Accuracy evaluation of solar irradiance forecasting technique using a meteorological model

October 1st, 2013

Yasushi MIWA

Electric power Research & Development CENTER

Chubu Electric Power Co.,Inc.
Electric Power Companies in Japan

10 Electric Power Companies for 10 Regions

- Tokyo EPCO
- Chubu EPCO
- Chugoku EPCO
- Kyushu EPCO
- Shikoku EPCO
- Tohoku EPCO
- Hokkaido EPCO
- Hokuriku EPCO
- Kansai EPCO
- Okinawa EPCO
1. Background of Irradiance Forecasting  
   --- For Large-Scale Penetration of PV Power Generation
2. Estimation for Current Irradiance
3. Forecasting of Irradiance and Accuracy Evaluation
Background of Irradiance Forecasting
Government Targets for Solar Power Penetration

**Household: About 70%**

- Home use: About 5.3 million homes
- 28 GW (7.6 Gt)

- 14 GW (3.5 Gt)

- About 20 times more than in 2005

- Technical system development required

- Initiation of purchase system

- Initiation of subsidy scheme for residential solar power

**PV power generation is installed over widespread area**

**It is necessary to analyze how it will affect the power system**

- Residence: About 80%
- Non-residential buildings: About 20%

- Household: About 70%
- Non-Household buildings: About 30%

Reference: Ministry of Economy, Trade and Industry.
In Preparation for Large-Scale Penetration of PV Power Generation

- The variation of PV power generation brings about the issue of power quality.
- Therefore, research is conducted in order to maintain the power quality.

<table>
<thead>
<tr>
<th>Demonstration project</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>• To be stable frequency</td>
<td>Accumulation/Analysis of PV generation data</td>
<td>Forecast / estimate of PV power Variation</td>
<td>Micro-grid demonstration project in islands</td>
<td>Power system simulator</td>
<td>Development of technology for demand-supply balance</td>
</tr>
<tr>
<td>• Surplus electric power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Participants of 3 next generation demonstration projects

- Development of voltage control technology on the distribution network
- Development of control technology of Demand-side facility
- Development of demand and supply planning and control technology of a total power system
- Development of equipment for voltage control on the distribution network
- Research of present communication standardizations and communication security
- Development of control technology of Demand-side facility
- Research of present communication standardizations and communication security
- Development of demand and supply planning and control technology of a total power system
- Development of equipment for voltage control on the distribution network

**Demonstration Projects for Power Control Systems by Two-Way Communications**

- Development of PCS with Two-Way communications
- Demonstration Projects for Next Generation Power Control Systems by Two-Way Communications (33 companies)

**Demonstration Projects for Next Generation Optimum Control of Power Transmission and Distribution Network**

- Development of PCS with Two-Way communications
- Demonstration Projects for Power Control Systems by Two-Way Communications (33 companies)

**Demonstration Projects for Next Generation Optimum Control of Power Transmission and Distribution Network**

- Development of PCS with Two-Way communications
- Demonstration Projects for Power Control Systems by Two-Way Communications (33 companies)

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
- Electric power companies: Hokkaido, Tohoku, Tokyo, Chubu, Kansai, Hokuriku, Chugoku, Shikoku, Kyushu, Okinawa

© 2013 Chubu Electric Power Co., Inc. All rights reserved.
In order to analyze variations in PV power generation, pyranometers, etc. were placed for measure & accumulate the solar irradiance data.

- **Time-synchronized data** is measured every 10 seconds.

- Pyranometers were placed at 321 points.
- Among them, PV power generation data is also measured at 116 points.
Smoothing Effect on long term variation

Although short term variation in solar irradiance are smaller, there is a **significant change in solar irradiance** due to the change in weather.

Weather condition in Nagoya
Sunny then rainy

Average solar irradiance of 42 points

- ●: Pyranometer measuring point
- ■: Waveform measuring point

© 2013 Chubu Electric Power Co., Inc. All rights reserved.
Impact on demand-supply balance due to large-scale penetration of PV

◆ When forecasted value of PV generation was overestimated, Electric Power Companies have to supply from their traditional supply source... Thermal, Hydro, etc.

◆ Or, Would Renewable Energy supplier apply energy storage for their RAMP? Or would Energy Storage Service be viable?

