WORLD ENERGY COUNCIL | ASIA

Renewable Energy System Integration in Asia

CHALLENGES & MEASURES FOR RENEWABLES PENETRATION

CONTENTS

1. Executive Summary 1
  1.1 Background 1
  1.2 Objectives 2
  1.3 Measures 3
  1.4 Study Team Members 5
  1.5 Results of survey 6
    1.5.1 Demand and Supply Balance 6
    1.5.2 Network Enhancement 7
    1.5.3 Power Markets 7
    1.5.4 Technical Issues 7
    1.5.5 Political Issues 8
    1.5.6 Innovation 8
    1.5.7 Best Practice 10
  1.6 Hidden Costs 11
  1.7 Recommendations 15
  1.8 Need of Hidden (Grid-level) Cost Reduction 15
  1.9 Method of Hidden Cost Sharing 16
    1.9.1 Evaluation of renewables' role and location in the grid 16
    1.9.2 Method of incremental cost for maintaining power quality due to RE integration 16
  1.10 Acronyms 17
2. Survey Results 18
  2.1 Profiles of Power Systems 18
    2.1.1 Electrical Energy Trend 18
    2.1.2 Electrical Facilities 19
    2.1.3 Reliability 20
    2.1.4 Power Systems Planning 21
  2.2 Current Status of RE Penetration and Future Prospect 30
    2.2.1 Demand Forecast 30
    2.2.2 Power Development Plans 30
    2.2.3 *Transmission Development Plan* 31
    2.2.4 Integration of Renewables 37
    2.2.5 Power *Market* 37
  2.3 Challenges on Technical Issues caused by RE Penetration 41
    2.3.1 Output fluctuation 41
    2.3.2 *Increase in uncertainty caused by DER* 43
    2.3.3 Ancillary services 43
    2.3.4 Difficulty of demand prediction due to integration of DERs 44
    2.3.5 Challenges in the transmission network planning 45
    2.3.6 Maintaining distribution network voltage 46
    2.3.7 Reverse Power Flow 47
    2.3.8 System inertia problem 47
    2.3.9 Complications with protection and control systems (PCS) 48
    2.3.10 Voltage Flicker 48
  2.4 Challenges in Political Issues caused by RE Penetration 49
    2.4.1 Subsidies 49
    2.4.2 Market Design 49

2.4.3 Wide area coordination system operation 50
2.4.4 Curtailment of VRE 50
2.4.5 Connect and Manage 51
2.4.6 Reuse, Recycle 53
2.5 Innovations 54
2.5.1 R&D 54
2.5.2 Required technologies and innovations for integration of VREs 55
2.6 Best Practices for mitigating challenges 57
2.6.1 Ongoing projects 57
2.6.2 Field tests 69
3. Hidden Costs and Cost Sharing 74
3.1 Hidden Costs 79
3.2 Cost Sharing 84
4. References 87

1. Executive Summary

1.1 Background

A majority of Asian countries are now putting RE at the centre of future energy development plans. They have also started R&D in electricity storage technologies, mainly focusing on batteries, which will be an essential tool in order to mitigate RE's output intermittency and maintain grid stability and power quality for customers.

This fact is reflected in the outcome of the 2017 Issues Survey in the Asian region. RE integration is the top "Need to Action" issue and Energy Storage has jumped up to the most critical uncertainty.

Some Asian countries have already encountered problems due to RE penetration and developed measures to mitigate them. It is also expected that most Asian countries will face new challenges due to greater penetration of RE in the near future.

According to the IEA, RE interconnection levels are categorised into Phase 1 through Phase 4 depending on how much impact is experienced in the power system. Each power utility in Japan, together with some Asian countries, is categorised as Phase 2. Kyushu EPCO is categorised as Phase 3, in which the RE generation determines the operation pattern of the system.

	Impact on the power system	PV-Wind generation ratio	Corresponding countries and area
Phase 1	RE has no noticeable impact on the system	About 3 %	Indonesia, Mexico, South Africa
Phase 2	RE has a minor to moderate effect on the system	About 3 – 15 %	Belgium, Australia, Sweden, China, Netherland Japan (excluding Kyushu)
Phase 3	RE generation determines the operation pattern of the system	About 10 – 25 %	Portugal, Spain, Greece, Germany, Italy, UK, CA(USA), Kyushu
Phase 4	The system experiences periods in which RE makes up all of the generation	About 25 – 50 %	Denmark, Ireland

Thus, it would be meaningful for Asian MCs to share their experiences and best practices, as well as expected future challenges and measures so that they will be able to efficiently integrate RE into the power grid.

1.2 Objectives

This study is conducted to identify the following:

- To investigate current and future RE penetration levels
- To identify challenges due to RE penetration, now and in the future
- To collect and share best practices for mitigating challenges
- To research "Hidden Costs*" and "Cost Sharing"

*Defined by the OECD as "Grid-level system costs", consisting of costs for

- Back-up (adequacy)
- Balancing
- Grid connection
- Grid reinforcement and extension

1.3 Measures

In order to achieve the objectives, a study team, consisting of Asian countries, was organised. The study team conducted surveys to gather information on the following:

1. Profile of Power System
    - Maximum Peak Demand (past 5 years)
    - Energy Sales (past 5 years)
    - Installed Generation Capacity (as of now)
    - Transmission Lines (as of now)
    - Substations (as of now)
    - Service Area & No. of customers (as of now)
    - SAIDI & SAIFI (past 5 years)
    - Demand Forecast (up to 2030)
    - Generation Development Plan (up to 2030)
    - Bulk Power Transmission System Plan (up to 2030)
    - Power Market Structure (present and future)
    - RE Development (past, present and future: 2000~2030)
    - Current Status of RE Power Purchasing (Price, Duration, Average Electricity Price, etc.)
2. Literature Survey on Hidden Costs
    - Title
    - Authors
    - Published Date
    - Source
    - Summary of Contents
    - URL
3. Technical Issues
    - Countermeasures for Variable Renewable Energy
    - Countermeasures for Duck curve
    - Increase in uncertainty due to DERs
    - Ancillary services
    - Difficulty of demand prediction due to integration of DERs
    - Challenges in transmission network planning
    - Maintaining distribution network voltage
    - Reverse Power Flow
    - System inertia problem
    - Complication of protection systems
4. Political Issues
    - Increase in cost burden
    - Perspective on future generation costs
    - Challenges in subsidy policies
    - Market Design
    - Wide area coordination system operation
    - Reuse, Recycle
5. Innovation and Best Practices

A timeline of the activities the study team has conducted is shown in Fig. 1-1.

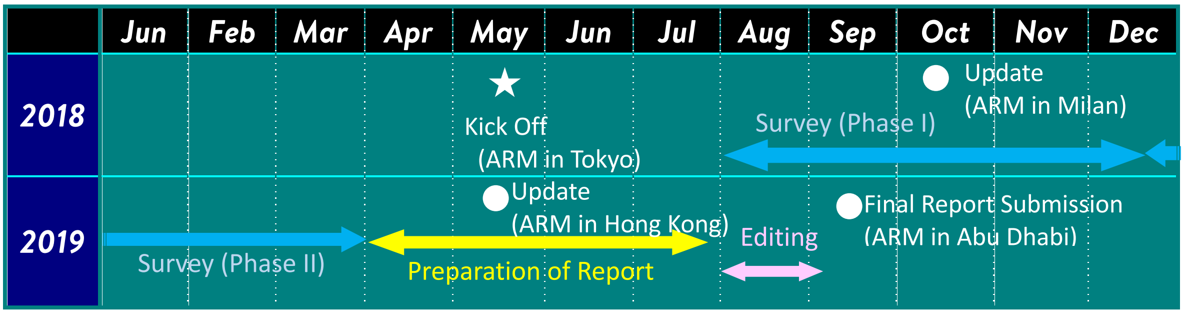


Fig. 1-1 Task Timeline

1.4 Study Team Members

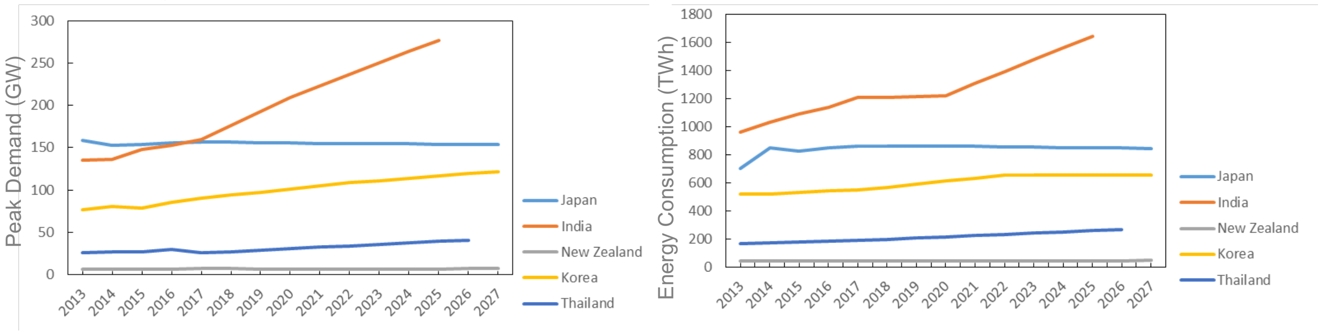
NAME	COMPANY	COUNTRY
Mr. Yoshimitsu Umahashi	TEPCO Holding	JAPAN
Dr. Teruo Ohno	TEPCO Power Grid	JAPAN
Dr. Hideaki Tanaka	WEC Japanese MC	JAPAN
Mr. Nobutoshi Saito	Chubu EPCO	JAPAN
Mr. Takeshi Kawaguchi	Kansai EPCO	JAPAN
Mr. Hiroshi Wani	Kyushu EPCO	JAPAN
Dr. Keii Gi	RITE	JAPAN
Mr. Vikram Singh	Central Electricity Authority	INDIA
Mr. Awdhesh Kumar Yadav	Central Electricity Authority	INDIA
Mr. Mohammad Ashfag	NTPC/WEC India	INDIA
Mr. Grant Telfer	Meridian Energy Limited.	NEW ZEALAND
Mr. Buddhika Rajapaske	Mercury NZ Limited.	NEW ZEALAND

1.5 *Results of survey*

1.5.1 *Demand and Supply Balance*

An overview of the current situation surrounding electric power business, demand and supply in typical Asian countries is shown in Fig. 1-2.

In these figures, there are two instances of demand and energy consumption increasing and becoming saturated



(a) Peak demand trend (GW)

(b) Energy consumption trend (TWh)

Fig.1-2 Electrical Energy Trend

In terms of supply capacity, thermal power is the main player and the rate of renewables is currently very small, but in the future the main player will shift from thermal power to renewables, as shown in Figs 1-3 and 1-4.

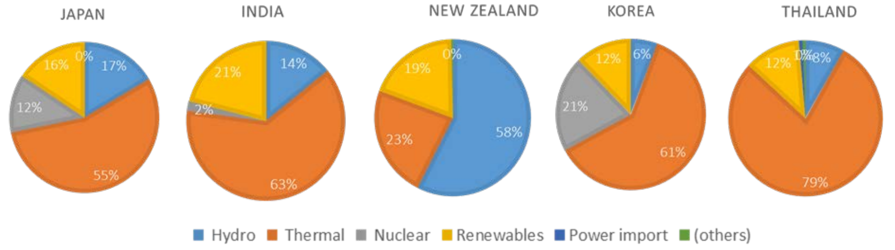


Fig.1-3 Installed Power Source Capacity

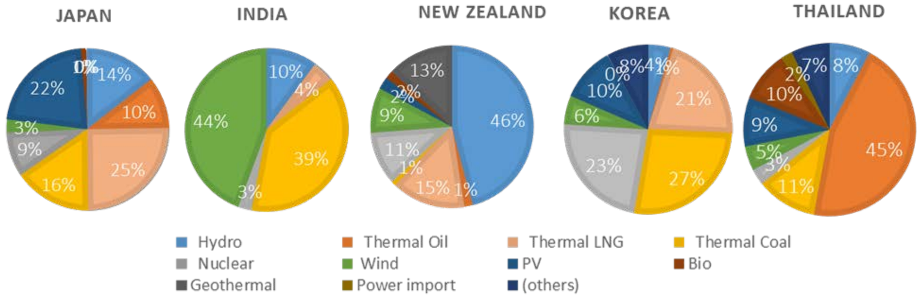


Fig.1-4 Power Development Plan

1.5.2 *Network Enhancement*

To cope with the integration of renewables, several inter-ties from country to country and from area to area are planned to be developed.
For system enhancement including inter-ties, it is necessary to consider the construction period and costs because it requires several years.
On the other hand, renewables require a short period to connect to power grids, so it is very important to match the network requirements and needs of the renewable suppliers.
Moreover, bidding systems for fair cost sharing should be prepared.

1.5.3 *Power Markets*

In some Asian countries, a capacity market and commodities to solve the issues surrounding integration of renewables are in place but in most the power market is just starting, and the various systems and commodities are to be studied and prepared.

1.5.4 *Technical Issues*

The technical issues and countermeasures on the integration of renewables are shown in Table1-1.

Table 1-1 Issues and countermeasures on integration of renewables

Issue	Countermeasures
Output fluctuation	Thermal power plant Demand response/ VPP Storage facility system (Battery, Pumped storage hydro power)
Duck curve	Demand response/ VPP Storage facility system (Battery, Pumped storage hydro power)
Uncertainty Due to DER	Power bidding, capacity market Hydrogen
Ancillary services	Bidding commodities Demand response/ VPP
Forecasting of VER’s output	Smart meter Forecasting system
Network congestion	Grid enhancement Dynamic rating
Voltage deviation	Smart meters Batteries Demand response/ VPP
Reverse power flow	LTC with functions to combat reverse power flow Batteries Demand response/ VPP
Decreasing of system inertia	Flywheels, Synchronous condensers, MG Virtual synchronous generators
Complications of protection	Multifunction PCS Special protection system
Voltage flicker	Adjustment of PCS operation

1.5.5 *Political Issues*

Political issues and countermeasures on the integration of renewables are shown in Table 1-2.

Table 1-2 Issues and countermeasures on integration of renewables

Issue	Countermeasures
Increase in cost burden	From subsidies to market trading
Termination of subsidies	Design renewable utilisation model for consumers focusing on self-consumption Design renewable utilisation model for supply side centred on power sale
Market design	Market reform program Future Power System Security program (Australia) Ancillary service market inertia (Australia) Reserves Regulation Ancillary Service (India)
Wide area coordination	Inter-regional planning
Curtailment of VER	Renewable energy power generation curtailment procedure (Japan)
Network congestion	Connect and manage
Reuse and recycle	Mechanisms for thoroughly discard Proper process for harmful substances Promotion of reuse and recycling of solar panels

1.5.6 *Innovation*

Integration of renewables provides many inferences. Fig 1-5 shows the inferences and expected innovations to counter them, focusing on supply reliability and system reliability.

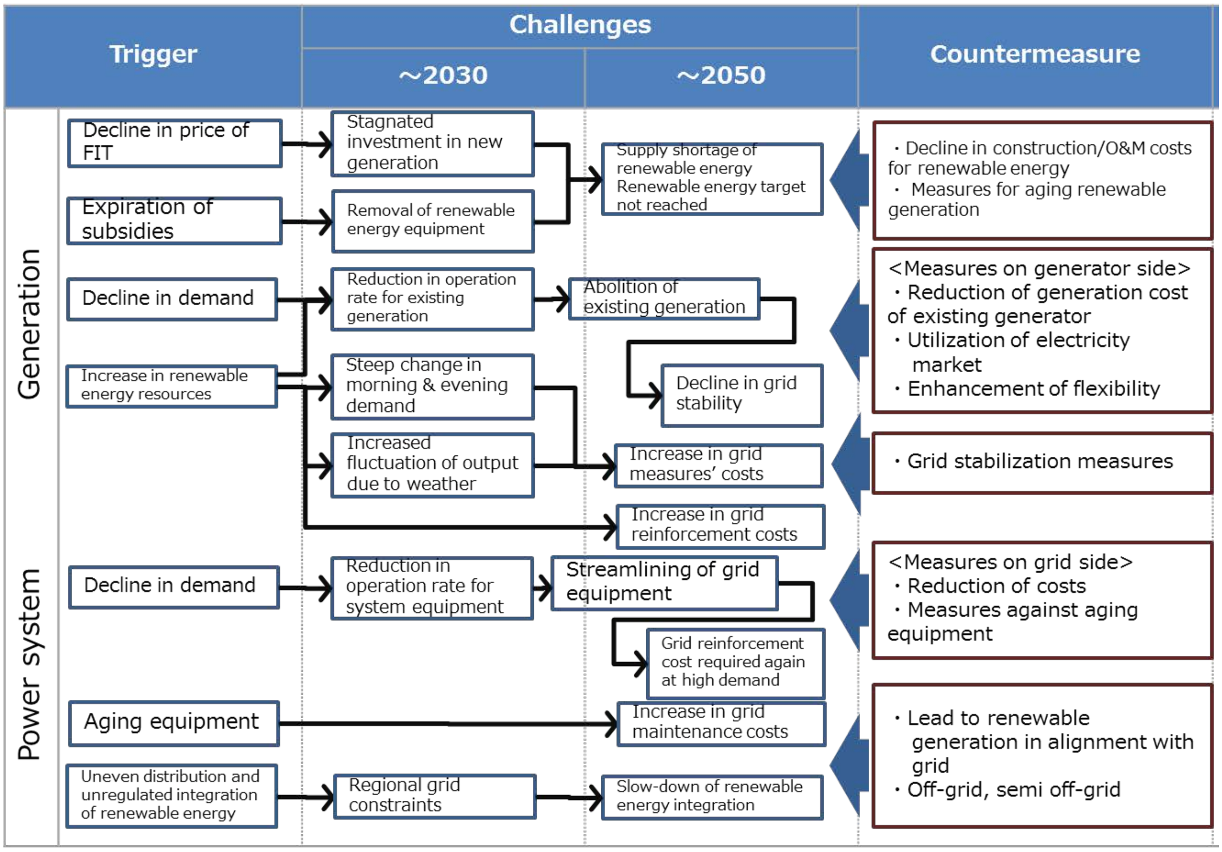


Fig. 1-5 Expected innovations led by integration of renewables

1.5.7 *Best Practice*

Table 1-3 shows the best practices for solving issues on integration of renewables.

Table 1-3 Best practice

Category		**Title**	
		Practical use	**Demonstration/Field test**
Technical Issues	Network congestion	Tender process for accepting application	
	Voltage deviation	Evolution in DMS with Smart Meter data	Field test of the voltage monitoring and control method in Wakasa, Japan
			NEDO R&D Project (Nii-jima Island Project)
	Frequency fluctuation	Demand and Supply balance improvement using large-scale energy storage batteries	NEDO R&D Project (Nii-jima Island Project)
		Renewable Management System	
	PV output forecast	Improving the accuracy of PV output prediction	NEDO R&D Project (Nii-jima Island Project)
		The development of PV output forecasting system called Apollon	
		PV Output Forecast System in the Central Dispatching Control Center	
	Maintaining reliability	Development of a new Protection and Control System	
		Expanding the transmission capacity of Kanmon interconnection	
	100% renewable power supply system		100% Renewable Energy for Hahajima Island
Institutional Issues	Political practices	RE curtailment experiences in Kyushu area	
		Connect and manage in Kyushu area	

1.6 Hidden Costs

We must evaluate the total cost of the renewable energy integrated in the grid, including so-called "hidden costs" such as backup costs and balancing (frequency regulation) costs, etc. These hidden costs include large-scale batteries installed on the grid side by the utilities.

We need to recognise that although no one asks who should pay those hidden costs, they have been borne by the end users (customers) in the end.

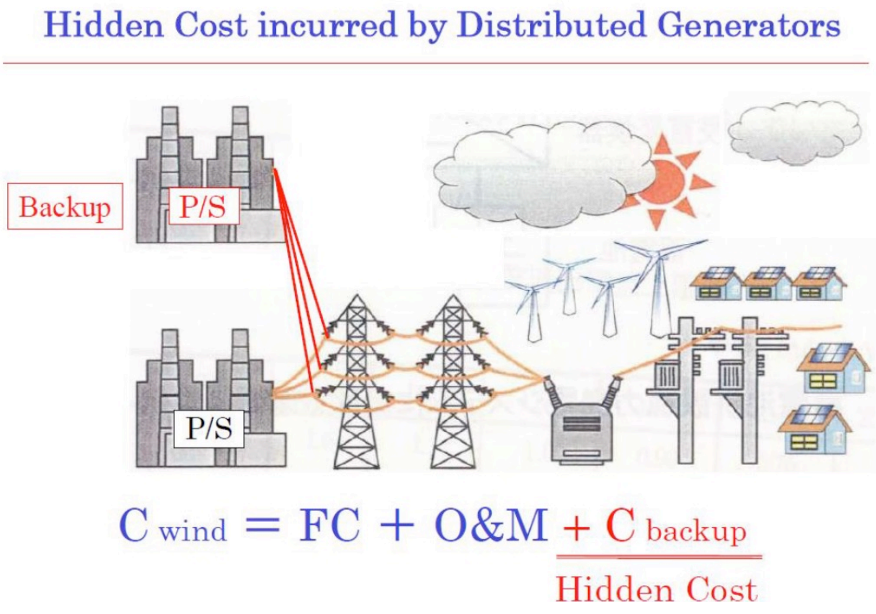


Fig. 1-6: Hidden Cost incurred by Distributed Generators

There have been frank comments by a senior manager at the Electric Power Research Institute (EPRI), USA.

"So far, most utilities have got through the issue of accumulating solar power by allowing homeowners with solar arrays to sell some of their power back to the grid. This is a practice called "Net Metering". You are basically using the grid as a battery. This is why some utilities are a little bit worried about this. The big question is "Who pays for it?"
The need for renewable energy storage has emerged recently among the engineers who worry about the health of the grid. But big grid-sized batteries can run into the millions of dollars."

There is also good news. In Germany, about half of household customers who installed rooftop PV panels installed low cost batteries at the same time. We don't deny the need for further renewable energy introduction, but we must say that "There is no free lunch."

The costs of large-scale batteries installed at substations by conventional utilities are widely borne by every customer.

However, what we need to consider is:
- Who should pay these costs?
- Is it fair for only customers to pay?
- Is there no need for mega solar developers and households owing rooftop PV panels to pay a portion?

All power generation technologies cause system effects. By virtue of being connected to the same physical grid and delivering into the same market, they exert impacts on each other as well as on the total load available to satisfy demand at any given time. The interdependencies are heightened by the fact that only small amounts of cost-efficient electricity storage are available. Variable renewables such as wind and solar, however, generate system effects that are at least an order of magnitude greater than those caused by dispatchable technologies.

System costs are defined as the total costs above plant-level costs to supply electricity at a given load and given level of security of supply. In principle, this definition would include costs external to the electricity market, such as environmental costs or impacts on the security of supply.

Focusing primarily on the costs that accrue inside the electricity system for producers, consumers and transport system operators, this subset of system costs that are mediated by the electricity grid are referred to in the following as "grid-level system costs" or "grid costs".

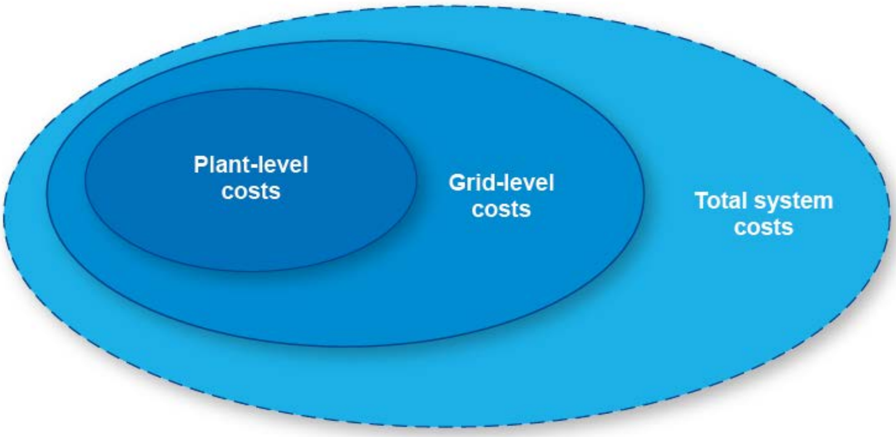
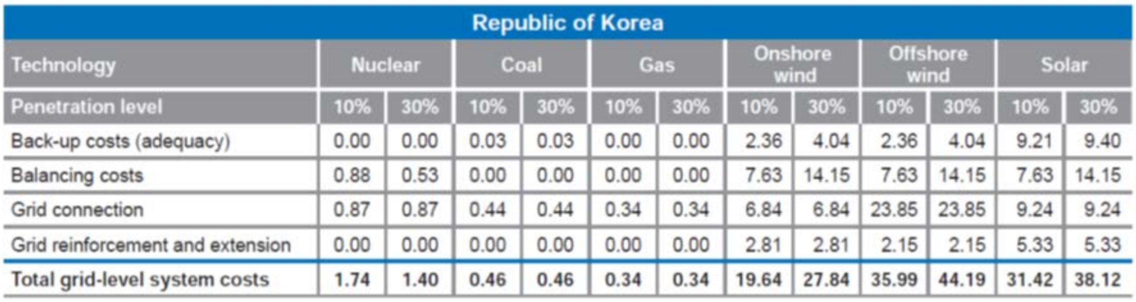


Fig. 1-7: Plant-level, grid-level and total system costs

Grid-level system costs already constitute real monetary costs. They are incurred as present or future liabilities by producers, consumers, taxpayers or transport grid operators. Such grid-level system costs can be divided broadly into two categories: (1) the costs for additional investments to extend and reinforce transport and distribution grids as well as to connect new capacity to the grid; and (2) the costs for increased short-term balancing and for maintaining the long-term adequacy of the electricity supply in the face of the intermittency of variable renewables.

Table 1-4 Grid-level system costs (US$/MWh)



Republic of Korea												
Technology	Nuclear		Coal		Gas		Onshore wind		Offshore wind		Solar	
Penetration level	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%
Back-up costs (adequacy)	0.00	0.00	0.03	0.03	0.00	0.00	2.36	4.04	2.36	4.04	9.21	9.40
Balancing costs	0.88	0.53	0.00	0.00	0.00	0.00	7.63	14.15	7.63	14.15	7.63	14.15
Grid connection	0.87	0.87	0.44	0.44	0.34	0.34	6.84	6.84	23.85	23.85	9.24	9.24
Grid reinforcement and extension	0.00	0.00	0.00	0.00	0.00	0.00	2.81	2.81	2.15	2.15	5.33	5.33
Total grid-level system costs	**1.74**	**1.40**	**0.46**	**0.46**	**0.34**	**0.34**	**19.64**	**27.84**	**35.99**	**44.19**	**31.42**	**38.12**

The results show that the system costs for integrating variable technologies into the electricity system are large: total grid-level costs lie in the range of USD 15-80/MWh, depending on the country and on the variable technology considered. Among renewable technologies, onshore wind has the lowest integration costs, while those of solar are generally the highest. Results also confirm that grid-level system cost may increase significantly with the penetration level of renewables. However, any accurate assessment of these effects would require a specific in-depth study using similar assumptions and methodology.

In terms of the mitigation of global warming, the popularity of renewable energy has risen worldwide. In fact, CO2 emissions from wind and solar are quite low.

It is said that if the availability of blowing wind is more than 2000 hours a year, a project could sufficiently pay off. Considering the high price of oil currently, the break-even point may be less than 2000 hours. Positive use of renewable energy is a requirement of the age. Its share will increase through being pushed by strong supporters among policy makers and citisens.

On the contrary, the quality of power required by consumers has become higher and higher. Unfortunately, many renewable energy technologies such as wind and solar rely on favourable weather conditions, making them an unstable source of energy. In short, they cannot meet the needs of society without compensation. Stand-alone use in an isolated private network is not realistic due to the uncertainty of power output. Inevitably, they need to be connected with the conventional power grid.

It is necessary for power grid engineers to technically evaluate the impact of the renewable energy connections on power flows through transmission lines, including international tie-lines, as well as the stability of the whole network. If there are unfavourable impacts, they must take the necessary measures.

The opinion from the grid side is as below.

Once connected with the power grid, output fluctuation of renewable energy can be compensated for. This means that backup power can be easily obtained by virtue of the unique features of the electric power system. Generally speaking, renewable energy can be fully utilised as a clean alternative energy to fossil fuel power plants when it is connected to the power grid. In other words, the power system must prepare reserve margin and provide ancillary services. According to a Japanese researcher, the cost of backup and stabilisation for renewable energies could amount to 10 to 14 Yen/kWh. In Japan, this “Hidden Cost” is now charged in the electricity rate paid by every customer.

However, in spite of the hidden costs, the great value of renewable energies will not decrease. Thus, it is essential for us to make it clear who should bear such costs, and then promote the use of renewable energies based on a public consensus on the hidden cost issue.

1.7 Recommendations

Needless to say, renewables are one of the key drivers for realizing a low-carbon society. However, as their output fluctuates depending on the weather conditions, interconnection to the grid is essential.

The more renewables are integrated into the grid, the greater the incremental costs for maintaining power supply reliability, such as those for backups and existing grid enhancement.

In this context, we conducted two phase surveys on the challenges in, and measures for, promoting the penetration of renewables, including best practices and literature research on hidden costs. In conclusion, we would like to make the following three recommendations.

1. Best Practices to be shared

We were able to collect 14 best practices, both technical and institutional. However, there is no one solution that fits all, as RE penetration levels and economic growth rates in Asian countries differ considerably. Among the 14 best practices, we recommend the following ones to be commonly shared regardless of RE penetration level.

Technical

- Balancing between supply and demand using large-capacity energy storage batteries.
- Improving the accuracy of PV output forecasting
- 100% RE supply system for remote islands

Institutional

- RE output curtailment rules (procedures)
- Connect & Manage

1.8 Need of Hidden (Grid-level) Cost Reduction

The promotion of renewables is an essential issue in order to realize a low-carbon society. The cost of renewables has reduced significantly in recent years. However, we must recognize that there exist "Hidden Costs" when integrating renewables into the grid.

The OECD defined "Grid-level costs" as consisting of the following four costs.

1) Backup costs
2) Balancing costs
3) Grid connection costs
4) Grid reinforcement and extension costs

Its trial calculations for six countries (Finland, France, Germany, the Republic of Korea, the United Kingdom and the United States) indicated that average grid-level costs were 15-80 USD/MWh depending on the RE penetration level.
Thus, in order to promote renewables further, we need to reduce the total costs, including these grid-level costs, using the following emerging measures:

- Output curtailment
- Connect & Manage
- Utilisation of smart meter data
- Frequency regulation by V2G

1.9 Method of Hidden Cost Sharing

We have now entered an era of "Grand Energy Transition" featuring the new trends of the "three Ds" (digitalisation, decentralisation and decarbonisation), where a large amount of renewables are integrated into the "downstream" (demand) side of electric power systems. In light of this paradigm shift, we should reconsider the method of hidden cost sharing, 100% of which has traditionally been borne by end-users.

From the literature survey we conducted, we have identified the following two main issues for discussion:

1.9.1 Evaluation of renewables' role and location in the grid

- It is true that renewables are power sources that supply electricity to all customers.
- It is also true that renewables contribute to national and/or global aims to reduce CO_2 emissions.
- However, there is a clear distinction between decentralized renewables and conventional centralized power stations in terms of position in the electric power supply chain. Conventional power stations are located on the upstream side, but renewables are located on the downstream, namely the demand side.

