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Impact of Photovoltaic Yield Forecasting on Future Power System Operations in Japan

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This paper is based on results obtained from a project commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

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Introduction

Japanese current situation

- 3-stage power market reform has been progressing in Japan toward 2020.

2015
- Establishing a nationwide grid management operator (OCCTO)

→

April 2016
- The market was fully opened to retail level competition.

→

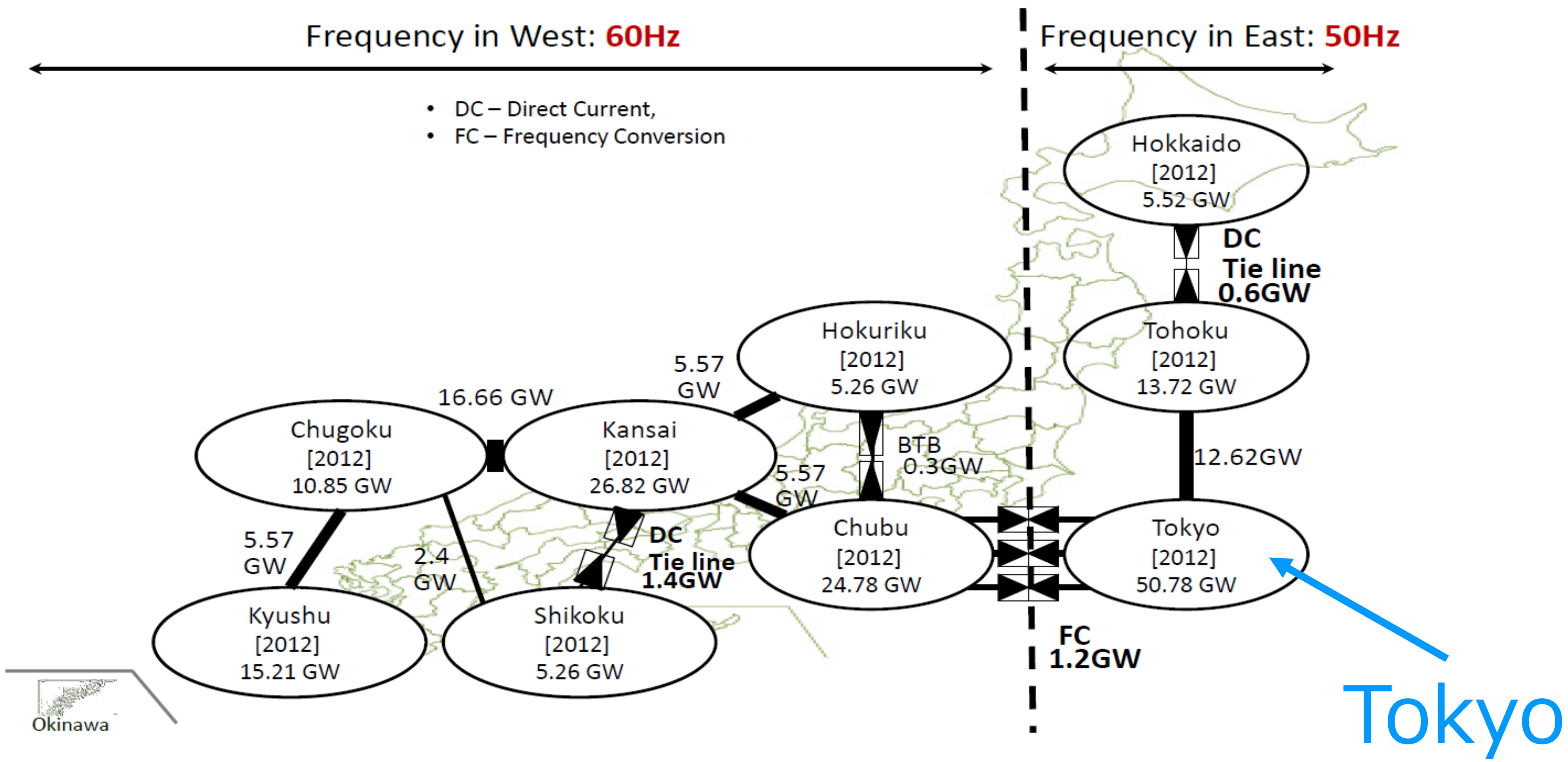
2020
- EPCO are expected to unbundle their power T&D sections

EPCO : Electricity Power Companies
OCCTO : the Organization for Cross-regional Coordination of Transmission Operators

Introduction

Japanese current situation

- 10 vertically integrated Electricity Power Companies (EPCOs)

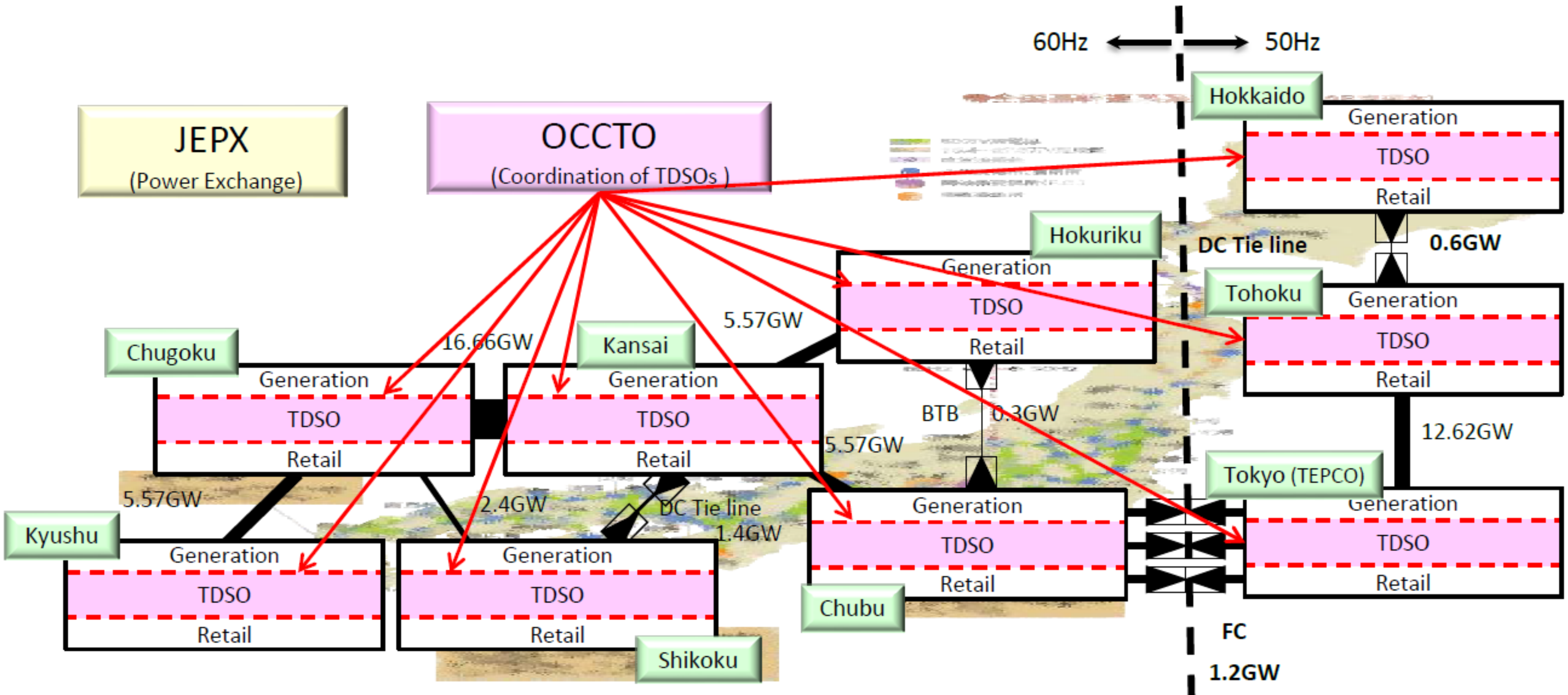


Ministry of Economy, Trade and Industry, Japan's Electricity Market Reform and Beyond
https://www.iea.org/media/workshops/2015/esapplenaryjuly2015/Yamazaki.pdf

Introduction

Japanese current situation

- the Organization for Cross-regional Coordination of Transmission Operators (OCCTO) was established.
- OCCTO reviews the EPCOs' supply-demand balance and grid plans.



