Power System Evolution

System wide issues related to massive penetration of PV in the electricity systems

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1. What will happen?
   - PV Penetration
   - Variation and Smoothing Effect of PV generation
   - Impacts on a Power System

2. How can we manage the power system?
   - Activated Demand
   - Smart Grid in Japan’s Energy Technology Strategy
   - Centralized/Decentralized Energy Management System

3. How can a power system evolve?  - analysis and planning -

4. Smart Grid R&D Activities in Japan

5. Conclusion
PV Dissemination target of Japan

What will happen?
Japan’s Energy Outlook

Under the maximum adoption scenario:
1) In addition to continued efforts to improve energy efficiency, a rapid adoption of machines and equipment that utilize the full potential of the technology will result in a decline of energy demand from its current peak.
2) The composition of energy supply is projected to become even more diversified. In the case of oil (including LPG), consumption volume will decline to just under 40% of domestic supply, while natural gas and coal will see a decline in both share and actual volume. The share of nuclear power will increase, as about nine new plants are expected to be built, and the share of new energies is projected to increase further.

If cutting-edge technology is adopted to the fullest extent, energy-origin CO2 emission volume will decline rapidly from 2005 onward;

by 2020, emissions would decrease a projected 13% versus total emissions in 2005 (down 3% versus total emissions in 1990), and by 22% versus 2005 (down 13% versus 1990) by 2030.

This level compares favorably with the EU’s target (down 14% versus 2005).

Source: METI’s Outlook for Long-Term Energy Supply and Demand
Variable Nature of PV Generation

PV generation has a variable nature due to time and changes of weather. Here, the nature is referred as “variable”, based on the understanding that it varies but is predictable to a certain extent.

Fig. 24hour PV output variation in 90days in summer

Fig. PV output variation at 14:00 in 90 days in summer
Issues of Renewable energy Integration

The penetration of the renewable energy generation such as PV and wind power will bring about the following impacts on a power system:

- Voltage fluctuation in local or distribution network
- Power flow fluctuation in local or distribution network
- Islanding
- Frequency instability due to sustained power imbalance and major supply and demand fluctuation
- Difficulty in generation scheduling
- Other power system instabilities of different time ranges
- Transmission expansion to renewable generation sites
- New generation mix

What will happen?

Today’s focus
Smoothing Effect and Voronoi Weighting method

- Total generation output of numerous PV systems in a broad is less variable in magnitude and frequency through the cancelation of each individual’s variation.

- Total PV generation can be estimated using Voronoi weighting method:

\[
H_{g_{total}} = A \cdot H_{g_a} + B \cdot H_{g_b} + C \cdot H_{g_c} + \sum Z \cdot H_{g_z}
\]

Oozeki et al: Statistical analysis of the smoothing effect for Photovoltaic systems in a large area, IEEJ Vol.130-B, No.5, pp491-pp500, 2010
Example of PV Smoothing Effect in a broad area

- The example shows the nature of PV smoothing effect.
- In order to evaluate the smoothing effect, it is necessary to accumulate the irradiation or PV generation data of many observing points in a power system for many years.

Image of Smoothing Effect

Oozeki et al: Statistical analysis of the smoothing effect for Photovoltaic systems in a large area, IEEJ Vol.130-B, No.5, pp491-pp500, 2010
Impact of PV Penetration on Demand-Supply balance

✓ The ultimate impact of PV Penetration on a power system is the difficulty of supply and demand balance.

✓ A power system is requested to keep the stability of various time range under reduced regulation capability and increased variability.

Fig. Comparison of hourly system load, PV generation, and an equivalent load on a holiday in May.
PV Penetration Impacts on Japan’s Power System

✓ In a mid-season when the original load is lowest and irradiation is maximum, the equivalent system load indicates substantial dip.

✓ In a peak load season in summer, PV reduces the system peak load. With power storage, the remaining system peak load in the evening is reduced effectively.

Equivalent system load of a 60GW model system under PV Penetration


What will happen?
What will happen in the long period

✓ In the progress to a low carbon power supply with security, the share of electricity will increase in the total end-use energy consumption.

✓ The increase of carbon-free RES, nuclear, and fossil generation will make a power system less capable to keep the supply-demand balance of power.

Necessity for additional supply-demand balancing resources

Source of figures: CoolEarth Innovative Energy technology Program
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What is a smart grid?

According to the US Energy Independence and Security Act of 2007:

The term “Smart Grid” refers to a modernization of the electricity delivery system so it monitors, protects and automatically optimizes the operation of its interconnected elements – from the central and distributed generator through the high-voltage network and distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances and other household devices.