1.9.2 Method of incremental cost for maintaining power quality due to RE integration

- Traditionally, all costs regarding power sources have been borne by customers. However, we have also witnessed large industrial customers causing voltage flicker mitigating this phenomenon at their own expense based on the principle of cost causation.
- As mentioned above, we can think of renewables as either "power sources" or "negative loads".
- But it would not appropriate that we make this issue a straight choice between two things; "power sources" or "negative loads".

We should rather aim at the best balancing point in a way that the stakeholders such as existing utilities, renewables developers, end-users and government evenly feel their burden fair and transparent.

1.10 Acronyms

Names of Organisations

Chubu EPCO	Chubu Electric Power Company
Kansai EPCO	Kansai Electric Power Company
Kyushu EPCO	Kyushu Electric Power Company
RITE	Research Institute of Innovative Technology for the Earth
NTPC	National Thermal Power Corporation Limited
PGCIL	Power Grid Corporation of India Limited
TEPCO Holdings	Tokyo Electric Power Company Holdings
IEA	International Energy Agency
OCCTO	Organisation for Cross-regional Coordination of Transmission Operators, Japan
JEPX	Japan Electric Power eXchange
METI	Ministry of Economy, Trade and Industry
NEDO	New Energy and Industrial Technology Development Organisation
OECD	Organisation for Economic Co-operation and Development
NREL	The National Renewable Energy Laboratory

Technical Terms

VPP	Virtual Power Plant
VRE	Variable Renewable Energy
LTC	Load Tap Changer
MG	Motor Generator
PCS	Power Conditioning Subsystem
ISTS	Inter-State Transmission System
DMS	Distribution Management System
PPA	Power Purchase Agreement
AFC	Automatic Frequency Control
DER	Distributed Energy Resource
CAES	Compressed Air Energy Storage
FACTS	Flexible AC Transmission System
FRT	Fault Ride Through
TSC	Transient Stability Control
FSC	Frequency Stability Control
ISC	Integrated Stability Control
FIT	Feed-in Tariff
VG	Variable Generation

2. *Survey Results*

2.1 *Profiles of Power Systems*

2.1.1 *Electrical Energy Trend*

(1) Peak Demand

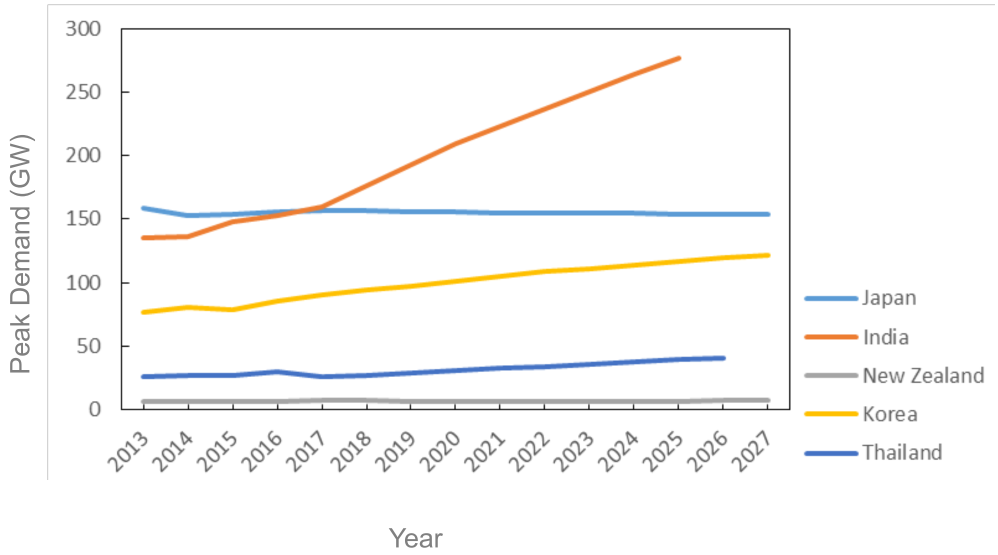


Fig. 2-1 Peak Demand

Table 2-1 Peak Demand

(GW)

	Japan	India	New Zealand	Korea	Thailand*1
2013	159	135	6.7	76.5	26.1
2014	153	136	6.7	80.2	26.9
2015	154	148	6.7	78.8	27.3
2016	156	153	6.7	85.2	29.6
2017	156	160	7.0		25.6
Record	183	177	7.0	85.2	29.6

*1 Thailand Power Development Plan 2015-2036(PDP 2015)

(2) Electricity sales

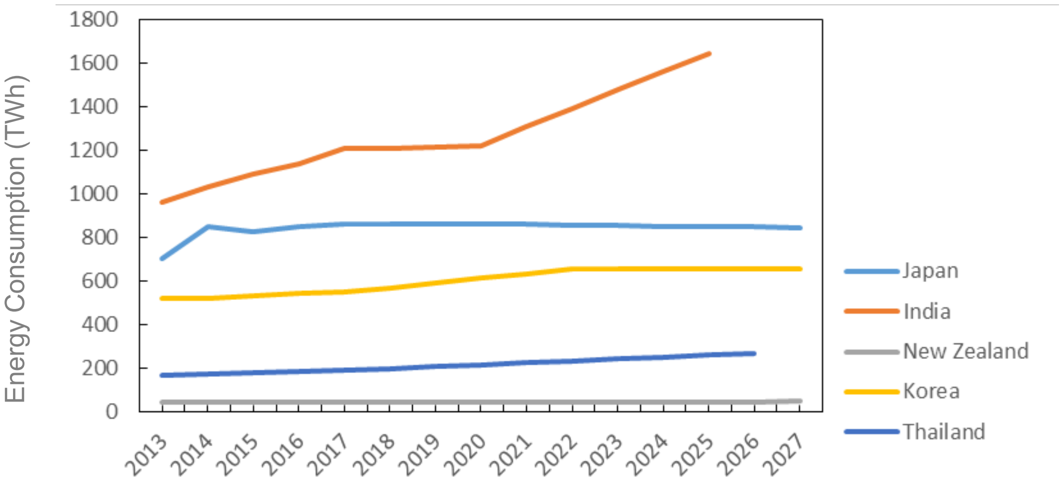


Fig. 2-2 Electricity Sales

Table 2-2 Electricity Sales

(TWh)

	Japan	India	New Zealand	Korea	Thailand*1
2013	701	960	40	517	164
2014	848	1,031	41	522	169
2015	823	1,091	41	528	175
2016	851	1,135	41	540	182
2017	863	1,205	41		187

*1 Electricity consumption by Tariff

2.1.2 *Electrical Facilities*

(1) Installed capacity

Table 2-3 Installed Capacity

(GW)

Type		Japan	India	New Zealand	Korea*2	Thailand*1
Hydro		49	50	5.7	6.4	3
Thermal	Oil	38	1	0.2	9.5	28.7
	LNG	82	25	1.6	28.7	
	Coal	44	196	0.5	30.6	
Nuclear		37	7		23.1	
Wind		0.3	34	0.7	13.7	0.2
PV		46	23	0.09		1.3
Bio		0.2	8	0.1		2.8
Geothermal		0.0	9	1		
Power imports		-				0.3
(others)		0.0		0.03		0.2

*1 Thailand Power Development Plan 2015-2036(PDP 2015)

*2 2017 ENERGY INFO, KOREA

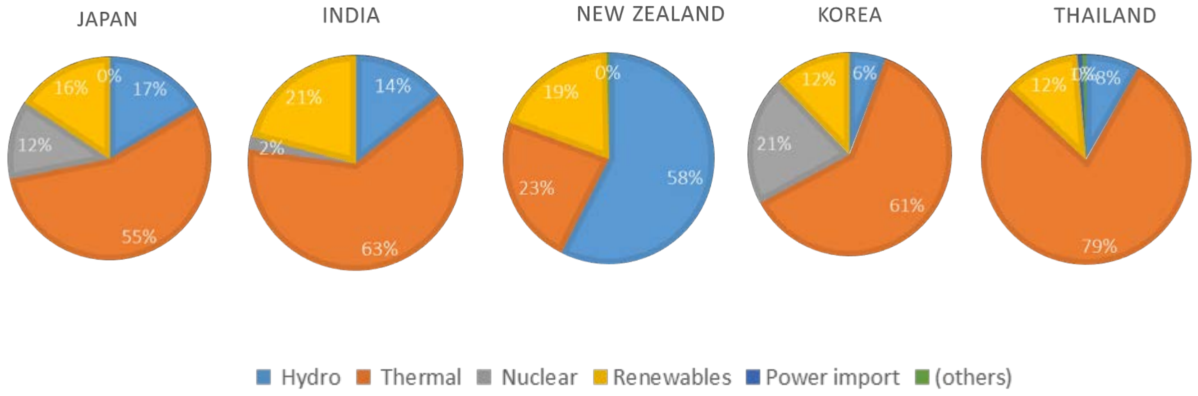


Fig. 2-3 Installed Capacity

(2) *Electricity production*

Table 2-4 Electricity Production

(TWh)

Type		Japan	India	New Zealand	Korea*1	Thailand
Hydro		84	126	25	7	
Thermal	Oil	44	1,037	0.04	14	
	LNG	397		5.8	121	
	Coal	297		1.2	213	
Nuclear		33	38		162	
Wind		6	3	2.2	23	
PV		50	3	0.1		
Bio		12	2	0.98		
Geothermal		2		7.9		
Power import		-	5			
(others)		6				

*1 2017 ENERGY INFO, KOREA

2.1.3 *Reliability*

Table 2-5 Reliability Index

	SAIFI (Times/Customer)	SAIDI (Min/Customer)	T&D loss *3 (%)
Japan*2	0.0	0.0	4
Korea*2	0.1	0.0	3
India*4	0.0/0.76-238793	0.04-1408	19
New Zealand	2.39	286.6	7
Australia*2	4.2	8.2	5
Indonesia*1	4.71	294	9
Thailand*1	1.61	48	7
Malaysia*1	0.87	60	6
Vietnam*1	5.75	806	10
Philippines*1	0.43	32	11
Singapore*1	0.01	14	6

*1 IEA, Publications of each country's government and local news

*2 World Bank Doing Business survey 2018

*3 World Bank Data

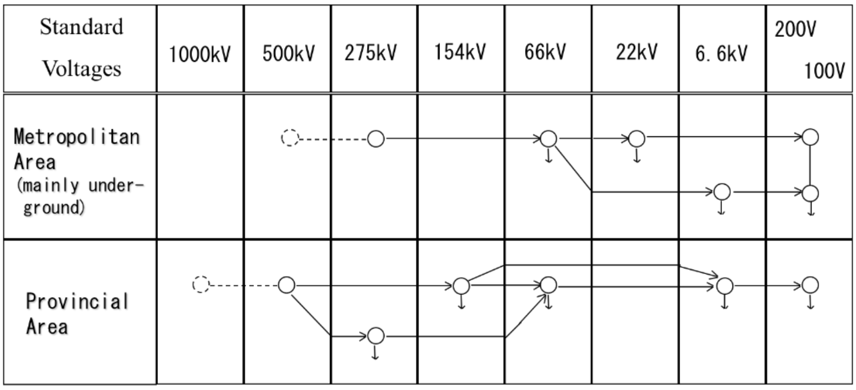
*4 India is a very large country with diverse circumstances across states, urban/rural set up , operational efficiencies and financial health of power distribution companies and consumer expectations. Added to data consistency/availability issues, the range of values makes interpretation challenging.

2.1.4 Power Systems Planning

2.1.4.1 Network characteristics

(1) TEPCO

- ✓ Transmission of large amount of Power per Route
  - ➢ Many Transmission lines are operated over SIL at peak time
  - ➢ Needs large amount of reactive power
- ✓ Increase of fault current through multiple loop network and difficulties in maintaining transient stability and voltage stability in transmission route contingencies
  - ➢ Upgrade of Circuit Breakers' breaking capacity to 63kA
  - ➢ Stabilising through system protection scheme



note : 1000kV overhead line and 500kV underground cable system will be introduced in the future.

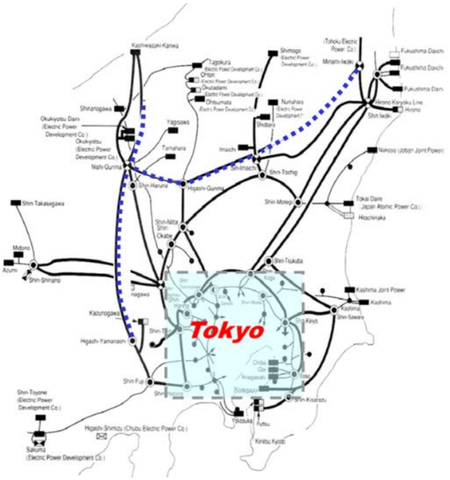


Fig. 2-4 TEPCO's voltage classes

Fig. 2-5 TEPCO's power systems

Table 2-6 TEPCO's transmission facility statics

Substations		*1,612 Stations*
Voltage Class (kV)	*500*	*24 Stations*
	275	*54 Stations*
	154	*182 Stations*
	66	*1,266 Stations*
	55 - 22	*86 Stations*

Voltage Class (kV)	*Transmission lines (circuit km)*		*Distribution lines (circuit km)*	
	Overhead	*Underground*	*Overhead*	*Underground*
500	4,520	79		
275	2,320	1,151		
154	6,000	762		
66	14,981	6,734		
55 - 22	544	3,599		
6.6			146,542	18,242
0.6			193,358	1,350

(2) Kansai EPCo

- ✓ 500kV crossed double outer ring bulk power transmission routes to maintain the fault current criteria and reliability
- ✓ Radial systems in 275kV and less to avoid a large-scale outage

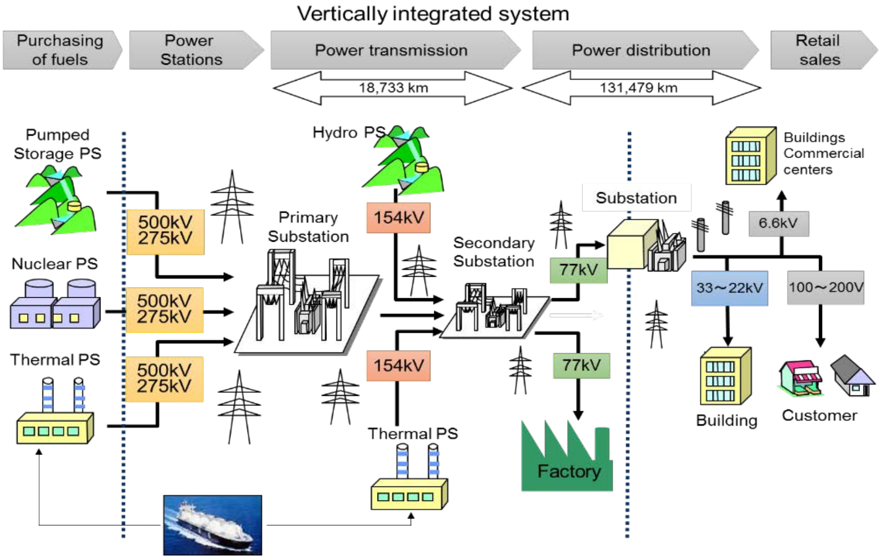


Fig. 2-6 Kansai EPCO's voltage classes

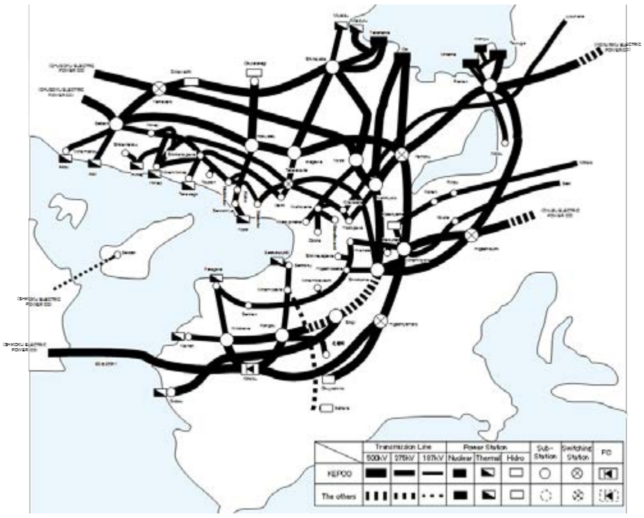


Fig. 2-7 Kansai EPCO's power systems

Table 2-7 Kansai EPCO's transmission facility statics

Type	*Number of stations*
Substations	*1596 stations*

Voltage Class (kV)	*Transmission lines (circuit km)*		*Distribution lines (circuit km)*	
	Overhead	*Underground*	*Overhead*	*Underground*
500	1,674	49 (DC)		
275	1,707	91		
187	10	5		
154	1,956	332		
77	4,197	1616		
Under 66	4,699	2467		

(3) Chubu EPCo

- ✓ 500kV transmission systems to maintain flexibility for large-scale power plant development sites
- ✓ 500kV outer ring bulk power transmission route to maintain stability by fully interconnecting the neighbouring areas

Fig. 2-8 Chubu EPCO’s power systems

Table 2-8 Chubu EPCO’s transmission facility statics

Type	*Number of stations*
Substations	*938 stations*

Voltage Class (kV)	*Transmission lines (circuit km)*		*Distribution lines (circuit km)*	
	Overhead	*Underground*	*Overhead*	*Underground*
500	890			
275	1,402	110		
154	1,855	53		
77	5,619	691		
44-11	1,045	535		
6.6			102,166	3,874
0.1/0.2			73,762	730

(4) India

At the time of independence, power systems in the country were essentially isolated systems developed in and around urban and industrial areas. The installed generating capacity in the country was only about 1300 MW and the power system consisted of small generating stations feeding power radially to load centres. The highest transmission voltage was 132 kV. The state-sector network grew at voltage level up to 132 kV during the 50s and 60s and then to 220 kV during the 60s and 70s. Substantial 400kV network growth in the State sector led to the development of regional grids. Further development of strong inter-regional links has resulted in one national grid.

The transmission systems in the country consist of an Inter-State Transmission System and Intra State Transmission Systems.

The Inter-State/Inter-regional transmission system is mainly owned and operated by the Central Transmission Utility (CTU), viz. PGCIL and other ISTS transmission licensees.

The Intra state transmission systems within states are mainly owned and operated by the state transmission utilities of each state.

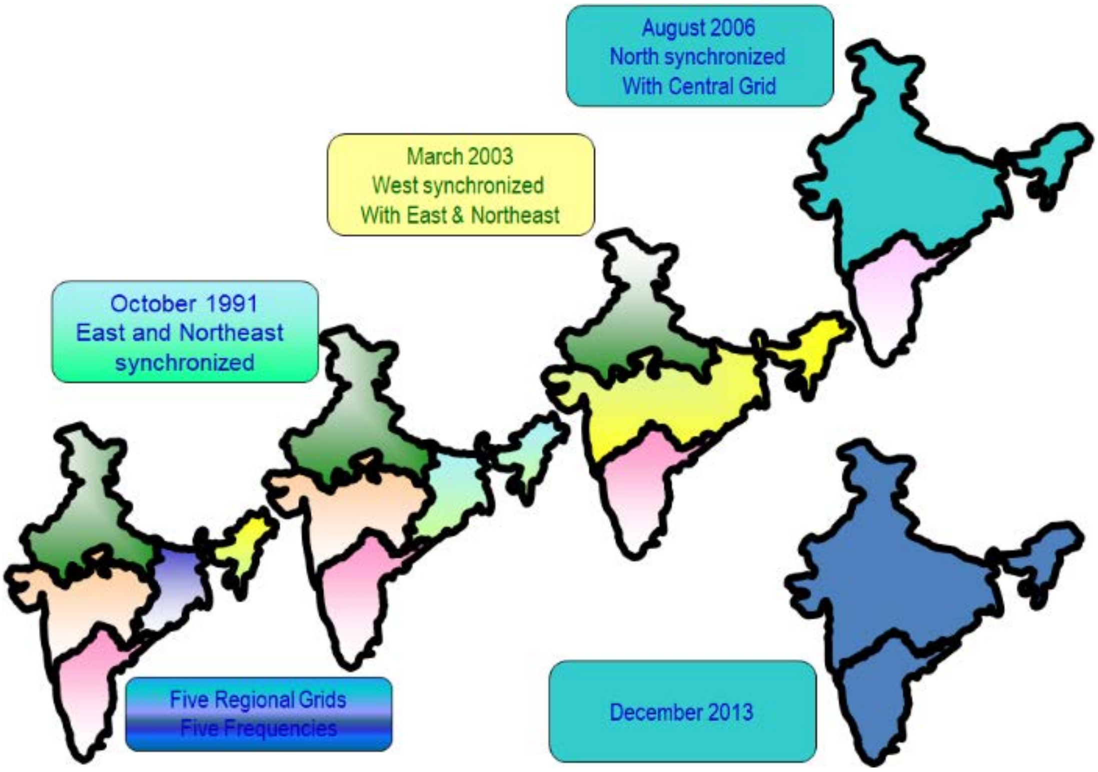
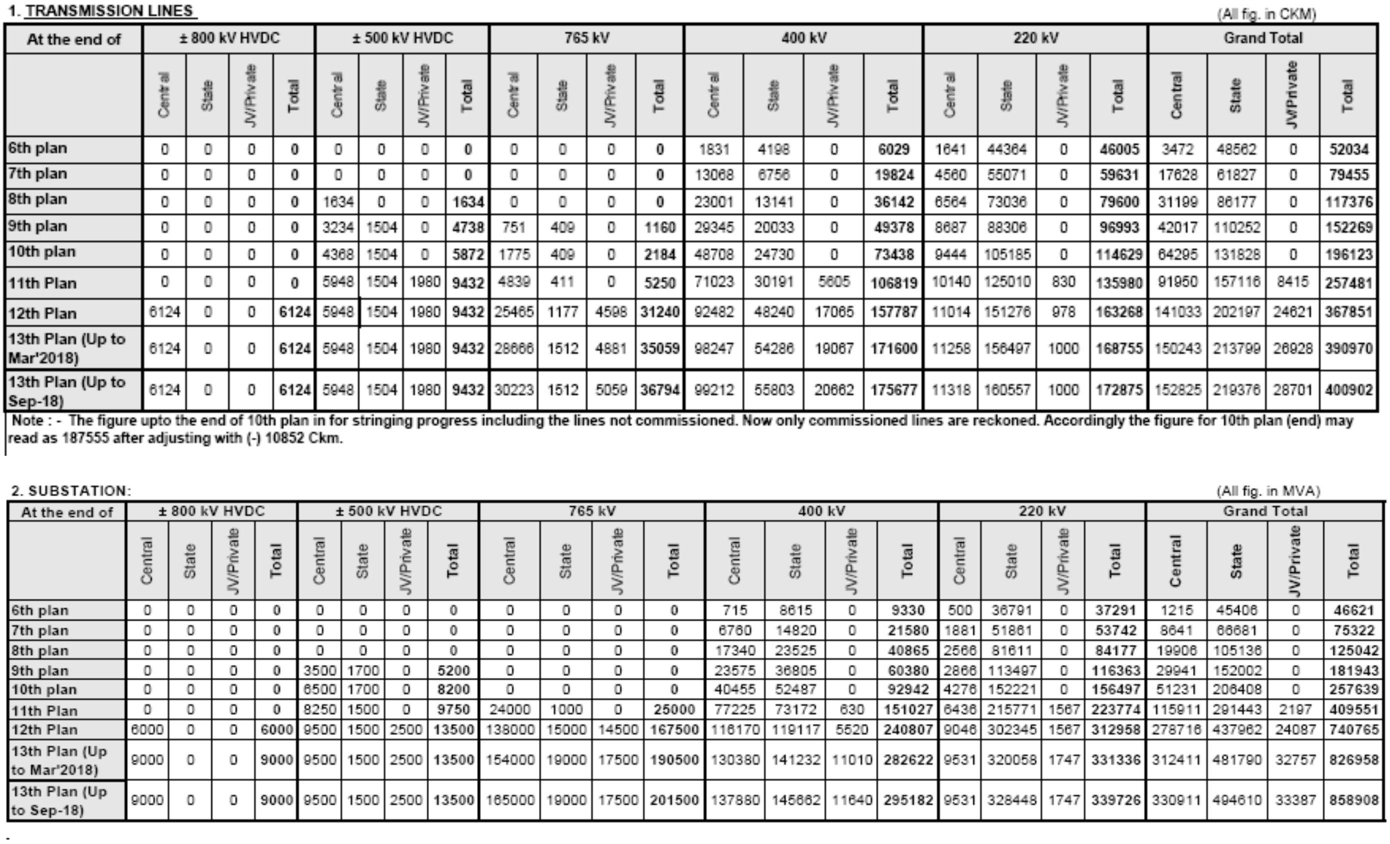


Fig. 2-9 Indian system development

The growth of the transmission system in the country is summarised below:



1. **TRANSMISSION LINES**

(All fig. in CKM)

At the end of	± 800 kV HVDC				± 500 kV HVDC				765 kV				400 kV				220 kV				Grand Total			
	Central	State	JV/Private	Total	Central	State	JV/Private	Total	Central	State	JV/Private	Total	Central	State	JV/Private	Total	Central	State	JV/Private	Total	**Central**	**State**	**JV/Private**	**Total**
6th plan	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	1831	4198	0	**6029**	1641	44364	0	**46005**	3472	48562	0	**52034**
7th plan	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	13068	6756	0	**19824**	4560	55071	0	**59631**	17628	61827	0	**79455**
8th plan	0	0	0	**0**	1634	0	0	**1634**	0	0	0	**0**	23001	13141	0	**36142**	6564	73036	0	**79600**	31199	86177	0	**117376**
9th plan	0	0	0	**0**	3234	1504	0	**4738**	751	409	0	**1160**	29345	20033	0	**49378**	8687	88306	0	**96993**	42017	110252	0	**152269**
10th plan	0	0	0	**0**	4368	1504	0	**5872**	1775	409	0	**2184**	48708	24730	0	**73438**	9444	105185	0	**114629**	64295	131828	0	**196123**
11th Plan	0	0	0	**0**	5948	1504	1980	**9432**	4839	411	0	**5250**	71023	30191	5605	**106819**	10140	125010	830	**135980**	91950	157116	8415	**257481**
12th Plan	6124	0	0	**6124**	5948	1504	1980	**9432**	25465	1177	4598	**31240**	92482	48240	17065	**157787**	11014	151276	978	**163268**	141033	202197	24621	**367851**
13th Plan (Up to Mar'2018)	6124	0	0	**6124**	5948	1504	1980	**9432**	28666	1512	4881	**35059**	98247	54286	19067	**171600**	11258	156497	1000	**168755**	150243	213799	26928	**390970**
13th Plan (Up to Sep-18)	6124	0	0	**6124**	5948	1504	1980	**9432**	30223	1512	5059	**36794**	99212	55803	20662	**175677**	11318	160557	1000	**172875**	152825	219376	28701	**400902**

Note : - The figure upto the end of 10th plan in for stringing progress including the lines not commissioned. Now only commissioned lines are reckoned. Accordingly the figure for 10th plan (end) may read as 187555 after adjusting with (-) 10852 Ckm.

2. **SUBSTATION:**

(All fig. in MVA)

At the end of	± 800 kV HVDC				± 500 kV HVDC				765 kV				400 kV				220 kV				Grand Total			
	Central	State	JV/Private	Total	Central	State	JV/Private	Total	Central	State	JV/Private	Total	Central	State	JV/Private	Total	Central	State	JV/Private	Total	**Central**	**State**	**JV/Private**	**Total**
6th plan	0	0	0	0	0	0	0	0	0	0	0	0	715	8615	0	9330	500	36791	0	37291	1215	45406	0	46621
7th plan	0	0	0	0	0	0	0	0	0	0	0	0	6760	14820	0	21580	1881	51861	0	53742	8641	66681	0	75322
8th plan	0	0	0	0	0	0	0	0	0	0	0	0	17340	23525	0	40865	2566	81611	0	84177	19906	105136	0	125042
9th plan	0	0	0	0	3500	1700	0	5200	0	0	0	0	23575	36805	0	60380	2866	113497	0	116363	29941	152002	0	181943
10th plan	0	0	0	0	6500	1700	0	8200	0	0	0	0	40455	52487	0	92942	4276	152221	0	156497	51231	206408	0	257639
11th Plan	0	0	0	0	8250	1500	0	9750	24000	1000	0	25000	77225	73172	630	151027	6436	215771	1567	223774	115911	291443	2197	409551
12th Plan	6000	0	0	6000	9500	1500	2500	13500	138000	15000	14500	167500	116170	119117	5520	240807	9046	302345	1567	312958	278716	437962	24087	740765
13th Plan (Up to Mar'2018)	9000	0	0	9000	9500	1500	2500	13500	154000	19000	17500	190500	130380	141232	11010	282622	9531	320058	1747	331336	312411	481790	32757	826958
13th Plan (Up to Sep-18)	9000	0	0	9000	9500	1500	2500	13500	165000	19000	17500	201500	137880	145662	11640	295182	9531	328448	1747	339726	330911	494610	33387	858908

