PV Integration In Japan

Present status and future prospects of smart grid technologies for massive PV system integration

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Government’s photovoltaic installation target (2009)

- Residential: About 5.3 million houses
  - 20 times the 2005 level
  - Requiring engineering development for grid improvement
  - Working out a new purchase system

- Residential: 80%
- Non-residential: 20%

- Residential: About 320,000 houses
  - Accelerated by 3 to 4 years

- 28GW (2020)
  - 10 times the 2005 level

- 53GW (2030)
Progress of METI Demonstration Projects

March.11 The Great East Japan Earthquake

~ FY2009

Low-carbon Power Supply System Study Group

Projects started with supplementary budget of 2009

FY2010

Next-Generation Power Transmission and Distribution Network Study Group

Projects started with budget at 2010

Study Group on the Scheme for Next-Generation Power Transmission and Distribution Systems

FY2011

Demonstration projects started with the budget of 2011

FY2012

• Next Generation Power Control Systems by two-way communication
• Forecast technologies for Photovoltaic Power Generation Prediction and Estimation
• Next Generation Optimum Control of Power Transmission and Distribution Network

1. Demonstration project for the introduction of new energy into the independent Grid in an isolated island
2. Project for power stabilization at the mass introduction of new energy (Pyranometer)
3. Grid Integration Assessment of the mass introduction of new energy (Simulator by CRIEP)
Issues of Massive Integration of PV into the Grid

1. Voltage Profile Issue

Electric current from PV to distribution network
↓
Overvoltage in power distribution network

2. System Stability Issue

Fluctuation of PV output, and decrease of balancing capability
↓
Fluctuation of frequency

3. Surplus Power Issue

Massive integration of PV
↓
Surplus power during off peak demand period

Source: Report of the Next-Generation Power Transmission and Distribution Network Study Group
Cost and Curtailment by Scenario

Battery Deployment

Scenario 1
No curtailment of PV power

16.2 trillion-yen
730GWh/year

Scenario 2
All amount curtailment in singularity

3.67 trillion-yen
360GWh/year

Scenario 3
Half amount curtailment in singularity

8.54 trillion-yen
1560GWh/year

Scenario 4
Curtailment in singularity and off-peak months

1.36 trillion-yen
960GWh/year

Scenario 5
Curtailment in singularity and off-peak month with demand shift and creation

1.45 trillion-yen

Source: Report of the Low-carbon Power Supply System Study Group
Features of RE Generation Curtailment

Wind generation
• Comparatively large unit capacity, limited number of generators
• Existing curtailment control of each turbine by established control methodology

Photovoltaic Generation
• Numerous small systems of small unit capacity, owned by households
• Difficulty with direct control through existing control methodology
• Curtailment by one day-ahead scheduling
Innovative Power Grid Operation in cooperation with Customers

To increase flexibility and reduce variability

- Aggressive use of thermal, hydro and pumped-hydro power generation
- To control Renewable Energy Generation
- Demand response including new storage devices
- Transmission/Distribution System and Interconnection with neighboring power systems
- Innovative Power System Operation with all the new technologies including PV generation forecast of PV and Wind

(R&D and of other areas are going on in parallel.)
Project for Power Stabilization at the Mass Introduction of New Energy (PV300)

10 Japanese electric power companies (1) collected irradiation and PV generation data, etc. and (2) analysed Solar power output fluctuation for the 3 years from 2009 to 2011, at 321 sites all over Japan.

The fluctuating output in areas of large solar power generation was analysed by a solar power output fluctuation estimation model, and the results were released by FECP in March, 2012.

(1) Data collected regarding solar power generation output, etc.

- Pyranometer, etc. set up in 321 locations nation-wide (of these, solar power output data was taken from 116 locations)
- The data collection is continued to support the on-going project.

(2) Analysis of PV output variability fluctuation

- For the benefit of controlling the supply and demand balance for the entire electric power system, the analysis of solar power output fluctuation is classified into short-term and long-term categories.

  - **Short-term fluctuation** (load frequency control)
    - Minor fluctuation over a period of less than 20 minutes
  - **Long-term fluctuation** (economic load dispatching control)
    - Fluctuations over a period of more than 20 minutes

http://www.fepc.or.jp/about_us/pr/pdf/s2_20120420.pdf
The data analysis in the project has verified the following features of the impact of massive PV penetration.