* DC – direct current, FC – frequency conversion, TDSO – Transmission and Distribution System Operator

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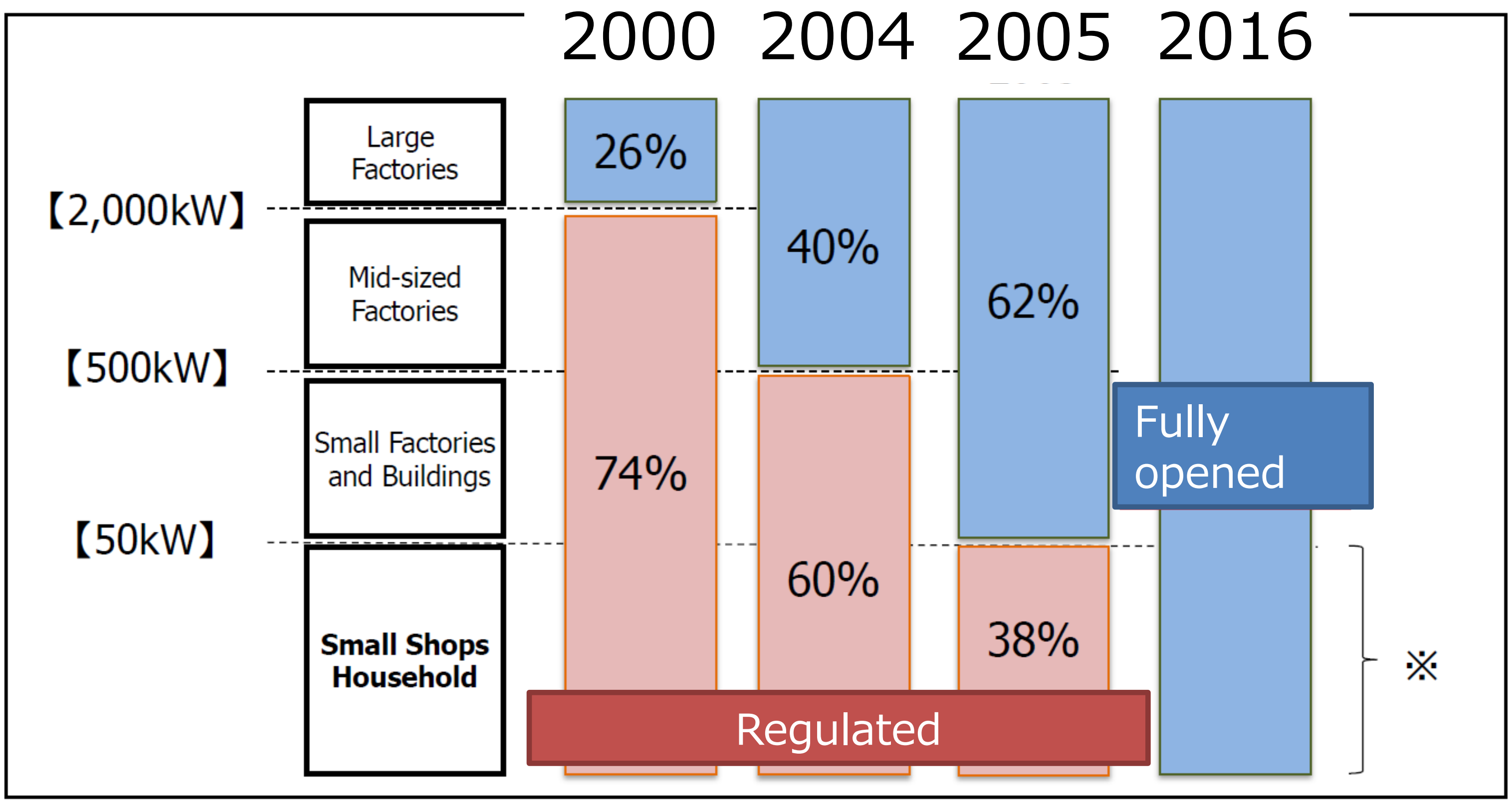
Introduction

Japanese current situation

- **Partial deregulation** has been starting from 2000.



※Regulated tariffs will be maintained as an option for customers at least until 2020.

Japan External Trade Organization, Japan's Energy Market Reform
https://www.jetro.go.jp/ext_images/canada/pdf/powermktseminar070416keynote.pdf

Introduction

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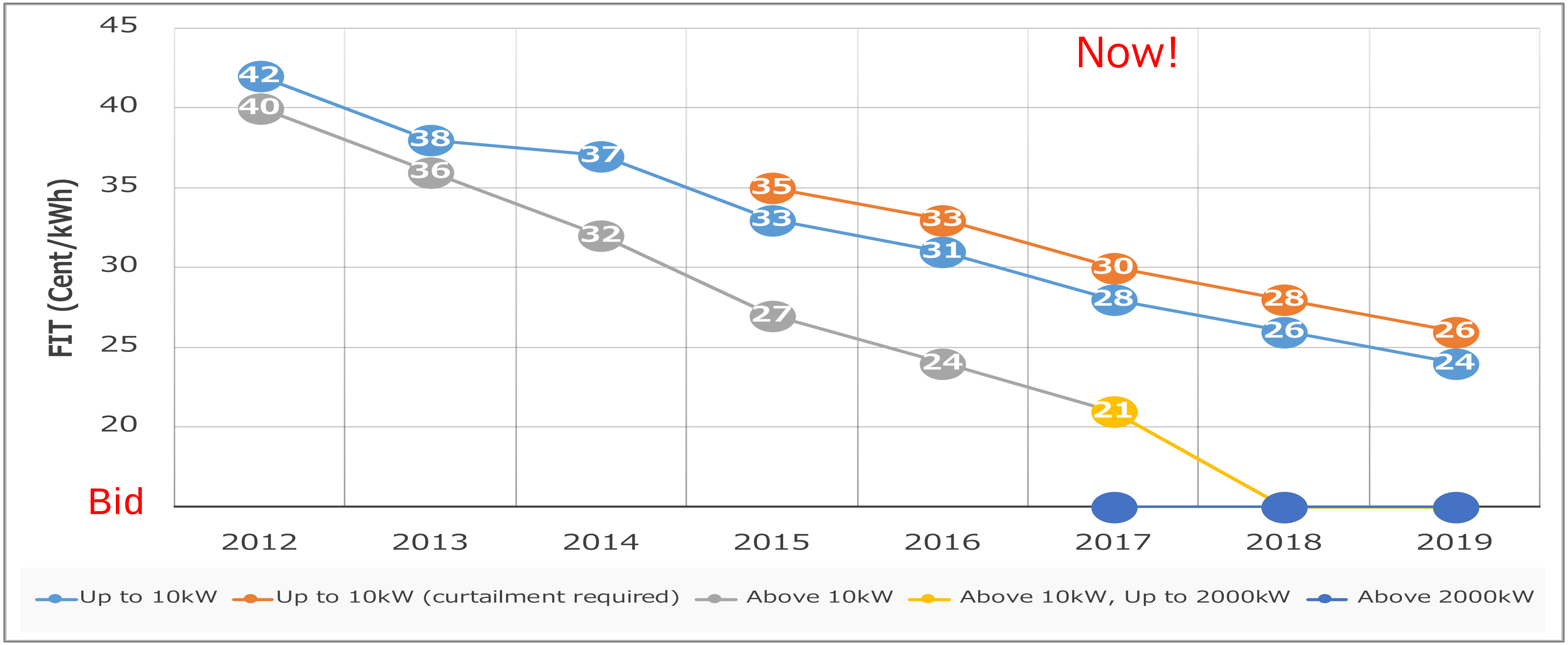
Introduction

Japanese current situation

- FIT program was launched in 2012
- Installed & approved PVs reached 28.5 GW & 84.5 GW, 2017.3
  - the Strategic Energy Plan of Japan for the next decade (revised)
    - 64GW of PV and 10GW of wind are expected to be installed by 2030.



Motivation

VRE : variable renewable energy

1. Japanese power system has been changing.
2. The share of VRE in overall power generation is rapidly increasing.

⇩

- "Integration study" is an good analytical framework to investigate power system operations with high penetration levels of VRE.
- "Integration study" has not been done yet in Japan.

