltage transmitted from power plants will improve energy efficiency by expanding the amount of power supply and reducing power loss, and will lead to simplification of distribution equipment. This up-conversion is also expected to result in reduced CO2 emissions.

- The realization of stepped-up distribution voltage will require a massive amount of investment as well as replacement of home appliances. However, such long-term investment in the interests of electricity consumers throughout Japan will create effective demand and may prove to be a substantial economic measure that will trickle down to local communities.

INTRODUCTION

This report introduces the concept of stepping up the distribution power voltage as one way to address one of the nationwide issues of strengthening the resilience of the electric power system in Japan. Stepping up the power distribution voltage will make it possible to improve power efficiency by expanding the amount of power supply and reducing power loss, and will simplify the existing overall power system that has been developed with large, extensive, and complex equipment over an expansive area. Expressed in terms of protecting the global environment, a reduction of power loss in transmission and distribution networks around the world could lower annual carbon dioxide emissions by an estimated 411-544 million metric tons a year, according to research[1]. Furthermore, simplification of the system is expected to provide other beneficial effects, such as diminishing the weaknesses in disaster prevention/counterterrorism preparedness and reducing maintenance costs.

[1] "The climate mitigation opportunity behind global power transmission and distribution," https://www.nature.com/articles/s41558-019-0544-3, *Nature*, August 12, 2019. Researchers estimate the amount of carbon dioxide equivalents attributable to electricity generation corresponding to losses from power transmission and distribution grids around the world amounts to approximately one billion metric tons per year. This is comparable to the amount of carbon dioxide emitted by the entire chemical industry in a year.

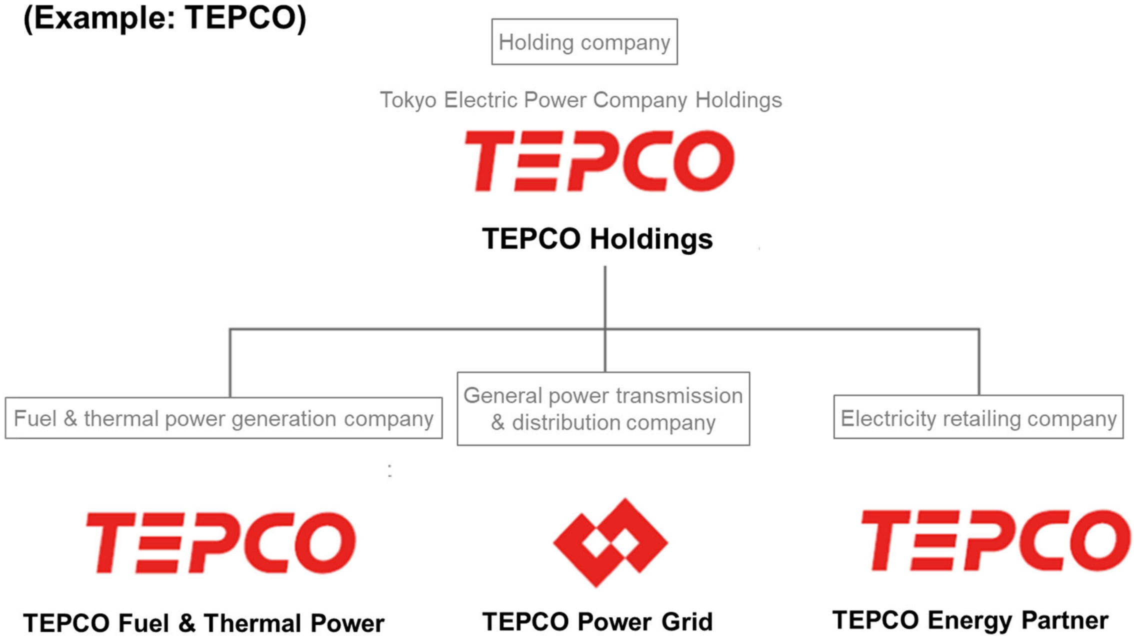
EVOLUTION OF THE ELECTRIC POWER SYSTEM

The voltage of electric power (distribution voltage) used by general households in Japan is 100V. In the early days when electric power systems were first introduced, electric power companies were established in various parts of Japan, and power generation systems were imported from overseas[2], such as German-made generators (100V) and US-made generators (110V). The equipment adopted and the distribution voltage were different depending on the region back then. Eventually, the integration of electric power companies progressed over time in the Meiji, Taisho, and Showa eras, and when the National Mobilization Law was finally enacted in 1938, all power generation and transmission companies were integrated into the Japan Electric Generation and Transmission Company. In 1941, the Distribution Control Ordinance was promulgated, and distribution companies were established to cover nine regions (Hokkaido, Tohoku, Kanto, Chubu, Hokuriku, Kinki, Chugoku, Shikoku, and Kyushu), with each distribution company having control over their respective regions. In this way, due to the necessities arising from the state of war at that time, the electric power system was integrated as a part of national measures to control electric power supplies, and the distribution voltage was unified to 100V, which continues to the present day.