- The smoothing effects in a broad power system reduce the variation in LFC control range (in the range within 20 minutes).
- The ramp up/down of the aggregated output of numerous PV systems.
- Continual data collection and analysis are necessary so as to understand the effects of increased PV power usage and its output fluctuations in both the short-term and long-term.

Source: material from Federation of Electric Power Companies of Japan
Three Packages of the Next Generation Power System Demonstration Projects

1. Development of voltage control technology on the distribution network
2. Development of demand and supply planning and control technology of a total power system
3. Development of control technology of Demand-side facility
4. Development of solar irradiance estimation and forecasting

Demonstration Projects for Next Generation Optimum Control of Power Transmission and Distribution Network (28 companies)

Demonstration Projects for Power Control Systems by Two-Way Communications

Research of present communication standardizations and communication security

Demonstration Projects for Next Generation Power Control Systems by Two-Way Communications (33 companies)

Development of equipment for voltage control on the distribution network

Development of control technology of Demand-side facility

Development of voltage control technology on the distribution network

Development of PCS with Two-Way communications

42 companies participate

University, Laboratories
The University of Tokyo, Tokyo institute of Technology, Waseda University, Central Research Institute of Electric Power Industry, Japan Weather Association

Manufacturers
IBM, Itochu, Itochu techno solutions, NEC, NRI Secure technologies, NTT docomo, Oki, Omron, Kandenko, KDDI, Sanyo, Sharp, Sumitomo Electric, Solar Frontier, Daikin, Takaoka Electric, TMEIC, Toshiba, Nissin Electric, Panasonic SS Japan, Panasonic SS nsfrastructure, Hitachi, Fujitsu, Fuji Electric, Mitsubishi Motors, Mitsubishi Electric, Meidensha

Electric power companies
Hokkaido, Tohoku, Tokyo, Chubu, Kansai, Hokuriku, Chugoku, Shikoku, Kyusyu, Okinawa
In order to solve problems associated with massive penetration of PV, this project is focusing on four technical issues:

- **Group1**: Allocation and control methods of voltage regulating devices
- **Group2**: High-performance voltage control devices for distribution line (small size, low cost, etc.)
- **Group3**: Control method of customer’s equipment for demand-supply balance
- **Group4**: Planning method of power grid operation and implementation in cooperation with customers

Cooperative Control of PV output & customer’s equipment according to demand-supply balance
Allocation and Control Methods of Voltage Regulating Devices

- Power utilities are continuing efforts to establish sophisticated voltage and current sensing system on the distribution system for better operation including voltage regulation.

- With the progress of PV integration into the distribution system, initial countermeasures are supposed to optimize the current autonomous control of voltage control devices. In the future, centralized real-time control will realize more effective performance of system control.

- In the project, the two types controls methods are verified digital and analog simulation.

2-1

• Large voltage drops caused by heavy electric loads.

• Short distribution line.
• 2,000 houses.
• Large voltage rising caused by reverse flow of PV.

• Long distribution line.
• Installing three SVRs.
• 1,500 houses.
• Complicated control and management.
Allocation and control methods of voltage regulating devices

Deviation from prescribed range

- PV of 3.5kW installed in 30% of residents

Control parameters optimized without considering PV Integration

Control parameters optimized using data from monitoring sensors (voltage and current)

PV of 3.5kW installed in 30% of residents
High-performance Voltage Control System for Distribution Line: STATCOM with MMC Converter

- Modular Multi-level Cascade (MMC) topology STATCOM demonstration model, capable of connecting to 6.6kV distribution grid without use of transformers, has been developed and tested to confirm its electrical characteristics.

<table>
<thead>
<tr>
<th>Items</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>300kvar</td>
</tr>
<tr>
<td>Connecting point AC voltage</td>
<td>6.6kVrms (50Hz)</td>
</tr>
<tr>
<td>Circuit topology</td>
<td>MMCC-SSBC (Modular Multilevel Cascade Converters-Single Star Bridge Cells)</td>
</tr>
<tr>
<td>Cascade number</td>
<td>4</td>
</tr>
<tr>
<td>Pulse number</td>
<td>7 pulses/cell</td>
</tr>
<tr>
<td>Limit of total Harmonic distortion</td>
<td>5%</td>
</tr>
<tr>
<td>Harmonic current limit</td>
<td>3% each</td>
</tr>
<tr>
<td>Immunity unbalanced voltage</td>
<td>&lt;5%</td>
</tr>
</tbody>
</table>

AC 6.6kV/50Hz

Circuit breaker
Incoming panel
Converter

Initial charging circuit
Reactor
Converter
Cell unit
Controller

STATCOM with MMC Converter
Operation test: The various tests to verify stable and effective operation were conducted.