Table 2-9 Growth of transmission system in India

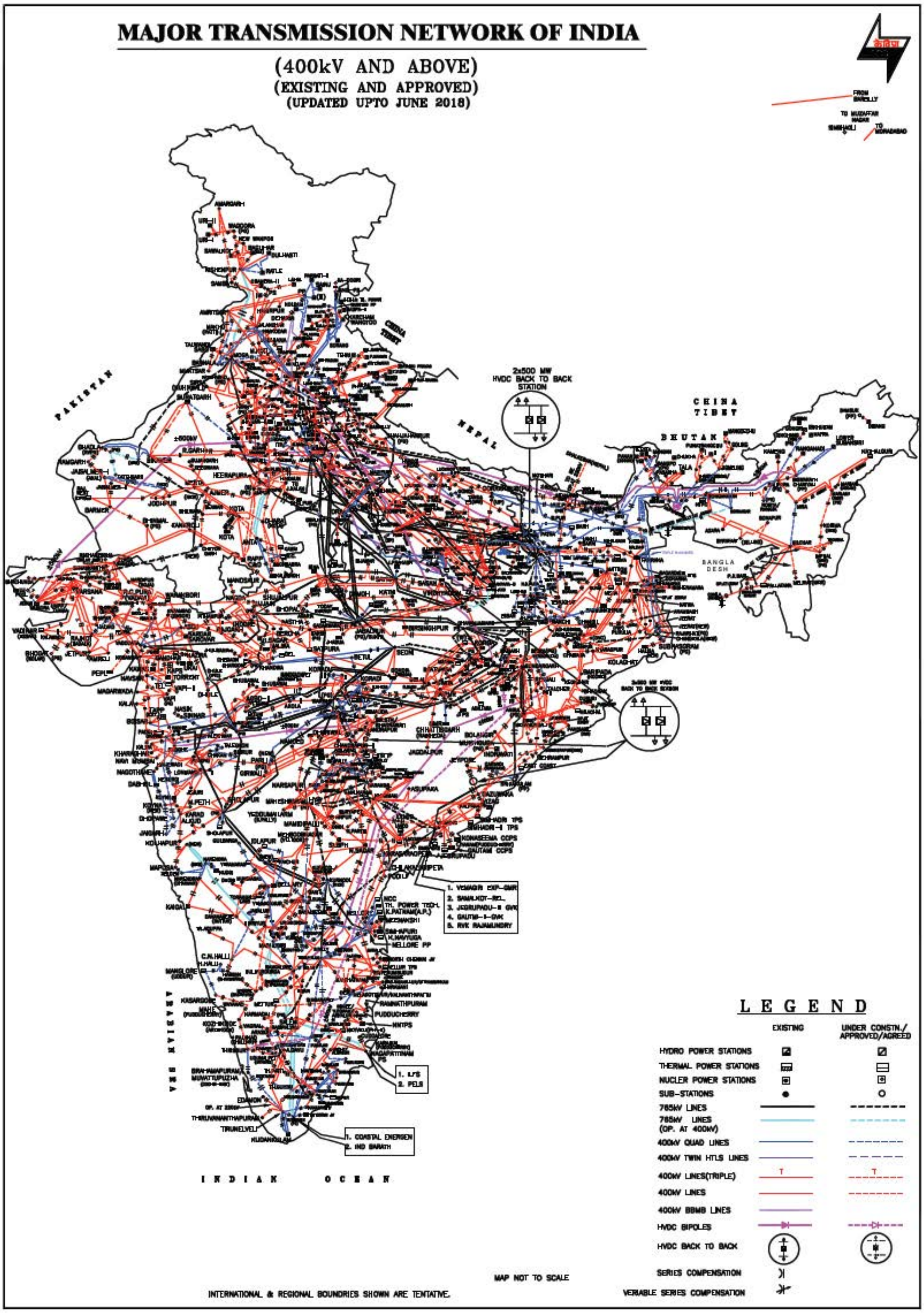
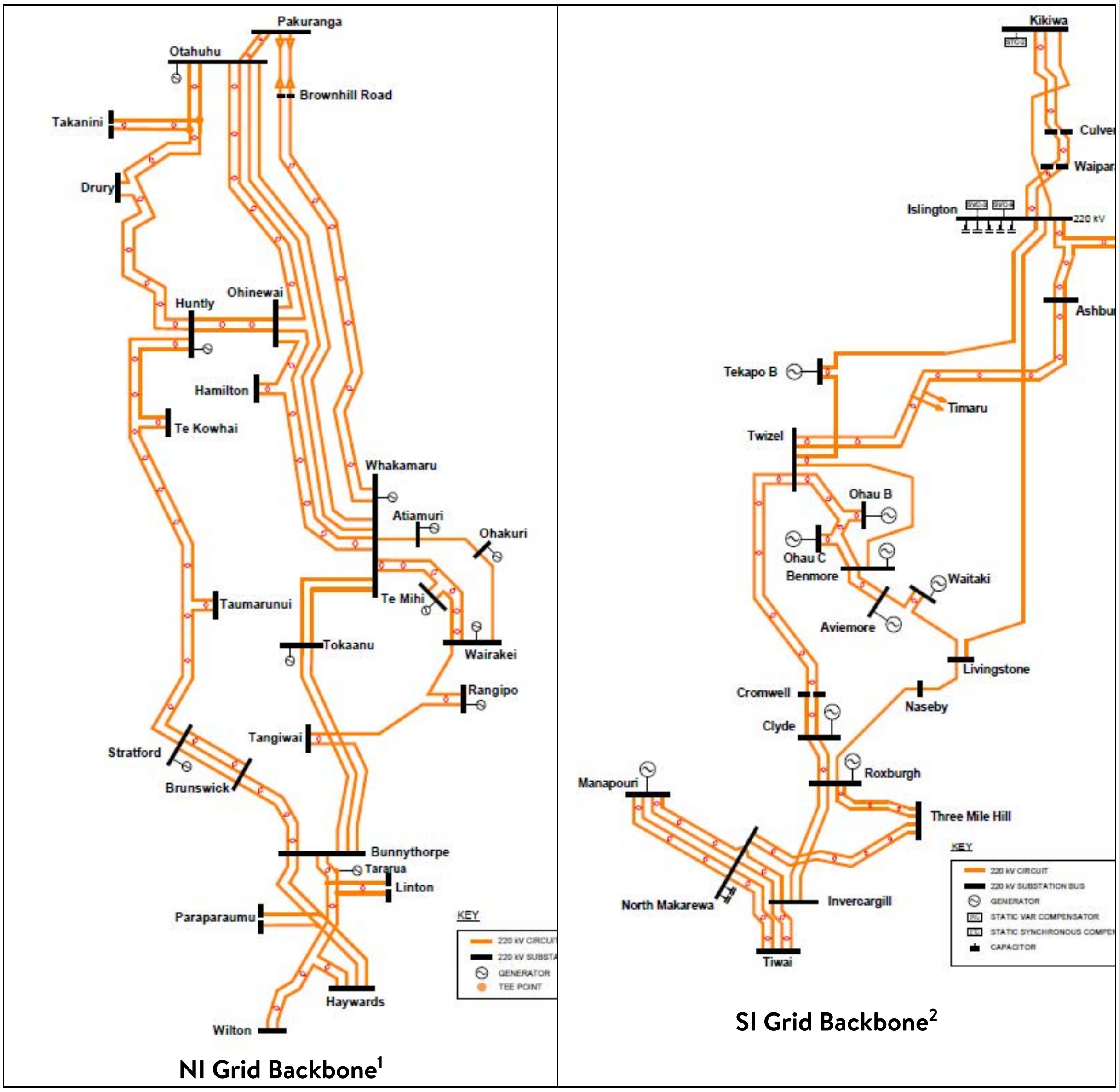


Fig. 2-10 Power systems in India

(5) New Zealand

The New Zealand transmission grid backbone mirrors the country's geography in that it is not a heavily "meshed" grid but rather a long one carrying distant generation (e.g., in the lower South Island and the Central North Island) to major load centres in the Upper North Island (Auckland and Northland), Lower North Island (Wellington) and Upper South Island (Christchurch).

The two islands' 220 kV AC transmission grid backbones (see below) are linked by a 1,200 MW HVDC link between Benmore in the South Island and Haywards in the North Island. Lower capacity AC transmission circuits operating at lower voltages (e.g., 110 kV) are not shown.



NI Grid Backbone[1]

SI Grid Backbone[2]

Fig. 2-11 Power systems in New Zealand

---

[1] Transpower Transmission Planning Report: https://www.transpower.co.nz/resources/transmission-planning-report-july-2017

[2] Transpower Transmission Planning Report: https://www.transpower.co.nz/resources/transmission-planning-report-july-2017

The North Island grid backbone comprises the following 220 kV circuits:

- four from Wellington to Bunnythorpe

Table 2-10 Transmission facilities' statics in New Zealand

Type	*Number of stations*
Substations	*175 transmission stations and 25,898 distribution stations*

Voltage Class (kV)	*Transmission lines (circuit km)*		*Distribution lines (circuit km)*	
	Overhead	*Underground*	*Overhead*	*Underground*
Distribution (largely 110 kV and below)			108,848	44,752
Transmission (largely 110 kV and 220 kV)	11,599			

2.2 Current Status of RE Penetration and Future Prospect

2.2.1 Demand Forecast

Table 2-11 Demand forecast

(GW)

	Japan*1	India	New Zealand	Korea*2	Thailand*3
2017	157.0	153.4(2015)	6.1(2015)	90.2	30.2(2016)
2022	154.6	209.4(2020)	6.5(2020)	108.6	
2027	154.1	277.4(2025) 370.5(2035)	6.8(2025) 7.1(2030)	127.2(2029)	40.8(2026) 49.7(2036)

(TWh)

	Japan*1	India	New Zealand	Korea*2	Thailand*3
2017	863	1,090(2015)	39.5(2015)	547	198(2016)
2022	857	1,222(2020)	42.5(2020)	655	
2027	843	1,645(2025) 2,192(2035)	44.5(2025) 46.7(2030)	657(2029)	267(2026) 326(2036)

*1 Calculated based on Aggregation of Electricity Supply Plans for FY2018

*2 7th Basic Plan for Long-term Supply & Demand, Korea

*3 Thailand Power Development Plan 2015-2036(PDP 2015)

2.2.2 Power Development Plans

Table 2-12 Power development plan

(GW)

Type		Japan (2027)	India (2035)	New Zealand (2030)	Korea*1 (2029)	Thailand*2 (2036)
Hydro		49	63	5.6	7	5
Thermal	Oil	35		0.2	1	29.5
	LNG	85	26	1.8	34	
	Coal	53	239	0.1	44	7.4
Nuclear		30	17	1.3	38	2.0
Wind		9	275	1.1	9	3.0
PV		74		0.3	17	6.0
Bio		3		0.2	0.2	6.2
Geothermal		0.4		1.6		
Power imports		-				1.4
(other)		0.7			13	4.7

*1 7th Basic Plan for Long-term Supply & Demand, Korea

*2 Thailand Power Development Plan 2015-2036(PDP 2015)

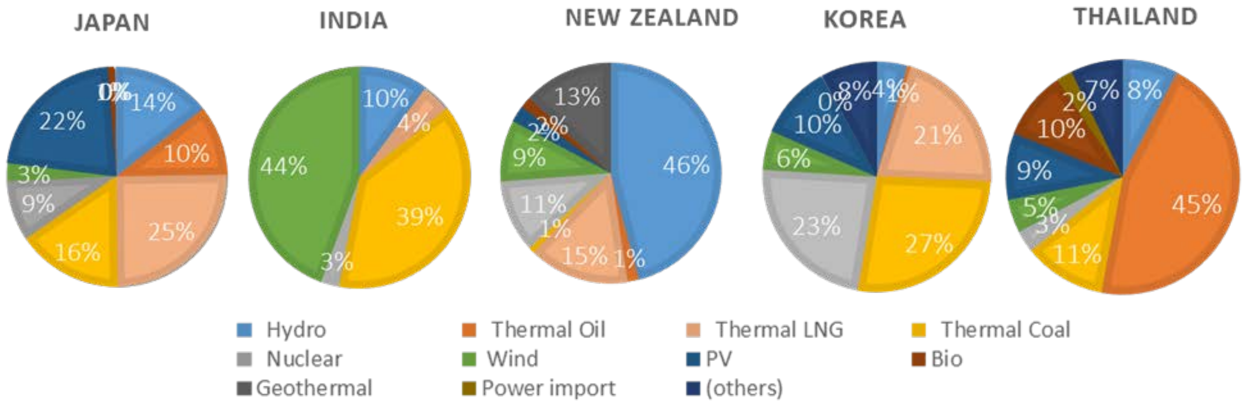


Fig. 2-12 Power development plan

2.2.3 *Transmission Development Plan*

(1) Japan

The Organisation has aggregated the development plans for 24 cross-regional transmission lines and substations (transformers and AC/DC converters) up to FY 2027 submitted by GT&D and transmission companies.

Increased Length of Transmission Lines: 601 km
Overhead Lines: 572 km
Underground Lines: 30 km
Uprated Capacities of Transformers: 18,020 MVA
Uprated Capacities of AC/DC Converters: 27 2,100 MW
Decreased Length of Transmission Lines
(Retirement) ▵ 50 km
Rerated Capacities of Transformers
(Retirement) ▵ 1,600 MVA

Enhancement plans for cross-regional transmission lines are summarised below.

- Interconnection Facility Enhancement Plan between Hokkaido and Tohoku
  (In-service: March 2019)
  AC/DC Converter Stations
  ・Hokuto Converter Station: 300 MW
  ・Imabetsu Converter Station: 300 MW
  DC Bulk Line
  275kV Transmission Lines
  ・Hokuto - Imabetsu DC Bulk Line: 122 km
  ・Customer Line AC/DC Converter Station Dπ lead-in:2 km

- Interconnection Facility Enhancement Plan between Tohoku and Tokyo
  (In-service: November 2027)
  500kV Transmission Lines
  ・Cross-regional North Bulk Line(prov.): 81 km
  ・Cross-regional South Bulk Line(prov.): 62 km
  ・Soma-Futaba Bulk Line/ Connecting Point Change: 15 km

・Shinchi Thermal Power Line/ Cross-regional Switching Station (prov.) lead-in: 1 km
・Joban Bulk Line/ Cross-regional Switching Station (prov.) Dπ lead-in: 1 km
Switching Stations 500kV Switching Station (prov.): 10 circuits

- Interconnection Facility Enhancement Plan between Tokyo and Chubu (120MW→210MW; In-service: FY 2020)
  AC/DC Converter Stations
    ・Shin Shinano AC/DC Converter Station: 900 MW
    ・Hida AC/DC Converter Station: 900 MW
  DC Bulk Line
  275kV Transmission Lines
    ・Hida-Shinano DC Bulk Line: 89 km
    ・Hida Branch Line: 1 km
- Interconnection Facility Enhancement Plan between Tokyo and Chubu (210MW→300MW; In-service: FY 2027)
  Frequency Converter Stations
    ・Shin Sakuma FC station (prov.): 300 MW
    ・Higashi Shimizu FC station: 300 MW→900 MW
  275kV Transmission Lines
    ・Higashi Shimizu Line (prov.): 20 km
    ・Sakuma Higashi Bulk Line/ Shin Sakuma FC Branch Line (prov.): 1 km
    ・Sakuma Nishi Bulk Line/ Shin Sakuma FC Branch Line (prov.): 1 km
    ・Shin Toyone-Toei Line: 1 km
    ・Sakuma Nishi Bulk Line/ Toei Branch Line (prov.): 2km
    ・Sakuma Higashi Bulk Line: 125 km
    ・Sakuma Nishi Bulk Line: 11 km
  500 kV Transformers
    ・Shin Fuji Substation: 1,500MVA×1
    ・Shizuoka Substation: 1,000MVA×1
    ・Toei Substation: 800MVA×1 →1,500MVA×2

- Interconnection Facility Enhancement Plan between Chubu and Kansai (In-service: Undetermined)
  500 kV Transmission Lines
    ・Sekigahara Kita Oomi Line: 2 km
    ・Sangi Bulk Line/ Sekigahara Switching Station π lead-in: 1 km
    ・Kita Oomi Line/ Kita Oomi Switching Station π lead-in: 1 km
  Switching Stations
    ・Sekigahara Switching Station: 6 circuits
    ・Kita Oomi Switching Station: 6 circuits

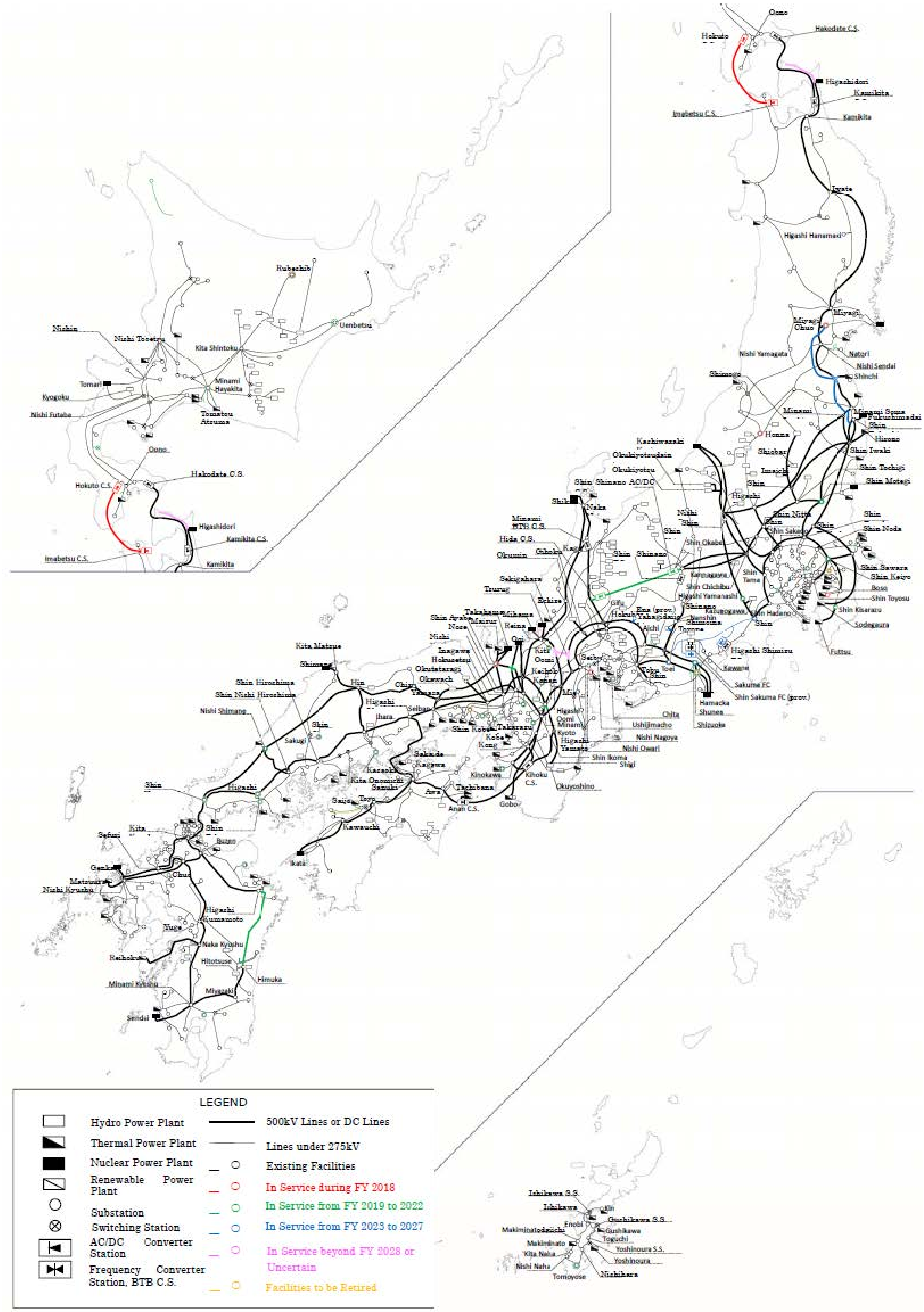


Fig. 2-13 Transmission development plan in Japan (2027)

(2) India

(a) Current power grid (2017)

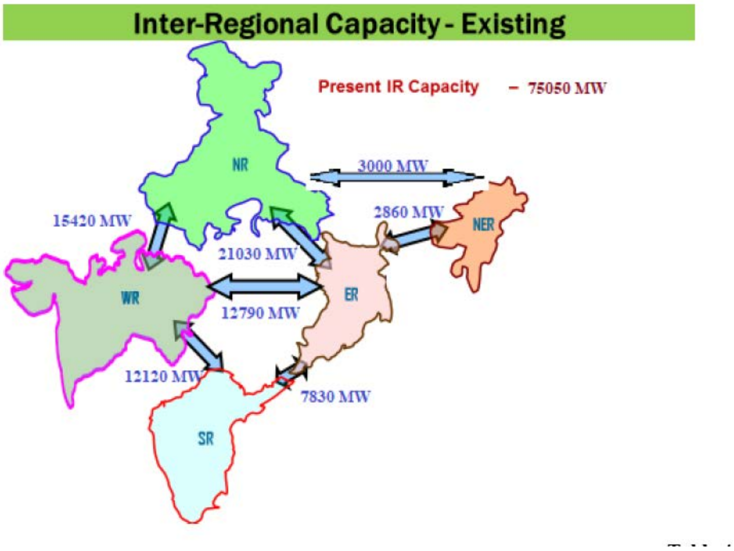


Fig. 2-14 Current power grid in India (2017)

Existing IR capacity by the end of the 12th plan i.e., March 2017

(b) Future power grid (2025)

Typical Inter-Regional flows 2021-22

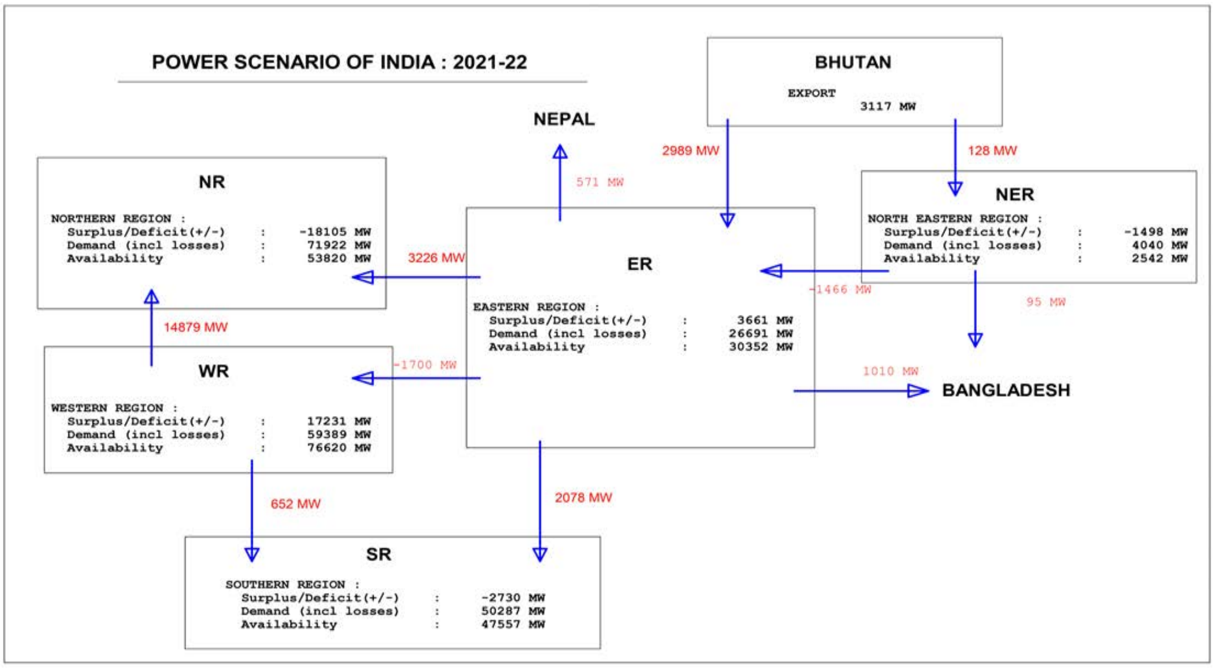
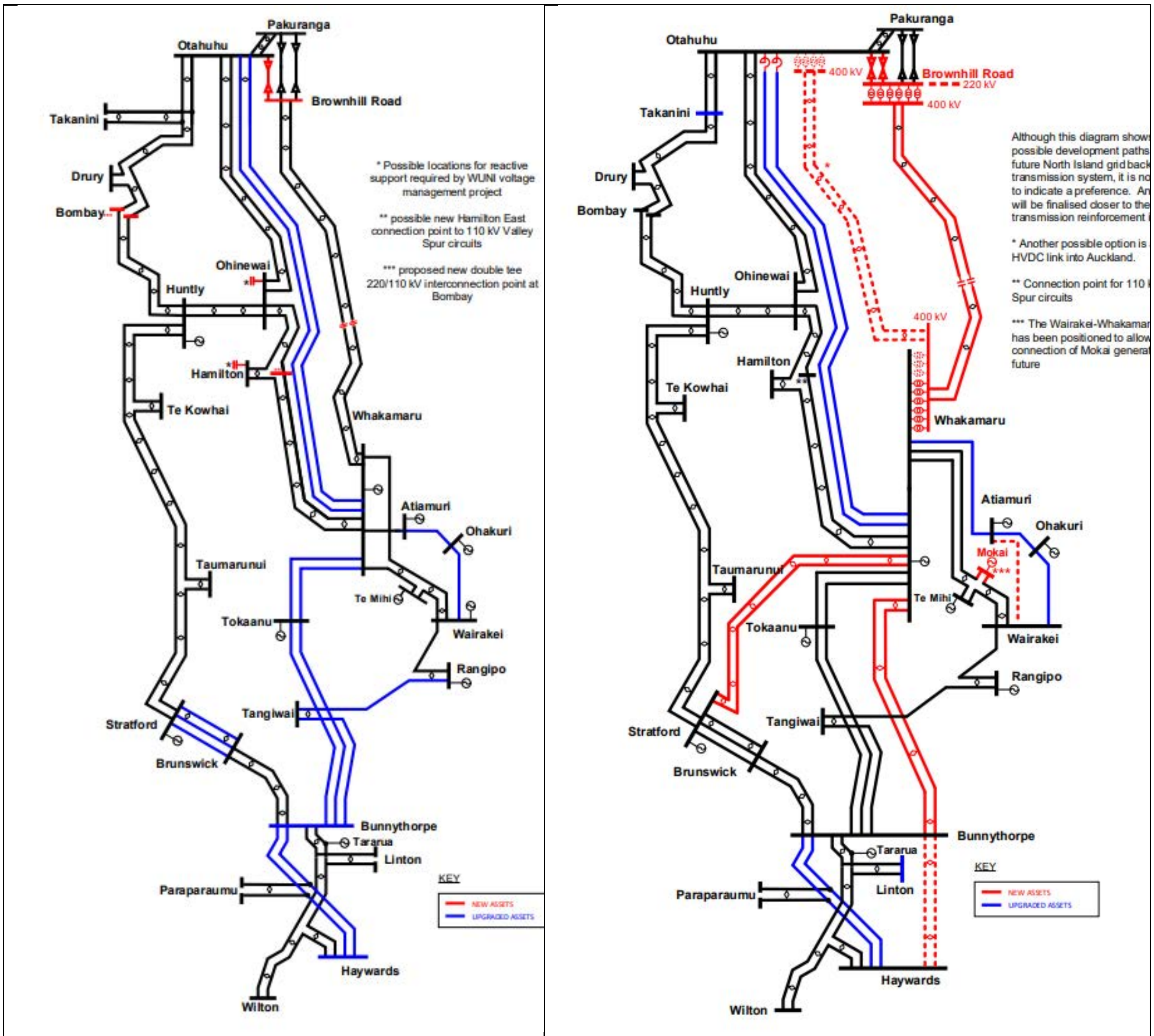


Fig. 2-15 Transmission development plans in India (2025)

(3) New Zealand



* Possible locations for reactive support required by WUNI voltage management project

** possible new Hamilton East connection point to 110 kV Valley Spur circuits

*** proposed new double tee 220/110 kV interconnection point at Bombay

Although this diagram show
possible development paths
future North Island grid back
transmission system, it is no
to indicate a preference. An
will be finalised closer to the
transmission reinforcement

* Another possible option is
HVDC link into Auckland.

** Connection point for 110
Spur circuits

*** The Wairakei-Whakamar
has been positioned to allow
connection of Mokai generat
future

NI Grid Backbone to 2032[3]

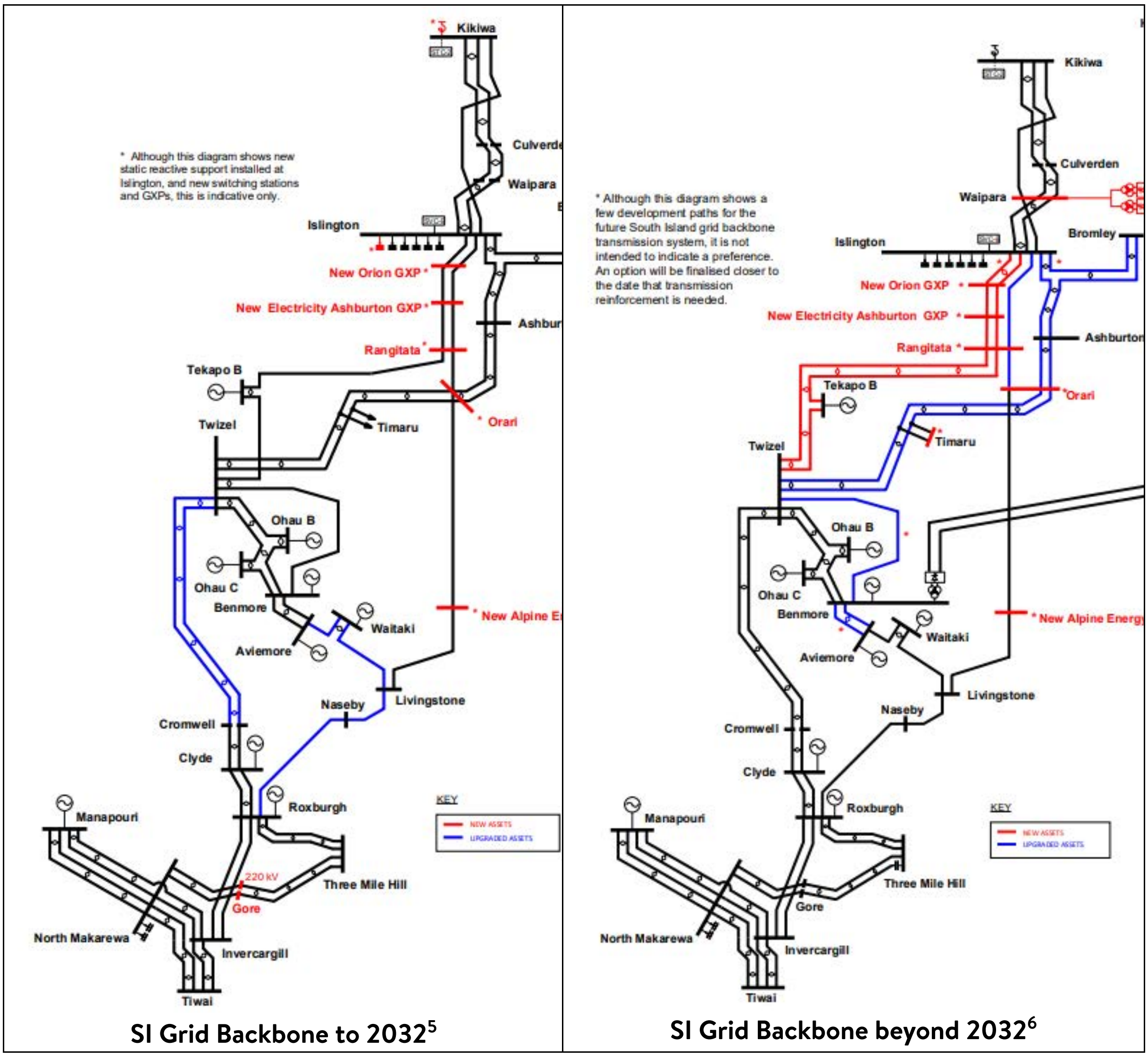
NI Grid Backbone beyond 2032[4]

Fig. 2-16 Transmission development plans in NI (2032)

---

[3] Transpower Transmission Planning Report: https://www.transpower.co.nz/resources/transmission-planning-report-july-2017

[4] Transpower Transmission Planning Report: https://www.transpower.co.nz/resources/transmission-planning-report-july-2017



* Although this diagram shows new static reactive support installed at Islington, and new switching stations and GXPs, this is indicative only.

* Although this diagram shows a few development paths for the future South Island grid backbone transmission system, it is not intended to indicate a preference. An option will be finalised closer to the date that transmission reinforcement is needed.

SI Grid Backbone to 2032[5]

SI Grid Backbone beyond 2032[6]

Fig. 2-17 Transmission development plans in SI (2032)

---

[5] Transpower Transmission Planning Report: https://www.transpower.co.nz/resources/transmission-planning-report-july-2017

[6] Transpower Transmission Planning Report: https://www.transpower.co.nz/resources/transmission-planning-report-july-2017

2.2.4 Integration of Renewables

Table 2-14 Integration of renewables

(GW)

	Japan*1	India	New Zealand	Korea*3	Thailand*2
2017	53.1	175	1.8	10.4	7.5(2014)
2027	87.3	275	3.2(2028)	32.9(2029)	19.6(2036)

*1 Aggregation of Electricity Supply Plans for FY2018

*2 Thailand Power Development Plan 2015-2036(PDP 2015)

*3 7th Basic Plan for Long-term Supply & Demand, Korea

2.2.5 *Power Market*

(1) Japan

(a) <u>Power Market Structure</u>

JEPX (Japan Electric Power eXchange) provides the following two types of market and bulletin board:

- Spot Market

The market where the electricity to be delivered the next day is traded. 48 products are traded every 30 minutes 24 hours a day.

The bidding is done via a single price auction system. Under the single price auction system, a bid is made for the combination of price and quantity of each product. A point of intersection where the buying and selling conditions comply with each other is sought, and the price and contract quantity are decided at this point.