STRENGTHENING THE RESILIENCY OF THE POWER SYSTEM AND TRANSMISSION/DISTRIBUTION GRIDS

The electric power system consists of (1) power generation facilities, which include plants producing energy using thermal, hydraulic, nuclear, solar, and wind power; (2) transmission and distribution networks, which include transmission lines, substations, and distribution lines; and (3) operational control systems for adjusting the supply and demand of electric power and dealing with failures. In Japan, with the deregulation of electricity in 2016, the operations of each of the nine regional electric power companies (Hokkaido, Tohoku, Tokyo, Chubu, Hokuriku, Kansai, Chugoku, Shikoku, and Kyushu [excluding Okinawa]) were separated to cover three business segments — generation, transmission and distribution, and retailing (Figure 1).

Figure 1: Separation of electric power business operations (Example: TEPCO)



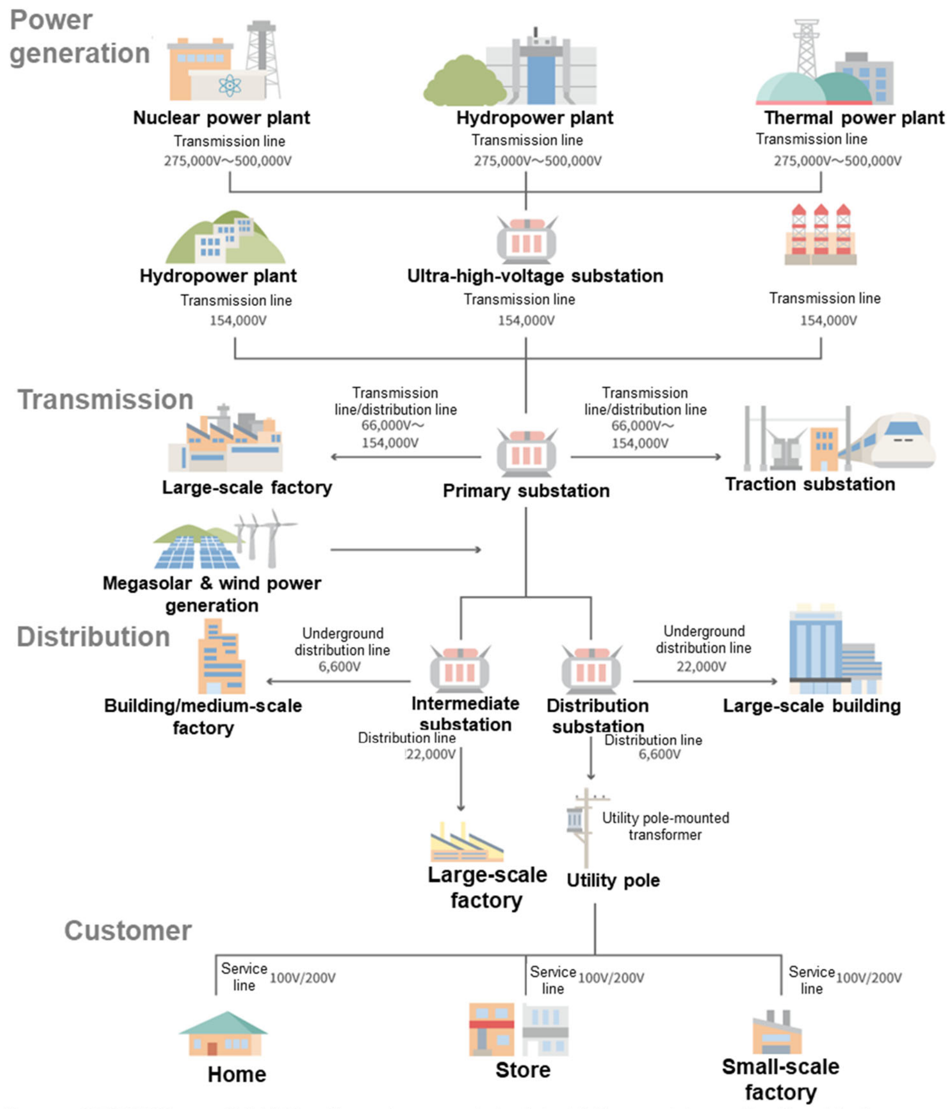
Note: TEPCO Power Grid uses a unique logo different from that used by the other two operating companies to ensure the neutrality of its power transmission and distribution business.
Source: Tokyo Electric Power Company Holdings (https://www.tepco.co.jp/toudenhou/ep/1271994_9044.html)