1) The specified lead/lag operation for voltage control were.
2) The balancing control of cell voltages are verified.
3) The integration with no transformer and no filter were verified.
4) The each harmonic current was verified to be less than the specified 3%.

Oscillograph of 300kVar lead operation
Modular Multilevel Cascade Convertor (MMCC) for battery energy storage systems has been developed and tested to confirm its electrical characteristics.

<table>
<thead>
<tr>
<th>Items</th>
<th>Verification test equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Capacity</td>
<td>500kW</td>
</tr>
<tr>
<td>Storage energy capacity</td>
<td>200kWh</td>
</tr>
<tr>
<td>Circuit topology</td>
<td>MMCC-SSBC (Modular Multilevel Cascade Converters-Single Star Bridge Cells)</td>
</tr>
<tr>
<td>Cascade number</td>
<td>6</td>
</tr>
<tr>
<td>Capacity of unit cell</td>
<td>28kVA</td>
</tr>
<tr>
<td>DC voltage range</td>
<td>280V-380V</td>
</tr>
<tr>
<td>Output AC voltage of converter</td>
<td>1500kV</td>
</tr>
<tr>
<td>Connecting point AC voltage</td>
<td>6600V</td>
</tr>
<tr>
<td>Power device</td>
<td>IGBT 600V-600A</td>
</tr>
<tr>
<td>Device configuration of a cell</td>
<td>1S-1P-4A</td>
</tr>
</tbody>
</table>
Emergency Preset Power Switch test: The system frequency instantaneously increases from 50Hz to 51Hz, and recovers
1) The Battery system detects the over frequency of 50.5Hz and reach the full charging operation after 1.1 second of preset delay time.
2) The system detects the recovery of the frequency and execute the soft stop of 1 second after a preset delay time.
Control Method of Customers’ Equipment for Demand-Supply Balance

Schematic Image of Experimental Facilities @ The Univ. of Tokyo

- Forecasting PV generation & load demand
- Determining command for operation
- Controlling Operation of PV, Energy Devices, Home Appliances
- Collecting DATA
- Monitoring Power Consumption
- Controlling Operation of HPWS
- Storing Operation DATA
- Commanding Max PV output
- Energy Management Server
- Smart Interface
- PV/Appliances Optimum Control System

Utility Dispatching Control Center

Internet

Analysis
(DB)
Displays
(Other Universities)
Display
(Handy terminal)
Showing Status of control & operation

Main Display (Laboratory)

1F outdoor

EV
PV
(A)
PV
(B)
PV
(C)

Roof

PV output control

PLC
BlueTooth
ZigBee

Heat pump hot water supplier

Distribution Panel

Schematic Image of Experimental Facilities @ The Univ. of Tokyo
Control Method of Customers’ Equipment for Demand-Supply Balance

- PV output is regulated to be 50% of rated capacity
- Operations of HPWH and EV charge are shifted from night to day time under curtailment signal
- Increase of PV output according to the operation of a water-heater or a EV charge
The communication between Smart Interface and appliances performed stable operation.

The control system of Smart Interface (SIF) verified a stable control performance with appliances under various actual irradiation and curtailment signal conditions.

With the load shift by SIF, the requested PV curtailment is effectively avoided.

Simulation analysis verified total performance of the proposed system.

Control Method of Customers’ Equipment for Demand-Supply Balance

- By EV charge
- By HP operation
- Residual curtailment

- w/o control
- With control

PV curtailment (kWh/day)

Spring and Autumn | Summer | Winter

PV Curtailment (kWh/day)

Spring and Autumn | Summer | Winter
Planning Method of Power Grid Operation in Cooperation with Customers

- A set of simulators is developed to model the existing and new functions of operation planning and real-time system operation so as to evaluate the impact of PV integration and effectiveness of countermeasures.
Planning Method of Power Grid Operation and Implementation in Cooperation with Customers

- Day-ahead and intraday unit commitment and scheduling include PV forecast, PV curtailment and Demand shift.
- There are two kinds of dispatch control simulation, the one is for long term analysis with 5 min. time step for example one year, another for detailed governor and frequency analysis with 2 seconds time step.

