Energy System Innovation for the Future of Asia: Review of State-of-the-art Distributed Energy Resources and Micro-grids in Japan

小さな地域において、分散した各種のエネルギーをどのように効率的に結び付けて利用するか。日本の最新のマイクログリッドから考える。

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Abstract In the past few years, the use of Distributed Energy Resources (DER) has been proposed as one of the possible solutions to energy and environmental challenges. However, as the diffusion of these technologies increases, many problems occur. In addition to the technical, commercial and safety issues posed by the connection of generation within the distribution system, the use of renewable sources and combined heat and power (CHP) usually adds more specific issues related to the actual method of generation used. If more creative thinking is applied to the way energy is supplied, used and controlled, it may be possible to satisfy the demand for energy, but accommodate the fluctuating resources which are a feature particularly of renewable energy sources. This may be possible by ensuring a satisfactory mixture of sources and loads to enable the demand and supply to match. Such a mixture in a grid-like fashion is called a 'micro-grid'. As a country lacking resources, Japan is active in the research, development and demonstration of micro-grid systems. In this study, first, the current status of DER is investigated. Then, the state-of-the-art micro-grids in Japan is reviewed. Finally, based on the discussion of the current situation, suggestions for future micro-grid development and necessary policies are suggested.

Keywords Distributed energy resources; Micro-grid; Renewable technologies; State-of-the-art; Japan

Introduction

Global warming due to rising greenhouse gas (GHG) emissions presents a great challenge to the stability of the world's climate, economy and population. [1)] To avoid such a huge risk, the pursuit of a low-carbon society is receiving more and more attention not only from the developed but also the developing countries. As a global target, 50% reduction of GHG emissions below 1990 levels by 2050 has been confirmed by the main developed countries. However, some recent studies have recommended that world-wide emissions should be reduced by 80% by 2050. [2)] Actually, whatever the final value of the reduction goal, it is believed that numerous innovations should be realized for technology, institutions and people's behavior, to secure a bright future.

Although there is global concern, individual countries have undertaken different steps in climate change mitigation. Recently, in order to make the global vision clear and realistic, as well as to cope with negotiations regarding climate issues in the post-Kyoto period, mid-term targets, with 2020 as the target year, have been illustrated by the USA, the UK, Germany, France and Japan, to reduce the emissions by 7%, 26%, 40%, 20% and 25%, respectively, from the 1990 level. As the largest GHG emitter in the world, instead of an absolute numerical target, China decided to reduce its emissions per unit of GDP in 2020 by 40% to 45% compared with that of 2005. In addition, some pioneer countries such as the UK and Japan have announced their long-term goals as well as scenarios for achieving those goals.[3-6] For example, in Japan, according to the research by National Institute for Environmental Studies (NIES), it may be feasible by 2050 to reach a 70% CO_2 emissions reduction below 1990 levels, from both technical and economical aspects. However, various innovations should be put into practice in technical, economical, social, as well as political fields. Based on the back-casting analysis, the change of activity, reduction of demand, improvement of energy intensity of end-use, improvement of carbon intensity of end-use, and improvement of carbon intensity of energy supply should contribute 2.6%, 9.1%, 39.1%, 15.7% and 33.5%, respectively, to the 70% reduction target.[6]

From the viewpoint of original sources of GHG emissions, it has been recognized that global climate destabilization is primarily due to the combustion of fossil fuels for energy and the resultant CO_2 emissions. Therefore, it is no exaggeration to say that the only way to achieve a sustainable low-carbon society is to have a sustainable low-carbon energy system. At the same time, decrease in fossil fuels results in a considerable increase in its price and the derivatives. Actually, in all the mid-term and long-term scenarios mentioned above, the most attention is always paid to the innovation of energy system. For example, according to Japanese low-carbon society strategy, the improvement of energy intensity of end-use and the improvement of carbon intensity of end-use, which can be realized through promotion of energy efficiency and distributed renewable energy resources, contributes nearly 50% of the total CO_2 emissions reduction target.[6] Thus, efficient use of energy and utilization of distributed energy resources (DER) are the order of the day when it comes to constructing a low-carbon society. A wide variety of appropriate technologies is on the market now. However, as penetration increases, many problems occur. In addition to the technical, commercial and safety issues posed by the connection of generation within the distribution system, the use of renewable sources and combined heat and power (CHP) usually adds more specific issues related to the actual method of generation used. An example that illustrates this point is photovoltaic (PV) generation. There is no generation at night, which is of course predictable, but in addition, the sun can be obscured by cloud cover on a random basis. A similar situation exists with CHP which is normally controlled to supply heat, with electricity production as a by-product. As a source of electrical energy, this has some disadvantages which, in the present format, have to be addressed by the operators of the public electricity supply. With more creative thinking about the way energy is supplied, used and controlled, it may be possible to satisfy the demand for energy while accommodating fluctuating resources, which are a feature particularly of renewable energy sources. This may be made possible by ensuring a satisfactory mixture of sources and loads to enable the demand and supply to match. Such a mixture in a grid-like fashion is called ‘micro-grid’.