[2] As major examples, Tokyo Electric Light adopted the 265kW/50Hz three-phase alternator manufactured by Argemeine of Germany in 1895 (Meiji 28), and in 1897 (Meiji 30), Osaka Electric Light adopted the 150kW/60Hz alternator manufactured by US-based Thomson-Houston Electric.

Under this framework, each power transmission and distribution company is in charge of monitoring and controlling the entire power system in their area. The power transmission and distribution company adjusts the supply and demand of electric power between the power generation company and the electricity retailer, and in the event of a failure, caused, for example, by a disconnection or natural disaster, the transmission and distribution company switches the connection route of the transmission line, or in the event of insufficient power supply, it may in some cases procure supplementary electricity from power generation companies outside of its area[3]. As such, its role encompasses careful and fine-tuned operations.

The power transmission and distribution company converts the power supplied by the power plant to a constant voltage at the high-voltage substation and transmits it to a power demand area (urban district, factory zone, etc.) by long-distance transmission lines. When the transmitted power approaches a power demand area, the voltage is reduced to 66,000V at the primary substation and supplied to high-volume users such as plants and automobile manufacturing facilities. After that, the power is transmitted to an intermediate substation, the voltage is lowered to 22,000V, and supplied to small and medium-sized factories. Then, it is sent to a distribution substation, the voltage is lowered to 6,600V, and it is distributed to commercial buildings, small plants, etc. through power lines within a city. Finally, the voltage of the 6,600V electricity is lowered to 100V through transformers installed on utility poles, and the power is provided to households and other end-users (Figure 2).

Figure 2: Flow of electricity



Source: TEPCO Power Grid (https://www.tepco.co.jp/pg/electricity-supply/operation/flow.html)

[3] In April 2021, a new supply-demand adjustment market was established in collaboration with the Transmission & Distribution Grid Council. Procurement of power from outside a designated region was permitted in order to promote more efficient electric power procurement and supply operations. https://www.tdgc.jp/jukyuchoseishijo/outline/outline.html

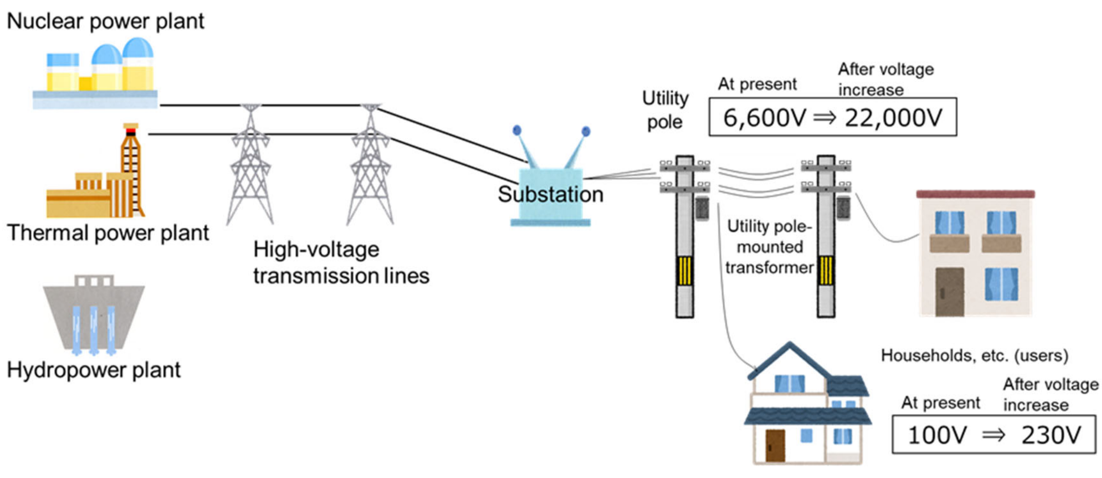
The framework is one in which the voltage of the generated power is gradually lowered through the transmission and distribution network, and the power is supplied to users at varying voltages appropriate to the size of the power consumer. In this way, the transmission and distribution grid serves as an important element for connecting the generated power to power consumers, such as homes and factories, and daily maintenance and inspection work is performed to ensure the supply of power from distant power plants to urban districts and all other corners of a region. However, Japan's electric power system, which has continued to supply electric power from the postwar economic recovery era to the high economic growth period and through to the present, also has problems, including aging infrastructure. In Japan, where natural disasters such as typhoons and earthquakes occur frequently, the strengthening of the resilience of power plants, substations, and transmission and distribution grids is something that cannot be discounted. Typhoon No. 15, which made landfall in Chiba Prefecture in September 2019, recorded a maximum instantaneous wind speed of 57.5 meters, and caused power outages across a wide area due to the collapse of transmission towers and the disconnection of utility poles and distribution lines from the network caused by fallen trees. It took a considerably long time to get the severed network up and running again, which had a devastating impact on local communities.