◆ Electric Power Companies would like to know how much they had to prepare their resources from the forecasted PV generation.

◆ Current PV generation is also essential for power system operation.
## Generation planning & PV generation Forecast & Estimation

### Generation Planning

<table>
<thead>
<tr>
<th>Six Days before</th>
<th>Five Days before</th>
<th>Four Days before</th>
<th>Three Days before</th>
<th>Two days before</th>
<th>Previous day</th>
<th>The Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekly ahead planning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Day ahead planning</td>
</tr>
<tr>
<td>Hour ahead planning &amp; operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Predictive operation</td>
</tr>
<tr>
<td>Real time operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Photovoltaic Generation Forecast & Estimation

<table>
<thead>
<tr>
<th>Six Days before</th>
<th>Five Days before</th>
<th>Four Days before</th>
<th>Three Days before</th>
<th>Two days before</th>
<th>Previous day</th>
<th>The Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekly ahead forecast</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Day ahead forecast</td>
</tr>
<tr>
<td>Hour ahead forecast</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>short-term forecast</td>
</tr>
<tr>
<td>Real time estimation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Estimation for Current Irradiance
Approach to estimate for current solar irradiance

Estimate current solar irradiance using meteorological satellite

Meteorological satellite → solar irradiance

Solar irradiance observation data → GPS precipitable water

Reference: JMA http://www.jma.go.jp/

Data source JWA

Caution: These figures are for different day
Correlation between measured and estimated irradiation

<table>
<thead>
<tr>
<th>Correlation factor</th>
<th># of mesh</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;0.9</td>
<td>213,934</td>
<td>56.7%</td>
</tr>
<tr>
<td>&gt;0.8</td>
<td>347,238</td>
<td>92.0%</td>
</tr>
<tr>
<td>Total</td>
<td>377,443</td>
<td>100%</td>
</tr>
</tbody>
</table>

- Good estimation Except northern area, small islands.
- There are Fewer households in those area, less PV, smaller impact on amount of PV generation.
Nagoya --- One of the Largest City Area in Japan

Nagoya is picked up for evaluation, estimate & forecast of Irradiation
In July and August, higher RMSE were found because of higher Irradiation during the summer in Japan.

In May and June, lower RMSE were found due to the rainy season in Japan, which give lower irradiation.
Accuracy of Estimation for Current Irradiation (hourly)

- At noon (12-15), higher RMSE were found because of higher Irradiation during the daytime. (Similar to the irradiation at the top of atmosphere)
- City Center of Nagoya, City area of Nagoya is almost same RMSE, also, West of AICHI area, which is wider than City area of Nagoya, shows higher RMSE, due to the higher density of Irradiation measuring in City center and City area than in West of AICHI area.
Forecasting of Irradiance and Accuracy Evaluation

7 days forecast of Irradiance

1st day, 2nd day, 3rd day, 4th day, 5th day, 6th day, 7th day

7 days forecast of Irradiance
Approach to forecast for solar irradiance

Weekly, Day-ahead solar irradiance forecasts using weather forecasting model

GSM data from JMA

Improvement of weather forecasting model to estimate for solar irradiance

Reference
GSM : Japan Meteorological Agency (JMA) http://www.jma.go.jp/
Solar irradiance : Japan Weather Association (JWA)

Caution : These figures are for different day
RMSE & ME of Forecast of Irradiation (monthly)

RMSE depends on season, higher Irradiation in Summer (Jun. Jul. Aug)
RMSE & ME on Forecast of Irradiation (by weather conditions)

Day Ahead Forecast

Hour ahead Forecast

Higher RMSE at Cloudy, Rainy days, compare to Clear & Fine days
Error Variance of Forecast of Irradiation (monthly)

- Larger variance for Day ahead Forecast, than Hour ahead Forecast
Error Variance of forecast of Irradiation
(by weather conditions)

Day Ahead Forecast

Hour ahead Forecast

- Lower Actual Irradiation on Cloudy & Rainy days, even Higher Forecast Irradiation
Reliability of Forecast of Irradiation

Ex. of Reliability of Forecast of Irradiation (at Nagoya area)