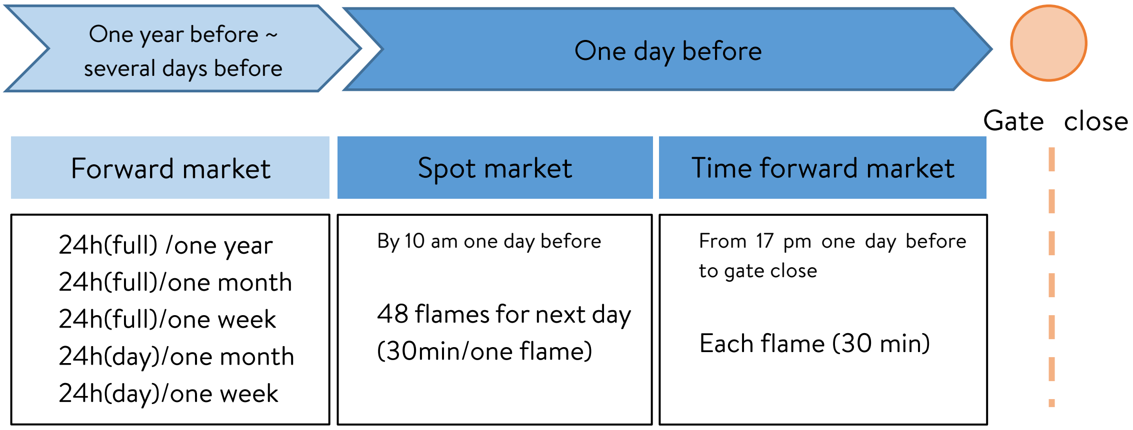


Fig. 2-18 Spot market in Japan

- Forward Market (Bulletin Board Products)

In the forward market for bulletin board products, participants freely post matters related to electricity trading.

(b) Future Market Needs

(i) Expected Market Structure

Table 2-15 Expected market structure

Value	Traded value	Market
Energy (kWh)	Generated energy →	Existing market Base load market
Capacity (kW)	Capacity to be generated	Capacity market
Operating (ΔkW)	Fast response	Operating market
Non carbon	Non carbon-oriented	Non carbon-oriented market

(ii) Market Outline

Table 2-16 Market outline in the future

Market	Outline
Base load market	Existing power plants will provide some of their supply capacity to the market for the base load. This will start in 2019.
Capacity market	A market to promote flexibility of supply power and investment in new generation projects and innovative technologies will be established in 2020.
Operating market	A market to respond quickly to changes in demand & supply will be established in 2021.
Non carbon	Non carbon-oriented electric power such as RE, nuclear and hydro power will be traded. This will start in 2019.

(2) India

Electricity is a concurrent subject in the Constitution of India and the sector in India is administered by both the central and the state governments, with distribution electricity (retail) managed by the states. The generation assets are owned by the central and state governments, as well as the private sector.

Since the early nineties, the power sector in India has been going through a process of reforms and restructuring. In the first phase of reforms, beginning in 1991, the focus of reforms was on the induction of private investment and the government opened up the Indian power sector via an amendment to the Electricity (Supply) Act, 1948, thereby promoting the entry of independent power producers. Reforms in the mid-90s led to the setting up of the Central Regulatory Commissions and State Regulatory Commissions.

The Electricity Act 2003 is currently the overarching legislation governing the Indian electricity sector. Promoting competition in the electricity sector is one of the cornerstones of the Electricity Act. With the advent of the Electricity Act, electricity generation was de-licensed. Wholesale procurement of power (mainly by state distribution companies) is by competitive bidding governed by Long-Term Power Purchase Agreements (PPAs for, say 25 years) as per guidelines by the Ministry of Power in the case of conventional generation and Ministry of New & Renewable Energy in the case of Electricity from Renewable sources. These have resulted in excellent price discoveries, especially in Renewables. A similar regime was put in place for enabling competition in power transmission as well. Large-scale solar and wind have mostly been weaned off Government support mechanisms.

As discussed above, most of the bulk power market consists of transactions through long-term agreements. The short term market constitutes only a small percentage (11 % in 2017-18)*. The buyers of bulk power are mainly distribution companies, mostly state discoms. While this describes the bulk power market, competition in power distribution has been very limited. The retail sector is governed by sets of subsidised consumers, such as residential and agricultural, with commercial and industrial consumers bearing the cost subsidised tariffs through cross subsidies.

The ancillary services market is currently very nascent. Cross border trading of electricity is also limited.

The Draft amendment to the Electricity Act currently under consultation and consideration is expected to pave the way for further competition, including in the electricity retail sector, through separation of content and carriage.

It may be noted that the Renewable landscape is dominated by wind and solar. In the case of hydro, as of now only capacities of 25 MW and below qualify as Renewable for administrative and policy purposes.

* Ref http://www.cercind.gov.in/2018/MMC/AR18.pdf- CERC report on short term market]

(3) New Zealand

(a) Power Market Structure

The New Zealand power system is characterised by an abundance of renewable energy (80-85%) and a fully deregulated power market with structural separation of competitive and non-competitive aspects of the power system. Deregulation began in earnest in the early 1990s with the spot market itself beginning operation in October 1995.

Generators and Retailers sell generation into and buy load from the wholesale spot market. The market is open access, with any institution that complies with the connection and prudential requirements able to enter either the generation or the retailing markets (or both) at any point in time. The market itself is characterised by a security-constrained, locational (nodal) pricing arrangement that co-optimises the provision of both energy and instantaneous reserves to meet system demand in every half-hour. The wholesale market is a ‘one part’ energy-only market with no provision made for additional capacity or reserve energy payments. Wholesale market provisions are able to be supplemented by bilateral financial trades (i.e., ‘over the counter’) between willing parties as well as a central futures market run by the ASX (Australian Stock Exchange) that allows financial trades up to 5 years ahead of real-time.

The high-voltage transmission network is owned and operated by the state-owned company Transpower with annual revenues regulated by the Government’s competition authority, the NZ Commerce Commission.

Multiple low-voltage distribution networks are owned and operated by a mix of public and private parties, with revenues regulated and/or overseen by the Government’s competition authority, the NZ Commerce Commission.

In general, neither Transpower nor the low-voltage distribution companies own and operate significant generation or retail businesses, although exceptions are allowed in some instances.

Current arrangements are described in detail in:
https://www.ea.govt.nz/dmsdocument/20410-electricity-in-new-zealand.pdf

(b) Future Market Needs

Reflecting the deregulated nature of the NZ power market, any party may invest in generation (or retailing) when they can see a viable commercial business reason to do so. This means that individual parties must convince themselves that *their* view of future market conditions – and in particular future supply, demand, and pricing – are sufficiently robust to warrant commitment of capital expenditure or to start a new business venture. The financial risk of investment sits firmly with the investor and *not* with the regulator or any central planner.

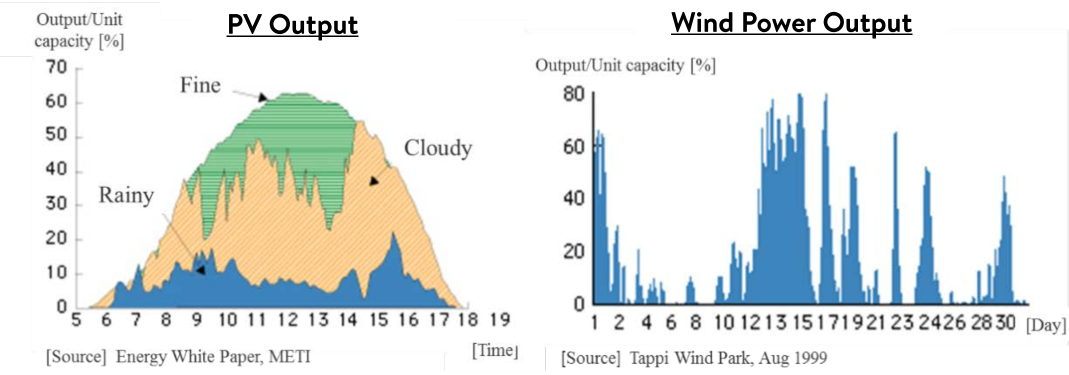
Transmission and low voltage distribution needs are managed more centrally. System adequacy and the future needs of managing the network and especially any significant capital expenditure are approved by the NZ competition authority, the Commerce Commission. If approval is given for a particular network project then the company involved is allow to recover the money (with little revenue risk) from its customer base.

2.3 Challenges on Technical Issues caused by RE Penetration

2.3.1 Output fluctuation

(1) Countermeasures for Variable Renewable Energy

The output of Variable Renewable Energies, such as PV and wind power, fluctuate depending on weather conditions. Therefore, when introducing VREs, in order to cope with short cycle fluctuation (output fluctuation up to several tens of minutes) and long cycle fluctuation (output fluctuation of several tens of minutes to several hours), it is necessary to prepare backup/adjustment systems with thermal power plants, pumped storage hydro power plants, and storage batteries.



[Source] Energy White Paper, METI

[Source] Tappi Wind Park, Aug 1999

Fig.2-16 Output fluctuation of VREs

For these adjustments, the following costs are required at present. How to lower these costs is a subject for investigation.

- ✓ Costs due to deterioration in power generation efficiency caused by lower operating rates of thermal power generation
- ✓ Costs associated with stopping thermal power generation and increasing the number of activations
- ✓ Expenses due to the creation of demand by installing power storage equipment to suppress the output of VRE
- ✓ Costs required to maintain power generation facilities for VRE

[Future developments and anticipated technology]

In the future, in promoting PV and wind power, output control and storage battery utilisation will be required. There is, however, the problem of their additional cost.

Estimated costs for these have been reported in Japan as follows.

Table 2-17 Example of additional costs for countering PV fluctuation in Japan

	Estimated Cost
Fluctuation Control	$40/kW
Long cycle fluctuation via batteries	$250 – 450/kW Battery system $50 -$90/kWh x 5h
Short cycle fluctuation via batteries	$100 – 150/kW Battery system $100 - $150/kWh x 1h

[Source] METI, Japan

Table 2-18 Estimated system enhancement costs when 5.9GW of RE is developed in Japan's Hokkaido and Tohoku area

Additional capacity of interconnection	Hokkaido (WF+PV)	Tohoku(WF)	Total
	2.7GW	3.2GW	5.9GW
System enhancement in each region	About $200B	About $70B	About $270B
Interties' enhancement between each systems	About $500B	About $330B+$70B	About $900B
Total construction cost	About $700B	About $470B	About $1,170B [About 10cc/kWh]

[Source] METI, Japan

(2) Countermeasures for Duck curve

Supply power fluctuates due to the output fluctuation of renewable energy, and its influence cannot be ignored as the amount of renewable energy increases. PV power supplies in particular suddenly rise in the morning and greatly exceed the speed of demand fluctuation. As a result, the apparent demand suddenly drops. On the contrary, in the evening, PV supply capacity drops sharply, and apparent demand rises sharply.

This phenomenon is a supply and demand problem called a "duck curve", typified by California.

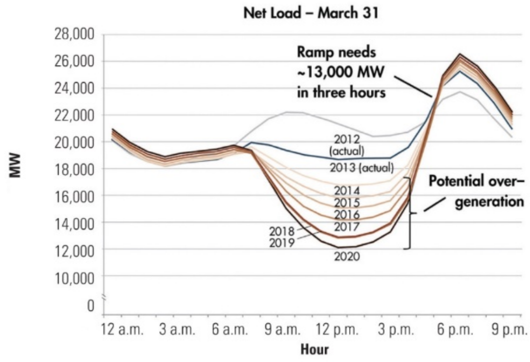


Fig.2-17 Duck curve in California

In order to cope with such sudden fluctuations in output, we mainly utilise power storage facilities, including pumped storage hydro power generation, and demand side resources such as DR/VPP. In pumped storage hydro power generation equipment, adjustable speed pumped storage is adopted in order to enhance the fluctuation suppression effect during pumping. Kyushu Electric Power Co., Ltd. (Omatugawa adjustable speed pumped storage hydro power plants) in Japan is very effective at this.

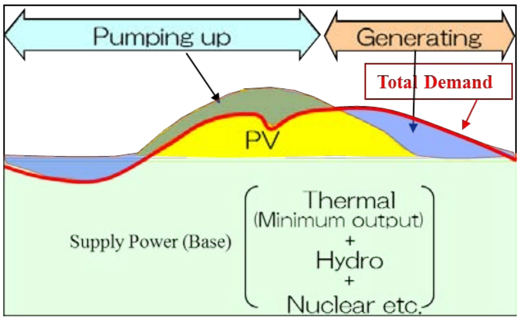


Fig.2-18 Example of suppressing of fluctuation by pumped storage hydro power

Currently, such adjustment power is imposed on the grid operator, which is regarded as the last resort, and it is secured via adjustment power electricity bidding etc.

[Future developments and anticipated technology]

Expansion of power bidding menus and further utilisation of storage batteries are expected as future initiatives.

For securing adjustment ability, the demand-and-supply operation greatly depends on the influence of the fluctuation prediction error beforehand, so improvement of prediction accuracy is desired.

Utilisation of storage batteries is listed as the expected technology.

2.3.2 Increase in uncertainty caused by DER

The proportion of existing large-scale power generation facilities has been decreasing due to the increase in the proportion of renewables in the supply capacity, driven by their political promotion. In particular, the amount of DERs (Distributed Energy Resources) such as PV is increasing, but they cannot be said to be long-term stable sources because the FIT period is 10 to 20 years and the project scales are mainly small. Meanwhile, the aging of existing power generation facilities such as thermal power plants, which have been used as base and middle power supplies, continues. In addition, due to difficulties in replacing these, their proportion will tend to further decrease in the future, and as a result, it will become difficult to secure stable power sources.

Currently, in addition to securing coordination power via power bidding, capacity markets are also appearing in some areas, including PJM.

[Future developments and anticipated technology]

With regard to securing a long-term stable power supply, there is great expectation for the creation of capacity markets as well. In Asia, power market menus will be expanded, such as the creation of a capacity market in Japan from 2020.

In addition, it is expected that the long-term use of renewable energy will be promoted through diversification of CO2-free power supplies and the promotion of reinvestment effects through the consolidation of aged facilities.

In addition, in terms of expected technology, the use of new renewable energy technologies typified by hydrogen can be noted.

2.3.3 Ancillary services

It is important to secure ancillary services as reserve capability for contingencies caused by the expansion of unstable power sources such as VRE.

In particular, due to the expansion of VRE, the lack of AFC capacity caused by a reduction in the amount of stable power supply (represented by the existing power generation) will impair the stability of the system.

In the current situation, suppression of VRE, utilisation of storage batteries, expansion of coordination power by strengthening regional interconnections, and protection control are used to maintain stability.

In addition, market procurement represents a method of securing a certain level of ancillary services, and in Japan, a bid menu for rare frequency events has been prepared in the adjustment bidding.

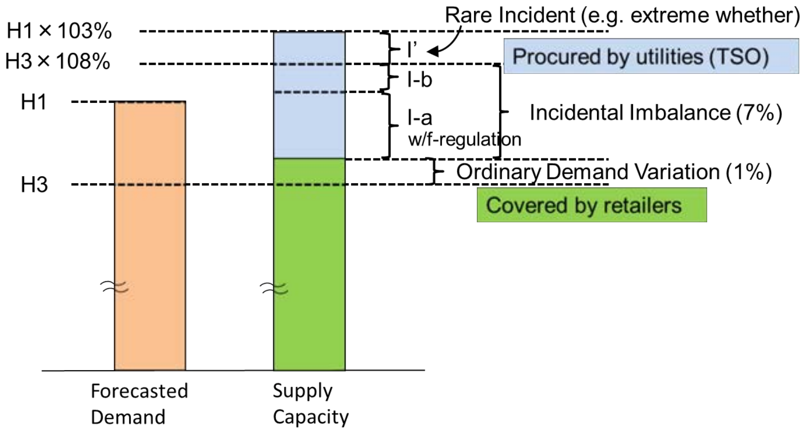


Fig.2-19 Adjustment bidding menu in Japan

[Future developments and anticipated technology]

From now on, securing AFC capacity may become increasingly difficult due to the reduction of existing large-scale power generators. To prepare for that situation, AFC markets and bidirectional Demand Response/Virtual Power Plants based on electricity storage technologies are anticipated. In addition, it is important to know in advance how much advance reservation should be made for these capacity shortages.

Studies on ascertaining the necessary amount of AFC, such as "demonstration of supply and demand simulation" by NEDO in Japan, are being conducted. In the future it will be desirable to expand the power bidding menu according to the situation.

In addition, it is expected that a variety of power storage facilities (fixed batteries, EV, CAES, etc.) will be employed to promote the utilisation of demand side resources such as DR/VPP.

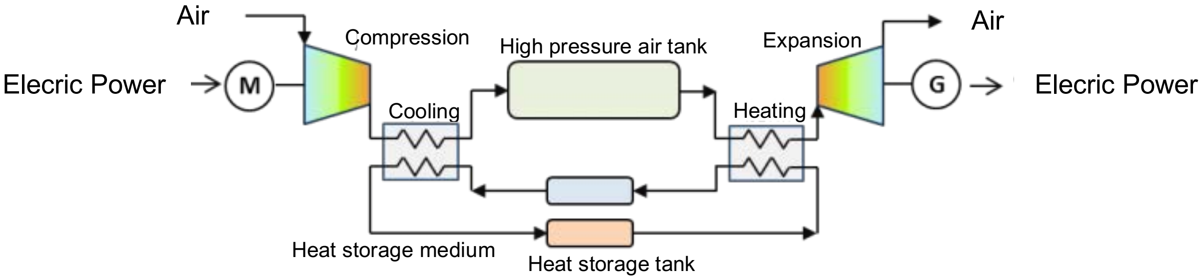


Fig.2-20 CAES System

2.3.4 *Difficulty of demand prediction due to integration of DERs*

The expansion in DERs has changed the role of end users. Until now, end users have taken a demand-centred behaviour as consumers of electric power, but DERs such as PV have given the end user the function of a power generator and urged market participation.

The complications in ascertaining power consumption behaviour by these end users make the demand assumption difficult, in turn making it difficult to secure the power supply capability.

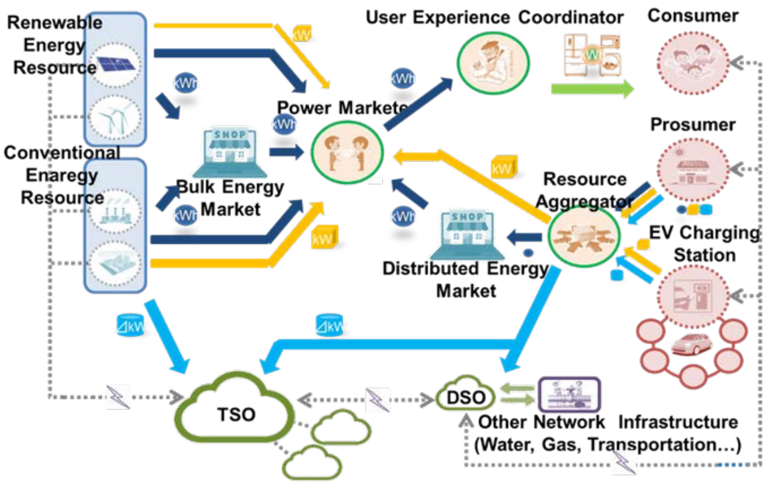


Fig.2-21 Change of power market structure

[Future developments and anticipated technology]

The device generally used to connect end users is the smart meter. Each country is currently introducing smart meters and expectations for them are great.

In addition, how to accurately and precisely conduct demand forecasts is a challenge. In China, several projects to improve prediction accuracy are being conducted.

Considering the future demand forecast, it is also necessary to minimise the rise in electricity charges due to increased investment in distribution facilities. As it entails enormous cost and time to upgrade the power system, it is important to determine the optimal investment timing while making the best use of existing equipment as much as possible.

2.3.5 Challenges in the transmission network planning

(1) Transmission network planning

To combat an uncertain power supply, there are countermeasures such as system reinforcement and power supply suppression. However, in the case of system reinforcement, even if reinforcement is undertaken, it is not always necessary in the long-term. In some cases, only equipment with low operation rate may remain.

To counter this, we formulate a long-term vision and maintain flexibility according to circumstances, rolling plans over every year.

[Future developments and anticipated technology]

How to secure flexibility of the system against VRE is a big problem. Especially in the power transmission system, construction for new transmission system would be require more than10 years, not to mention the investment amount of the construction of the transmission line.

Considering such a situation, it is important to promote cooperation with policy aspects, including restraining access of VRE.

By improving the forecasting accuracy of the VRE output such as PV or Wind turbine, it is expected that facility formation will be more efficient.

(2) Network congestion

Since VREs are ubiquitous due to there being no restriction in their installation sites they are often connected to a specific network, resulting in system congestion, requiring network augmentations, and producing problems of cost burdens. In the case of Japan, basically the cause should own the costs. If congestion occurs when offering access to the grid, the applicant will sometimes bear enormous costs for mitigating system congestion. As a solution to this problem, in Japan we have introduced a mechanism called a recruitment process.

Also, depending on the case, most of the construction costs may be a general burden, so it is desirable to suppress the amount of system reinforcement as much as possible.

[Future developments and anticipated technology]

With regard to system reinforcement, as mentioned above, considerable capital investment is required, so it is desirable to reduce costs as much as possible.

Therefore, it is necessary to identify weaknesses in the existing infrastructure that may cause a bottleneck. In order to address weaknesses without having to upgrade large-scale power transmission lines, promotion of connect & management in institutional aspects, introduction of Dynamic Rating, and the utilisation of FACTS and electric wires with high heat resistance are anticipated.

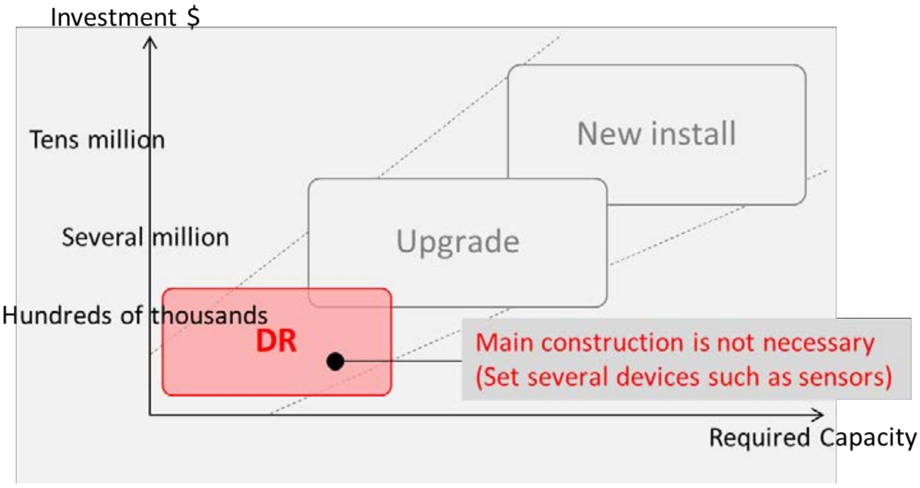


Fig.2-22 Relationship between investment and required capacity

2.3.6 *Maintaining distribution network voltage*

The distribution system has specific problems such as greatly depending on countermeasures for voltage fluctuation and the end user's power consumption behaviour.

In addition, measures to combat voltage fluctuation and overloading of the distribution system are sometimes in a trade-off with supply-demand adjustment.

Currently, expectations for smart meters are high, and measures to improve the reliability of distribution lines are being taken.

[Future developments and anticipated technology]

In the future, utilisation of DERs, as typified by VPP, will be promoted, so more flexible voltage control in the distribution system will be required. In terms of countermeasures, it is expected that reactive power will be controlled via storage batteries and EV.

Improvement of demand prediction is also effective in restraining capital investment. Currently, network facilities are installed according to the maximum demand, but if it is not necessary in the long term, the option of not increasing the amount of facilities may be considered.

Furthermore, it is also possible to restrain investment by promoting local production for local consumption, so it is also important to develop the network together with local communities.

2.3.7 Reverse Power Flow

The increase in DER connections to the distribution system causes reverse power flow from the lower voltage electric power system to the upper voltage electric power system, so power flow becomes more complicated compared to conventional power flow, which is only one way from large power generation sites to the load centre.

In response to this, various countermeasures such as a review of the voltage profile at substations have been taken.

In Japan, not only technical measures, such as introducing LTC with functions to cope with reverse power flow and the utilising of power storage equipment, but also political ones, such as the introduction of acceptance rules for reverse power flow by reviewing the grid interconnection regulations, and the promotion of local production for local consumption, have been taken.

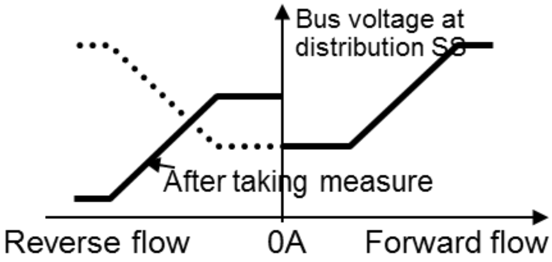


Fig. 2-23 6kV Voltage control according to flow direction

[Future developments and anticipated technology]

In the future, current adjustment of the distribution line via storage batteries, measurement technology and load prediction technology are anticipated.

2.3.8 System inertia problem

The system inertia decreases due to an increase in inverter equipment typified by VREs and the decrease in rotary machines, and the risk of blackouts increase.

Table 2-19 Large scale blackout due to a shortage of system inertia

Date/Area	**MW Loss, Duration**	**Cause (Trigger)**
Sep 9th 2016 Australia	1,750MW 3h	WFs were stepped out due to a tornado

Suppression of VREs, utilisation of storage batteries, and protection control systems are used as countermeasures to avoid large-scale blackouts.

[Future developments and anticipated technology]

To maintain the system inertia, flywheels, MG and synchronous rotary condensers are used. The development of virtual synchronous generators is being studied.

In addition, technological innovation such as estimation of system inertia by PMUs on the measurement side is desired.

2.3.9 Complications with protection and control systems (PCS)

With the increase in power supply with inverter devices such as PV and wind power, countermeasures under contingency and protection systems are becoming difficult. Especially in the cases of large-scale blackouts in Europe and Hokkaido, the demand and supply balance could not be maintained due to the continuous stepping out of renewables from the grid, resulting in said large-scale blackouts.

Table 2-20 Large scale blackout due to stepping out of renewables

Date/Area	MW Loss, Duration	Causes (Trigger)
Sep 6th 2018 Japan	3,000 MW, 48h	Major generators' loss due to the earthquake

I In addition, as problems such as difficulties in identifying fault points appear, various functions are added to PCS and studies are on these are performed.
On the other hand, new problems, such as the occurrence of flicker due to the functions added to PCS for the purpose of preventing islanding operation of power generation facilities, are also occurring.

[Future developments and anticipated technology]
Basically, the major countermeasure is to develop the new PCS. In addition, fault point estimation technology is currently being studied.

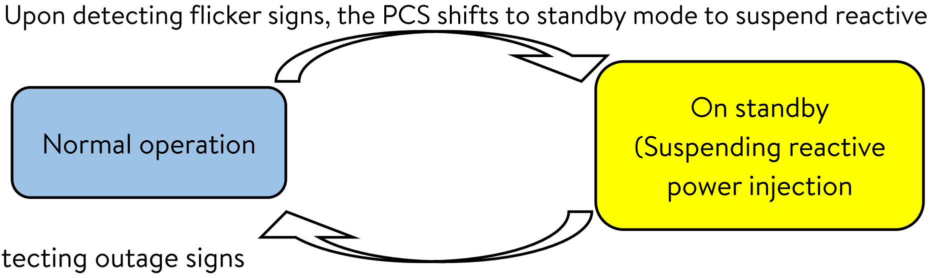
2.3.10 Voltage Flicker

Voltage flicker is a phenomenon whereby line voltage repeatedly changes causing corresponding changes in light output (the phenomenon does not have any safety problems such as electric shocks or trigger any blackouts). PV penetration may generate local voltage flickers during the daytime, especially when power demand is very low.
In January and February 2017, a wide-area voltage flicker phenomenon occurred in the southern part of Kyushu, where the system voltage continuously fluctuated and light flicked due to PCS reconfiguration measures, which responded too sensitively in regulating the voltage and put too much reactive power into the grid.

[Future developments and anticipated technology]
Each PCS has the safety feature of switching to standby mode when it detects a voltage flicker sign.

Detecting voltage flicker signs

Upon detecting flicker signs, the PCS shifts to standby mode to suspend reactive power injection.



Detecting outage signs

Upon detecting outage signs, the PCS shifts back to normal operation mode to detect Individual operation.

Fig. 2-24 Future expected functions

2.4 Challenges in Political Issues caused by RE Penetration

2.4.1 Subsidies

(1) Increase in cost burden

The current generation costs for renewables are collected from all customers through FIT etc., so if the amount introduced increases, the electricity charges will rise.

[Future development and expected technology]

In the future it may be possible to shift to market transactions for more effective utilisation of existing facilities across a wide area. Furthermore, it may be considered that demand for real-time transactions will increase for VREs.

Therefore, expectations for real-time prediction technology will increase.

(2) Future generation cost perspective

The current generation costs for renewables are recovered from all customers through FIT etc., but the period for these subsidiaries is individually determined by each facility.

In the case of Japan, the cost is higher than in other countries and it is also higher than for other power sources, which may lead to an increase in electricity charges.

In Japan, the rate of FIT obligation is 10% of the electricity bill but it is estimated that it will rise to around 40%.

[Future developments and anticipated technology]

In the future it will be possible to review the purchase price and shift to market trading. However, reviewing the purchase price reduces the profit range of the business operators and shifting to a market will reduce the incentive for the business by increasing its risks in terms of stable electric power revenue. It could also result in putting the brakes on the promotion of renewables.

(3) Challenges for subsidising policy

Problems have arisen with regard to subsidy policies due to the timing of subsidy termination, reductions in the selling price, etc.

In Japan, the purchase price of electricity will be the same as the electricity charge for home use, so the consumption will become more advantageous. In addition, since those introduced since 2009 will end sequentially, there is concern that the supply capacity will become insufficient.

[Future developments and anticipated technology]

It is important what the government show as institutional design from the present to the future.

Major efforts are as follows:

- ✓ Design renewable utilisation model for consumers focusing on self-consumption
- ✓ Design renewable utilisation model for supply side centred on power sales

2.4.2 Market Design

Stable operation in the electric power system is highly dependent on the services that contribute to maintaining the system frequency and the proper voltage levels. A special function may be required when restarting the system after a large blackout (so-called black start). The same function may be secured in different ways depending on the power network. For example, it may be prepared through definitions in interconnection regulations, or using procurement or market mechanisms.

The need for such services and their economic value may change as the introduction of renewables increases. One reason behind this is that conventional generators have traditionally provided these services (voltage control, governor free functions including inertia, and frequency maintenance). VREs generally have a limited capability to provide these services (particularly fast frequency response), which can make it necessary to explicitly procure them.

As the capacity of renewables increases, the variability and uncertainty of the demand and supply balance also increases. Consequently, securing power sources with flexibility, such as electricity storage and DR/VPP, at a higher level has become a priority, and market reform of grid services plays an important role in this, together with other measures.

[Future developments and anticipated technology]

In Asia, the following programs are being implemented for market reforms.

Table 2-21 Market reform programs for VREs in Asia

Operator	Country	Contents
AEMO 2017b	Australia	Future Power System Security program Frequency control, system strength, management of extreme power system condition and visibility of the power system
AEMC 2017b	Australia	Ancillary service market for inertia Rule change to establish an ancillary services market for inertia
POSOCO	India	Reserves Regulation Ancillary Service Procedure detailing the implementation of a new Reserves Regulation Ancillary Services

2.4.3 Wide area coordination system operation

By increasing the scale of the area where demand and supply adjustment is made using interregional interconnection lines, it is possible to reduce the influence of the suppression of VRE fluctuation, and uncertainty in the power supply, to offset the imbalance and to enable utilities to prepare/share reserve capacity. Appropriate operation of interconnection lines makes it possible to use flexible resources much more efficiently than other methods and increases the flexibility of the system. In addition, interconnection can provide frequency response, and interconnection via AC transmission lines can also contribute to the sharing of inertia between systems.