Source: NIST Smart Grid Interoperability Standards Roadmap (2009.6)
What’s a Smart Grid?

A smart grid can be anything, but - -

- Smart grids can be anything which improves a power system including:
  - Various measures to enhance the flexibility of the existing system,
  - An East–West "Green transmission highway" to transmit electricity generated at large-scale solar or wind farms in the central US
  - Electricity transmission cables linking European marine wind farms to demand centers
  - Super-grids such as the trans-Mediterranean grid

- However, the core concept SMART GRID is to increase the power balancing capability of a power system through activating demand, or changing the shape of demand.

- The activation of demand will be realized by the harmonization of centralized/decentralized (distributed) energy management.

- The key technologies are energy management, communication between energy technologies, and controllable energy demand technologies including heat and power storage.

- Smart grids can take various forms depending on regional, social and economic conditions and energy resources of a power system, adopting a variety of technologies in different stages.
The demand-supply balance in a power system is now managed by centralized energy management using major generation units. In the future, when renewable energy generation penetrate into the system and the regulation capacity of existing units is expected to share the management of the power balancing.

Current Balancing

Balancing only w/ Battery

Balancing w/ activated demand and battery

Traditional gens offer additional regulation.

Batteries, if economically available, in appropriate locations can compensate all the demand-supply gaps.

If power system balancing can be shared by the activated demand response, the total economy and resource usage and economy should be enhanced.
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Distributed Energy Management
Home, Building, and Area Energy Management

✓ HEMS and BEMS are the appropriate hub for the autonomic and distributed energy management because they can pursue three targets of enhancement of ambient quality, economy and harmonized system demand-supply balance control with a power system.

✓ The distributed energy management autonomously control demand, energy storage and some others.  

✓ Area EMS will be effective to enhance the autonomic control capability of demand side with more resources.

✓ Area EMS enables harmonized operation between network (centralized EMS) and demand (de-centralized EMSs) to enhance total system quality.
Renewable Energy Deployment and Centralized/Decentralized Energy Management

- Centralized Energy Management
  - Optimum Load Dispatch
  - 1-day-ahead operation planning and power pricing
  - weather forecast, demand forecast

- Decentralized Energy Management
  - Optimum Controller of Appliances, Storages and DGs
  - 1-day-ahead power price or direct appliance control
  - 1-day-ahead weather and insolation forecast

- Centralized/distributed Energy Management
  - Optimum Operation
  - 1-day-ahead power price, energy demand forecast, PV generation forecast, power storage capacity, hot water storage capacity
  - 1-day-ahead scheduling of storage and operation of home appliances
  - * Ambient Quality
  - * Economy
  - * Harmonization with grid

- Dispatch Area
  - Grid Power
  - Photovoltaics
  - Other Appliances
  - Hot Water Tank
  - Battery
  - Heat Pump
  - Water Heater
  - Air Conditioner
  - EV/PHEV

- Utility
  - Specific Location
  - 1-day-ahead weather and insolation forecast
Example of HEMS Operation

- The operation of a heat pump moved from early in the morning to mid day to reduce the energy consumption and electricity fee, under the dynamic pricing reflecting the PV generation variation.

Future Buildings and communities with distributed EMS

- Harmonized cooperation with grid, in addition to energy saving and comfort
- Standardization and low pricing of distributed energy management and household information technology are the keys for dissemination.

- Establishment of optimized combination of building energy technologies, including roof top PV, roof top solar water heater, heat pump water heater, battery, various kinds of appliances
- Establishment of optimized operation control of building energy technologies
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Time-Series Load Dispatch (TSLD) Analysis

- TSLD analysis quantifies the impacts of PV penetration and evaluates the maximum possible PV penetration into a power system with/without various countermeasures.

- The countermeasures include enhancement of existing generation capability, PV generation curtailment, demand response including energy storage.

TSLD Analysis: Optimum Storage Specification for Annual system peak load reduction

✓ For an assumed 60GW system, optimum storage specification was searched for effective reduction of system peak.

✓ The identified optimum storage is 40% charge-discharge capacity and 40% storage capacity which realizes 45% peak load reduction.

✓ This means 53GW PV with 21GW storage reduce system peak load by 25GW. This evaluation needs further studies of PV generation characteristics, future load curb and so on.