- Reliability Range of Forecast of Irradiation is deeply depending on the day, season, weather conditions.
- Further Study on Reliability Range of Forecast of Irradiation is required.
Thank you
Additional Slides
Error Variance of forecast of Irradiation (by Time)

Day Ahead Forecast

Today's Forecast

Higher ME at 9-15, due to high Irradiation at noon
3 different methodology applied for Irradiation Forecast in the Project. In Jun. Higher ME were found due to Rainy Season.
Error Variance of forecast of Irradiation (by Time)

Relatively small difference between in the morning, noon, afternoon at ME

Each methodology (JWA, denken, CTC) has its own character
Error Variance of forecast of Irradiation (by weather conditions)

ME depends on weather conditions
3 methodologies also depends on weather conditions.
Weather Conditions Must consider at Forecasting of Irradiation
Point for changing Time Scale
About "Accumulation/Analysis of PV generation data (PV300)"

Ministry of Economy, Trade and Industry project
From 2009 To 2011 (3 Years)

R&D Items

① Accumulation of PV generation data
② Analysis of PV power variation

Project organization

- Hokkaido Electric Power Co., Inc.
- Tohoku Electric Power Co., Inc.
- Tokyo Electric Power Co., Inc.
- Chubu Electric Power Co., Inc.
- Hokuriku Electric Power Co., Inc.
- Kansai Electric Power Co., Inc.
- Chugoku Electric Power Co., Inc.
- Shikoku Electric Power Co., Inc.
- Kyushu Electric Power Co., Inc.
- Okinawa Electric Power Co., Inc.
In Preparation for Large-Scale Penetration of PV Power Generation

Measuring equipment

Basic system

- Horizontal pyranometer
- Thermometer

PV power measuring system

- Horizontal pyranometer
- Thermometer
- Inclined pyranometer
- PV panel
Characteristics of Weather and PV power variation

Sunny without cloud

Sunny with cloud

Rainy

Bell curve with little variation

PV power vary when clouds pass by

Little power with little variation
Smoothing Effect on short term variation

Variation in solar irradiance from movements of small clouds differ in every location. So if the variation is large in every point, the total variation of multiple locations becomes small. It is called “smoothing effect” and is observed by these data.

Average solar irradiance of 42 points

Weather condition in Nagoya
Sunny (cloud cover: 2-6)
Characteristics of Weather and PV power Variation

Sunny then Rainy (or cloudy)

PV power changes according to changes in weather
PV generation forecasting technology from the perspective of Power System Operation
Requirements for PV generation forecasting

Generator power must be controlled depending on the changes of PV generation.

The "The Demonstration Project of Forecast Technologies for Photovoltaic Generation (METI project)" has been in place since 2011.
Requirements for PV generation forecasting

① Current PV power

② When PV power will change.

③ How much PV power will change.
Approach to estimate for PV power

Estimate for PV power variation

**Input**
- Solar irradiance
- Temperature

**Convert Tool** (Computer)

**Output**
- PV Power

Additional information:
- Installed place
- Rated value of PV, PCS
- Front direction of PV
- Longitude and latitude of PV
- Type of PV panel (e.g., crystalline CIS)
- Efficiency of PCS

Considering these information need or not
Ex. Results of forecasted solar irradiance

Day-ahead forecasts May / 2011

Measurement : Average of 42 points within a radius of 200km
Forecast : By Japan Weather Association (JWA)
Ex. Results of forecasted solar irradiance

Month (11/2010 - 10/2011)

The results vary in months?
The results depend on extra-terrestrial solar irradiance?

Data source: Japan Weather Association (JWA)
Ex. Results of forecasted solar irradiance

Weather (11/2010 - 10/2011)

The results also depend on weather

Data source: Japan Weather Association (JWA)
Ex. Results of forecasted solar irradiance

Weather (11/2010 - 10/2011)

We are checking using percentile
- Plus error or Minus error
- Range of forecasted error
- There are terrible error or not

Data source: Japan Weather Association (JWA)

Now we improve forecasting quality
Power Demand-Supply Balance for changes of PV Power Generation

• In order to provide a stable power supply, the power generation (supply) of generator (thermal, etc.) is finely adjusted according to changes in demand to maintain a certain frequency.