On the other hand, for interconnection lines, it is not always possible to enjoy such benefits.

[Future developments and anticipated technology]

Regional cooperation between balancing areas effectively requires inter-regional planning between different jurisdictions. This can also be a platform for achieving market integration. The IGCC (International Grid Control Cooperation), which implements the process of offsetting imbalances, interconnects line management and cooperation across balancing areas by Nord Pool and Japan's eastern area demonstration is a good example.

2.4.4 Curtailment of VRE

Basically, renewables are provided as the priority power supply source in each country, so they are accepted in power networks to the extent possible. However, most of them are VRE and their volumes are reaching the limits the networks can accept. In such cases, several countermeasures, such as output control of conventional power plants, the use of energy storage, and wide area control, are exercised.

If this is still insufficient, the curtailment of VRE is a reasonable option. In Japan, some companies have executed this according to national rules and were able to maintain the demand and supply balance. In the short term, curtailment is cost effective in many cases but definitive countermeasures should now be discussed taking into account cost burdens.

i) Using pumped storage plants to absorb surplus electricity from RE power plants, cutting output from thermal and other power plants
ii) Transmission of power to other areas via interconnection lines
iii) Curtailing biomass power plants
iv) Curtailing PV and wind power
v) Curtailing power plants at long term fixed power sources (hydro, nuclear and geothermal power plants)

Fig. 2-25 Renewable energy power generation curtailment procedure in Japan

[Future developments and anticipated technology]

Real-time demand and supply balance improvement using energy storage, such as battery systems, is a major technology.

In Japan, a Renewable Energy Management System, which manages 22,000 units' curtailment automatically and fairly, has been developed.

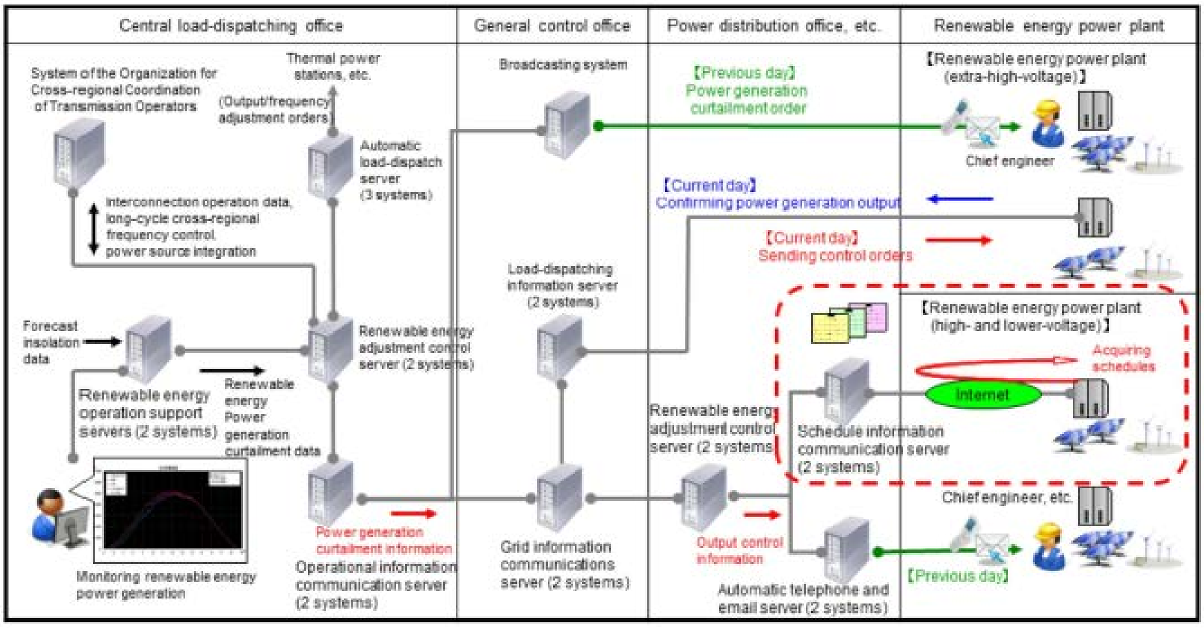


Fig. 2-26 Renewable Energy Management System of Kyushu EPCO

2.4.5 *Connect and Manage*

Connect and manage is a measure which tolerates certain constraints and interconnects right away because grid expansion takes a long time.

This method depends on the governmental policy and circumstances at each utility so it should be formulated to match the individual situation.

In Japan, the following three types of measures have been set.

(1) Rationalisation of assumed power flow (After April 2018)
Considering conditions such as area demand and supply balance, and long-term offline generators, a probability evaluation of running generators is carried out.
The point of maximum power flow (maximum difference between demand and supply) is evaluated as the assumed power flow.

(2) N-1 generator shedding (After July 2014)
Conventionally, sufficient transmission capacity was secured even after N-1 contingency. Under the new rule, N-1 generation shedding is executed to meet the transmission capacity constraint.

(3) Non-firm connection (After April 2020)
A new type of connection which does not possess transmission capacity and only transmits power when there is an opening in the transmission capacity.
Non-firm connections allow RE companies to connect using this capacity margin and curtail RE output when the transmission line is over capacity.

[Future developments and anticipated technology]

The following content will be further considered with regard to “Connect and Manage”.

Table 2-22 Connect and manage

Approach	Rationalisation of assumed power flow	Connect and Manage	
		N-1 generation shedding	Non-firm connection
Operation constraints	In principle, no management	In case of N-1 contingency, generation shedding is carried out	Generation shedding is carried out if transmission exceeds operation capacity
Capital investments	✓ Technical consideration for grid interconnection based on transmission capacity vacancy ✓ Capital investments necessary when assumed power flow exceeds transmission capacity		✓ Grid interconnection with N-1 generation shedding as a prerequisite, regardless of transmission capacity vacancy ✓ Cost to benefit evaluation
Contents of effort	Accuracy improvement and rationalisation of assumed power flow ✓ Probability evaluation of operating generators ✓ Output evaluation of RE output	Increased transmission capacity carrying out immediate generation shedding following N-1 contingency	
Congestion	(Normally) No congestion	(Normally) No congestion	(Normally) No congestion
	(Contingency) Congestion, Generation shedding*1 is carried out	(Contingency) Congestion, Generation shedding*2 is carried out	(Contingency) Congestion

*1 Generation shedding by TSO control signal

*2 Immediate generation shedding by electrical protection system

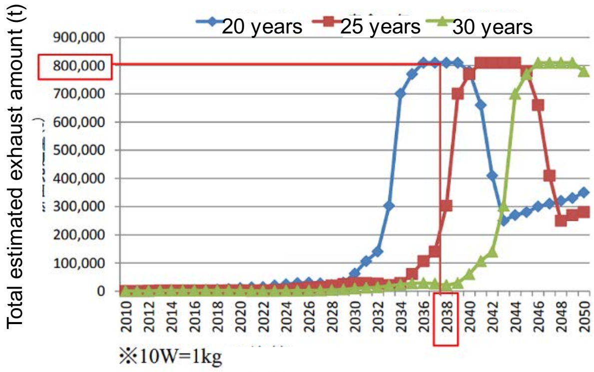
2.4.6 Reuse, Recycle

As it is common for PV installed in buildings to be disposed of when the buildings are demolished, and businesses engaged in PV power generation which is carried out on leased land are obligated to revert the land to the current state at the end of the lease period, the possibility of this being neglected is considered to be low.

The problem is with PV business carried out on land owned by the business operator. Even if the project is substantially ended, there is a possibility that valuable panels will be left to avoid costly disposal.

In addition, if the cost of disposal cannot be met, equipment may be illegally dumped on other land. In order to prevent such abandonment and illegal dumping, it is effective to accumulate part of the income obtained by selling electricity as expenses for areas such as disposal in advance, but there are few businesses actually doing this.

In addition, solar panels installed at the same time will reach a time of mass disposal. There is an estimate that, at the peak time, the annual discharge of used solar panels will reach 6% of the overall disposal amount of industrial waste, resulting in final disposal sites temporarily becoming crowded.



[Source] METI, Japan

Fig. 2-27 Estimated exhaust amounts of PV panels in Japan

Furthermore, depending on the type of panel, harmful substances such as lead, selenium, cadmium, etc. may be contained in it. Each has an appropriate disposal method, and appropriate treatment is required from an environmental aspect.

[Future developments and anticipated technology]

In response to these concerns, the following specific investigations are necessary to promote proper treatment of solar panels, including recycling.

- ✓ Creating mechanisms through which businesses can thoroughly discard them
- ✓ Eliminate information shortages and complete the proper process for harmful substances
- ✓ Promotion of reuse and recycling of solar panels

2.5 Innovations

2.5.1 R&D

Many factors, such as the significant introduction of DER, digitisation, business model innovation, and coupling between electric power, heat and transportation, are changing the plans and operations of today's local grids. In the future, these trends will revolutionise this sector of the energy system. Reliability and cost effectiveness are considered to be increasingly important as essential elements of clean energy systems.

From the standpoint of the system operator, DERs, including renewables, have the following problems.

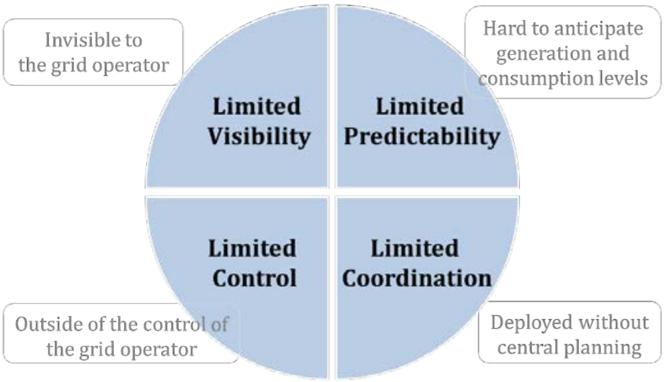


Fig. 2-28 Challenges posed by DERs

The main factor in supporting the evolution of the local grid is to make the system smart, but basically, unless this solves the above problems, DERs will be insufficient as stable power sources that contribute to stable operation of the grid.

In terms of new technologies for solving these problems, the following can be mentioned.

✓ Big Data Analytics

Accurate Energy Consumption and Insights (Improve Limited Predictability)

✓ Artificial Intelligence

Renewable Generation and Demand Prediction (Improve Limited Predictability)

✓ Edge Computing

Collect Asset Data, Control using Local Intelligence (Limited Visibility)

✓ 5th Generation Wireless Communications

Transmit and Collect Data Reliably (Improve Limited Visibility, Control and Coordination)

✓ Low-Power Wide-Area Networks

Provide Sensing and Control Functions (Improve Limited Visibility, Control and Predictability)

✓ Time Sensitive Networks

Transmit Critical Data and Control (Improve Safe and Stable Gird Operation)

✓ The Internet of Things

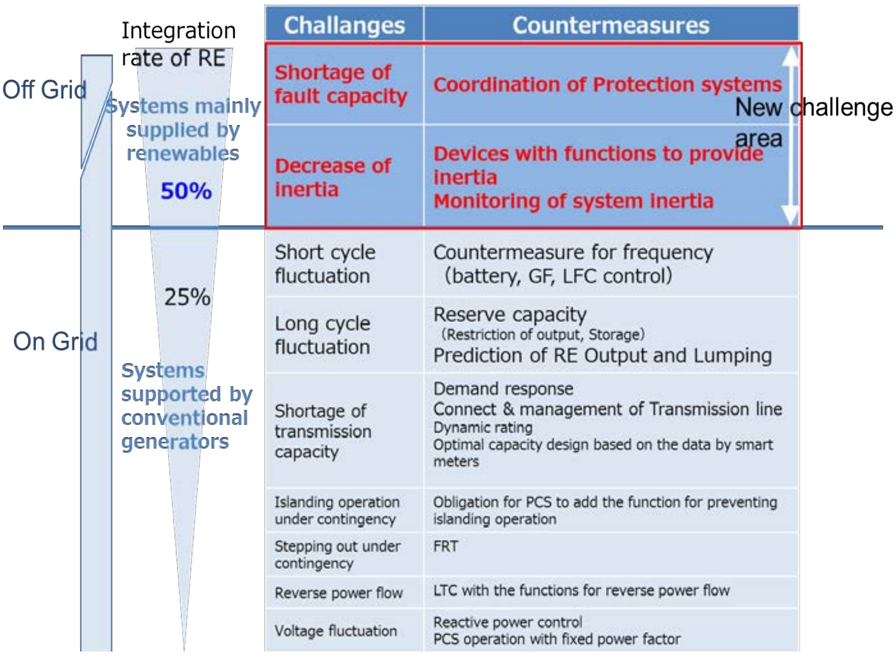
Connect and Enable Two-way Communication (Improve Limited Visibility and Control)

✓ Energy Management Systems

Monitor and Control Functions (Improve Limited Visibility and Control)

In promoting renewables, there are technological challenges to overcome for each stage.

These are shown in the following figures.



Challanges	Countermeasures
Shortage of fault capacity	Coordination of Protection systems
Decrease of inertia	Devices with functions to provide inertia Monitoring of system inertia
Short cycle fluctuation	Countermeasure for frequency (battery, GF, LFC control)
Long cycle fluctuation	Reserve capacity (Restriction of output, Storage) Prediction of RE Output and Lumping
Shortage of transmission capacity	Demand response Connect & management of Transmission line Dynamic rating Optimal capacity design based on the data by smart meters
Islanding operation under contingency	Obligation for PCS to add the function for preventing islanding operation
Stepping out under contingency	FRT
Reverse power flow	LTC with the functions for reverse power flow
Voltage fluctuation	Reactive power control PCS operation with fixed power factor

Fig. 2-29 Integration of Renewables and its challenges

2.5.2 Required technologies and innovations for integration of VREs

As mentioned previously, the integration of renewables provides many inferences. Fig. 2-30 shows the inferences and expected innovations needed to counter them, focusing on supply reliability and system reliability.

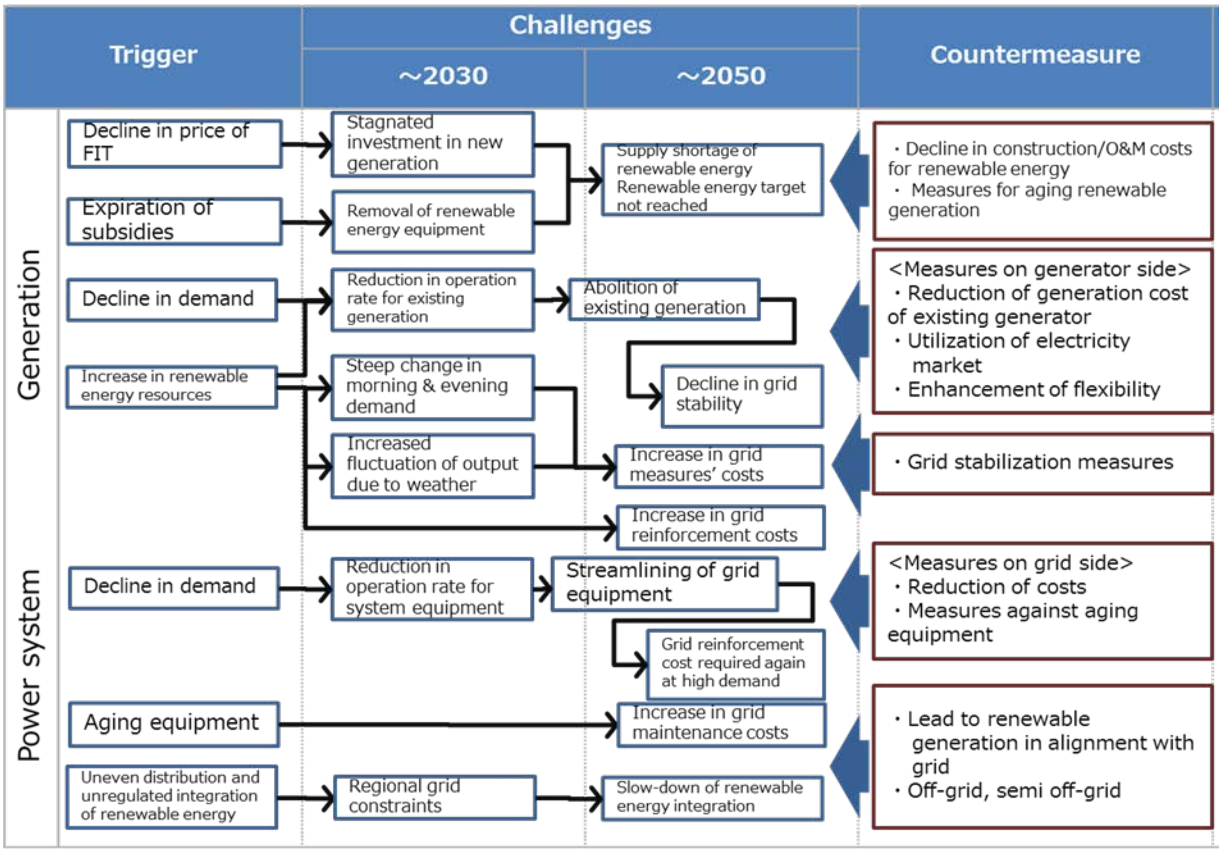


Fig. 2-30 Expected innovations led by integration of renewables

The expected technologies are as follows:

Storage: Exploiting the potential of Pumped Storage and use of Storage for ancillary services.
EV management: Penetration of Electric Vehicles, charged from Renewable Energy, and their participation in grid management.
Protection schemes: How to counter many DC components, such as PCS, connecting to the grid and match them with the existing protection system.
Resource monitoring: Having sufficient information to robustly forecast the likely future generation output of any RE project.
Resource consent: Approval from a regional consenting authority to be able to build and operate a RE project.
Resource location: Ensure that a RE project can connect to and be accommodated within the national (or local) transmission network.
Resource configuration: Flexible operation of conventional plants - nuclear, thermal and hydro - to counter the system inertia problem. Penetration of Hybrid RE technologies such as solar-wind hybrid is one option.
Financial adequacy: Ensure that the future cash-flow associated with an RE project can meet or exceed the initial capital outlay and the on-going costs for plant operation.
Company strategy and fit: Ensure that a RE project fits within the company's strategic direction and is affordable from a financing and balance sheet perspective.

Taken together this means that different utilities will have different views on what and when various RE projects should proceed. Any proposed new renewable energy project must meet a number of criteria before commissioning can occur.

2.6 Best Practices for mitigating challenges

2.6.1 Ongoing projects

(1) Network Congestion

Title: Tender process for accepting application
Objective: For multiple interconnection applicants to share construction cost jointly by their desired prices.
Effective date: April 2015
Contact: Yoshimitsu Umahashi (TEPCO)
umahashi.y@tepco.co.jp

Issues in accepting applications in Japan

Until now	- Applications are received first-come-first-served and ideas for minimum engineering work cost (shared cost) are considered and proposed. - The first applicant who makes the reinforcement necessary bears all cost for the required work. When other applicants are interconnected to the same facility within 3 years, the cost is settled and shared.
Issues	- First applicant covers large cost with the low chances of predicting the cost. - If multiple applicants desire to interconnect in one area, reinforcement may not be implemented in an optimal fashion as a whole.

Consideration is given to a scheme whereby multiple applications are bundled for designing rational reinforcement considering the scale merits and sharing the cost among the applicants.

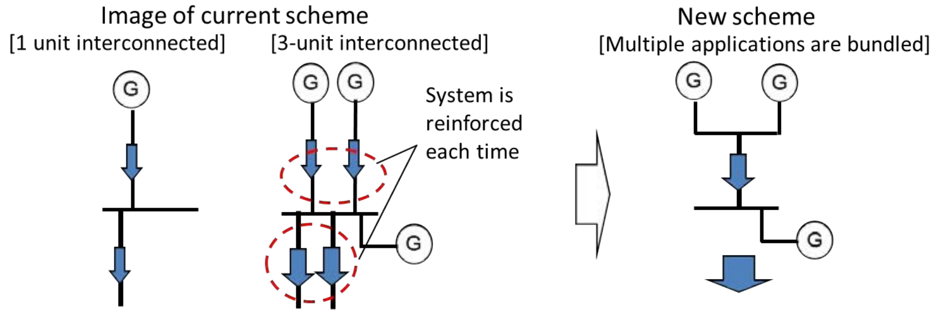


Fig. 2-31 Multiple application scheme

Outline of new scheme (Application scheme)

- When consideration of all RE interconnection requires reinforcement of large-scale transmission capacity ,construction cost to be burdened may be expensive.
- In this case, it is possible for multiple interconnection applicants to share construction cost jointly by their desired prices.
- This procedure is called "An offer process for accepting application " (called "application scheme" as follows.) and is a network access rule established by OCCTO※ that started in April, 2015. ※OCCTO : Organization for Cross-regional Coordination of Transmission Operators , JAPAN

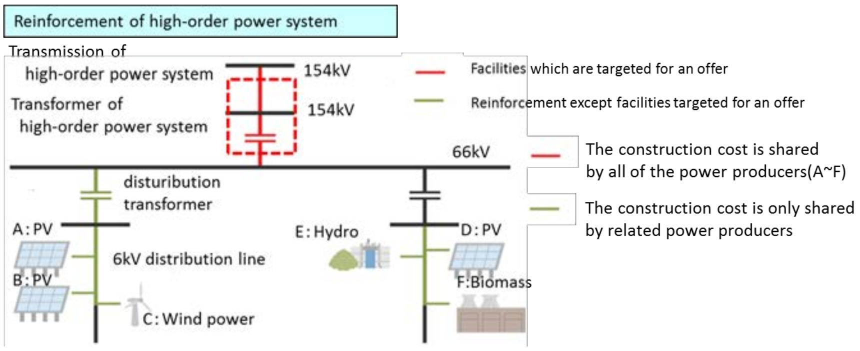


Fig. 2-32 Reinforcement of high-order power system

(2) Control System

Title: Evolution in DMS with Smart Meter data
Objective: “Collaboration on Voltage Control in DMS and Smart Meter Systems”, and “Open circuit detection for branch distribution lines” using smart meter data
Contact: Nobutoshi Saito (Chubu EPCO)
Saitou.Nobutoshi@chuden.co.jp

The CEPCO distribution network has approximately 8,700 distribution feeders, 2.8 million poles, 70,000 sectionalising switches, and 1.6 million pole-mounted transformers. A major function of a DMS (Distribution Management System) is to monitor and control distribution equipment within the entire network. Various network changes include diversified energy usage by customers, mass PV penetration, and smart meter installation. To better maintain reliability and sustainability in the distribution network, CEPCO will adopt two measures: “Collaboration on Voltage Control in DMS and Smart Meter Systems”, and “Open circuit detection for branch distribution lines” using smart meter data.

At present, the SVR (Step Voltage Regulator) reference voltage and its dead band are manually managed. In addition, LRT (on-Load Ratio Transformer) in distribution substations and DMS are independently operated. With mass PV penetration it becomes increasingly difficult to maintain the proper voltage in each distribution line and reduce the number of SVRs and their activation times. The Collaboration on Voltage Control in DMS and Smart Meter Systems will integrate data from sectionalising switches, SVRs, smart meters and LRT, and will realise optimal voltage control in the entire distribution network, as shown in in Fig. 3-33.

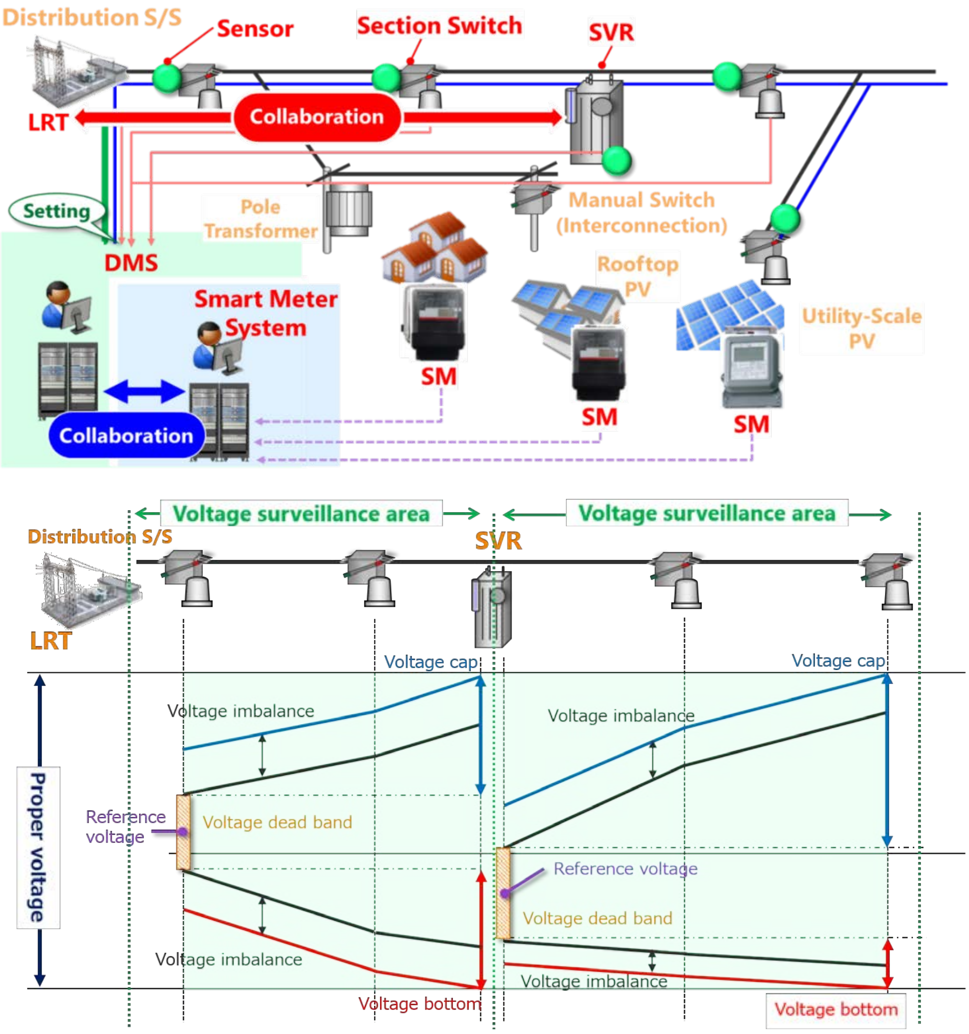


Fig. 3-33 Collaboration in Voltage Control using data from sectionalising Switches, SVRs, SMs and LRT

CEPCO will adopt the central and automatic management of all SVR reference voltages and voltage dead bands.

New SVRs will also feature telecommunication functions for remotely monitoring and automatically controlling settings to maintain proper voltage in each voltage surveillance area, as shown in Figure 6. CEPCO will also reduce the life-cycle cost of SVRs through the remote monitoring and control of various SVR tap changes, value settings, over-loads, and activation times. The voltage dead band will be flexibly changed depending on the time of day. During the night, when PV generation output is zero, the dead band of the SVR will automatically widen to reduce SVR activation times. Electrical current data will be used to determine the proper reference voltage in each SVR because the intermittent PV generation current causes inappropriate solutions from the traditional capacity-based power flow estimation method.

Surplus electricity purchases and total electricity purchases comprise the two types of solar energy purchase contracts used in Japan. To properly estimate the PV generation current it is necessary to decouple the demand current and PV generation current. However, a surplus electricity purchase contract nets the demand current and PV generation current. Therefore, the PV generation current in the surplus electricity purchase contract will be estimated from smart meter data using the nearby PV generation current.

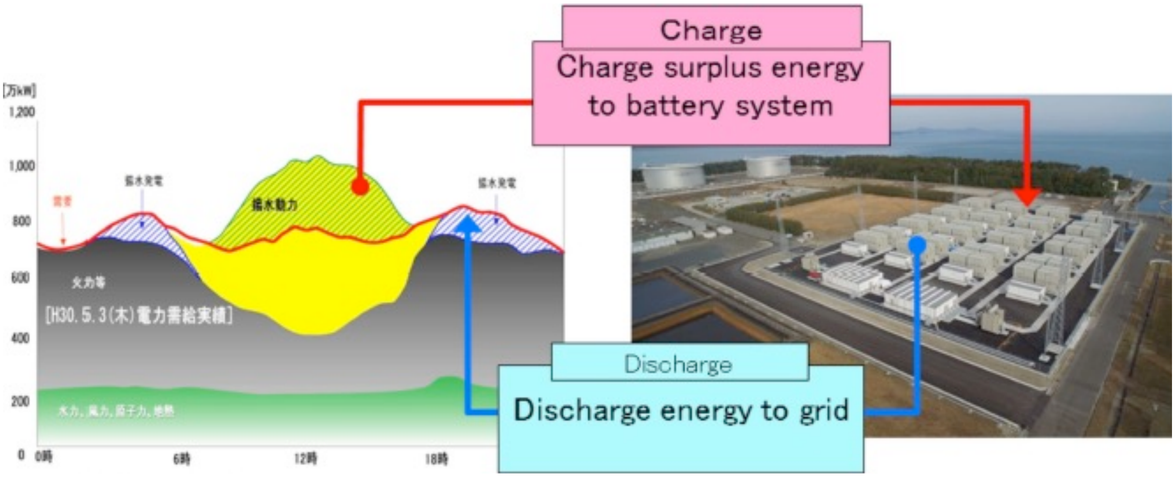
Insulated wires adopted in distribution lines sometimes make it difficult for protection relays in distribution substations to detect open circuits due to the limited change of zero-phase voltage and current. CEPCO will utilise smart meters as sensors for open circuit detection of branch distribution lines and main distribution lines using sectionalising switches. The smart meter system can monitor the telecommunication (outage) conditions of reference smart meters in each pole transformer. Smart meter telecommunication conditions automatically transfer to DMS upon the occurrence of open circuits on branch distribution lines.

In the future, new components such as inverters, storage devices, and micro-grids will be connected to distribution networks. CEPCO assumes that these new components will be integrated into DMS to realise additional advanced distribution network control.

Title: Demand and Supply balance improvement using large-scale energy storage batteries
Objective: To charge and discharge power depending on the RE output situation
Contact: Atsushi Fukura (Kyushu EPCO)
Atsushi_Fukura@kyuden.co.jp

K Kyushu EPCO exercises several measures in an effort to reduce RE curtailment, and “Demand and balance improvement using large-scale energy storage batteries” is one solution for this.

This energy storage facility is equipped with Sodium Sulfide batteries, and can charge or discharge up to 50MW in 6 hours at 300MWh capacity. But compared to pumped storage hydro it is much less cost efficient, because it is about 2 soccer fields in size and has much less energy density.



*Buzen storage battery station is among the world's largest energy storage facilities

Fig. 2-34 Buzen storage battery station

Title: Renewable Management System
Objective: To ensure RE curtailments are exercised orderly
Contact: Atsushi Fukura (Kyushu EPCO)
Atsushi_Fukura@kyuden.co.jp

Kyushu EPCO has developed a Renewable Management System in order to ensure RE curtailments are exercised orderly. The RE units subject to curtailment number up to 22,000 units, and therefore, manual operation of RE output forecasting, estimation of necessary RE curtailment, and actual RE curtailment commands are simply impossible.

This system enables these measures to be taken consistently and automatically. The system is also equipped with a feature to log when and how much each RE unit has been curtailed to maintain fairness among RE companies.