Purpose of our study

- To **develop** a production cost model (UC) and **start** "Integration Study" of VRE.
  - Batteries, EVs in the near future

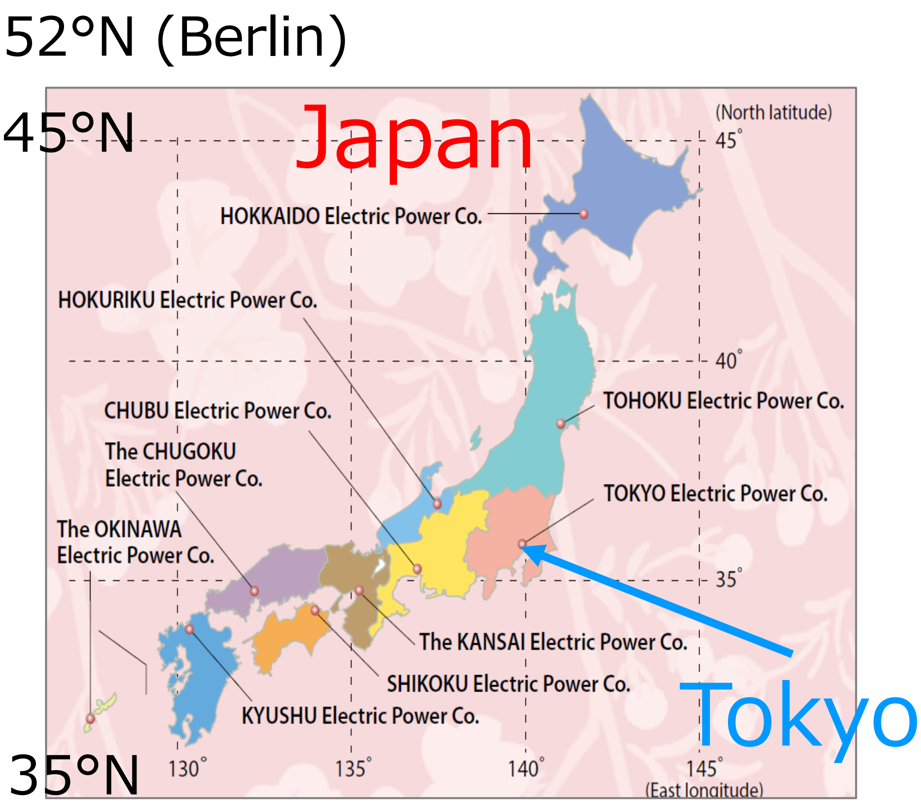
Today's topic

- To **evaluate** the impact of PV yield forecast error using UC.
  - Our project goal was to improve the forecast technology.
  - To give feedback to the forecast team about the requirement from the view point of power system operation

❐Today's contents

What we have done

- We have been studying the impacts of PV in TEPCO area.
  - Developing Unit Commitment & Economic Dispatch model.
- We have evaluated the value of day ahead PV prediction tech..



ELECTRICITYREVIEWJAPAN, The Federation of Electric Power Companies of Japan

✓TEPCO is the largest power balancing area in Japan and has high potential for PV deployment.

✓17.5 GW PV capacity was assumed in the area in 2030

✓55GW peak load in summer and 70GW of total supply capacity.

Methodology

Model

- Day ahead Unit Commitment and real time Economic Dispatch simulation.
  - A deterministic UC approach

    which can consider confidence interval to consider the forecast error

referred to as
operational cost

- Formulation
  - Objective function
    - Min. fuel cost + start cost of thermal power plants

      ※not considering costs of pumped storage generator
  - Variables (main)
    - $p_{n,t}$: power generated by thermal gen. n
    - $g_{m,t}$ and $h_{m,t}$: power generated and consumed by pumped storage gen. m
    - decision variables of the unit commitment (turn on or not, work or not, etc)

For details, see our paper

Methodology

Model

- Constraints (main)
  - Power balance

$$\sum_{n=1}^{N}(p_{n,t}) + \sum_{m=1}^{M}(g_{m,t} - h_{m,t}) + pv_t^{(f)} \geq d_t^{(f)} \ \forall_t$$

Thermal + pumped storage + PV forecast = demand

  - Upward and downward hot reserves

$$\sum_{n=1}^{N}(\bar{p}_{n,t} - p_{n,t}) \geq pv_t^{(f)} - pv_t^{(fd)} \ \forall_t$$

Upward reserve ≧ PV yield forecast error(lower confidence interval)

$$\sum_{n=1}^{N}[p_{n,t} - pWk_{n,t} \cdot (mnT_n + mxT_n) + \bar{p}_{n,t}] \geq pv_t^{(fu)} - pv_t^{(f)} \ \forall_t$$

Downward reserve ≧ PV yield forecast error(upper confidence interval)

This formulation will ensure supply-demand balance and the secondary reserve **when the actual PV yield is within the CI.**

Methodology

Model

- Constraints
  - Secondary reserve

$$\sqrt{(demand \times 3\%)^2 + (pv \times 20\%)^2} \leq$$

Short term variation

Secondary reserve

Rated power of thermal ×20%

\+ Rated power of pumped storage (generation) ×33%

\+ Rated power of pumped storage (pumping) ×10%

Only in operation

Only adjustable speed type

Secondary reserve capacity		Pump mode	Generation mode
Thermal (Coal, LNG, Oil)		—	±5% of the rated power
Pump	Const. speed	—	±16.5% of the rated power
	Adjustable speed	±10% of the rated power	±16.5% of the rated power

PS : Pumped Storage hydro

Model

- Calculation process for 1-day

UC process

Input data
- Fuel & start-up costs
- Rated value, min. output
- Etc.

Input Forecast data
- PV yield forecast
  - Scenario (case 1 – 5)
- Demand forecast (Perfect)

UC
- Minimizing operational cost

Output data
- On/Off schedule (thermal units)
- On/Off & output schedule (PS)

❐Methodology

NWP : numerical weather prediction
JMA : Japan Meteorological Agency

Forecast data (input data)

- Regional forecasts of solar irradiance [kW/m2]
  - calculated in NWP of the JMA
    - the initial time of the forecast of 12:00 JST in the day preceding the target day.
  - multiplied by the system output coefficient (0.8) and a PV capacity in TEPCO area (17.5GW).

<u>For details, see these papers</u>

[12] H. Ohtake, Joao Gari da Silva Fonseca Jr, T. Takashima., T. Oozeki, K-I. Shimose, and Y. Yamada, "Regional and seasonal characteristics of global horizontal irradiance forecasts obtained from the Japan Meteorological Agency mesoscale model", Solar Energy, 116, pp. 83-99. /doi:10.1016/j.solener., Mar 2015
[13] J. G. da S. Fonseca Junior, T. Oozeki, H. Ohtake, T. Takashima, and K. Ogimoto, "Regional forecasts of photovoltaic power generation according to different data availability scenarios: a study of four methods," Prog. Photovolt. Res. Appl., vol. 23, no. 10, pp. 1203–1218, Oct. 2015

Methodology

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Methodology

Simulation scenarios

- We used 5-type of PV yield forecast.

Case	Detail
Persistence	Persistence forecast, assuming the conditions at the time today should not change at the same time tomorrow.
Predict.	Day-ahead PV yield forecast without Confidence Interval
Predict. w/ 80% CI	Day-ahead PV yield forecast with forecast error (80% CI)
Predict. w/ 90% CI	Day-ahead PV yield forecast with forecast error (90% CI)
Predict. w/ 95% CI	Day-ahead PV yield forecast with forecast error (95% CI)

Methodology

PS：Pumped Storage hydro

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Methodology

PS : Pumped Storage hydro
ED : Economic Dispatch

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- Calculation process for 1-day

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UC
- Minimizing operational cost

Output data
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- On/Off & output schedule (PS)