The micro-grid is a concept based around the assumption of a cluster of electrical and thermal loads together with small-scale sources of electrical power and heat. The power sources will generally be mixed, including renewable sources such as PV or wind generators together with fossil-fuel generators meeting local heating requirements and generating electricity. The connection between this network and the wider electrical power network will be through a well defined and controlled interface. The micro-grid is responsible for servicing the needs of consumers, ensuring a quality of supply and possibly controlling some of the non-critical loads. The interface with the local electricity utility will be one of exchanging power so that the micro-grid will appear as a consist, dependable load or generator.

In this study, first, the current status of DER adoption in Japan is investigated. Then, the state-of-the-art micro-grids in Japan are reviewed. Based on the above investigation, policies related to DER and micro-grid adoption are discussed. In addition, a SWOT analysis is employed to understand the problems and feasible strategies for realizing a wide penetration of micro-grids in Japan.

Current status of distributed energy resources adoption in Japan

In the past few years, both developed and developing countries have experienced an increasing contribution of distributed generation to their electricity supply. The share of distributed generation in the world market has increased to 7.2%, up from 7% in 2002. Global installed distributed generation capacity stood at around 281.9 GWe at the end of 2004. Furthermore, it is expected that the annual distributed electricity output will grow by 4.2% between 2000 and 2030 reaching 35 GWe by the year 2030. The use of renewable energy (solar, biogas, wind and hydro) and CHP to reduce GHG emissions is one of the main drivers of distributed generation.[7)]

In Japan, as shown in Fig. 1, distributed generation only accounts for about 16% in the total power generation. Although this value is above the world mean level, it is greatly below that of some EU countries. This implies that Japan has significant potential for developing distributed generation before reaching the market penetration in leading countries such as Denmark, the Netherlands and Finland. Currently in Japan, the most common use of distributed generation is for backup power whenever the normal source of electricity fails. In 2003, the Japanese government established the Energy Master plan, describing the importance of development and widespread use of distributed energy systems. It is expected that 20% of electricity will be generated by distributed energy in 2030 according to Japan's energy supply

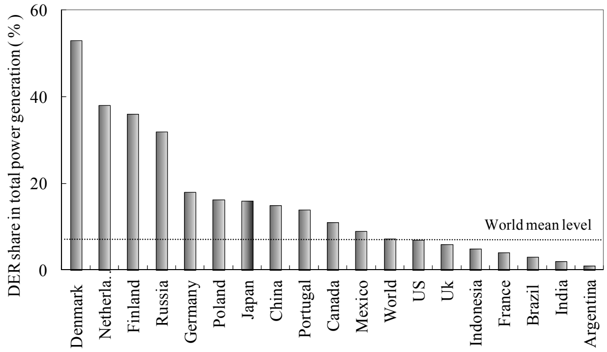

Fig. 1 Distributed generation share of total power generation

and demand perspective [8)].

Compared with traditional central energy supply, DER can utilize a wide range of power generators including biomass-based generators, combustion turbines, concentrating solar power and photovoltaic systems, fuel cell, wind turbines, micro turbines, diesel generator sets, hybrid systems and electrical power storage, as well as all kinds of thermal recovery technologies. In the following, the state of the art of various DER technologies in Japan is assessed by grouping them into thermal (CHP) and renewable technologies.

Combined heat and power technologies

Thermal distributed generation is mainly based on fossil fuels but can also be based on bio-fuels, therefore thermal technologies are also renewable. Thermal generating units can be equipped to recover the heat that results from combustion, and such CHP systems can have high total efficiencies. CHP systems can provide heat and power for both industrial and commercial buildings. Tri-generation systems, which can utilize recovered heat in absorption chillers as well as in heat exchangers, have significant potential in regions with sufficient cooling loads. Thermal distributed generation technologies can successfully be applied to such things as stand-by power and peak-shaving.