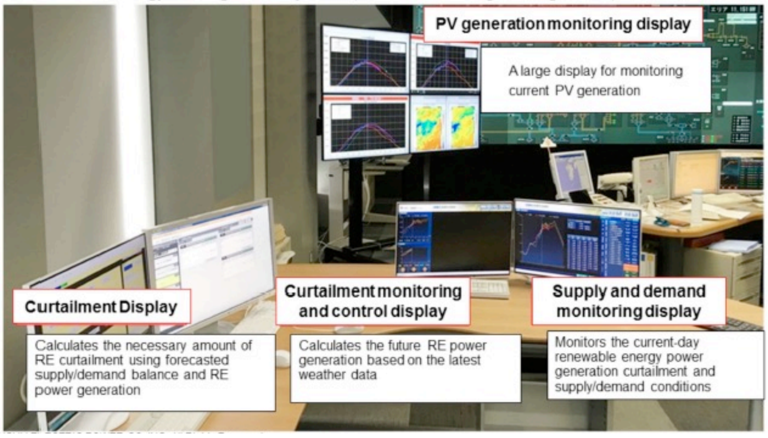


Fig. 2-35 Renewable Energy System

For RE units that have PCS with a telecoms function, the management system commands the curtailments directly. For those which do not, curtailment commands are performed by telephone and email.

There are many types of RE companies that are subject to RE curtailment and many types of systems are involved. Some of the commands and data signals between these systems are established through internet connections.

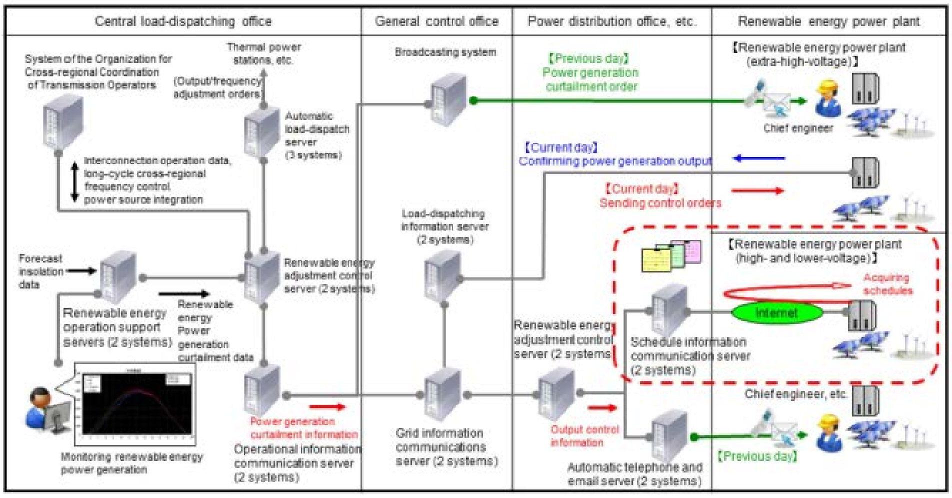


Fig. 2-36 Curtailment command flow

To establish commands and data links with these companies, we utilise ID verification and SSL telecommunication to maintain information security.

Among all of the RE curtailments up until now, we have experienced about 2 incidents of major system trouble where we failed to cancel some unnecessary RE curtailments because our cancelation commands did not get through to the RE companies. The cause for this was a simple software error, so we have fixed the error and checked for any other similar errors.

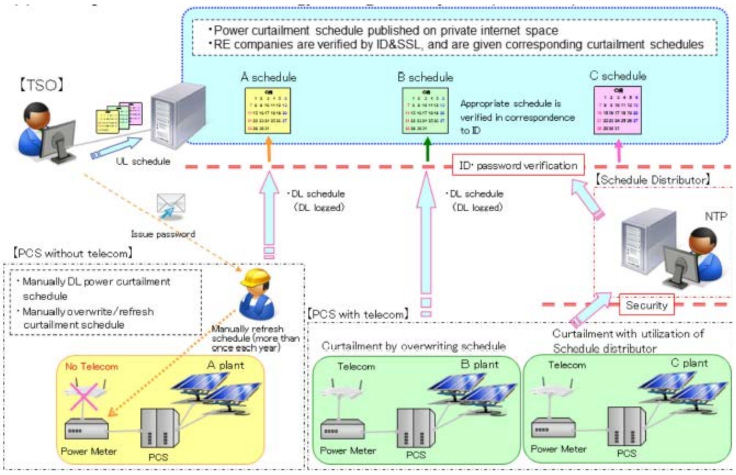
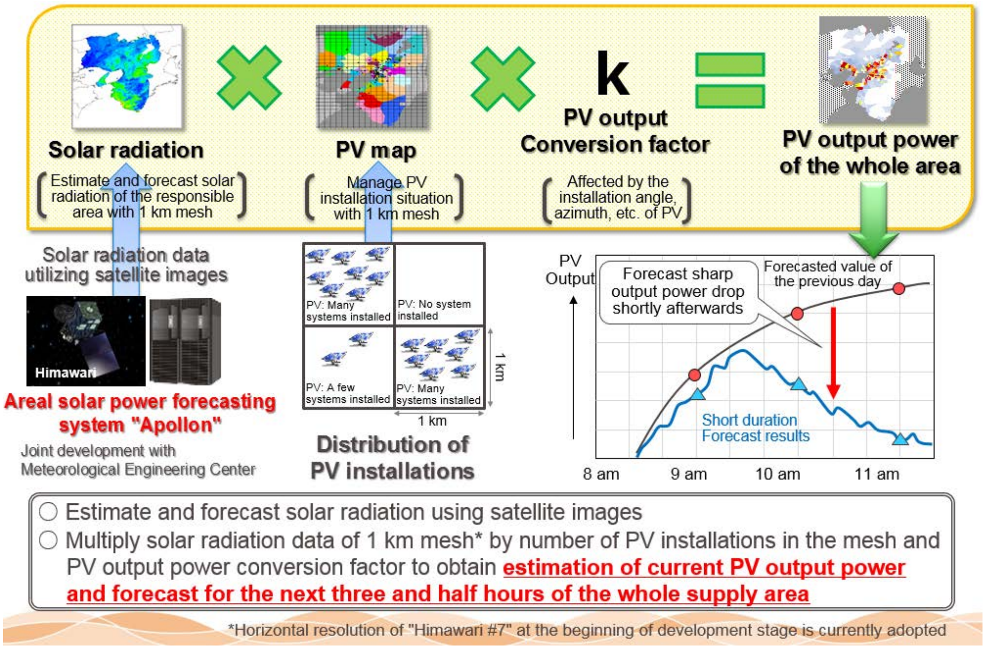


Fig. 2-37 System security measure

(3) Forecast System

Title: The development of PV output forecasting system called Apollon
Objective: Development of a system capable of ascertaining the current and short term future output of PV generation widely distributed in the power system
Contact: Takeshi Kawaguchi (Kansai EPCO)
kawaguchi.takeshi@b5.kepco.co.jp



○ Estimate and forecast solar radiation using satellite images
○ Multiply solar radiation data of 1 km mesh* by number of PV installations in the mesh and PV output power conversion factor to obtain **estimation of current PV output power and forecast for the next three and half hours of the whole supply area**

*Horizontal resolution of "Himawari #7" at the beginning of development stage is currently adopted

Fig. 2-38 PV output forecasting system: Apollon

Title: PV Output Forecast System in the Central Dispatching Control Centre
Objective: To integrate intermittent renewable energy resources into the CEPCO power network
Contact: Nobutoshi Saito (Chubu EPCO)
Saitou.Nobutoshi@chuden.co.jp

The Central Dispatching Control Centre (CDCC) of CEPCO is responsible for maintaining the balance between generation supply and area demand [MW]. Based on past demand trends and current weather forecasts, CDCC continuously estimates area demand and determines the necessary generation units and output scheduling of each unit in detail, while minimising fuel costs and the number of stand-by units to the greatest possible extent.

However, as of the end of fiscal year 2016 there was already over 6,300 MW of third-party, grid-connected solar (PV) generation, which presents difficulties for CDCC in properly estimating its area demand due to the intermittent PV output. Moreover, it is not practical for CDCC to remotely measure the actual output of hundreds of thousands of PV systems.

To integrate intermittent renewable energy resources into the CEPCO power network, since 2014 CDCC has employed a PV output forecasting system that ensures the accuracy of demand-supply balancing operations. This system enables system operators to better understand and estimate the total solar generation output [MW] based on weather forecasts and real-time solar radiation data from multiple measurement points (Fig. 2-39).

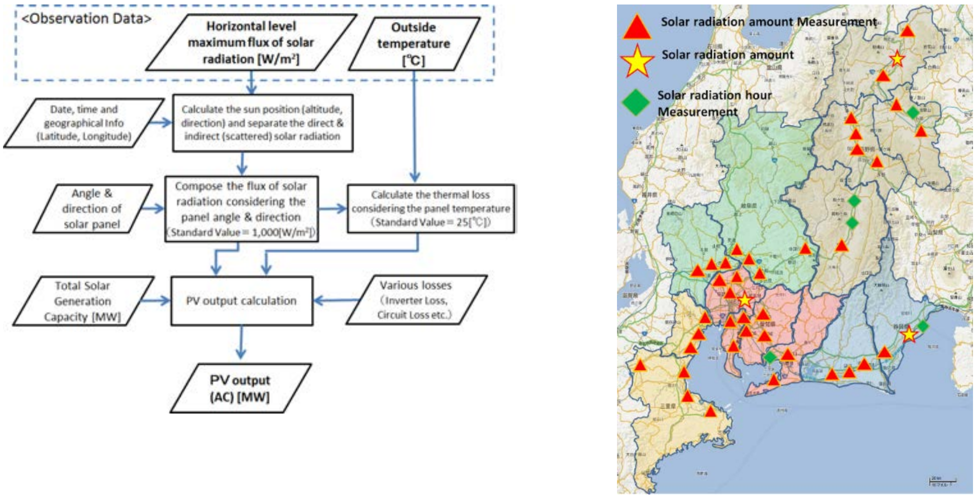


Fig. 2-39 Algorithm model for PV output forecasting system in CEPCO CDCC

The forecasting system provides two functions, “Situational Awareness of Real-time PV output” and “Estimation of future PV output”. Both functions are realised based on various input data, such as solar radiation, outside temperature, date, time, geographical information, angle and direction of solar panels and solar generation capacity. This also integrates data from multiple measurement points of solar radiation owned by both CEPCO and the Japan Meteorological Agency.

In this system, CEPCO’s T&D supply area is divided into 14 sub-areas, taking into account the meteorological similarities and the jurisdictions of weather forecasters. PV outputs in each area are calculated based on the algorithm model shown in Figure 3, and these PV outputs are summed to determine the total PV output for the entire system. In the “Situational Awareness of Real-time PV output” function, total PV output in CEPCO is calculated every minute. Each area has more than 3 solar radiation measurement points to allow for the contingency loss of measurement data. In the “Estimation of future PV output” function, 48-hour-ahead PV output is continuously forecasted three times a day.

Since the installation of this system, CEPCO has been able to properly operate its generation dispatching control even with the large amount of PV penetration. Optimisation of generation unit operation is one of the most important missions for CDCC because it has a large financial and reliability impact on CEPCO. If CEPCO overestimates the area demand, unnecessary generation units would operate (costing several million US dollars/day, a significant negative financial impact). If CEPCO underestimates the area demand, generation capacity shortages and potential blackouts could result. CEPCO has been continuously improving the estimation accuracy of this forecasting system by reviewing the algorithm model, which considers 3D geospatial data and snowfall impact.

Title: Improving the accuracy of PV output prediction
Objective: To improve the accuracy of PV output predictions or reduce the PV output forecast error
Contact: Atsushi Fukura (Kyushu EPCO)
Atsushi_Fukura@kyuden.co.jp

It is easy to predict when the weather is sunny or rainy all day long, but on a cloudy day, there is always some amount of forecast error. If the PV output forecast has poor accuracy, Kyushu EPCO is bound to keep a large amount of power supply just in case, and command a large amount of RE curtailment considering the risk.

Before, the PV output forecast based on a 4am weather forecast and the actual PV output used to have up to 1,000 to 1,500MW of error. 1,000 to 1,500MW is equivalent to 2 large coal-fired thermal units, so this error can lead to critical situations in terms of stable power supply.

Therefore, to ensure stable power supply, it is very important to improve the accuracy of PV output predictions, and prepare supply/demand measures accordingly.

Traditionally, Kyushu EPCO has used 8 insolation data to predict the PV output, but since Jan 2018, Kyushu EPCO has increased the insolation data areas from 8 to 47 to improve the accuracy of the predictions.

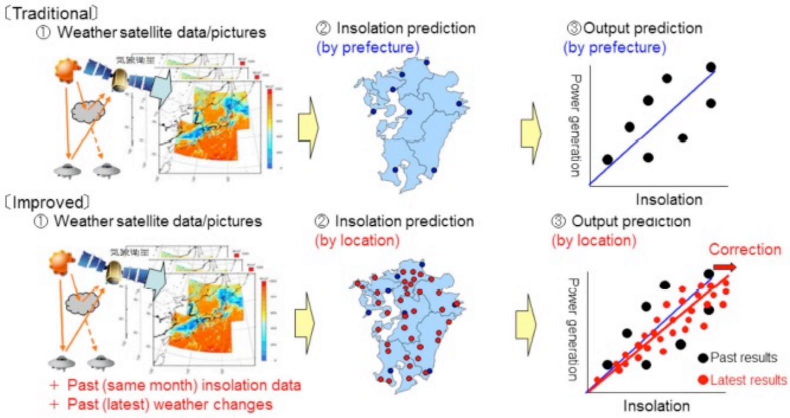
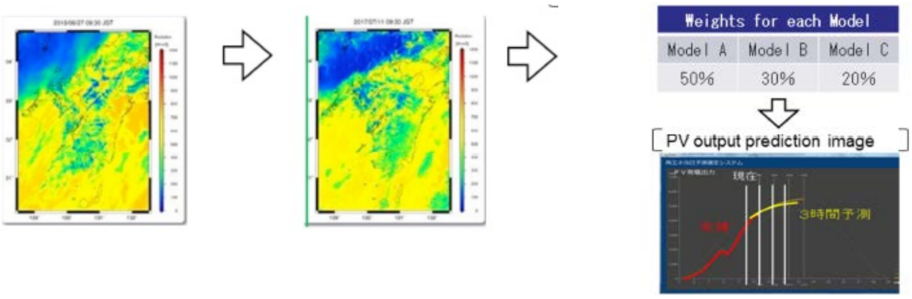


Fig. 2-40 Improved Prediction Method

PV output predictions are carried out using 3 different PV output prediction models from 3 different companies, each equipped with different algorithms to predict PV outputs and therefore having its own strength and weakness depending on the weather. Presently, skilled operators are choosing which model to use by putting into consideration the atmospheric pressure and cloud movements, but at the same time, Kyushu EPCO is accumulating these data to train an AI so that these decisions can be made automatically.



Weights for each Model

Model A	Model B	Model C
50%	30%	20%

Isolation data

Choose similar weather in past

Place 3 prediction in order
Calculate the weighted avg.
PV prediction

Fig. 2-41 Prediction Procedure

(4) Protection System

Title: Development of a new Protection and Control System
Objective: To improve stability of phase angle and frequency performance
Contact: Nobutoshi Saito (Chubu EPCO)
Saitou.Nobutoshi@chuden.co.jp

Generally, stability of phase angle and frequency performance worsens for heavily loaded transmission networks, which may be exposed to transmission contingencies that cause cascading wide-area blackouts. However, restricting the power flow sacrifices economic dispatch operation. To solve these issues simultaneously, CEPCO implemented the on-line Transient and Frequency Stability Control System, as shown in Fig. 2-42.

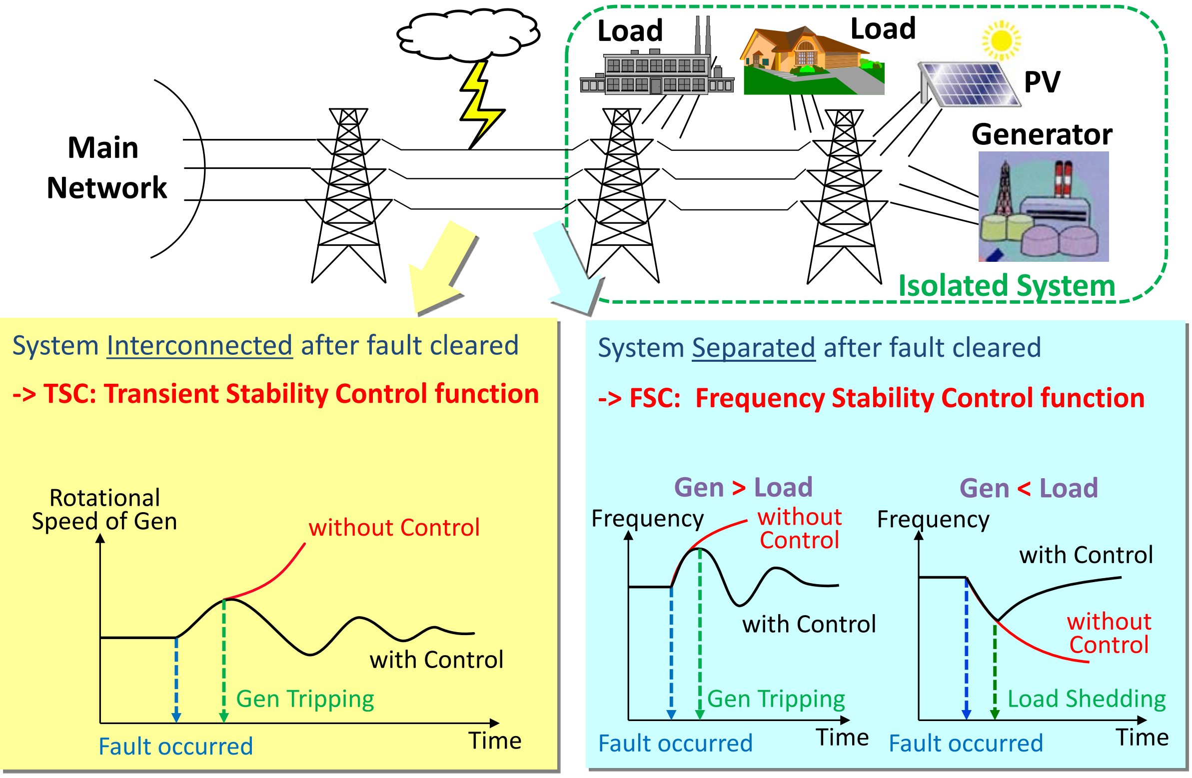


Fig. 2-42 CEPCO TSC & FSC system

Traditional TSC and FSC systems were installed independently more than 20 years ago. However, the CEPCO T&D network situation drastically changed with the more recent large penetration of DER and an increase in nationwide cross-regional power interchanges.

To cope with these changes, CEPCO developed a new PCS (Protection & Control System) to prevent cascading wide-area blackouts under severe transmission faults. CEPCO named this system ISC (Integrated Stability Control). It can realise TSC and FSC functions as a unified system, adapt to the large penetration of DER, and increase the amount of power interchange among different T&D supply areas, nationwide and cross-regionally.

The ISC system comprises ISC-P (Processing), ISC-C (Control), ISC-S (Sensing), and ISC-T (Transfer Trip) components. ISC-Ps utilise high-performance electronic computers made by two different manufacturers (HITACHI & TOSHIBA), and ISC-C/S/Ts use the latest protection relay equipment built by MITSUBISHI. Fig.2-43 shows a diagram of the ISC system.

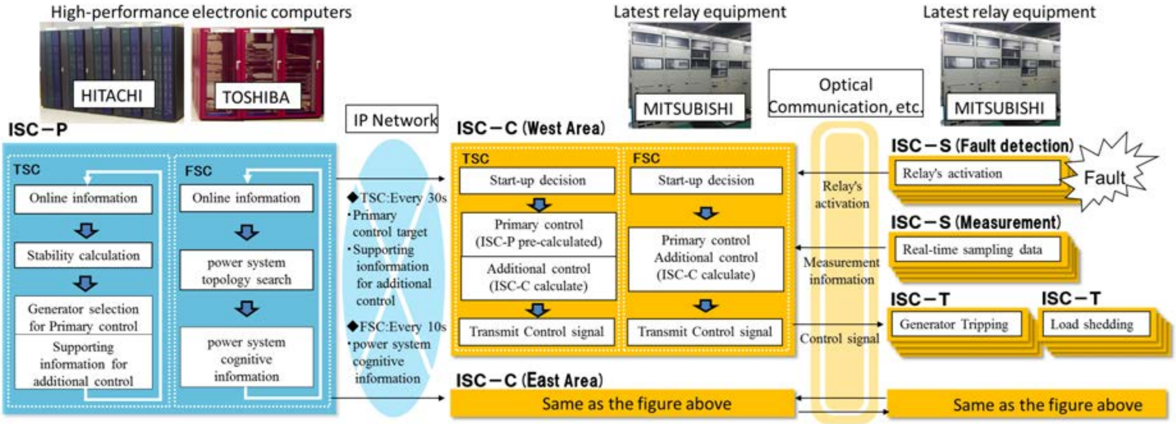


Fig. 2-43 System diagram and overview of ISC system

In the TSC function, ISC-P reads online data from RTUs, executes detailed transient (angle) stability simulations, and sends simulation results to ISC-C. ISC-S sends fault detection data from protection relays and real-time power flow conditions to ISC-C. ISC-C sends control signals to ISC-T utilising simulation results from ISC-P, and fault detection and real-time power flow data from ISC-S. ISC-T executes load and generator shedding when it recognises both control signals from ISC-C and fail-safe relay activation, such as 91D (power flow oscillation protection). In the FSC function, ISC-P sends network topology information for each surveillance point to ISC-C based on online data from RTUs. ISC-S sends fault detection data from protection relays, circuit breakers (CBs), and real-time frequency data to ISC-C. ISC-C sends control signals to ISC-T based on network topology from ISC-P, and fault detection and real-time frequency data from ISC-S. ISC-T executes load and generator shedding when it recognises both control signals from ISC-C and fail-safe relay activation such as 95UF (under frequency). Thus, each ISC component has multiple roles in order to realise the wide-area PCS functions.

Transmission line power flows tend to fluctuate due to the intermittent generation output of DER (PV). By combining data from both ISC-P pre-calculation results and ISC-S real-time power flow, ISC-C can optimise the generator/load shedding amount to maintain the transient (angle) stability of the transmission network. In addition to adapting to the large number and total production of DER (PV) interconnections, the ISC system can also coordinate TSC/FSC functions at all voltage levels (500kV, 275kV, 154kV and 77kV) in the CEPCO transmission network. The ISC can adapt to various future changes such as the addition of large-scale thermal generation interconnections (West-Nagoya No. 7 series 2,376 MW LNG-fired generation in March 2018 and Taketoyo No. 5 1,070 MW coal-fired generation in March 2022) in the 154kV transmission network, or increases in cross-regional power interchange among different T&D supply areas. The ISC system also optimises its telecommunications network. By adopting the ring telecommunication method among ISC-Cs, ISC-Ss and ISC-Ts (about 90 equipment units), it reduces telecommunications equipment usage to less than half when compared to traditional TSC/FSC systems.

Title: Expanding the transmission capacity of Kanmon interconnection
Objective: To make maximum use of PV output, surplus power is transmitted to other areas using the Kanmon interconnection
Contact: Atsushi Fukura (Kyushu EPCO)
Atsushi_Fukura@kyuden.co.jp

This system allows Kyushu EPCO to export more RE output to other areas using the 500kV interconnection line. In the case of a contingency on the Kanmon interconnection line, the east bound power flow is cut off, causing the system frequency in Kyushu to rise. Therefore, Kyushu EPCO can only export a limited amount of power through the interconnection.

In order to increase the amount of exportable power, Kyushu EPCO is developing the "transfer trip system", which detects contingencies on the Kanmon interconnection line, and quickly sends stop signals to thermal, biomass, and RE plants within the Kyushu area to keep the system frequency at a nominal level. This system utilises IoT technology and predicts the system frequency increase before the contingency, calculates how much transfer trip is required, and executes the transfer trip when necessary.

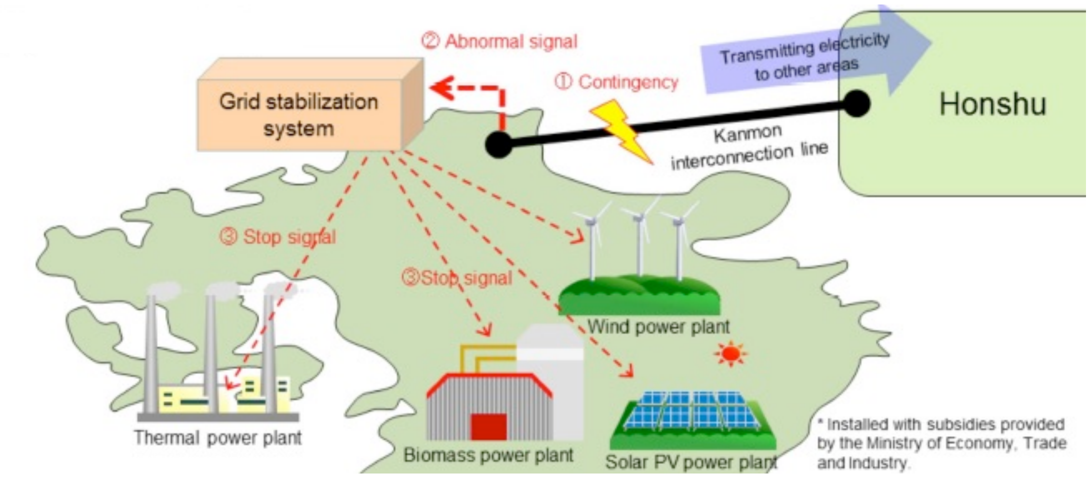
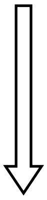


Fig. 2-44 System overview

(5) Institutional Issues

Title: RE curtailment experiences in Kyushu area
Objective: To explain actual procedure for RE curtailment in Kyushu area
Contact: Atsushi Fukura (Kyushu EPCO)
Atsushi_Fukura@kyuden.co.jp

On a sunny day when PV output becomes larger, and supply exceeds the demand, as I explained earlier, we exercise measures like decreasing thermal outputs, pump hydro storage, charge large-scale energy storage battery, and export power to other areas using the interconnection.



i) Using pumped storage plants to absorb surplus electricity from RE power plants, cutting output from thermal and other power plants
ii) Transmission of power to other areas via interconnection lines
iii) Curtailing biomass power plants
iv) Curtailing PV and wind power
v) Curtailing power plants at long term fixed power sources (hydro, nuclear and geothermal power plants)

Fig. 2-45 Renewable energy power generation curtailment procedure in Japan

Table 2-23 RE curtailment procedure in a timeline

1 day before operation		Operation day	
Time	Action	Time	Action
		4:00	Plan today's supply demand balance Receive meteorological forecast data
10:00	Receive meteorological forecast data (Demand forecast, RE output forecast)	| 2hr | Operation	Send curtailment schedule to designated RE companies (2 hour prior notice
1200	Plan next day's demand/supply balance (Including priority power rule)		
16:00	Command curtailment of thermal power outputs Command power exports to other area using the interconnection line		
17:00	1-day-ahead RE curtailment command to former rule RE companies (1-day-ahead prior notice to designated RE company)		

There are 2 types of RE companies: 1 is the former rule RE company which require a 1-day-ahead curtailment command to respond. And the other is the designated rule RE company which can respond to curtailment with a 2 hour prior command. In Japan, the power exchange market handles the “forward market”, “spot market”, and the “Intraday market”. And the spot market, which deals the 1-day-ahead trade, is the most active market of all. RE curtailment decision must be handled quickly right after the spot market deal is complete in the morning, and the 1-day-ahead RE curtailment command must be executed by 16:00pm. This rushed operation is like walking on a slack-rope

Title: Connect and manage in Kyushu area
Objective: To explain connect and manage experiences in Kyushu area
Contact: Atsushi Fukura (Kyushu EPCO)
Atsushi_Fukura@kyuden.co.jp

In Japan, there are 3 types of measures:

(1) Rationalisation of assumed power flow
When assuming the power flow on transmission lines or transformers, instead of using the most severe case, we use a more realistic value to evaluate the interconnection is used.

(2) N-1 generator shedding
With double circuit transmission lines, only a single circuit capacity is available for transmission to prepare for N-1 contingency. N-1 generation shedding is a measure where we allow double circuit transmission capacity, and execute generation shedding when there is an N-1 contingency.

(3) Non-firm connection
Currently, transmission lines need expansion hen it is over capacitated at any time during the year even though a significant portion of the 8,760hrs still have a capacity margin. The Non-firm connection allows RE companies to connect using this capacity margin, and curtails RE output when the transmission line becomes over capacitated.

In Kyushu, RE interconnections are processed under these new assumptions. N-1 generation shedding is already introduced in Kyushu electric after July 2014. And Non-firm connection is currently being discussed with OCCTO, and is scheduled to begin operation in 2020.

2.6.2 Field tests

(1) EMS Development

Title: NEDO R&D Project (Nii-jima Island Project)
Objective: To create a total control system on the Island
Contact: Yoshimitsu Umahashi (TEPCO)
umahashi.y@tepco.co.jp

TEPCO implemented the pilot project to create a total control system as part of a NEDO project. In this project, a demand and supply balancing system with renewables, conventional diesel generators and demand side management was formulated. An output prediction system for renewables was also developed.

This project started in 2016 and was completed in 2018.