Note:
100% storage capacity means maximum daily PV generation.
100% Charge-discharge capacity means maximum hourly PV generation.
(1998 weather condition)

Probabilistic Load Dispatch (PLD) Analysis

- The PLD Analysis uses an equivalent load duration curb, which convolutes original load curb with several probabilistic features of generation outages and demand fluctuation and PV variation.

- The analysis delivers the probabilistic evaluation of production cost, fuel consumption, power supply reliability indices.

How can a power system evolve?
Base case and Max. PV case in 2030

- In the base case and Max. PV case of 2030, 27 GW and 53 GW PV were added to the 241 GW supply capacity of Japan, respectively.
- The increase of 26 GW PV from base case to Max. PV case mainly reduced the generation of pumped-hydro, oil, and LNG.
- The PV penetration affects the total economy of the power system.

Table: Total power generation of 10 utilities (TWh)

<table>
<thead>
<tr>
<th>Generation Type</th>
<th>Base</th>
<th>Max. PV</th>
<th>Difference</th>
<th>Difference(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>954</td>
<td>930</td>
<td>-24</td>
<td>-2.5</td>
</tr>
<tr>
<td>Hydro</td>
<td>781</td>
<td>781</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Pump</td>
<td>173</td>
<td>149</td>
<td>-24</td>
<td>-13.8</td>
</tr>
<tr>
<td>Thermal</td>
<td>5,614</td>
<td>5,323</td>
<td>-292</td>
<td>-5.2</td>
</tr>
<tr>
<td>Coal</td>
<td>2,535</td>
<td>2,521</td>
<td>-15</td>
<td>-0.6</td>
</tr>
<tr>
<td>LNG</td>
<td>2,602</td>
<td>2,425</td>
<td>-177</td>
<td>-6.8</td>
</tr>
<tr>
<td>Oil</td>
<td>443</td>
<td>343</td>
<td>-101</td>
<td>-22.7</td>
</tr>
<tr>
<td>Geo</td>
<td>33</td>
<td>33</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Nuclear</td>
<td>4,373</td>
<td>4,386</td>
<td>14</td>
<td>0.3</td>
</tr>
<tr>
<td>Renewable and Others</td>
<td>508</td>
<td>785</td>
<td>277</td>
<td>54.5</td>
</tr>
<tr>
<td>Total</td>
<td>11,449</td>
<td>11,424</td>
<td>-25</td>
<td>-0.2</td>
</tr>
</tbody>
</table>


Fig. Image of the Load dispatch to units in summer in one grid
Probabilistic Load Dispatch Analysis of 8 years

- With the penetration of 53GW PV, the annual generation range from 57.1 TWh to 63.4 TWh according to the annual climate condition.

- With the different climate condition, the variation of PV generation affects various parts of other generation.

- These analysis suggest the optimum power system expansion plan.

Table Load Dispatch analysis (1998-2005, TWh)

<table>
<thead>
<tr>
<th>Year</th>
<th>Nuclear</th>
<th>Oil</th>
<th>Coal</th>
<th>Geo</th>
<th>LNG</th>
<th>Hydro</th>
<th>Pump</th>
<th>PV</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>437.3</td>
<td>38.0</td>
<td>247.5</td>
<td>3.1</td>
<td>232.2</td>
<td>77.9</td>
<td>5.1</td>
<td>57.1</td>
<td>1,098.2</td>
</tr>
<tr>
<td>1999</td>
<td>437.3</td>
<td>41.0</td>
<td>244.9</td>
<td>3.1</td>
<td>228.9</td>
<td>77.9</td>
<td>8.7</td>
<td>62.2</td>
<td>1,103.9</td>
</tr>
<tr>
<td>2000</td>
<td>437.3</td>
<td>37.3</td>
<td>246.9</td>
<td>3.1</td>
<td>229.9</td>
<td>77.9</td>
<td>6.8</td>
<td>61.6</td>
<td>1,100.8</td>
</tr>
<tr>
<td>2001</td>
<td>437.3</td>
<td>30.9</td>
<td>245.6</td>
<td>3.1</td>
<td>233.7</td>
<td>77.9</td>
<td>3.8</td>
<td>63.4</td>
<td>1,095.6</td>
</tr>
<tr>
<td>2002</td>
<td>437.3</td>
<td>34.4</td>
<td>246.6</td>
<td>3.1</td>
<td>231.3</td>
<td>77.9</td>
<td>6.0</td>
<td>62.0</td>
<td>1,098.6</td>
</tr>
<tr>
<td>2003</td>
<td>437.3</td>
<td>37.3</td>
<td>246.5</td>
<td>3.1</td>
<td>232.1</td>
<td>77.9</td>
<td>6.5</td>
<td>59.4</td>
<td>1,100.2</td>
</tr>
<tr>
<td>2004</td>
<td>437.3</td>
<td>33.7</td>
<td>247.1</td>
<td>3.1</td>
<td>232.4</td>
<td>77.9</td>
<td>7.2</td>
<td>62.6</td>
<td>1,101.3</td>
</tr>
<tr>
<td>2005</td>
<td>437.3</td>
<td>40.7</td>
<td>245.5</td>
<td>3.1</td>
<td>228.7</td>
<td>77.9</td>
<td>9.0</td>
<td>62.5</td>
<td>1,104.7</td>
</tr>
</tbody>
</table>