![Graph](image)

- **PV generation before curtailment**
- **Gross demand before demand shift**
- **Pumped storage**: Generation with + and Pumping with -
- **Battery**: Discharge with + and Charge with -

- **PV Curtailment and Demand Shift**: Shift, from night with + and to daytime with -
The cost performance of Curtailment of PV is higher.

<table>
<thead>
<tr>
<th>Measures</th>
<th>Cost of fuel, curtailment, and battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curtailment of PV</td>
<td>5.4billion JPY – 27.5billion JPY</td>
</tr>
<tr>
<td>batteries</td>
<td>49.7billion JPY</td>
</tr>
</tbody>
</table>

The demand shift is effective.

<table>
<thead>
<tr>
<th>Measures</th>
<th>Amount of curtailment of PV</th>
</tr>
</thead>
<tbody>
<tr>
<td>With demand shift</td>
<td>231.87GWh</td>
</tr>
<tr>
<td>Without demand shift</td>
<td>250.39GWh</td>
</tr>
</tbody>
</table>
Standardization of Communications Method and Cyber Security

- Trend survey of standardization of communication method and consideration of communications security measures

Overview of Consideration for Security Measures

1. Understanding of coverage
2. Arrangement of Threat/Risk
3. Risk Assessment
4. Consideration of Countermeasure
Demonstration Projects for Next Generation Power Control Systems by Two-Way Communications

◆ Facilities constitution of the demonstration (Aomori field)
# Demonstration Project of Forecast Technologies for Photovoltaic Generation

<table>
<thead>
<tr>
<th>A week ahead for planning</th>
<th>A few day ahead for planning</th>
<th>A few hour ahead (intra-day) for operation</th>
<th>Short-term for operation</th>
<th>Real time estimation for operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numerical weather prediction (NWP)</td>
<td>NWP</td>
<td>NWP, satellite images, etc.</td>
<td>satellite images, measuring data, etc…</td>
<td>Satellite images, measuring data, Up-scaling etc…..</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Meteorological data</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Satellite imagery, AMeDAS*, etc.</td>
</tr>
</tbody>
</table>

Meteorological model

- Automated Meteorological Data Acquisition System

Irradiation Estimation/Forecast

PV power Estimation/Forecast including up-scaling methods

Verification
- Irradiation, Temperature

PV Generation

Pyranometer

PV panels

Thermometer

[Image of map with Pyranometer locations]
Demonstration Project of Forecast Technologies for Photovoltaic Generation (tentative results)

### Forecast

- **Solar radiation prediction result (May, 2011)**
  - A graph showing solar radiation prediction over time, categorized by weather class (Clear and Sunny, Very Fair, Fair, Cloudy, Rain).
  - Error of solar radiation prediction by weather class.

### Estimation

- **Solar radiation estimation**
  - A graph showing the estimated solar radiation compared to measured values.
- **Estimation Error by weather class**
  - Graphs showing error distribution by weather class (Clear and Sunny, Very Fair, Fair, Cloudy, Rain).
- **Estimation Error by month**
  - Graphs showing error distribution by month (Nov, Dec, Jan, Feb, Mar, April, May, June, July, Aug, Sept, Oct).

### Evaluation of PV generation estimation

- **RMSE (%)**
  - Graphs showing root mean square error by sites (1 through 20).
- **Forecast** vs **Estimation**
  - Comparison of estimated and measured values for solar radiation and temperature.

Several statistical measures are also provided, including correlation coefficient ($R^2$) and linear regression equation ($y = 0.9985x + 3.8456$).
Conclusion and the future prospects

• We, major Japanese entities, have been demonstrating national projects in order to establish fundamental technologies to solve the issues caused by massive integration of PV systems.

• We have been establishing various quantitative findings including the effectiveness and timing of the countermeasures against the issues.

• We will continue the demonstration test utilizing the established test facilities in the 3-year follow-up activities so as to continue to accumulate data and establish the fundamental technologies.

• For the dissemination of the smart grid technologies, verification in the actual power grids is inevitable. The further support of the Japan government and international cooperation are plausible.
Thank you