In Japan, during the last 20 years, CHP has rapidly developed. As shown in Fig. 2, the number of

CHP systems has increased from 67 in 1986 to 8,578 in 2009, of which, 6467 sites are in the commercial sector and 2111 sites are in the industrial sector. The total generation capacity has increased from 200 kW in 1986 to 9,402 MW as of March 2010, with 2,000 MW in the commercial sector and 7,402 MW in the industrial sector. Furthermore, although the commercial sector has more installation number than the industrial sector, the generation capacity is relatively small, which is about 24% of the industrial sector.

Besides the above technologies, the fuel cell is becoming more and more popular in Japanese CHP application. Fuel cells are an entirely different approach to the production of electricity from traditional prime mover technologies, and are currently in the early stages of development. Fuel cells can generate electricity at high electric efficiencies (up to 60 percent) using hydrogen as the fuel. They are silent in operation and have very low emissions. However, as with most new technologies, the fuel cell technology is presently very high. Still, fuel cells are available on the market and systems are installed, but in 2001 the worldwide capacity was no more than 70 MW. The commercially available units are usually a few hundred kW, but recently, the 1 kW fuel cell CHP plant has been introduced for residential use in Japan.

Figure 3 is the number of fuel cell system adoption sites as of March 2008. It should be noted that the residential fuel cell system (20 thousand units had been installed around Japan by 2010) is not considered here. The figure shows that the larger system is dominate, and most of the systems are between 200 kW and 500 kW.

Renewable energy technologies

Renewable energy is another main part of distributed generations. It can be used to provide part or all of the electricity for residential and commercial buildings. Renewable generation is typically highly capital intensive but has low operating costs since there is no fuel cost. In general, renewable generation is intermittent but sometimes has some storage potential.

In Japan, the energy self-sufficiency share remains

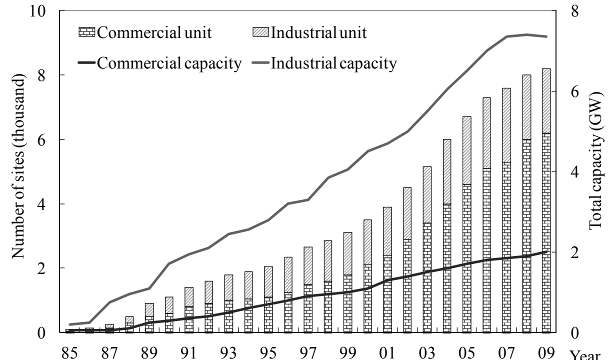

Fig. 2 Accumulative number and capacity of CHP systems in each fiscal year

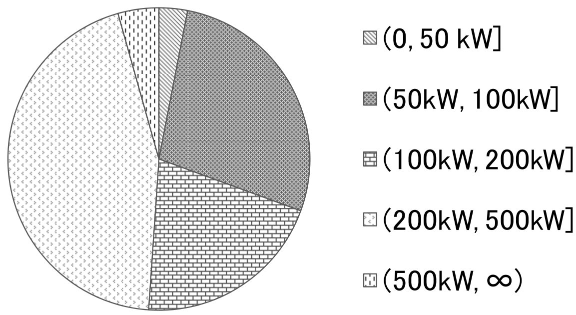

Fig. 3 Number of commercial fuel cell systems adopted by 2008

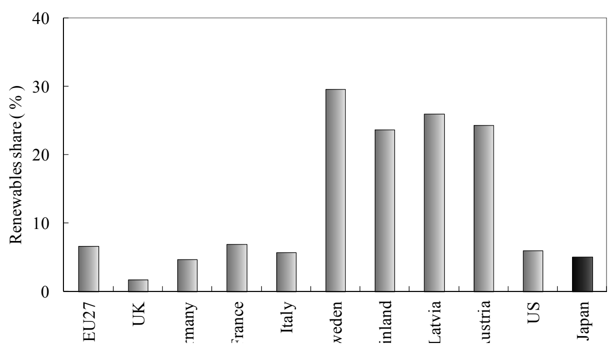

Fig. 4 Electricity generation from renewable energy resources in various countries

at a low level of about 4% and with the development of economy, total energy consumption will continue to increase. Meanwhile, fossil fuel recoverable reserves are very limited. The government is now taking assorted measures to save energy and develop new energies. Energy conservation in Japan has already progressed to a relatively high level but renewable energy accounted for only about 5.1% of the total primary energy supply in the year 2005 (see Fig. 4). The value is significantly lower than that of EU countries, such as Sweden, Finland, Latvia and Austria. Therefore, there is great potential for the spread of renewable energy and the government has made a plan to increase the share of renewable energy in the total primary energy consumption to 10% by the year 2030.