RT ED process

Input data
- Same as UC process
- UC out put data

Input Actual data
- Observed PV yield
- Observed Demand

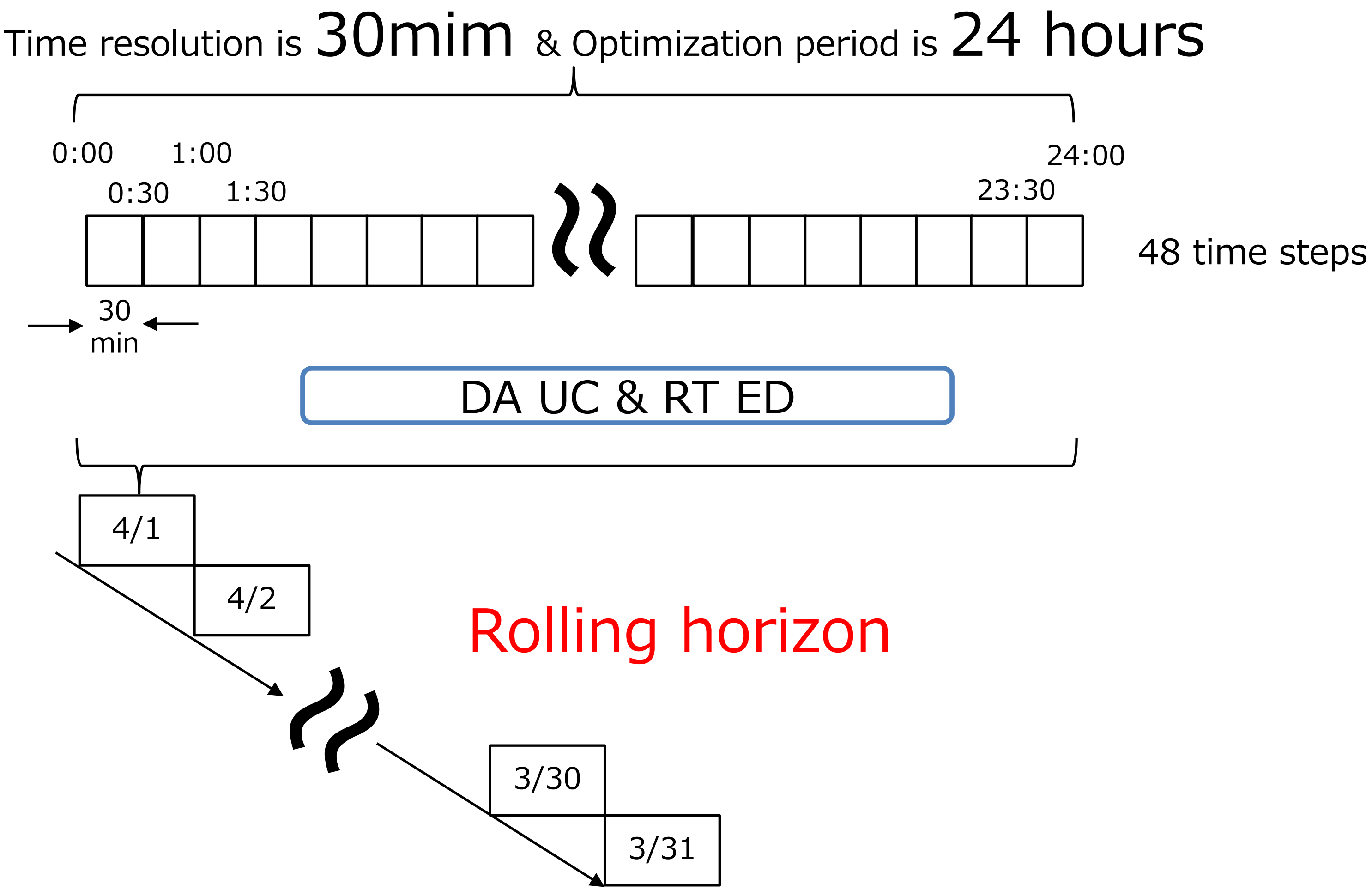
ED
- Minimizing operational cost

Output data
- Operational behavior & cost
- Unserved energy due to forecast error

Methodology

Model

- Analysis period is 1 year (365days)



Methodology

Analysis area

- Investigating the impact of PV yield forecast on TEPCO's operations in 2030. (Base data : FY2010)

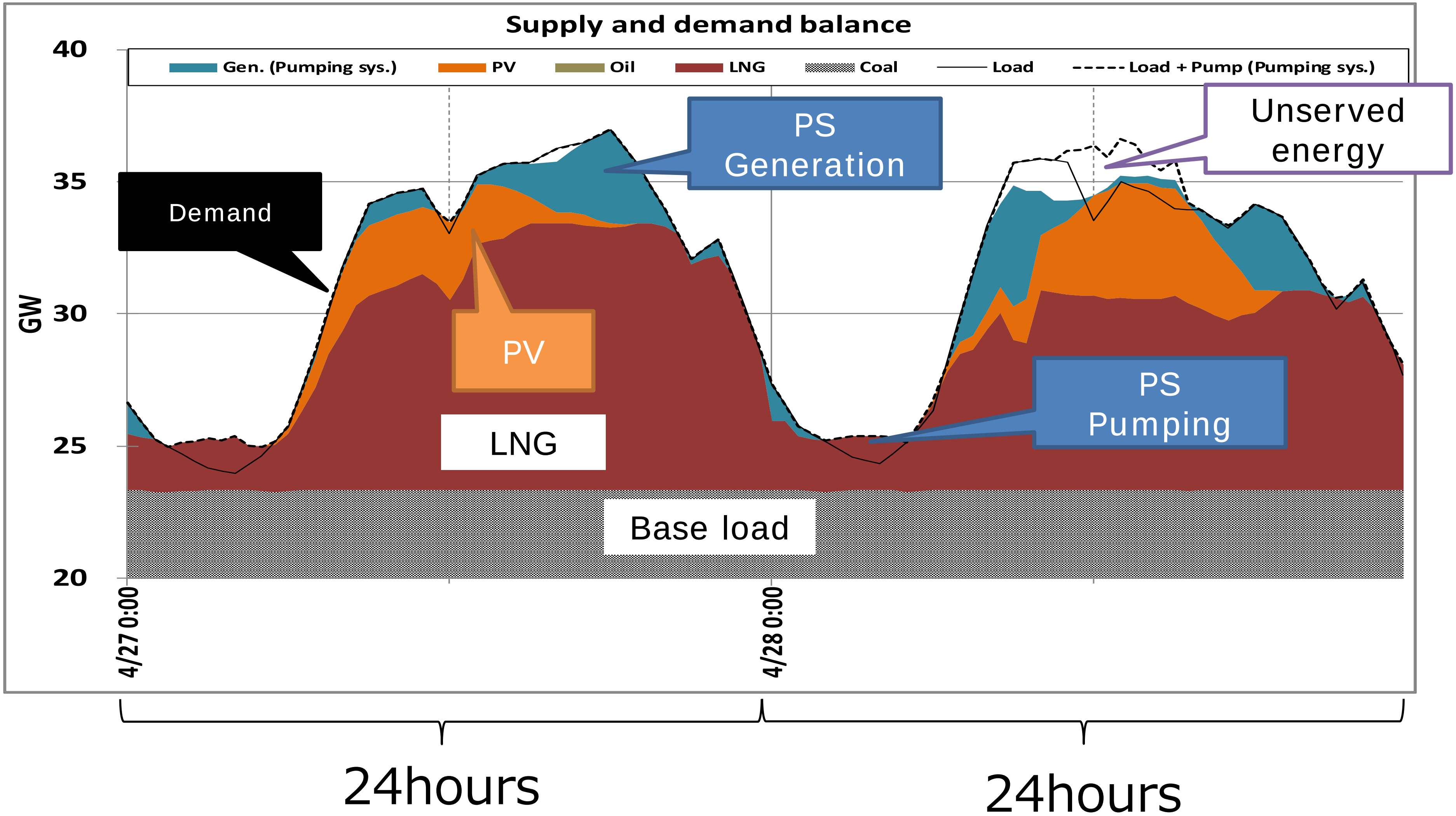
	Type	Installed capacity	Detail
Peak & Middle load	Thermal	42.60 [GW]	Coal : 9.6 [GW] (15) LNG : 22.16 [GW] (57) OIL : 10.84 [GW] (20)
	Pump	13.68 [GW]	Adjustable speed : 4.30 [GW] (11) Constant speed : 9.38 [GW] (41)
Base load	–	13.71 [GW]	Nuclear : 6.01 [GW] Hydro : 5.14 [GW] Others : 2.56 [GW]

A lot of pumped storage hydro is one of the TEPCO's characteristics.