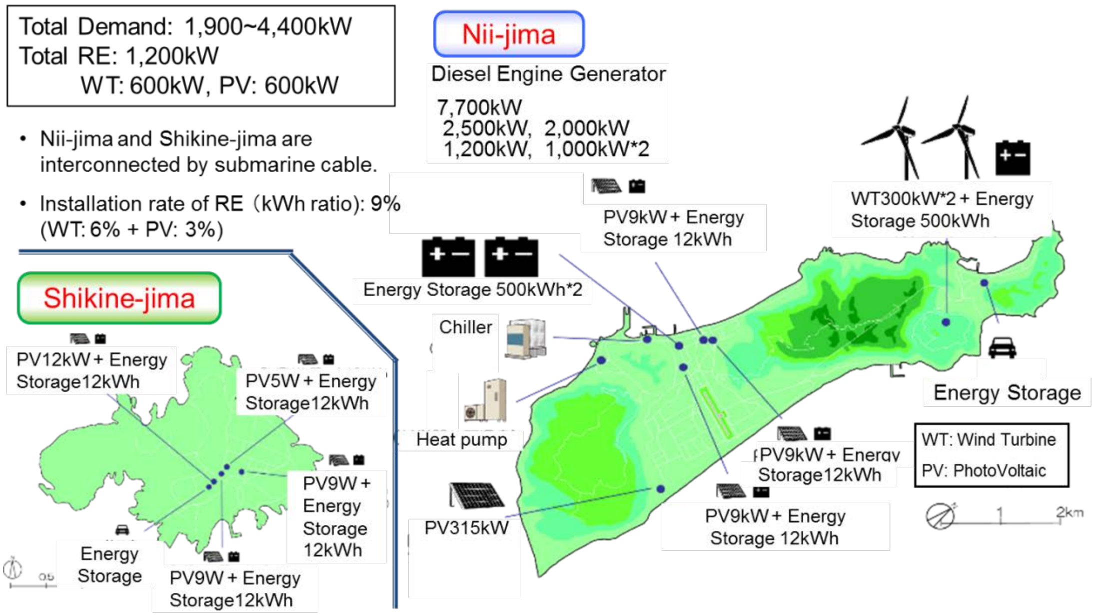


Fig. 2-46 Installed facilities

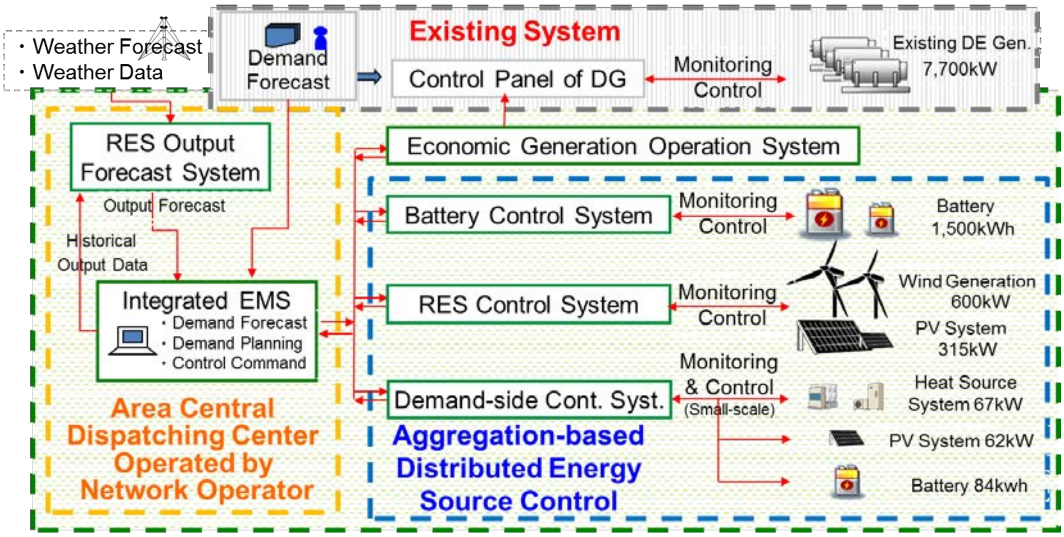


Fig. 2-47 System overview of Nii-jima project

(2) Voltage monitoring and control

Title: Field test of the voltage monitoring and control method in Wakasa, Japan
Objective: An examination of voltage monitoring and control methods that can maintain the proper voltage by using switches with sensors etc. for problems such as voltage errors due to PV power generation
Contact: Hideyasu Hokazono (Kansai EPCO)
hokazono.hideyasu@e2.kepco.co.jp

➢ From April 2013 to March 2016 : Demonstration project in Wakasa, Japan.

・Verification with two distribution lines connecting two PV power stations（500kW×2）

・There are customers with leading power factor such as waste disposal site and tunnel construction site.

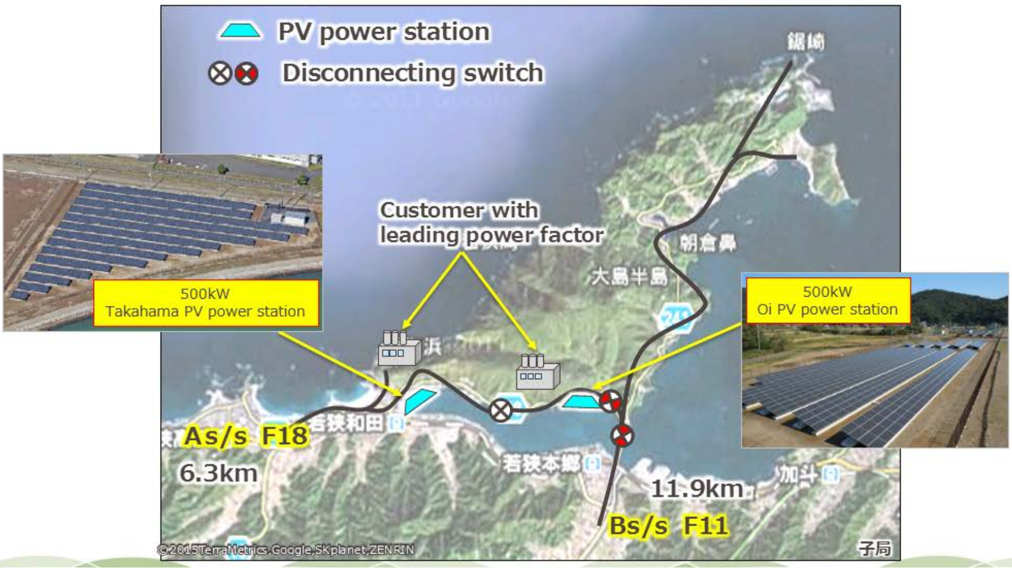


Fig. 2-48 System components (PV)

➢ We installed some switches and measuring devices that can measure V, I, P, Q every one second

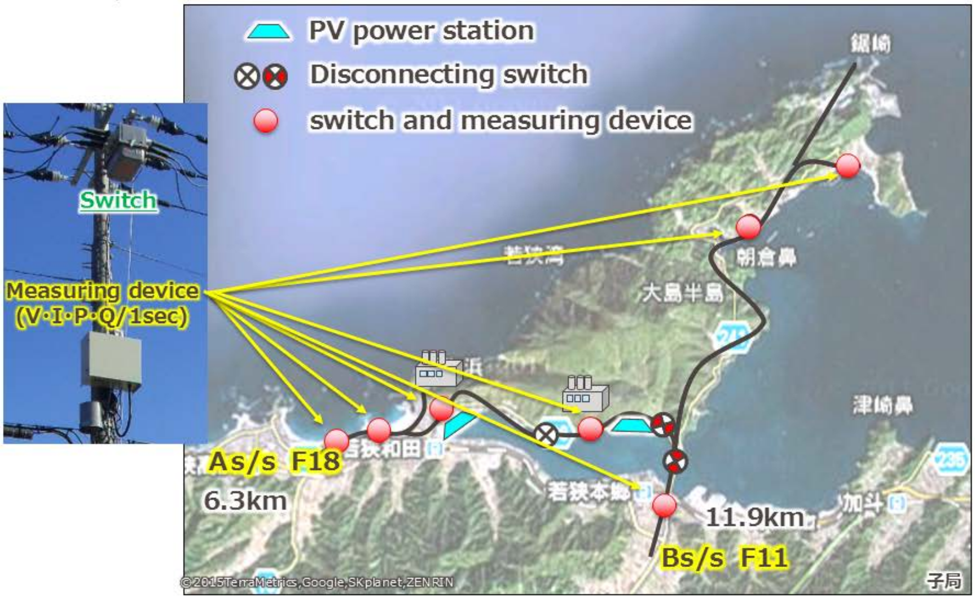


Fig. 2-49 System components (Switches)

- As voltage regulator, we installed power electronics equipment such as TVR, SVC that can perform high-speed voltage control in addition to SVR.

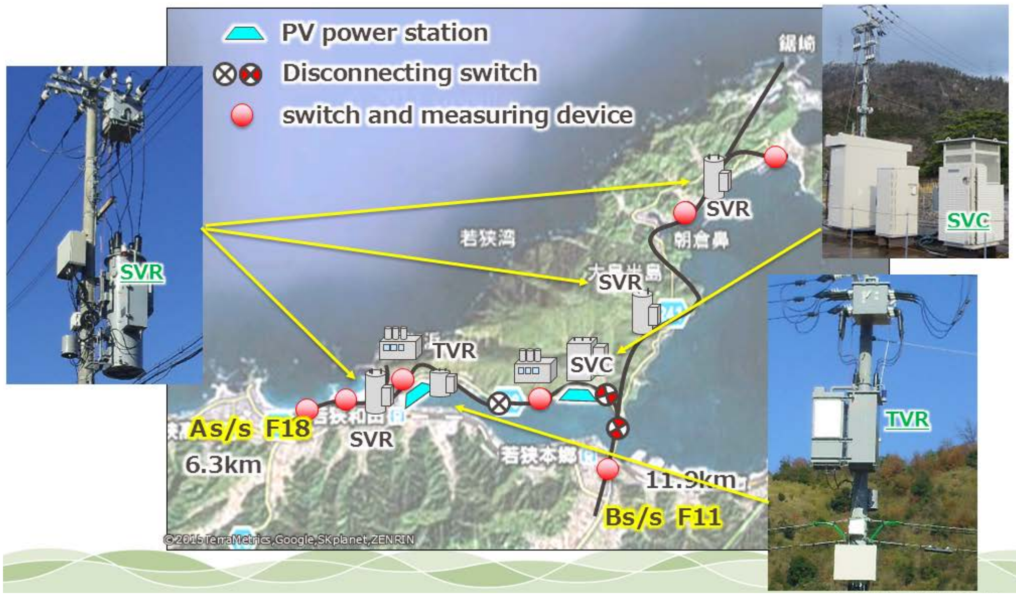


Fig. 2-50 System components (SVR)

(3) 100% Renewable micro grid

Title: 100% Renewable Energy for Hahajima Island
Objective: To realise 100% renewable power supply system in Island
Contact: Yoshimitsu Umahashi (TEPCO)
umahashi.y@tepco.co.jp

TEPCO complemented the pilot project to realise 100% renewable power supply system.
Supply concept is as follows:

- ✓ To combine PV and batteries to supply electricity
- ✓ To supply electricity by PV during the daytime and charge the surplus PV energy to batteries
- ✓ During hours when the PV system does not generate electricity, supply electricity by discharging from batteries.
- ✓ In case of shortage, use backup electricity from a diesel generator

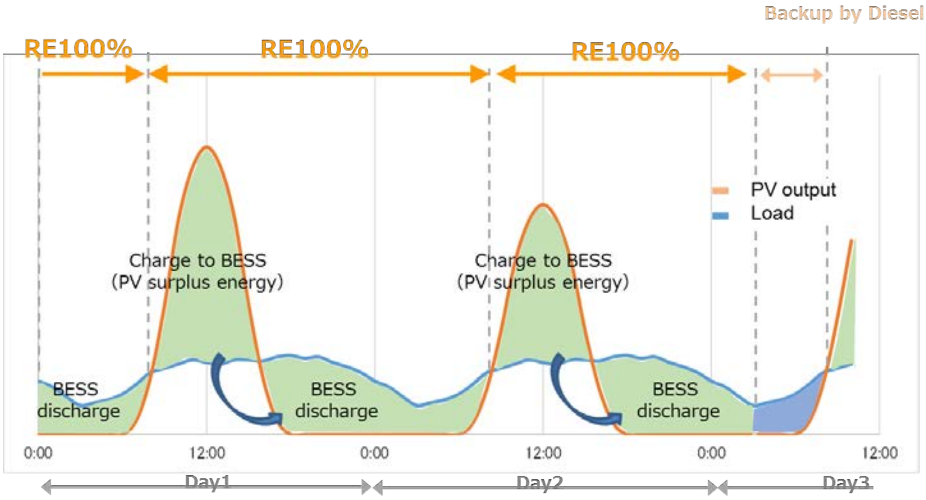
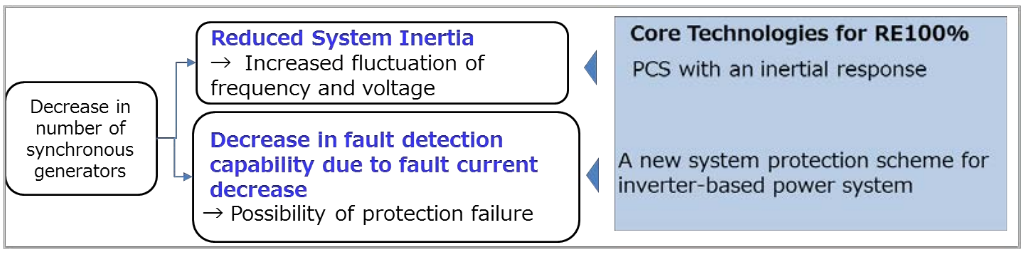


Fig. 2-51 Power Supply Constitution

Core technologies for RE100% are Inverters with inertial response ability and System protection scheme for inverter-based power system.



Decrease in number of synchronous generators

Reduced System Inertia
→ Increased fluctuation of frequency and voltage

Decrease in fault detection capability due to fault current decrease
→ Possibility of protection failure

Core Technologies for RE100%

PCS with an inertial response

A new system protection scheme for inverter-based power system

Fig. 2-52 Core technologies

Basic control logic development and Mini model verification have been completed.

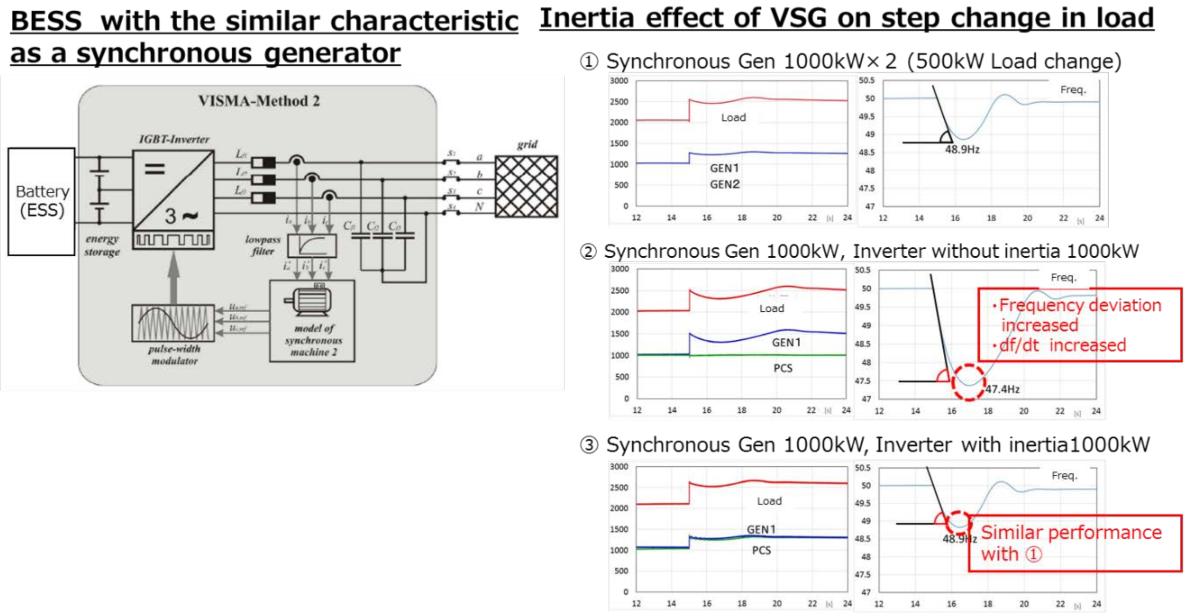
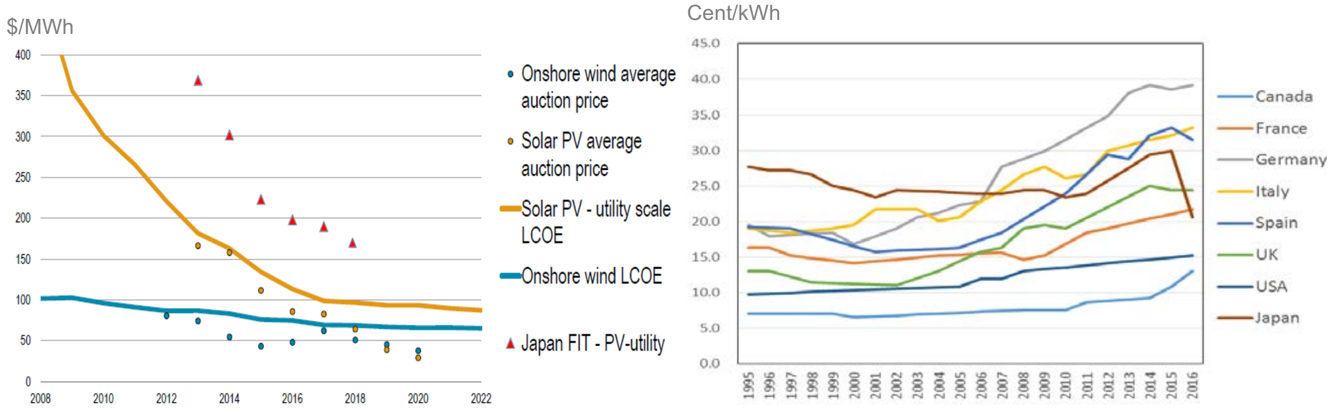


Fig. 2-53 inverter with inertia function

3. *Hidden Costs and Cost Sharing*

There are currently reports of a tremendous reduction in PV costs (nearly 3 cents/kWh) in regions with long hours of sunshine, such as Middle Eastern countries.

However, if we thoroughly observe the trend of electricity bills in the countries where the share of renewables have been growing, we should recognise that the bills have been growing as well, instead of decreasing or leveled off.



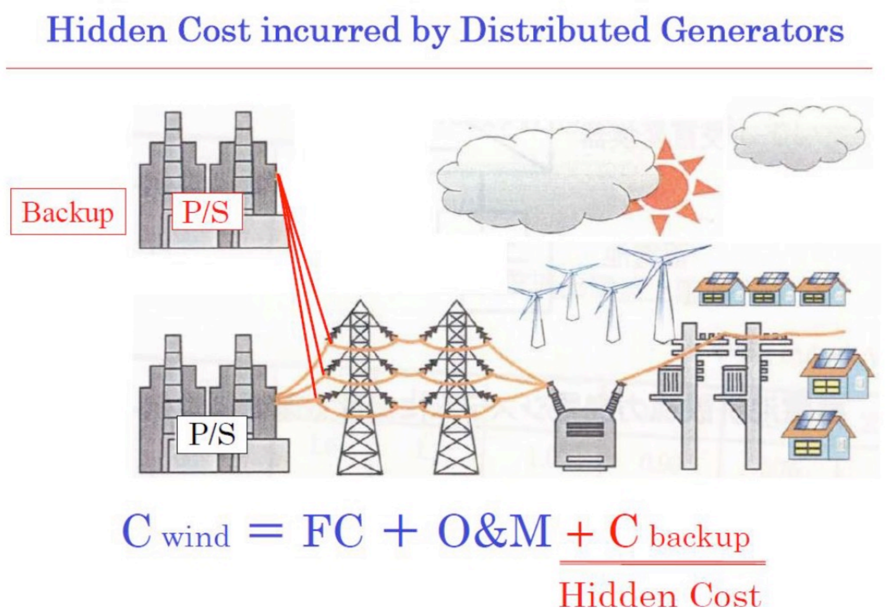
[Source] METI, Japan　　　　Calculated based on IEA data

(a) LCOE of renewables　　　　(b) Electricity price trends

Fig. 3-1 Levelised Cost of Electricity (LCOE) and Electricity price

It is obvious that one of the reasons of rising electricity bill is FIT system, but we must evaluate the total cost of renewable energy integrated in the grid, including so-called “hidden costs” such as backup cost and balancing (frequency regulation) cost, etc. These hidden costs include large scale batteries installed on the grid-side by the utilities.

Furthermore, we need to recognise that although no one asks who should pay those hidden costs, they have been borne by the end users (customers) in the end.



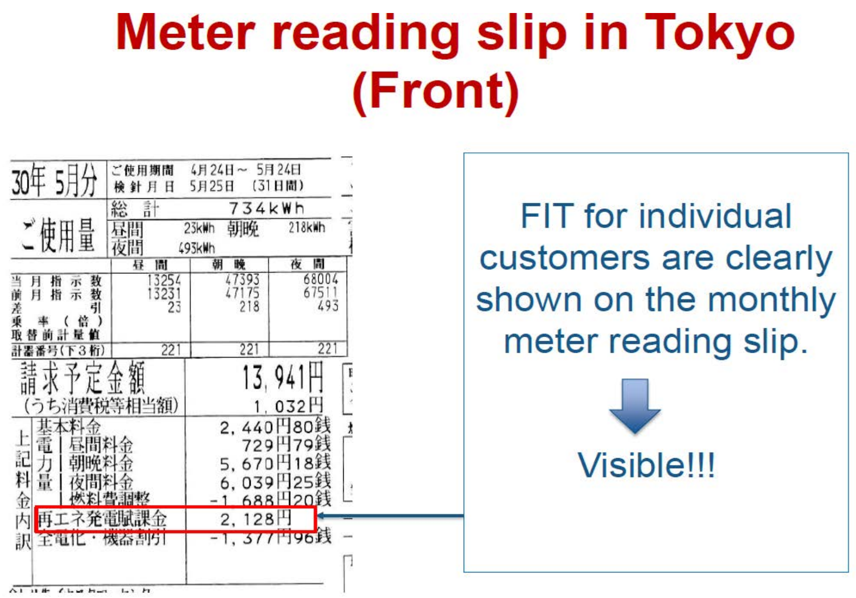
Hidden Cost incurred by Distributed Generators

$$C_{\text{wind}} = FC + O\&M + \underbrace{C_{\text{backup}}}_{\text{Hidden Cost}}$$

Fig. 3-2 Hidden Costs incurred due to Distributed Generators

<u>Figure 3-3 and 3-3 are a copy of a meter reading slip posted to a customer in Tokyo.</u>

<u>FIT is clearly shown on the slip</u>. The amount is proportional to the total energy consumption. In May 2018, this customer consumed 734 kWh and paid about 140 dollars, which included 20 dollars of FIT, or about 15% of total bill. Thus, <u>we can say that FIT is visible</u>.



Meter reading slip in Tokyo (Front)

30年 5月分

ご使用期間 4月24日～ 5月24日
検針月日 5月25日 (31日間)

ご使用量	総計	734kWh		
	昼間	23kWh	朝晩	218kWh
	夜間	493kWh		

	昼間	朝晩	夜間
当月指示数	13254	47393	68004
前月指示数	13231	47175	67511
差引	23	218	493
乗率（倍）			
取替前計量値			
計器番号(下3桁)	221	221	221

請求予定金額	13,941円
(うち消費税等相当額)	1,032円
上記料金内訳 基本料金	2,440円80銭
電力量 昼間料金	729円79銭
電力量 朝晩料金	5,670円18銭
電力量 夜間料金	6,039円25銭
燃料費調整	-1,688円20銭
再エネ発電賦課金	2,128円
全電化・機器割引	-1,377円96銭

FIT for individual customers are clearly shown on the monthly meter reading slip.

Visible!!!

Fig. 3-3 Meter reading slip in Tokyo (Front)

On the back of this slip, there are two very important figures. The first one is the unit price of FIT, which is 2.9 Yen/kWh. The second one is the unit price of the wheeling tariff, which is 9.26 Yen/kWh.

Meter reading slip in Tokyo (Back)

再生可能エネルギー
発電促進賦課金のご案内

2018年5月分~2019年4月分までの
単価は以下のとおりです。
[2.90円／kWh(税込)]

託送料金相当額(低圧)のご案内

ご請求金額には託送料金相当額を含んで
おります。
なお、託送料金相当額の目安はご使用量
に平均単価を乗じて算定いただけます。
[平均単価9.26円／kWh(税込)]

Unit price of FIT
2.9 Yen/kWh
* Visible

Unit price of wheeling tariff
9.26 Yen/kWh
* Grid-level costs are included but invisible (hidden).

Fig. 3-4 Meter reading slip in Tokyo (Back)

What we should observe is that this wheeling tariff includes grid-level costs, but they are not shown individually. In other words, they are invisible or hidden.

(Cost Sharing)

There have been frank comments by a senior manager at the Electric Power Research Institute (EPRI), USA.

“So far, most utilities have got through the issue of accumulating solar power by allowing homeowners with solar arrays to sell some of their power back to the grid. This is a practice called “Net Metering”. You are basically using the grid as a battery. This is why some utilities are a little bit worried about this. The big question is “Who pays for it?”
The need for renewable energy storage has emerged recently among engineers who worry about the health of the grid. But big grid-sized batteries can run into the millions of dollars.”
There is also good news. In Germany, about half of household customers who installed rooftop PV panels installed low cost batteries at the same time. We don’t deny the need for further renewable energy introduction, but we must say that “There is no free lunch.”

The costs of large-scale batteries installed at substations by conventional utilities are widely borne by every customer.

However, what we need to consider is:

- Who should pay these costs?
- Is it fair for only customers to pay?
- Is there no need for mega solar developers and households owing rooftop PV panels to pay a portion?

The Japanese government is now considering a new wheeling tariff sharing scheme, in which all generation companies, including renewable companies, bear part of the wheeling tariffs evenly, based on a common unit price per kW. If this scheme is implemented, it might be the first in the world.

Box-1: Battery Cost Sharing in the USA

Battery application is divided into four cases (1: Electric Utilities, 2: Developers in Ancillary Service Market, 3: RE Developers, 4: Customers) and the method of cost sharing varies depending on the application model and ownership.

Regardless of the case, if subsidies for batteries by the government are available, the burden of installation costs will be reduced, making cost recovery easier.

Case-1 : Electric Utilities

- Electric utilities started installing large capacity batteries at their substations to utilise them for supply and demand balancing or power flow and voltage management in the local distribution network.
- The costs are eventually paid by all customers as part of the wheeling tariff in the electricity bill.

Case-2 : Developers in Ancillary Service Market

- In this case, batteries are utilised for the ancillary service (frequency regulation) market in the wholesale electricity market. As the market is open to everyone, various developers started to participate in it utilising batteries, which have now become cost competitive.
- They are recovering the costs of the batteries from revenue through market transactions.

Case-3: RE Developers

- RE developers started to combine their photovoltaic and wind power with batteries in order to mitigate output fluctuation.
- The cost of batteries can be recovered from the electric power purchasers. There are two types of trading.
  - Bilateral contract with PPA (Power Purchase Agreement)
  - Spot trading in the wholesale market

Case-4 : Customers

- More and more venders have started providing the following solutions utilising batteries with commercial and industrial customers.
  - Demand Charge Reduction (by reducing peak kW)
  - Entering into the market by aggregating customers' batteries
  - Arbitrage trading checking the electricity price on the market (when the price is high, they sell power from the battery, and when the price is low, they purchase power from the market)
  - Utilisation as standby or emergency power supply
- The costs of batteries are borne by customers in the following two ways.
  1) They own and operate the battery.
  2) They pay a fee to the service provider who installed the battery at the customer's site.
- In any case, the costs of batteries are eventually paid by the customers who will benefit from the service.

Box-2: How the "Wheeling tariff system" Should be Formulated under the Electricity and Gas Market Surveillance Commission

- O&M costs for the power network are collected via the wheeling tariff (20 - 30% of electricity charge).
- Perform studies based on the following to maintain high power supply reliability and promote adequate investment in order to solve the issues caused by the integration of RE.
  - (i) Realize fair and adequate cost burdens based on the associated costs and benefits of facility users
  - (ii) Establish a system that gives rational incentives to the power suppliers and customers who use the power grids, as well as transmission and distribution companies
- Perform studies that recognize that power suppliers also have cost burdens based on their benefits, because the network enhancement costs for the commissioning of installed power sources are estimated to increase in a situation whereby demand is saturated, in contrast to the current situation in which customers bear the whole cost of wheeling tariffs.

At present, the following two schemes are being studied thoroughly:

1- Introduction of Power Producer-side Basic Charge

- 100% of the wheeling tariff has thus far been borne by customers via retail companies, but a new system will be introduced whereby a portion of this will be charged to all power producers who utilize the transmission and distribution network.
- The fixed costs for the bulk power transmission network will be equally shared between the power producer side and customer side.
- If 10% of the whole tariff is charged on the power producer side, each power producer, including RE suppliers, will pay around 1,800 JPY/kW, annually.

2- Amendment of Upper Limit for General Assessment

- Costs for bulk power transmission lines have fundamentally been borne by transmission and distribution companies, as a general assessment.
- However, there were upper limits to the general assessment depending on the kind of generation source and, if the cost exceeded the limit, the surplus cost was to be borne by power suppliers as a local assessment.
- Under the condition that the power producer-side basic charge is paid by the power suppliers on a monthly basis, the upper limit to the general assessment borne by the transmission and distribution companies will be raised up to a uniform kW unit price (around $400/kW) so that the RE suppliers' initial burden can be reduced.

<References> General assessments and local assessments

(i) Bulk power system enhancement costs are essentially dealt with as a general assessment.

(ii) Transmission enhancement costs other than those for bulk power systems are allocated general and local assessments considering the following:
  a. Benefits from replacement of facilities
  b. Benefits from reduction in facilities
  c. Benefits from improvement of power supply reliability

(iii) Costs beyond the standard value OCCTO determines as an extremely large burden for the scale of power sources connecting to power grids are dealt with as local assessments.

3.1 Hidden Costs

The task team conducted a literature survey on hidden costs and identified the OECD report "Nuclear Energy and Renewables: system Effects in Low-carbon Electricity Systems (2012)" as a comprehensive reference report that includes a quantitative analysis on hidden costs. The following are the key contents of this study report.

Electricity generating power plants do not exist in isolation. They interact with each other and their customers through the electricity grid as well as with the wider natural, economic and social environment. This means that electricity production generates costs beyond the perimeter of the individual plant. Such external effects or system effects can take the form of intermittency, network congestion or greater instability but can also affect the quality of the natural environment or pose risks in terms of security of supply. Accounting for such system costs can make significant differences to the social and private investor costs of different power generation technologies.

In the short run, with the current structure of the power generation mix remaining in place, all dispatchable technologies, nuclear, coal and gas, will suffer due to lower average electricity prices and reduced load factors. Due to their relatively low variable costs, existing nuclear power plants will do better than gas and coal plants, which are already substantially affected in some countries. In the long run, however, high fixed-cost technologies such as nuclear will be affected disproportionately by the increased difficulties in financing further investments in volatile low-price environments.

All power generation technologies cause system effects. By virtue of being connected to the same physical grid and delivering into the same market, they exert impacts on each other as well as on the total load available to satisfy demand at any given time. The interdependencies are heightened by the fact that only small amounts of cost-efficient electricity storage are available. Variable renewables such as wind and solar, however, generate system effects that are at least an order of magnitude greater than those caused by dispatchable technologies.

System costs are defined as the total costs above plant-level costs to supply electricity at a given load and given level of security of supply. In principle, this definition would include costs external to the electricity market such as environmental costs or impacts on the security of supply.

However, this study focuses primarily on the costs that accrue inside the electricity system to producers, consumers and transport system operators. This subset of system costs that are mediated by the electricity grid are referred to in the following as "grid-level system costs" or "grid costs".

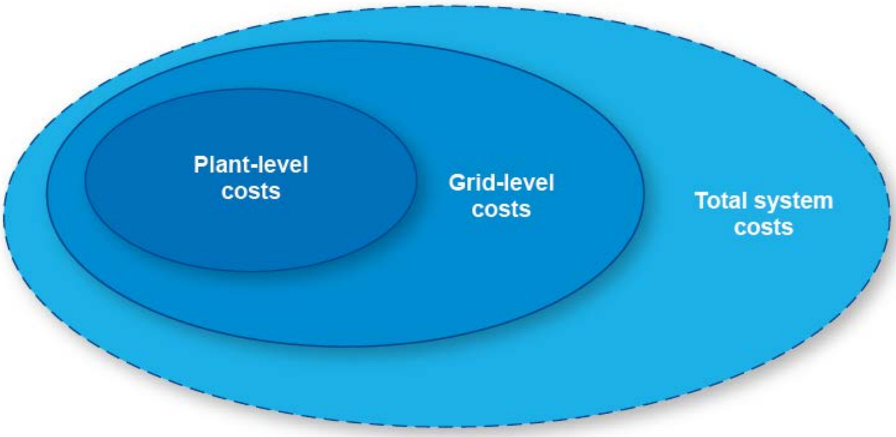


Fig. 3-5 Plant-level, grid-level and total system costs

Grid-level system costs already constitute real monetary costs. They are incurred as present or future liabilities by producers, consumers, taxpayers or transport grid operators. Such grid-level system costs can be divided broadly into two categories: (1) the costs for additional investments to extend and reinforce transport and distribution grids as well as to connect new capacity to the grid; and (2) the costs for increased short-term balancing and for maintaining the long-term adequacy of the electricity supply in the face of the intermittency of variable renewables.