Generally, the renewable energy resources include biomass, PV, wind power, tidal power, solar heater and geothermal. Among them, the most important renewable distributed generation technologies are PV, wind power and biomass energy. In the following, the current situation of these three technologies is introduced in detail.

① PV

In the last few years, the installation of PV systems has increased steadily by an average of 30% per year. By the end of 2004, the total capacity of PV installations in the world has reached 2,596 MW, of which Japan had a share of 1,132 MW, more than 40%. The Japanese government is making solar energy an important part of its overall energy mix, with a goal of 10 percent electricity production form PV by 2030.

② Wind power

By the end of 2005, the total installed capacity of wind turbines in the world reached 59,322 MW, of which Japan had a share of 1,231 MW, which is much less than the top country, Germany, which has an installation capacity of 18,428 MW. Since the year 2000, the installed capacity is increasing greatly, about 200–300 MW year by year. Correspondingly, the number of installed units has also increased. By the year 2005, the total installed units of wind turbine had exceeded 1000 units.

③ Biomass

In Japan, biomass has been a relatively small portion of the overall energy budget, supplying about 1% of the total primary energy consumed in 2004. In recent years, the Japanese government has been trying a variety of methods to promote biomass energy use in an effort to alleviate global warming. For instance, the Ministry of Agriculture, Forestry and Fisheries (MAFF) has predicted biomass energy use of 110.5~210.1 PJ in the future energy demand and supply plan in 2010.

State-of-the-art of micro-grid in Japan

As a country lacking resources, Japan is most active in the research, development and demonstration of micro-grid system. To increase potential renewable energy harvesting near demand centers, Japan's micro-grid research focuses on utilizing controllable prime movers, such as natural gas or biogas-fired generators, to compensate for variable demand and local small-scale intermittent renewable supply. Between 2003 and 2007, the New Energy and Industrial Technology Development Organization (NEDO) have started four demonstrations, as shown in Table 1.

The first of Japan's micro-grid demonstration project started during the 2005 World Exposition, using a combination of varied chemistry fuel cells, 270 kW and 300 kW MCFC, four 200 kW PAFC, and a 25 kW SOFC. The MCFCs use a gas derived from wood waste and plastic bottles; experimental intentional islanding has also been conducted. Recently, the system was permanently moved to the Central Japan Airport City in Nagoya, where it will supply the Tokoname city office and a sewage treatment plant using a private feeder.

The Hachinohe, Aomori Prefecture, project began

Table 1 Demonstrative projects of micro-grid in Japan

Name	Time	System
Aichi-Expo	2005	Co-generation with private distribution line, all resources are inverter type (PV, PAFC, MCFC and SOFC)
Kyoto Project	2005	Virtual micro-grid with utility distribution line, main resource is gas engine and MCFC consuming bio-gas
Hachinohe-city	2005	Power supply by private distribution line, main resource is gas engine burning digestion gas
Sendai	2007	The energy centre and a dedicated distribution line are connected at a single point of common coupling

operation in October 2005 and is being evaluated for security, reliability, cost effectiveness, and carbon emissions reduction over its demonstration period stretching through March 2008. The micro-grid has PV and wind turbines totaling 100 kW, 510 kW of controllable engine generators supplied by digester gas from a sewage plant, and a 100 kW lead-acid battery bank. Seven Hachinohe City buildings are supplied via a private 6 kV, 5.4 km distribution feeder, with the whole system connected to the commercial grid at a single point. Test islanding operation is also planned for this project.

In a third NEDO project, the municipal government of Kyotango City, north of Kyoto, leads a virtual micro-grid demonstration. The DER included are 50 kW each of PV and wind turbines, five 80 kW biogas engines, a 250 kW MCFC, and 100 kW of battery back-up. In this project, an energy centre communicates with the DER over the existing utility network to coordinate demand and supply. Imbalances between supply and demand are resolved within five minutes.

Finally, NEDO sponsors an ambitious and interesting multiple security, quality, reliability and availability demonstration project in Sendai, Miyagi Prefecture. This micro-grid adjoins a nursing home, high school, university, and waste treatment facilities. The main DER are a 250 kW MCFC, two 350 kW natural gas-fired generators, 50 kW of PV, and batteries.