The Ministry of Economy, Trade, and Industry has set up the Working Group on Electricity Resilience to verify disaster response efforts and consider future measures, and the group released an interim summary of key issues in November 2019. In the interim report, the working group pointed out the necessity of strengthening electric system resiliency by: (1) reviewing the technical standards for transmission towers and utility poles, (2) promoting the elimination of aboveground utility poles (installing cables underground), and (3) strengthening transmission and distribution grids by enhancing resiliency and further incorporating smart technologies. In addition to these measures, there is the option of stepping up the voltage of power used for distribution as a means to strengthen the resiliency of Japan's electric power system. What would this entail?

PROS AND CONS OF STEPPING UP THE DISTRIBUTION VOLTAGE

Stepping up the distribution voltage means to increase the voltage of the supplied power, which is currently being delivered from power plants to households via transmission and distribution grids by lowering the voltage in stages. To accommodate distribution voltage up-conversion, modifications would be needed at two points along the transmission/distribution route: (1) an increase in the voltage of utility pole power lines within a city from the current 6,600V to 22,000V, and (2) an increase in the voltage used by households from 100V to 230V (Figure 3). Although discussions on stepping up the distribution voltage were pursued at length after the war, it has not been implemented to this day[4] in consideration of the major impact it would have on the social

Figure 3: Voltage step up of power lines and distribution lines



Source: Compiled by MGSSI

[4] In the postwar economic recovery period, the voltage of utility poles was boosted from 3,300V to the current 6,600V, in order to respond to burgeoning power demand and to improve the efficiency of power usage.

infrastructure that is indispensable for people's daily lives. Currently, Japan is the only developed country that uses a distribution voltage of 100V. Except for the US, which uses 120V, the generally adopted world standard distribution voltage is 22,000V/200-230V (voltage of utility pole power lines/household voltage).

The advantages of stepping up the distribution voltage include (1) expansion of power supply and (2) reduction of power loss. The amount of power supplied at 230V is about 5.3 times that of 100V when comparing the voltages of 100V and 230V for power lines of the same wire gauge. Furthermore, it is possible to reduce power loss by increasing the voltage. Theoretically, the amount of power loss is inversely proportional to the square of the voltage. The reduction of power loss will lead to simplification of equipment, such as distribution system loss reduction devices and voltage regulators installed in the distribution network. This is expected to have the effect of reducing the volume of equipment requiring maintenance and management in the entire power system, which would reduce maintenance costs as well as strengthen the transmission and distribution network. In addition, if the voltage of the utility pole power lines is raised to 22,000V, there will no longer be a need to reduce the voltage from 22,000V at the intermediate substation to 6,600V at the distribution substation, as described in the previous section on strengthening the resiliency of the power system and transmission/distribution grids, making it possible to essentially eliminate the need for distribution substations. This is also expected to strengthen the transmission and distribution network and yield considerable economic benefits[5] (Figure 4), because it can reduce power loss and expand power supply capacity by raising the voltage, as described above. Furthermore, as mentioned at the beginning of this report, distribution voltage up-conversion is expected to reduce carbon dioxide emissions.