Fig. Image of the Load dispatch to units in summer in one grid

Power System Planning Analysis for PV Integration

Irradiation Data of each observation point

PV Total Generation Analysis including Smoothing Effect

PV Generation Analysis of Each Candidate Location

PV Planning of each candidate

Load Frequency Control Analysis and other analysis

Probabilistic Production Analysis using Load Duration Curve

Time series Load Dispatch Analysis using Time Series Load Curve

Generation and Transmission Expansion Analysis

Operation Cost Analysis

Operation Constraints Evaluation

System PV Expansion Planning System Reinforcement Planning

System Operation Planning System Reinforcement Planning


How can a power system evolve?
Further Analysis Tools for PV Penetration

- The time-series analysis needs various PV generation data sets which reflect a variety of irradiation characteristics and the smoothing effects.

- The existing Probabilistic Load Dispatch analysis include only the stochastic nature of generation failures and load variations assuming their time-independent characteristics.

- For enhanced operation and capacity planning under PV penetration, we need more sophisticated tools to cover the various aspects including:
  - the co-relation between load variation and PV generation variation,
  - the interaction between of centralized/decentralized EMSs, and
  - PV generation forecast and its error.
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Global Environment Research Fund, Ministry of the Environment

Autonomic cooperative energy management system to support large-scale introduction of renewable energy resources (2009-2010)

Sub-group 3: Cooperative control of distributed/central energy management

Sub-group 1: Generation forecast of renewable energy generation

Sub-group 2: Distributed autonomous energy management

Sub-group 4: Energy demand-supply analysis and planning
METI’s Smart Grid Demonstration Test by Power Utilities (2010 – 2012)

Social requirements for CO2 reduction
Tangible constraints of fossil fuels

Low-carbon power grid
Massive penetration of renewables

Possible impacts to power quality and security

Central power plants
Industrial customers

Wind turbines, Mega solar

Houses

PV

Central power plants

Perturbation

Two way power flow

PV

EV/PHEV

Battery Storage

Industrial customers

Perturbation

Vision:
Minimizing CO2 emissions and social costs
Enhancing power quality and security by making both the power grid and customers smarter

Smarter monitoring & control

Home Automation

PV

Load

Controllable load

Heat storage

Storage

Residential customer

Smart Grid R&D Activities of Japan
METI’s Smart Grid Demonstration Test
Details of a residential house
NEDO’s Smart Energy Network Demonstration Project by Gas utilities (2010 – )

Optimum distributed energy management of cogeneration and PV for the best use of power and heat utilizing ICT technologies
IEA-PVPS Task 14
High-Penetration of PV Systems in Electricity Grids”

Subtask 1: PV generation in correlation to energy demand

Subtask 2: High penetration PV in local distribution grids, and

Subtask 3: High penetration solutions for central PV generation scenarios

Subtask 4: Smart inverter technology for PV penetration

Cross-cutting subtask: Information Gathering, Analysis and Outreach

PV generation forecast of Subtask 1:and 3
CONCLUSION

- PV Penetration will bring about issues of a local and total power system.
- The smoothing effect is an important nature when considering the issues of a total power system.
- The ultimate issue of PV penetration into power system is the difficulty of power balancing under increased demand and supply variation under decreased power regulation capability.
- The core concept of the Smart Grid is the power demand activation so as to enhance the power balancing capability of a power system.
- For the demand activation, residential and commercial buildings with distributed energy management will play a crucial role through the harmonization of central and decentralized energy managements.
- The existing and additional analysis tools will be effective to analyze and plan the future power system with high PV penetration.
- Many R&D and demonstration projects of Smart Grid are going on in Japan.
- The PVPS Task 14 will be a strong hub for international cooperation for PV penetration into a power system.
Thank you
If PV generation has a co-relation with the system load through irradiance and atmospheric temperature, PV can have a capacity value to reduce the required system generation capacity.