PS：Pumped Storage hydro

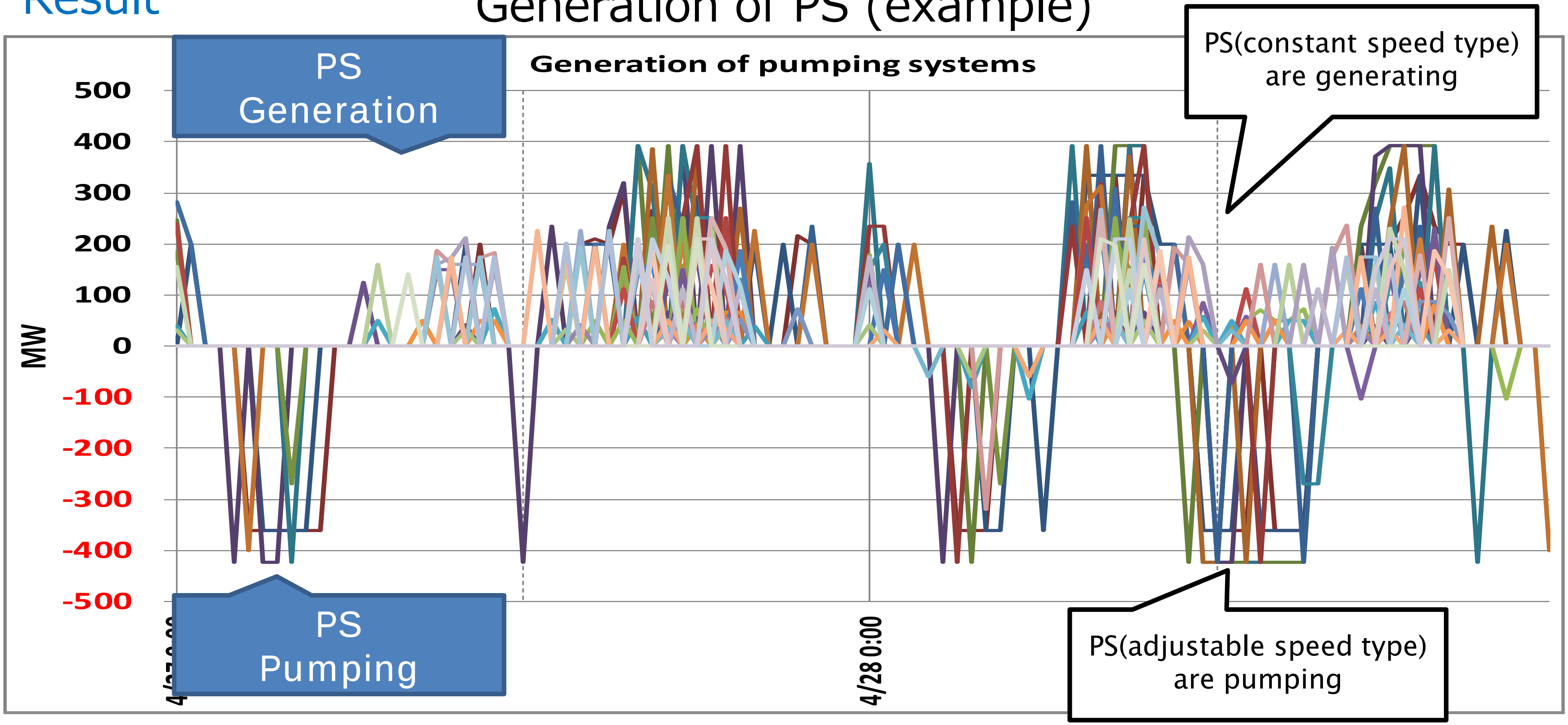
Result

Supply - demand balance (example)



Result

Generation of PS (example)



- Some PS units are generating, but the others are pumping, simultaneously, in the day time.
- At first glance, this operation is inefficient.
- This operation is better to satisfy the secondary reserve in the future operation.
    - The mode (generating or pumping) of all of the PS agrees in real operation at the moment.

❐Results

RT : Real time
ED : Economic Dispatch

Fig. A

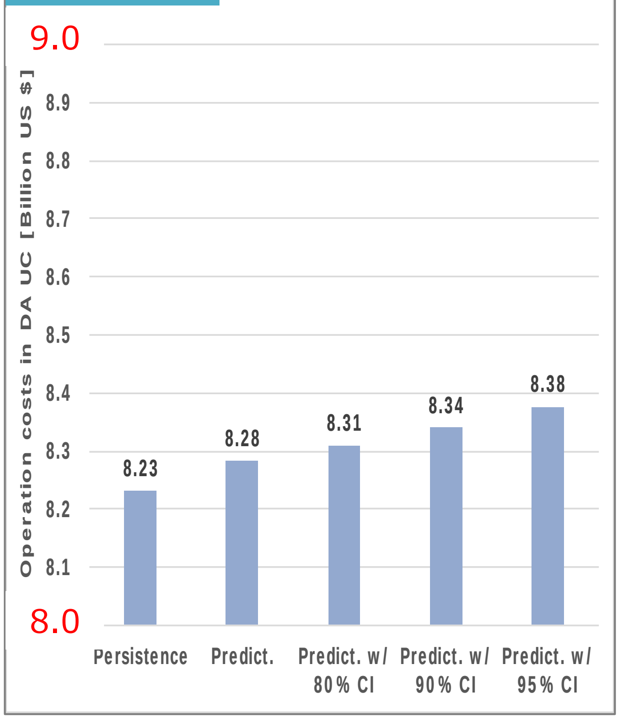


Fig. B

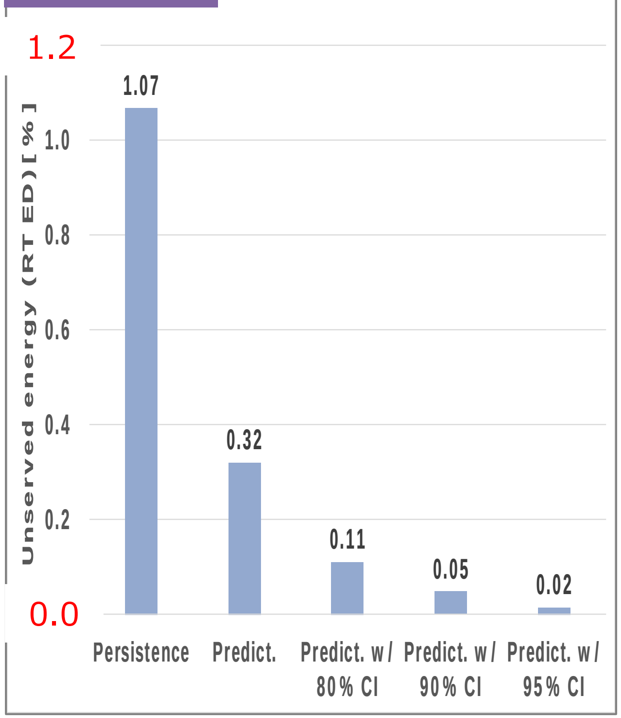
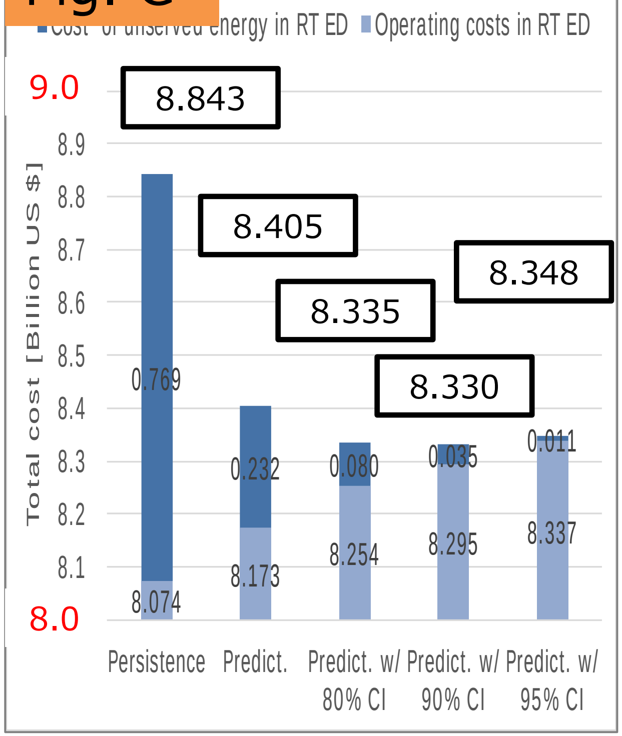


Fig. C



Operating costs in RT ED (Billion US$/year)

Unserved energy per total demand (%)

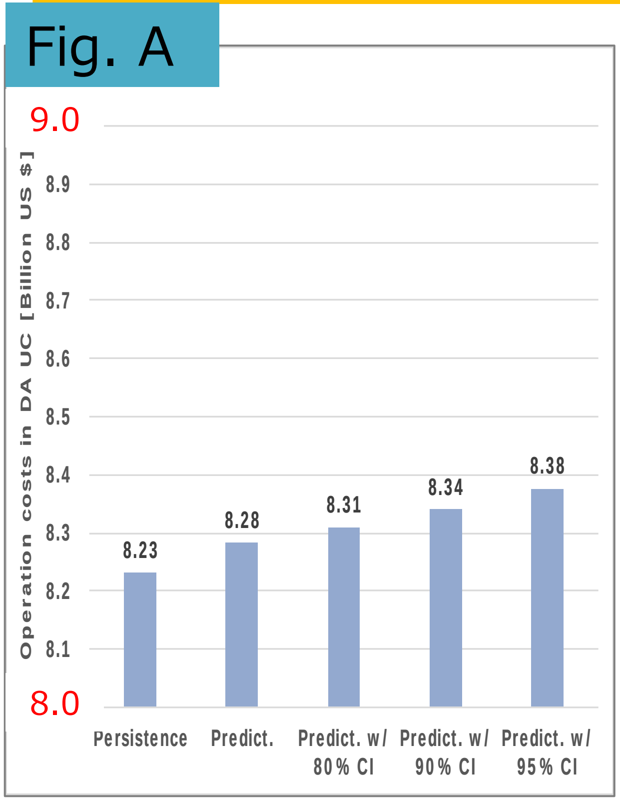
Total costs in RT ED (Billion US$/year)