Figure 4: Pros and cons of stepping up distribution voltage

PRO	Expansion of power supply	Power supply volume at a voltage of 230V is approximately 5.3 times that at 100V
PRO	Reduction of power losses	Reduction of power loss is inversely proportional to the square of the voltage
PRO	Simplification of transmission & distribution network	Power line voltage boost will make it possible to eliminate distribution substations
PRO	Reduction of CO2 emissions	Reduction of 5 million metric tons per year, according to earlier estimates[Note 1]
CON	Massive investment requirement	Cost of more than ¥1.53 trillion, according to earlier estimates[Note 2]
CON	Long-term project	Project to take 15 to 20 years
CON	Necessity to replace home appliances	Eventually, consumers will need to purchase 230V-compatible home appliances
CON	Impact on all citizens/businesses	All users of electricity will be affected

Note 1: See footnote 5 in the text.
Note 2: "*Shin ene dōnyū CO2 sakugen ni kōken suru haiden den'atsu shōatsu-ka no igi*" [The significance of boosting distribution voltage to contribute to reducing CO2 emissions by introducing new energy sources] published by OHM, 2009)
The additional cost of upgrading facilities to accommodate the step up in distribution voltage is estimated to exceed ¥1,030 billion over the 15-25 years of the project. Other one-time transitional costs are estimated at ¥500 billion.
Source: Compiled by MGSSI

On the other hand, the disadvantages of stepping up the distribution voltage include the need for massive investment (more than JPY 1.53 trillion, according to a 2009 estimate, see Note 2 in Figure 4), and replacement of 100V-compatible home appliances with products that can run on 230V. Even after up-converting the distribution voltage, it will be possible to accommodate 100V-compatible products during the transition period by inserting a simple transformer between the outlet and the home appliance, but eventually, the appliances will need to be replaced with 230V-compatible products. This was a bottleneck in earlier discussions and prevented

[5] In an earlier discussion on stepping up the distribution voltage, ("*Shin ene dōnyū CO2 sakugen ni kōken suru haiden den'atsu shōatsu-ka no igi*" [The significance of boosting distribution voltage to contribute to reducing CO2 emissions by introducing new energy sources] Ohmsha, 2009) it was estimated that the energy-saving effect would be 7 billion kWh per year, which is equivalent to just under 1% of total power consumption in Japan, and the carbon dioxide reduction effect would be 5 million metric tons per year.

a decision to step up the distribution voltage. However, stepping up this voltage will undeniably improve day-to-day conveniences, such as by allowing for cooking equipment featuring shorter cooking times, ultra-high-speed and powerful dishwashers, washing machines, and dryers, powerful air conditioners, and refrigerators with quick freezing functions. In addition, by making the distribution voltage conform with the international standard, domestic electronics companies will no longer need to differentiate the home appliances they manufacture into separate product categories for the domestic and overseas markets, and the synergistic effects from product unification, parts procurement, and other aspects will lead to a reduction in product costs.

In addition, should a decision be reached to step up the distribution voltage, recommendations call for the infrastructure to be developed over a long period of 15 to 20 years, with consideration given to support a gradual, affordable shift from 100V-compatible home appliances to 230V-compatible products, in order to avoid confusion that could arise should the transition be attempted over a short time frame. The important point is for the government to devise and implement measures to give preferential treatment to Japanese products from the perspective of promoting domestic industries during the transition to replace home appliances. Two ideas are to provide tax incentives for Japanese manufactures that shift to the production of 230V-compatible products, and to offer large discounts to citizens, for example, when they purchase Japanese products using their My Number personal identification card linked to a bank account, with the discounted amount being promptly transferred to a predetermined bank account. The opportunity presented by this shift calls for multi-layered government policies that will spark the promotion and expansion of further digitalization in Japan.

CONCLUSION

In April 2020, the power transmission and distribution business was legally separated from the electric power companies, and a set of institutional measures planned under the electric power system reform was completed. However, tangible measures such as those for strengthening the power system have been implemented only partially[6]. Meanwhile, the government has announced to the rest of the world that Japan aims to achieve carbon neutrality by 2050. In view of this, it is vital for the electric power industry to continue to strengthen its transmission and distribution grids. In doing so, the major challenge is how to switch to a next-generation electric power system, while minimizing the burden on people. And now that the economy is recovering from the global COVID-19 pandemic, it is a great opportunity to invest in public infrastructure to strengthen the resilience of the power infrastructure. Such long-term investment, implemented with the interests of electricity consumers throughout Japan in mind, may be a powerful economic measure for creating effective demand that could spread to local communities.

[6] As a result of the revision to the Electricity Business Act, reflecting the June 2020 enactment of the "Act of Partial Revision of the Electricity Business Act and Other Acts for Establishing Resilient and Sustainable Electricity Supply Systems", consideration is being given to measures such as a system for the power distribution business that would allow new entrants to operate by using the transmission and distribution grids of existing power transmission and distribution companies (to go into effect from April 2022).

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