The study does not neglect "total system costs" but does not attempt to systematically assess them in monetised form. Total system costs would include those effects that are difficult to monetise and that could affect a country's wider economy and well-being beyond the power sector itself. This broader set of system costs would include environmental externalities other than CO2 emissions, impacts on the security of the energy supply and a country's strategic position as well as other positive or negative spill over effects relating to technological innovation, economic development, accidents, waste, competitiveness or exports.

This study also examines the pecuniary and dynamic effects of variable renewables. These are difficult to conceptualise clearly, may not constitute externalities in the traditional sense of the term and are difficult to quantify fully at the current stage of debate. However, they may well constitute the impacts that are most acutely felt by electricity producers and may in the long run have the most profound effect on the operations and structure of electricity markets. The three principal effects falling into this category are:

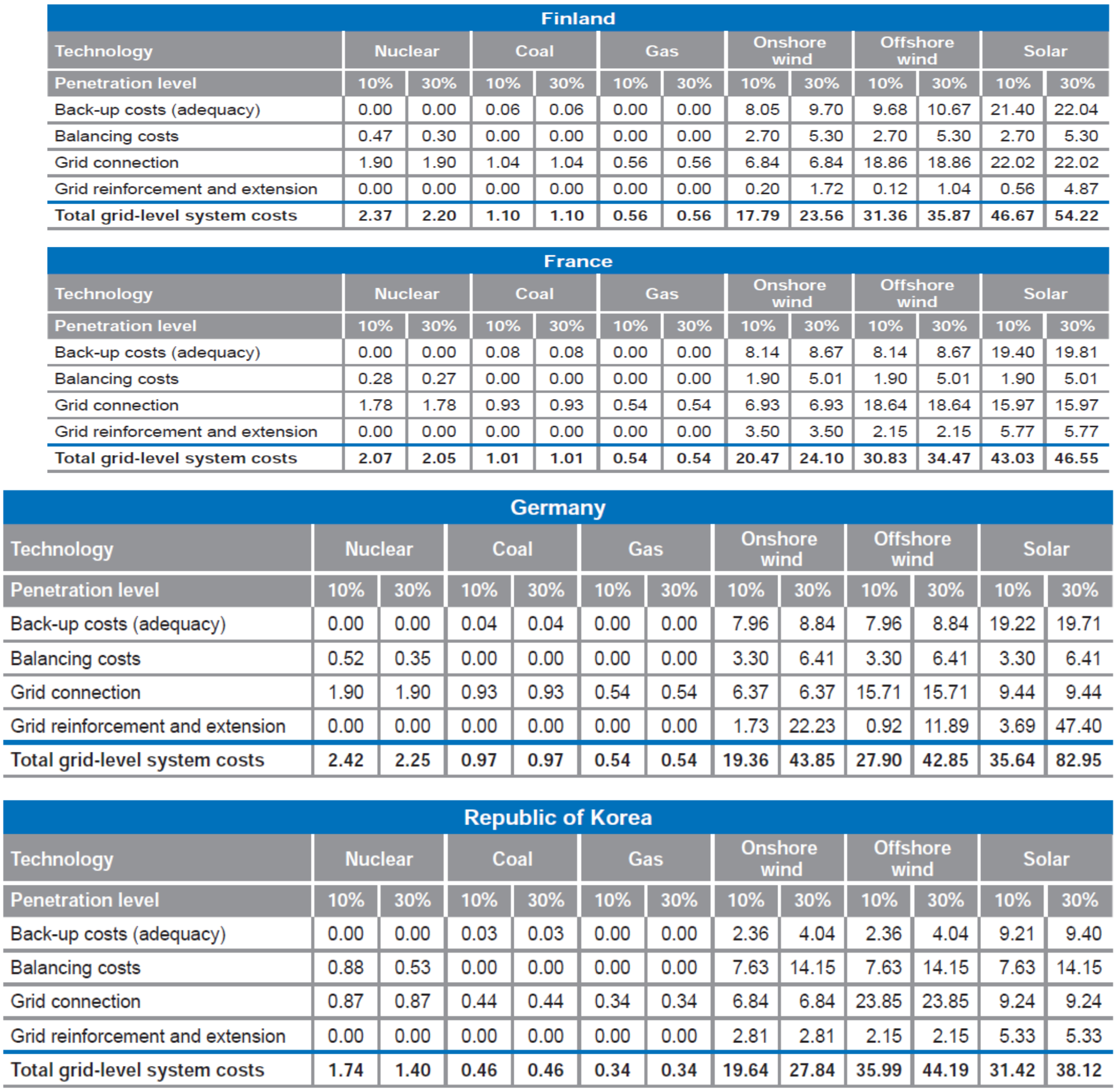
- Lower and more volatile electricity prices in wholesale markets due to the influx of variable renewables with low marginal costs.
- The reduction of the load factors of dispatchable power generators (the compression effect) as low-marginal cost renewables have priority over dispatchable supply.
- The de-optimisation of the current production structure coupled with the influx of renewables implies an increasing wedge between the costs of producing electricity and prices on electricity wholesale markets.

Nevertheless, the study has the objective of drawing attention to the fact that system costs are an increasingly important portion of the total costs of electricity and must be recognised and internalised in order to avoid serious challenges to the security of the electricity supply in the coming years. It also provides the first systematic assessment of the grid-level system costs for different technologies in six OECD countries.

The most innovative contribution of the study, however, is certainly the systematic quantitative assessment of grid-level system costs in a number of selected OECD countries. On the basis of a common methodology and a large number of country-specific studies for the underlying data, the costs for short-term balancing and long-term adequacy, as well as the costs for grid connection, extension and reinforcement required for different technologies, were calculated for Finland, France, Germany, the Republic of Korea, the United Kingdom and the United States. Technologies included were nuclear, coal, gas, onshore wind, offshore wind and solar PV. System costs were calculated at 10% and 30% penetration levels of the main generating sources.

The results show that the system costs for integrating variable technologies into the electricity system are large: total grid-level costs lie in the range of USD 15-80/MWh, depending on the country and on the variable technology considered. Among renewable technologies, onshore wind has the lowest integration costs, while those of solar are generally the highest. The results also confirm that grid-level system costs may increase significantly with the penetration level of renewables. However, any accurate assessment of these effects would require a specific in-depth study using similar assumptions and methodology.

Table 3-1 Grid-level system costs in selected OECD countries (US$/MWh)



Finland

Technology	Nuclear		Coal		Gas		Onshore wind		Offshore wind		Solar	
Penetration level	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%
Back-up costs (adequacy)	0.00	0.00	0.06	0.06	0.00	0.00	8.05	9.70	9.68	10.67	21.40	22.04
Balancing costs	0.47	0.30	0.00	0.00	0.00	0.00	2.70	5.30	2.70	5.30	2.70	5.30
Grid connection	1.90	1.90	1.04	1.04	0.56	0.56	6.84	6.84	18.86	18.86	22.02	22.02
Grid reinforcement and extension	0.00	0.00	0.00	0.00	0.00	0.00	0.20	1.72	0.12	1.04	0.56	4.87
Total grid-level system costs	**2.37**	**2.20**	**1.10**	**1.10**	**0.56**	**0.56**	**17.79**	**23.56**	**31.36**	**35.87**	**46.67**	**54.22**

France

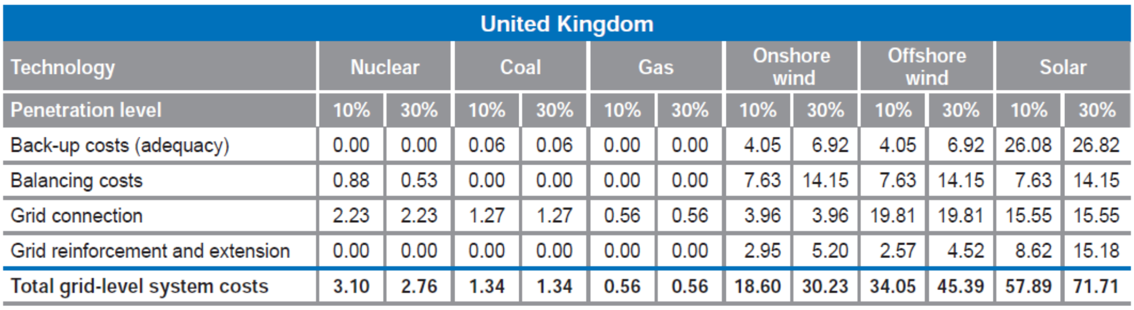
Technology	Nuclear		Coal		Gas		Onshore wind		Offshore wind		Solar	
Penetration level	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%
Back-up costs (adequacy)	0.00	0.00	0.08	0.08	0.00	0.00	8.14	8.67	8.14	8.67	19.40	19.81
Balancing costs	0.28	0.27	0.00	0.00	0.00	0.00	1.90	5.01	1.90	5.01	1.90	5.01
Grid connection	1.78	1.78	0.93	0.93	0.54	0.54	6.93	6.93	18.64	18.64	15.97	15.97
Grid reinforcement and extension	0.00	0.00	0.00	0.00	0.00	0.00	3.50	3.50	2.15	2.15	5.77	5.77
Total grid-level system costs	**2.07**	**2.05**	**1.01**	**1.01**	**0.54**	**0.54**	**20.47**	**24.10**	**30.83**	**34.47**	**43.03**	**46.55**

Germany

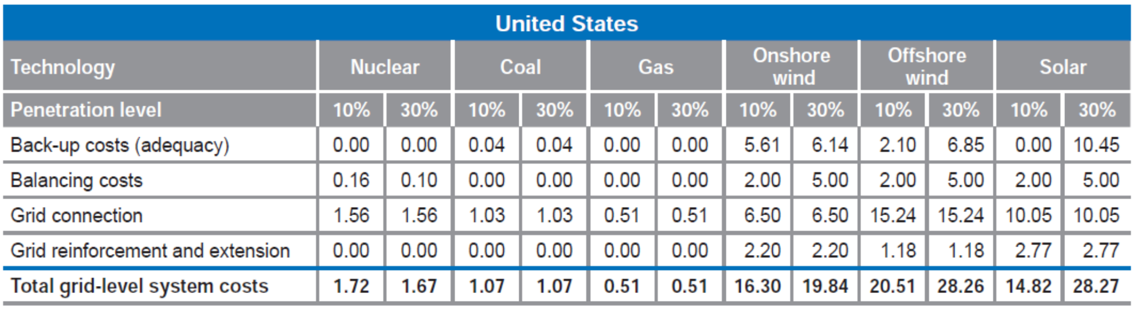
Technology	Nuclear		Coal		Gas		Onshore wind		Offshore wind		Solar	
Penetration level	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%
Back-up costs (adequacy)	0.00	0.00	0.04	0.04	0.00	0.00	7.96	8.84	7.96	8.84	19.22	19.71
Balancing costs	0.52	0.35	0.00	0.00	0.00	0.00	3.30	6.41	3.30	6.41	3.30	6.41
Grid connection	1.90	1.90	0.93	0.93	0.54	0.54	6.37	6.37	15.71	15.71	9.44	9.44
Grid reinforcement and extension	0.00	0.00	0.00	0.00	0.00	0.00	1.73	22.23	0.92	11.89	3.69	47.40
Total grid-level system costs	**2.42**	**2.25**	**0.97**	**0.97**	**0.54**	**0.54**	**19.36**	**43.85**	**27.90**	**42.85**	**35.64**	**82.95**

Republic of Korea

Technology	Nuclear		Coal		Gas		Onshore wind		Offshore wind		Solar	
Penetration level	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%
Back-up costs (adequacy)	0.00	0.00	0.03	0.03	0.00	0.00	2.36	4.04	2.36	4.04	9.21	9.40
Balancing costs	0.88	0.53	0.00	0.00	0.00	0.00	7.63	14.15	7.63	14.15	7.63	14.15
Grid connection	0.87	0.87	0.44	0.44	0.34	0.34	6.84	6.84	23.85	23.85	9.24	9.24
Grid reinforcement and extension	0.00	0.00	0.00	0.00	0.00	0.00	2.81	2.81	2.15	2.15	5.33	5.33
Total grid-level system costs	**1.74**	**1.40**	**0.46**	**0.46**	**0.34**	**0.34**	**19.64**	**27.84**	**35.99**	**44.19**	**31.42**	**38.12**



United Kingdom												
Technology	Nuclear		Coal		Gas		Onshore wind		Offshore wind		Solar	
Penetration level	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%
Back-up costs (adequacy)	0.00	0.00	0.06	0.06	0.00	0.00	4.05	6.92	4.05	6.92	26.08	26.82
Balancing costs	0.88	0.53	0.00	0.00	0.00	0.00	7.63	14.15	7.63	14.15	7.63	14.15
Grid connection	2.23	2.23	1.27	1.27	0.56	0.56	3.96	3.96	19.81	19.81	15.55	15.55
Grid reinforcement and extension	0.00	0.00	0.00	0.00	0.00	0.00	2.95	5.20	2.57	4.52	8.62	15.18
Total grid-level system costs	**3.10**	**2.76**	**1.34**	**1.34**	**0.56**	**0.56**	**18.60**	**30.23**	**34.05**	**45.39**	**57.89**	**71.71**



United States												
Technology	Nuclear		Coal		Gas		Onshore wind		Offshore wind		Solar	
Penetration level	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%
Back-up costs (adequacy)	0.00	0.00	0.04	0.04	0.00	0.00	5.61	6.14	2.10	6.85	0.00	10.45
Balancing costs	0.16	0.10	0.00	0.00	0.00	0.00	2.00	5.00	2.00	5.00	2.00	5.00
Grid connection	1.56	1.56	1.03	1.03	0.51	0.51	6.50	6.50	15.24	15.24	10.05	10.05
Grid reinforcement and extension	0.00	0.00	0.00	0.00	0.00	0.00	2.20	2.20	1.18	1.18	2.77	2.77
Total grid-level system costs	**1.72**	**1.67**	**1.07**	**1.07**	**0.51**	**0.51**	**16.30**	**19.84**	**20.51**	**28.26**	**14.82**	**28.27**

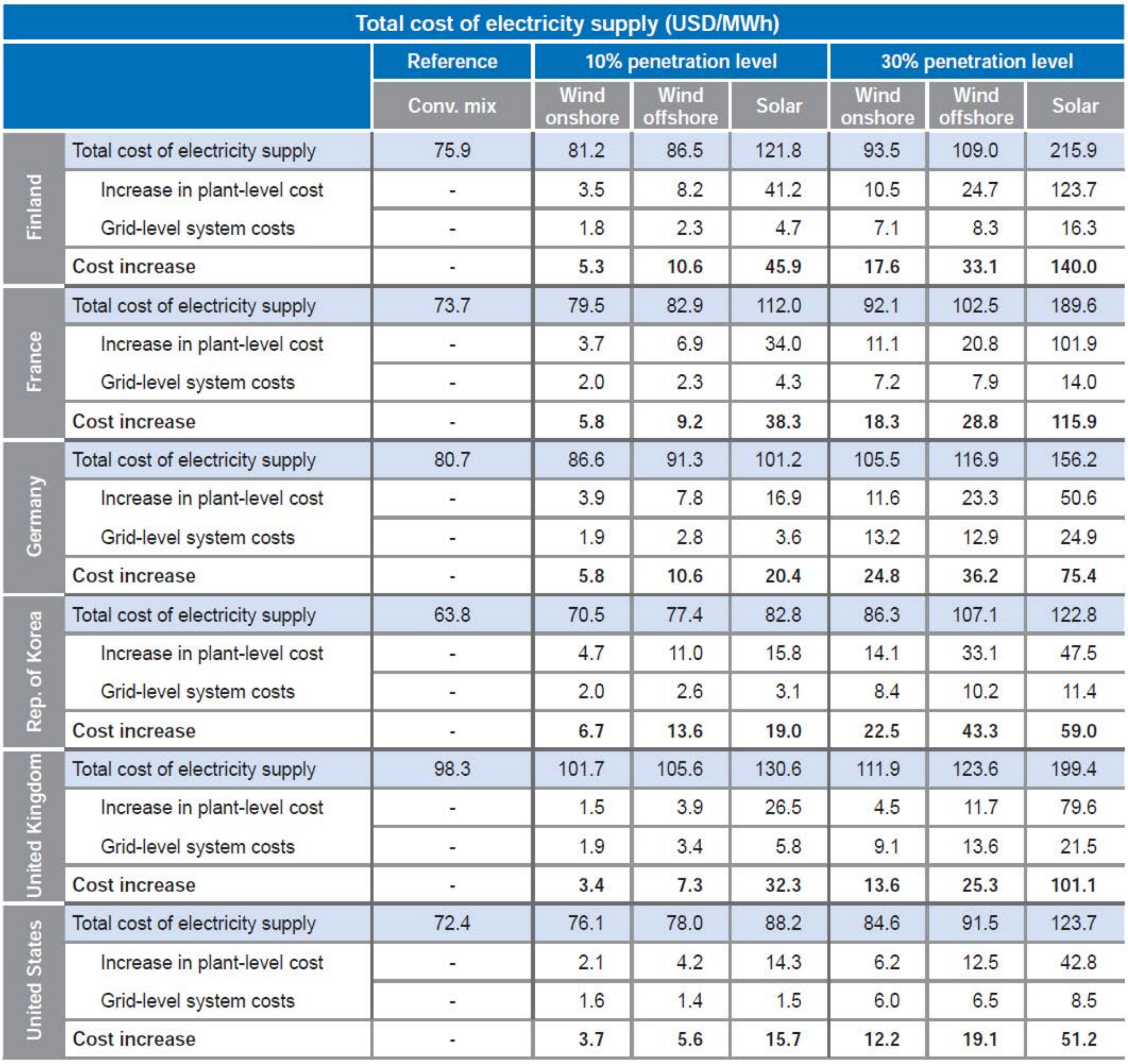
*The grid-level costs expressed in this table are normalised to the electricity produced by the specific technology in question.

Establishing estimates for grid-level system costs also allows calculation of the total costs of electricity supply with and without variable renewables. Introducing variable renewables up to 10% of the total electricity supply will increase per MWh costs, depending on the country, between 5% and 50%, whereas satisfying 30% of demand might increase per MWh costs by anything between 16% and 180% (the latter relating to solar in Finland).

While the range of values for different countries and technologies is very large indeed, even in the most favourable cases system costs are too large to be ignored. While onshore wind is usually the variable technology with the lowest grid-level system costs and solar PV the one with the highest, country-by-country differences are more important than technology-by-technology differences. This means that natural endowments and circumstances matter enormously. It may also explain to some extent differing public and policy attitudes towards the large-scale deployment of variable renewables in different countries.

Grid-level system costs, however, represent only part of the electricity production cost increase. Currently, plant-level generation costs for renewables are also still significantly higher than those of conventional technologies and their integration in the generating mix would thus cause a further increase of electricity production costs. On average, the total costs of electricity production would increase for on- and offshore wind technology by 30% to 50% at a 30% penetration rate and by 8 to 15% at a 10% penetration rate. Depending on a country's size, this means that billions of USD need to be added to the annual costs of electricity systems which are borne by society as a whole. Covering 30% of the electricity supply of the United States with offshore wind would thus cost an astonishing additional outlay of USD 86 billion per year. Table 3-2 reports the total cost of electricity supply on a USD/MWh basis for all scenarios analysed.

Table 3-2 Total cost of electricity supply at different penetration levels of renewable energy (US$/MWh)



Total cost of electricity supply (USD/MWh)

		Reference	10% penetration level			30% penetration level		
		Conv. mix	Wind onshore	Wind offshore	Solar	Wind onshore	Wind offshore	Solar
Finland	Total cost of electricity supply	75.9	81.2	86.5	121.8	93.5	109.0	215.9
	Increase in plant-level cost	-	3.5	8.2	41.2	10.5	24.7	123.7
	Grid-level system costs	-	1.8	2.3	4.7	7.1	8.3	16.3
	Cost increase	-	**5.3**	**10.6**	**45.9**	**17.6**	**33.1**	**140.0**
France	Total cost of electricity supply	73.7	79.5	82.9	112.0	92.1	102.5	189.6
	Increase in plant-level cost	-	3.7	6.9	34.0	11.1	20.8	101.9
	Grid-level system costs	-	2.0	2.3	4.3	7.2	7.9	14.0
	Cost increase	-	**5.8**	**9.2**	**38.3**	**18.3**	**28.8**	**115.9**
Germany	Total cost of electricity supply	80.7	86.6	91.3	101.2	105.5	116.9	156.2
	Increase in plant-level cost	-	3.9	7.8	16.9	11.6	23.3	50.6
	Grid-level system costs	-	1.9	2.8	3.6	13.2	12.9	24.9
	Cost increase	-	**5.8**	**10.6**	**20.4**	**24.8**	**36.2**	**75.4**
Rep. of Korea	Total cost of electricity supply	63.8	70.5	77.4	82.8	86.3	107.1	122.8
	Increase in plant-level cost	-	4.7	11.0	15.8	14.1	33.1	47.5
	Grid-level system costs	-	2.0	2.6	3.1	8.4	10.2	11.4
	Cost increase	-	**6.7**	**13.6**	**19.0**	**22.5**	**43.3**	**59.0**
United Kingdom	Total cost of electricity supply	98.3	101.7	105.6	130.6	111.9	123.6	199.4
	Increase in plant-level cost	-	1.5	3.9	26.5	4.5	11.7	79.6
	Grid-level system costs	-	1.9	3.4	5.8	9.1	13.6	21.5
	Cost increase	-	**3.4**	**7.3**	**32.3**	**13.6**	**25.3**	**101.1**
United States	Total cost of electricity supply	72.4	76.1	78.0	88.2	84.6	91.5	123.7
	Increase in plant-level cost	-	2.1	4.2	14.3	6.2	12.5	42.8
	Grid-level system costs	-	1.6	1.4	1.5	6.0	6.5	8.5
	Cost increase	-	**3.7**	**5.6**	**15.7**	**12.2**	**19.1**	**51.2**

*The grid -level costs expressed in this table are normalised to the electricity generated in the whole system.

As to the grid-level costs in Japan that are not included in the OECD report, we identified these in a report, "Power Generation Cost Estimates (2014)", written by Dr. Keigo Akimoto of RITE (Research Institute of Innovative Technologies for the Earth). Table 3-3 shows his estimation results.

The results show that the system costs for integrating variable technologies into the electricity system are large compared with the conventional generation sources: total grid-costs lie in the range of 1-8 JPY/kWh) depending on the penetration level (2-10%).

Table 3-3 Grid-level system costs in Japan (JPY/kWh)

	Nuclear	Thermal	Wind			Solar		
Penetration level [%]	-	-	2	5	10	2	5	10
Backup costs	0	0	4	7	8	0.8	4	8
Balancing costs	0.05	0						
Grid connection	0.2	0.1						
Grid enhancement & extension	0	0						
Total grid level system costs	0.25	0.1	4	7	8	0.8	4	8

*The grid-level costs expressed in this table are normalised to the electricity produced by the specific technology in question.

Increasing shares of wind and solar power in the electricity system have a considerable impact on electricity markets. The variable and uncertain generation from these renewables is a source of additional costs. These costs include the costs for back-up needed for periods with low wind and solar production, the costs for transmission to reach demand centres, and the costs for balancing the electricity system to adjust for wind and solar power forecast errors. Furthermore, electricity generation from wind and solar with very low marginal costs depresses electricity prices on the wholesale market. While these cost increases and price effects are common to all electricity markets, the magnitude of the effects will depend on the local characteristics of an electricity market, such as the incumbent generation mix and the interconnections with other markets.

Wind and Solar are non-dispatchable resources and their variability will cause increased cycling for almost all traditional resources from base loaded coal units to intermediate and possibly peaking gas units. It is common to see power plants, built for base loaded operation, now running in cycling mode (load following) with steep ramp rates and on/off cycling. Moreover, current dispatch systems, with a growing mix of variable generation resources, are not optimised in terms of minimising steady state heat rates and realising long-term costs of operation. Failing to determine these true costs to the cycle will likely result in the operator bidding the incorrect marginal unit, directly impacting the operating revenues of the power plant owner.

Reliability is also an issue because increased cycling results in more component failures at the power plant and long downtimes. Thus, it is desirable to identify not only increases in the costs of operation (due to ramping and start/stop cycling), but also increases in the costs of maintenance, capital maintenance, forced outages and derating effects, and long-term heat rate effects. This thorough examination of operating costs results in an understanding of, and ability to implement, the true O&M costs associated with the cycling of power plants.

3.2 Cost Sharing

The task team also conducted a literature survey on renewable energy integration cost sharing and identified several opinions including the OECD report. The following are the key opinions which must be kept in mind when discussing an ideal method of hidden cost sharing.

(1) OECD report (2012)

The magnitude of both the technical and pecuniary system costs implies that they can no longer be borne in a diffuse and unacknowledged manner by the operators of dispatchable technologies as an unspecific system service. Currently, dispatchable technologies are expected to provide the back-up for intermittent renewables to cover demand when the latter are unavailable. This service is costly, but is currently not remunerated. Economically speaking, dispatchable technologies are expected to provide the unremunerated positive externality of long-term flexible capacity for back-up. System costs require (a) fair and transparent allocation mechanisms to maintain economically sustainable electricity markets and (b) new regulatory frameworks to ensure that balancing and long-term capacity provision can be provided at least cost.

(2) NREL "Integration of Variable Generation and Cost-Causation" (2012)

(Integration costs do not apply to Solar and Wind alone)

Large generators impose contingency reserve requirements, gas scheduling restrictions impose system costs, nuclear plants increase the cycling of other base-load generation, and hydro and other generators create minimum-load reliability problems. However, none of these costs is allocated to the generators that impose them on the power system.

Although there are technical difficulties calculating VG integration costs, there are also public policy and regulatory questions concerning what to do with the integration costs of renewables, if they can be accurately calculated. Other generation technologies impose integration costs that are not allocated to those technologies. Assigning integration costs should be considered very carefully to ensure they are not discriminatory.

Generation integration costs are typically broadly shared because the benefits are also broadly shared. Contingency reserves are shared within a large reserve sharing pool because aggregation reduces the physical reserve requirements and therefore reduces everyone's costs. Variable renewables bring fuel diversity, price stability, energy security, and environmental benefits that accrue widely for all users of the power system. With such broad and intertwined benefits, integration costs could neither be broadly shared nor be assessed based on generation type.

(Integration costs are generally manageable, but calculating costs is challenging)

Integration costs have been found by various utilities to be manageable and modest compared with electricity prices, but there is little agreement on methodologies used to determine those costs or even whether they are measurable.

Calculating RE integration costs is challenging because it is difficult to accurately develop a baseline scenario without variable generation (VG). It is also difficult to appropriately allocate costs given the complex, nonlinear interactions between resources and loads.

(3) NREL, "Integration Costs: Are they Unique to Wind and Solar Energy?"

(Principles of cost-causation wind and solar)

Integration cost analysis can be predicated upon the notion of cost-causation. The principle says that additional costs in operating the power system with wind/solar generation are caused by the wind/solar generation. Therefore, it is an integration cost. Although this is a very simple principle, it has some important implications. (1) If the wind/solar generation is removed from the system, the integration cost would disappear. (2) If wind/solar generation helps the system (for example, by reducing costs elsewhere in the power system) then there should be a credit to the integration cost.

Furthermore, if integration costs are based on cost-causation, it would follow that costs that are imposed by other technologies would then also incur an integration cost.

(Changes in contingency reserves for a pool)

Contingency reserve is typically based on the loss of the largest generating unit. Reserve sharing groups (RSGs) are common, allowing for the sharing of contingency reserves over a broader electrical area, which can reduce costs for all. In RSGs, there are typically multiple entities, which may include generation owners, traditional utilities, or other parties. The cost of providing the contingency reserves is not typically allocated to those who cause the need for the reserve.

As an example, consider an RSG composed of five utilities, with the largest generator a 350-MW coal unit. If the five utilities share the burden equally (for simplicity in the example), they each carry a 70-MW contingency reserve. Suppose now that one of the utilities builds a new 500-MW generator. Each member is now obligated to carry 100 MW of reserve, a 30-MW increase. This new 500-MW generator incurs a real contingency reserve cost, but it is not charged back to the 500-MW unit –– or even exclusively to the utility that acquired it. The cost of providing contingency reserve is therefore not calculated on the basis of the units that drive the need.

Costs could be allocated based on cost causation, but they are not. Instead, these costs are socialised to loads, and have been for many years.

(Loads)

Loads differ dramatically in the burdens they place on the power system. Individual load accounts for the majority of the regulation requirements for one utility. Although regulation costs are typically allocated to loads in aggregate, they are never allocated among loads based on cost causation. Regulation costs are broadly allocated to all loads regardless of individual load requirements.

(Summary)

In terms of mitigating global warming, the popularity of renewable energy has risen worldwide. In fact, CO2 emissions from wind and solar are quite low.

It is said that if the availability of blowing wind is more than 2000 hours a year, the project could sufficiently pay off. Considering the high price of oil currently, the break-even point may be less than 2000 hours. Positive use of renewable energy is a requirement of the age. Its share will increase through being pushed by strong supporters among policy makers and citizens.

On the contrary, the quality of power required by consumers has become higher and higher. Unfortunately, many renewable energy technologies such as wind and solar rely on favourable weather conditions, making them an unstable source of energy. In short, they cannot meet the needs of society without compensation. Stand-alone use in an isolated private network is not realistic due to the uncertainty of power output. Inevitably, they need to be connected with the conventional power grid.

It is necessary for power grid engineers to technically evaluate the impact of the renewable energy connections on power flows through transmission lines, including international tie-lines, as well as the stability of the whole network. If there are unfavourable impacts, they must take the necessary measures.

The opinion from the grid side is as below.

Once connected with the power grid, output fluctuation of renewable energy can be compensated for. This means that backup power can be easily obtained by virtue of the unique features of the electric power system. Generally speaking, renewable energy can be fully utilised as a clean alternative energy to fossil fuel power plants when it is connected to the power grid. In other words, the power system must prepare reserve margin and provide ancillary services. According to a Japanese researcher, the cost of the backup and stabilisation for renewable energies could amount to 10 to 14 Yen/kWh. In Japan, this “Hidden Cost” is now charged in the electricity rate paid by every customer.

However, in spite of the hidden costs, the great value of renewable energies will not decrease. Thus, it is essential for us to make it clear who should bear such costs, and then to promote the use of renewable energies based on a public consensus on the hidden cost issue.

4. References

1) Oze Ozdemira, Marit van Houta, Paul Koutstaal - Policy Studies, Energy Research Centre of the Netherlands & Integration costs - a market value of variable renewables: A study for the Dutch power market

https://www.ecn.nl/publicaties/PdfFetch.aspx?nr=ECN-W--17-035

2) NREL - Integration of Variable Generation and Cost-Causation

https://www.nrel.gov/docs/fy12osti/56235.pdf

3) Intertek - Evaluating the Cost of Renewable Energy Integration

http://www.intertek.com/power-generation/renewable-energy-integration-costs/

4) Michael Milligan (NREL), Bri-Mathias Hodge (NREL), Brendan Kirby (Consultant), and Charlton Clark (U.S. Department of Energy) - Integration Costs: Are They Unique to Wind and Solar Energy? (2012)

https://www.nrel.gov/docs/fy12osti/54905.pdf

5) OECD/NEA - Nuclear Energy and Renewables: System Effects in Low-carbon Electricity Systems (2012)
http://www.oecd-nea.org/ndd¥pubs/2012/7056-system-effects.pdf

6) RITE - Power Generation Cost Estimates (2014)
http://www.rite.or.jp/systrem/global-warming-ouyou/download-data/PowerGenerationCost_estimates_20141020.pdf