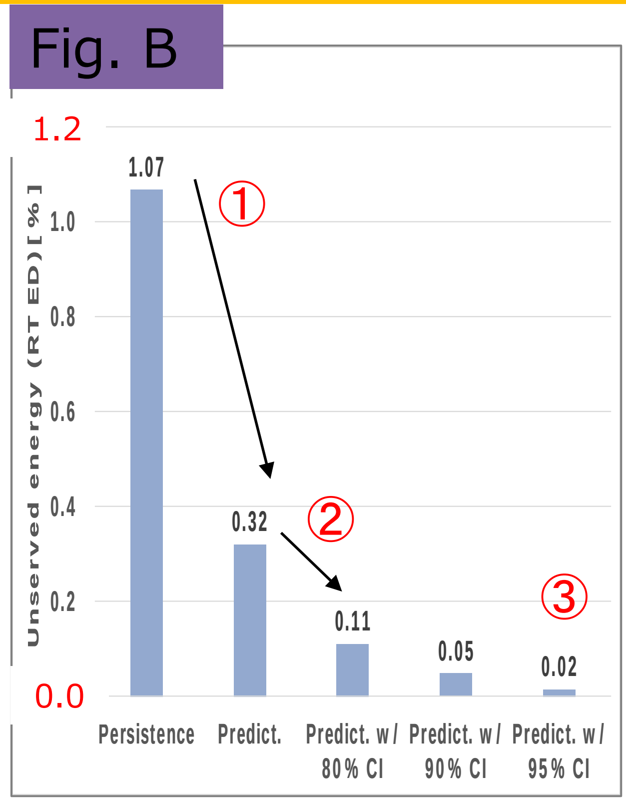
Total costs in RT ED (Fig. C) = Operating costs in RT ED (Fig. A)
+ Unserved energy (Fig. B) × cost of peak load plant (25 Cent/kWh)

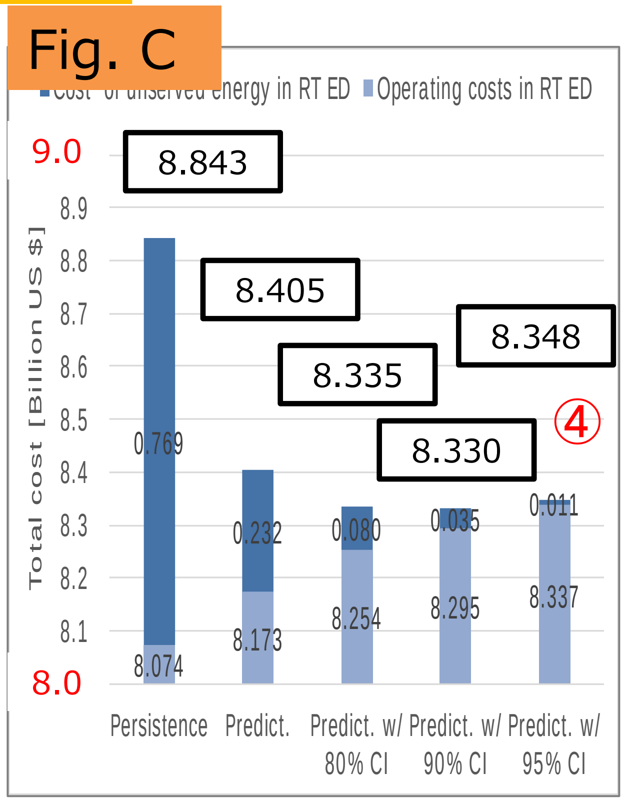
Japanese household electric bill

Results

RT : Real time
ED : Economic Dispatch







① DA PV forecasts can strongly reduce the amount of unserved energy.

② Using CI reduce the unserved energy.

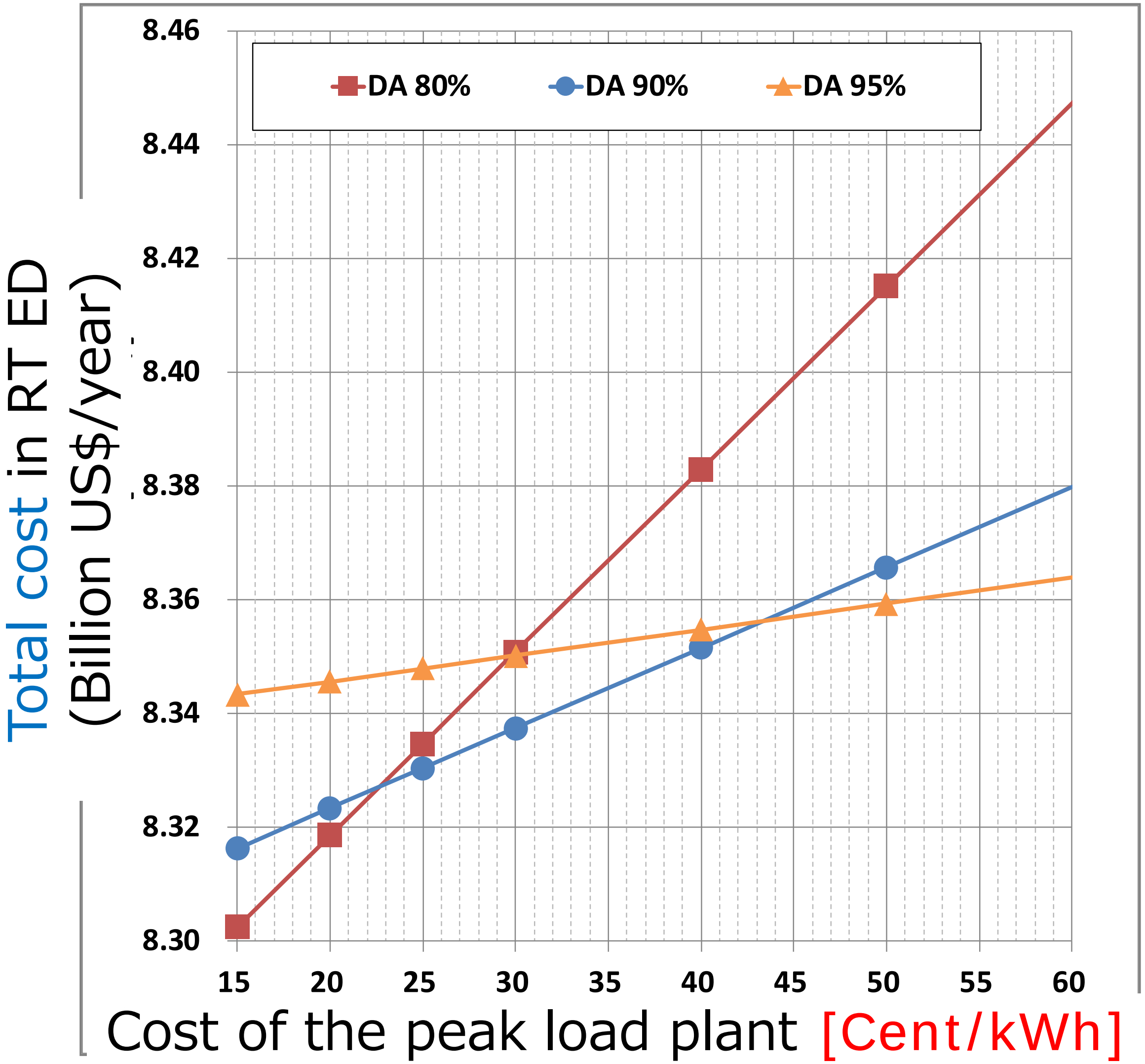
③ Even with 95% CI, 0.02% unserved energy with 41hours occurrence.

④ The lowest cost occurred in the case with 90% CI.

⑤ The order of the total costs depended on the cost of the peak load plant (next slide).