• If the demand-supply balance is lost, the frequency changes, resulting in problems such as abnormal operation of electrical equipment.

• It is also necessary to maintain balance by controlling the thermal power generations, etc., in response to changes in the power of PV generation.
Results of forecasted solar irradiance

Weather (11/2010 - 10/2011)

Data source: Japan Weather Association (JWA)

We are checking using percentile
• Plus error or Minus error
• Range of forecasted error
• There are terrible error or not
In Preparation for Large-Scale Penetration of PV Power Generation

- The variation of PV power generation brings about the issue of power quality.
- Therefore, research is conducted in order to maintain the power quality.

<table>
<thead>
<tr>
<th>Demonstration project</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accumulation/Analysis of PV generation data</td>
<td></td>
<td>Forecast / estimate of PV power Variation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Micro-grid demonstration project in islands</td>
<td></td>
<td>Power system simulator</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Development of technology for demand-supply balance</td>
<td></td>
<td>Smart power system technology</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Forecasting of Irradiation -- Time Scale

<table>
<thead>
<tr>
<th></th>
<th>Forecasting of Irradiation</th>
<th>Generation planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekly</td>
<td>Every 30 min in 168 hours+</td>
<td>(same as on the left)</td>
</tr>
<tr>
<td>Day ahead</td>
<td>Every 30 min in 24 hours+</td>
<td>(same as on the left)</td>
</tr>
<tr>
<td>Today</td>
<td>Every 30 min for today</td>
<td>(same as on the left)</td>
</tr>
<tr>
<td>hourly</td>
<td>Every 30 min for next few hours</td>
<td>(Commitment/ELD)</td>
</tr>
<tr>
<td>minutely</td>
<td>Next Few minutes</td>
<td>(Governor Free/ELD)</td>
</tr>
</tbody>
</table>
Participants of 3 next generation demonstration projects

- Development of voltage control technology on the distribution network
- Development of demand and supply planning and control technology of a total power system
- Development of control technology of demand-side facility
- Development of equipment for voltage control on the distribution network
- Research of present communication standardizations and communication security
- Analysis of solar irradiance
- Development of solar irradiance estimation and forecasting
- Development of PV generation estimation
- Development of PCS with Two-way communications
- Demonstration projects for power control systems by two way communications
- Demonstration Projects for Next Generation Optimum Control of Power Transmission and Distribution Network (28 companies)
- Demonstration Projects for Next Generation Power Control Systems by Two-Way Communications (33 companies)
- Demonstration Projects of forecast technologies for photovoltaic generation (17 companies)

**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 technosolutions, NEC, NRI secure technologies, NTT docomo, Omron, Kandenko, KDDI, Sanyo, Sharp, Sumitomo Electric, Solar Frontier, Daikin, Takaoka Electric, TMEIC, Toshiba, Nissin Electric, Panasonic SS Japan, Panasonic SS infrastructure, Hitachi, Fujitsu, Fuji Electric, Mitsubishi Motors, Mitsubishi Electric, Meidensha
- **Electric Power companies**
Hokkaido, Tohoku, Tokyo, Chubu, Kansai, Hokuriku, Chugoku, Shikoku, Kyusyu, Okinawa
About "The Demonstration Project of Forecast Technologies for Photovoltaic Generation"

R&D Items

Ministry of Economy, Trade and Industry project
From 2011 To 2013 (3 Years)

1. PV generation estimation methodology
2. PV generation forecast methodology

Project organization

- The University of Tokyo
  Prof. Kazuhiko OGIMOTO (Project Leader)
- ITOCHU Techno-Solutions Corporation
- Solar Frontier K.K.
- Japan Weather Association
- Hitachi, Ltd.
- Mitsubishi Electric Corporation
- Central Research Institute of Electric Power Industry
- Hokkaido Electric Power Co., Inc.
- Tohoku Electric Power Co., Inc.
- Tokyo Electric Power Co., Inc.
- Chubu Electric Power Co., Inc.
- Hokuriku Electric Power Co., Inc.
- Kansai Electric Power Co., Inc.
- Chugoku Electric Power Co., Inc.
- Shikoku Electric Power Co., Inc.
- Kyushu Electric Power Co., Inc.
- Okinawa Electric Power Co., Inc.