In addition to the government-sponsored projects described above, there are significant research activities in Japan's private sector. Shimizu Corporation is developing a micro-grid control system at its Tokyo test facility. Also, Tokyo Gas, together with the University of Tokyo, plans to establish a micro-grid to supply three-level power quality to a building of the Yokohama Research Institute.

DER and micro-grid related policies in Japan

Japanese government support for DER is important at a time of rapidly rising fuel prices. Investment subsidies and tax benefits are used as the main tools, rather than a feed-in tariff approach. Subsidies are regularly reviewed in the light of technological and economic developments, but the government is committed to continued support for DER. Taking the CHP system for example, the main support mechanisms are described below.

○ Subsidies for High-Efficiency Natural Gas CHP (10 kW to 3000 kW)

The Support Programme for New Energy Users provides subsidies for businesses that introduce qualifying new energy systems such as natural gas CHP systems and fuel cells. The fiscal year 2008 budget stands at ¥33.58 billion; the grant rate is up to one-third of the installation cost. The ceiling is ¥500 million for natural gas CHP systems and ¥1 billion for fuel cells.

○ The Programme for the Promotion of New Energy in Local Areas

This Programme provides subsidies for local public entities that plan to introduce qualifying new energy systems, which are close to being commercial but still have high system costs. Eligible technologies include energy efficient applications such as clean energy vehicles, natural gas fuelled CHP systems and fuel cells, as well as renewables. For 2008, the project budget stands at ¥4.15 billion and the grant can cover up to half of the installation cost.

○ Accelerated tax depreciation of CHP investment

The Taxation System for the Promotion of Investment in Energy Supply-Demand offers a 7% tax exemption for small- and medium-sized businesses or an accelerated tax depreciation of 30%of the standard acquisition value of CHP equipment.

○ R&D on high-efficiency natural gas CHP and fuel cells

The Japanese government also actively supports R&D, demonstration and commercialization of gas-engine and fuel cell CHP systems for residential use.

○ Administrative procedures for grid connection

The government has introduced special procedures for grid connection of CHP systems. This includes the development of guidelines for the administrative arrangements required for electricity supply to third party. While this is a move in the right direction, some critics have argued that the guidelines require excessively technical specifications, artificially raising the cost of CHP in the market place.

Residential CHP systems still have to meet technical standards for grid connection, but do not require on-site inspection by the utility. Simplified network access is particularly important for supporting the emerging market for small and micro-CHP systems to avoid prohibitive administrative overheads during the installation.

○ Low-interest loans for district energy

This loan scheme provided by the Development Bank of Japan consists of low-interest loans for DHC projects. The objective is to reduce costs and accelerate investment in DHC. The scheme targets electricity utilities in particular.

Table 2 shows the policies for CHP system adoption in Japan. Generally, it includes two parts: subsidies and tax benefits.

Table 2 Policies for distributed energy resource in Japan

Policy	Content
Subsidies for High-Efficiency Natural Gas CHP(10kW to 3000 kW)	Subsidy: up to one-third of the installation cost)
The Programme for the Promotion of New Energy in Local Areas	Subsidy: up to half of the installation cost
Accelerated tax depreciation of CHP investment	Tax benefits: 7% tax exemption for small and medium-sized businesses of CHP equipment
Global Warming Prevention Support Enterprise	Subsidy: up to half of the installation cost
Basic energy project	Plan to install eight million kW natural gas CHP system by the end of 2020 and 11 million kW by 2030.
High-energy efficiency system installation enterprise for residential building	Subsidy: up to one-third of the installation cost

SWOT analysis of DER and micro-grid diffusion in Japan

From the above, it can be seen that despite losing out in economies of scale, distributed energy could be a key solution to Japan's problems with central power, such as transmission losses, investment risks and possibility of earthquake damage.

Good performance of an energy plan is the result of correct interaction of system characteristic with its internal and external environment. In order to have a deep understand of the DER situation in Japan, a SWOT (strengths, weaknesses, opportunities and threats) analysis is performed.

SWOT analysis is a very efficient way of identifying strong and weak points and of examining the opportunities and threats of a certain practice. The SWOT method, which was developed in the 1960s, has been used recently within the context of many private and public organizations. The SWOT analysis is widely recognized and it constitutes an important basis for learning about the situation and for designing future procedures which can be seen as necessary for thinking in a strategic way. In the following, a SWOT analysis is presented to highlight the Japanese DER and micro-grid spread constraints, potentials and challenges. The resulting SWOT matrix is shown in Table 3.