Results

Sensitivity analysis of the peak load plant



Set the cost of the peak load plant as a parameter

↓

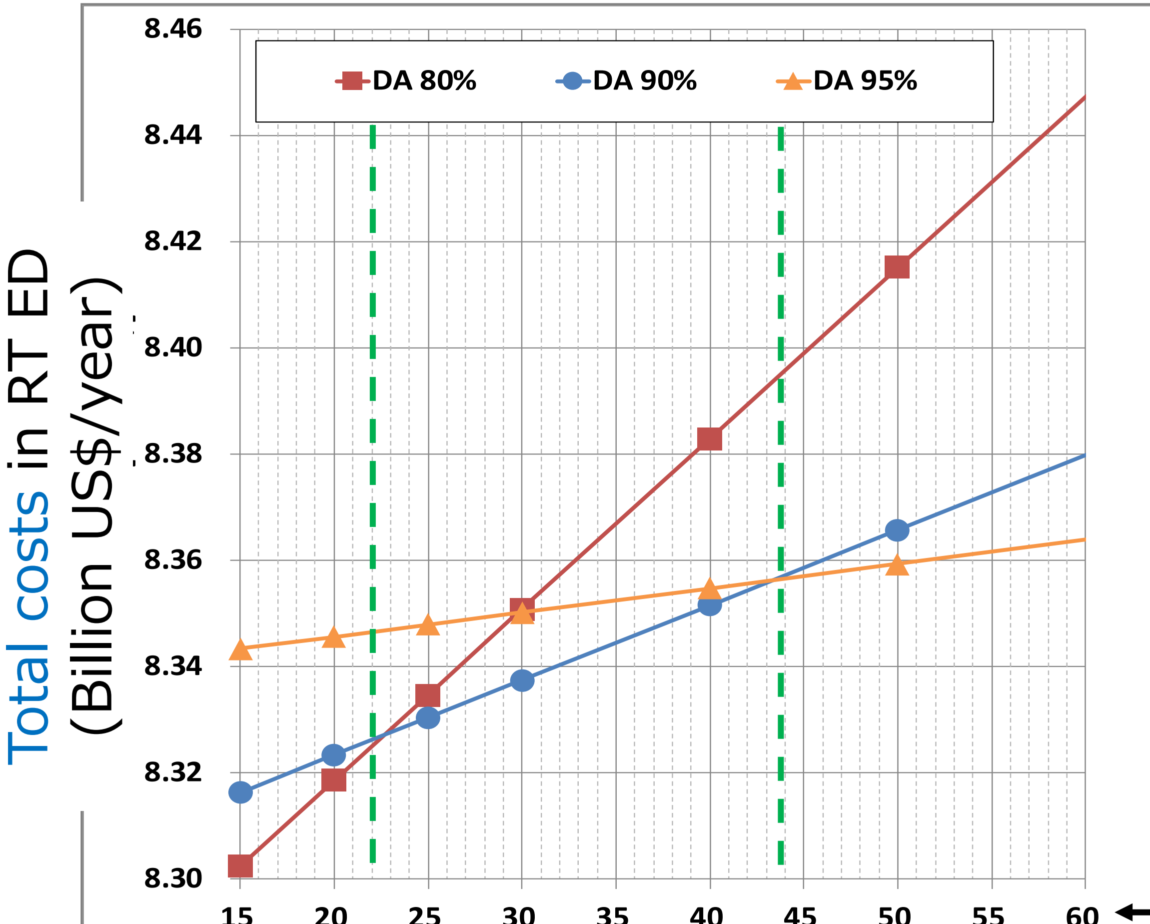
Calculate the total cost
(operating cost
+ fuel cost of peak load plant)

↓

Find the minimum cost case

Results

Sensitivity analysis of the peak load plant



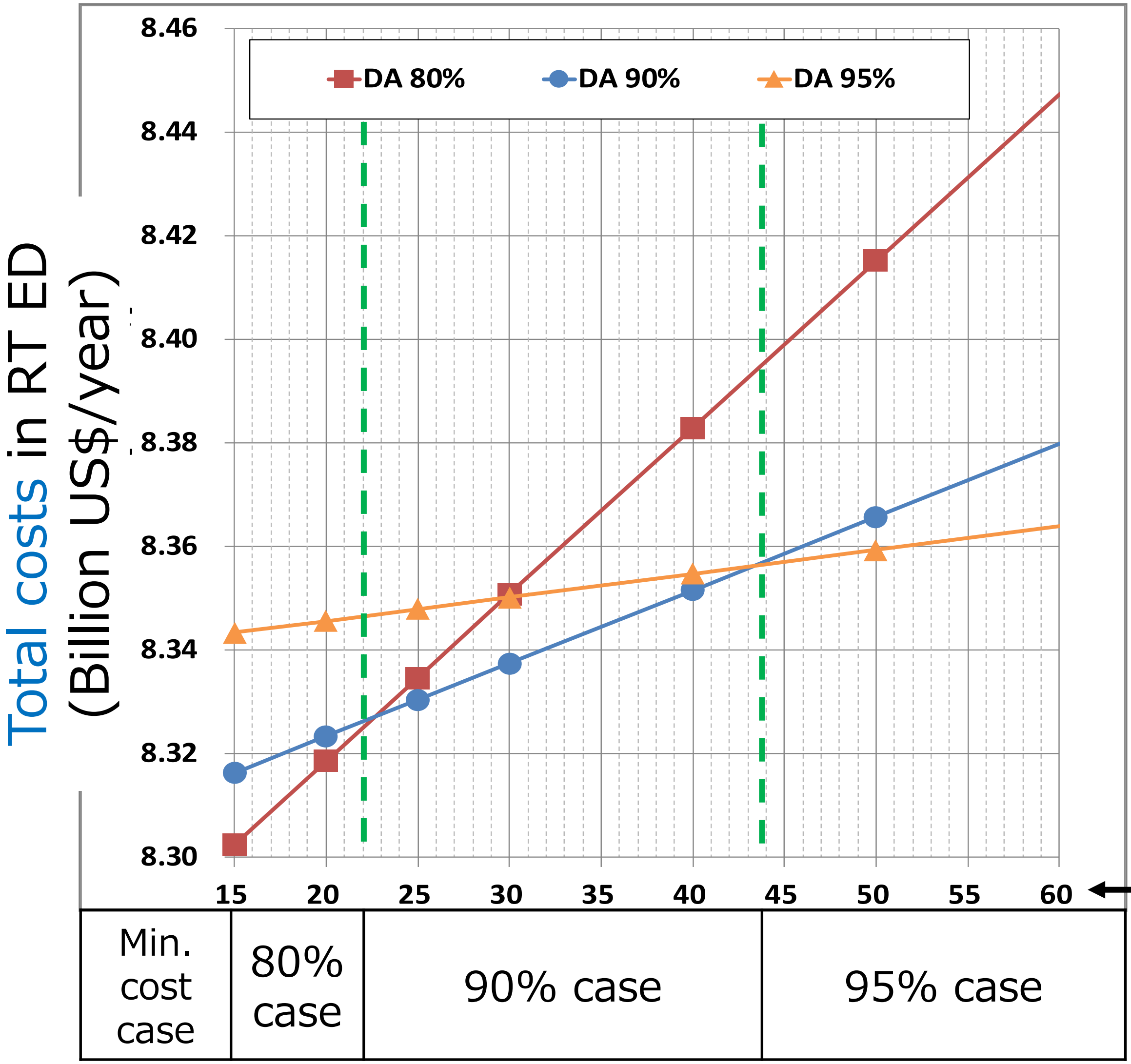
Min. cost case	80% case	90% case	95% case

Cost of the peak load plant [Cent/kWh]

- The minimum cost case changes at 22.5 Cents/kWh and 43Cents/kWh.
- The total cost is sensitive to the cost of peak load plant.
- The acceptable forecast error, CI, depends on the peak load plant.

Results

Sensitivity analysis of the peak load plant



Cost of the peak load plant [Cent/kWh]

- System operators can decide which criteria of CI is better through the market price of the peak load plant.
- The cost of peak load plant can be considered as DR costs.
- If system operators can secure the DR capacity prior to DA market, they can change the criteria of CI.

Conclusions

- We evaluated the impact of PV yield forecast error.

⇩

- DA PV yield forecasts can strongly reduce the amount of unserved energy.
- Even considering large PV yield forecast errors (95% CI), unserved energy still occur (0.02%).
  - DR is a good way to compensate a small amount of the energy shortfall.
- PV yield forecast with CI should be considered in DA UC, increasing the system reliability and decreasing the operational cost.
  - The size of CI which should be considered in DA UC can be decided through the market cost of the peak load plant and DR.
  - If system operators can secure the DR capacity prior to DA market, they can change the criteria of CI.

Conclusions

PS : Pumped Storage hydro
VRE : variable renewable energy

- We evaluated the impact of PV yield forecast error.

↓

- In the daytime, PV yield is abundant and that is stored by pumping operation of PS.
  - PS conventionally pumps water in the daytime w/o highly installed VRE.
  - In the future power system, the operation of pumped storage generators drastically changes.
    - Our results indicated that some PS units are generating, but the others are pumping, simultaneously, in the day time.
    - This operation might be better to satisfy the secondary reserve.

- As actual power systems operations are more complicated, we have to model and simulate not only day ahead UC but also intraday UC with updated PV yield and/or the other VRE sources' forecasts.

Thank you very much
for your attention!

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Motivation

Japanese power system has been changing.

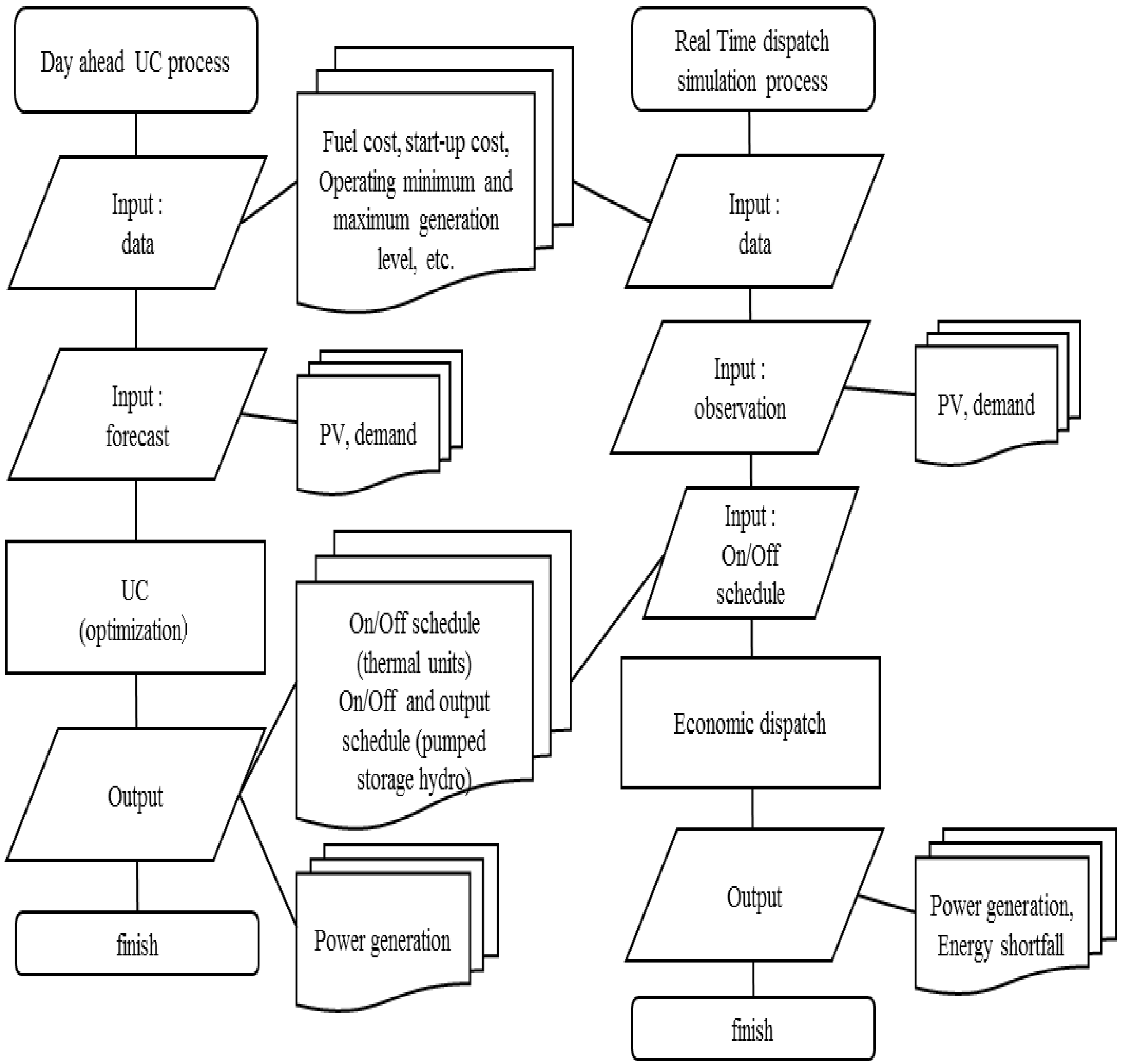
The share of VRE in overall power generation is rapidly increasing.

"Integration study" is an good analytical framework to evaluate a power system with high penetration levels of VRE.

Purpose of our study

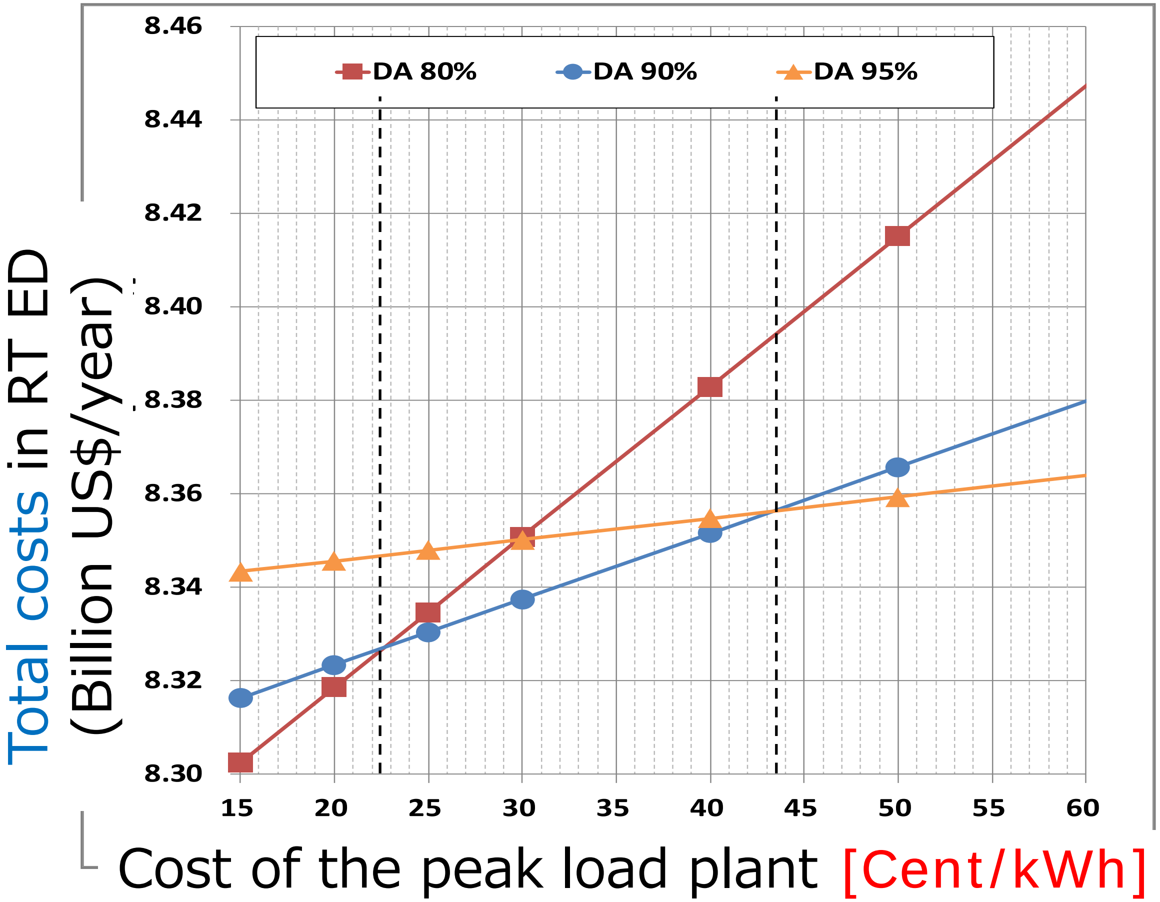
- The share of PV as VRE in overall power generation is rapidly increasing,
  1. To evaluate the impact of PV yield forecast error.
     - our project goal was to improve the forecast technology.
     - give feedback to the forecast team about the requirement from the view point of power system operating
  2. To simulate power systems operating with highly installed VRE
     - uncertainty due
     - to unexpected changes in resource availability

Methodology



Results

Sensitivity analysis of the peak load plant



- The minimum cost case changes at 22.5 JPY/kWh or 43JPY/kWh.
- The difference in the costs is sensitive to the cost of peak load plant.
- The acceptable forecast error depends on the market value (price) of peak load plant and/or DR costs.

Conclusions

揚水運用を入れる

- We evaluated the impact of PV yield forecast error.

↓

- DA PV yield forecasts can strongly reduce the amount of unserved energy.　定量的な数字を入れる

- Even considering large PV yield forecast errors (95% CI), hours with unserved energy still occur (0.02%).
  - DR is good way to compensate a small amount of the energy shortfall.

- PV yield forecast with CI should be considered in DA UC, increasing the system reliability and decreasing the operational cost. is related to the cost of the peak load plant and is sensitive of the cost.
- 予測に信頼区間をつけることは大きな価値があるが、その大きさは、市場のDR価格やピーク火力の単価が大きく効いてくる
- If system operators can secure the DR capacity prior to DA market, they can vary the criteria of CI.
- 将来的な運用として揚水が大きな役割を担う

PS：Pumped Storage hydro
ED：Economic Dispatch

Model

- Calculation process for 1-day

UC process

Input data
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