According to the results, the main strengths for the development of DER and micro-grid in Japan are the positive policy support from the government. On the contrary, the weakness is the high cost and misunderstanding by the end-users. As to the extrinsic factors, the main opportunities are a resuscitated national economy and the meeting the promises in the Kyoto Protocol. On the contrary, the threats include uncertainties of economy and relying on nuclear power plants.

Based on the above analysis, the internal and external aspects of introducing DER and micro-grid in Japan have been recognized. After understanding these problems, in order to accelerate the diffusion of DER and micro-grid, suitable strategies should be promoted. In the following, according to the four aspects above, the strategies are also grouped into four types.

S-O Strategies: pursue opportunities that are a good fit with the strengths. W-O Strategies: over-

Table 3 SWOT matrix for DER in Japan

Intrinsic factors	
S: Strength	**W: Weakness**
※ Technical guidelines for grid-connected operation have been established ※ The government’s positive attitude towards the Kyoto Protocol and promoting renewables ※ Ageing boiler steam turbine plants in the industrial sector lead to high potential for turbine and engine CHP systems ※ Japan’s Energy Master plan promotes the coexistence of distributed energy system with large-scale central power ※ Subsidies, accelerated capital allowances and long-term loans for distributed generation	※ High cost of protection devices for gridconnected operation, especially for small-scale distributed generation ※ Insufficient deregulation of the power sector ※ Liberalization continues to reduce electricity prices ※ The cost of CHP and renewable equipment remains high ※ Inherent intermittency of renewable energy ※ The low price of electricity sold back to the grid ※ Lack of user understanding
Extrinsic factors	
O: Opportunity	**T: Threat**
※ The promises to the Kyoto Protocol ※ Many villages need local energy solutions ※ Resuscitation of national economy ※ Advancement of public environmental consciousness ※ Widened cooperation with other countries ※ Promotion of biomass utilization ※ Green energy premium ※ Development of ESCO business ※ The persistent rise of international petroleum price ※ Economic and social benefits of DER	※ Rely on nuclear power plant too much ※ Carbon tax uncertainty delays projects ※ Future gas reserves are expensive ※ Economic uncertainty ※ Lack of clear / strong policy ※ Negative attitude by network companies ※ Lack of well defined and supported technical and commercial framework for DER and micro-grid ※ Concerns about noise & reliability ※ Risk that DER investment will be stranded if major supply-side investment go ahead ※ Uncertainty regarding capacity needed to be achieved to defer or avoid transmission investment ※ No methodology determined for allocating payment for the benefits of avoided transmission to alternatives

Table 4 Strategic action for DER in Japan

Action	S: Strength	W: Weakness
O: Opportunity	S-O Strategies ☆ Promote stricter environmental policy to meet the Kyoto Protocol ☆ Stimulate international cooperation in the field of distributed energy ☆ Try to low down the import dependence of primary energy ☆ Offer more subsidies to the adoption of DER and micro-grid systems	W-O Strategies ☆ Advance the research of distributed generation technologies ☆ Make all tries to low down the installation price of DER and micro-grid ☆ Stimulate the deregulation of electricity market ☆ Increase the buy-back price from distributed generators
T: Threat	S-T Strategies ☆ Issue of carbon tax ☆ Set base share of electricity from DER to the network companies ☆ Reduce the noise and advance the reliability of DER technologies ☆ Develop design and evaluation tool for the adoption of DER and micro-grid	W-T Strategies ☆ Continue the subsides for introduction of DER and micro-grid ☆ Make all kinds of ways to enhance the user's awareness of environmental protection ☆ Try to reduce the rely on nuclear power plant

come weaknesses to pursue opportunities. S-T Strategies: identify ways of using the strengths to reduce the vulnerability to external threats. W-T Strategies: establish a defensive plan to prevent the weaknesses from making it highly susceptible to external threats. Table 4 illustrates the detailed strategic action for DER and micro-grid diffusion in Japan.

Conclusions

In this study, first, the present situation of DER in Japan is investigated. Then, the state-of-the-art of micro-grids in Japan is reviewed. Based on the above investigation, the policies related to DER and micro-grid adoption have been discussed. In addition, a SWOT analysis has been executed to understand the problems and feasible strategies to realize a wide penetration of micro-grid in Japan.

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