EVALUATION OF VERIFICATION TEST RESULT IN HOKUTO MEGA-SOLAR PROJECT

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3. DEVELOPING ITEMS AND SOME RESULTS
   3.1 LARGE-SCALE PCS
   3.2 PV MODULE
4. CONCLUSIONS
Solar generation systems are one of the measures for reducing global warming.

An installed capacity target of solar generation systems in our country will be set 53GW in 2030.


The verification tests are carried out in two sites of Hokuto City, Yamanashi Prefecture and Wakkanai City, Hokkaido.

The outlines and the evaluation test results so far in the Hokuto Mega-solar project are introduced.
Installed capacity and its target

Cited:
http://www.jema-net.or.jp/Japanese/sinsyou/sinene/taiyo/mokuhyou.htm
www.fepc.or.jp/future/new_energy/jisseki/index.html
Location of HMP

Mega-solar PS

- Installed capacity: nearly 2MW
- Area: 95,656m²
- Developing period: 2006-2010
- Location: Hokuto city, Yamanashi Prefecture

Hokuto City
- Birth: March 2006
- Population: 50,000 people
- Area: 602.89km²
- Feature:
  Longest irradiation time in Japan
  Sightseeing and agriculture

Yatsugatake mountains

1st stage(600kW)
2nd stage(1,200kW)
3rd stage(40kW)
System configuration of HMP
Hokuto site bird's-eye view

(Photography 2009.3.16)
24 kinds of PV modules in 1st stage
### Table 1 Specifications and developing targets of 400kW PCS

<table>
<thead>
<tr>
<th>Capacity</th>
<th>400kW/420kVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC voltage</td>
<td>420Vac±10%</td>
</tr>
<tr>
<td>Insulation</td>
<td>Transformerless, Non-insulation</td>
</tr>
<tr>
<td>Max. permissible DC voltage</td>
<td>600Vdc</td>
</tr>
<tr>
<td>Input DC voltage</td>
<td>230-600Vdc</td>
</tr>
<tr>
<td>Switching freq.</td>
<td>4 kHz</td>
</tr>
<tr>
<td>Conversion efficiency</td>
<td>&gt; 95% from 30-100% output</td>
</tr>
<tr>
<td>Control functions</td>
<td>/ MPPT by choppers</td>
</tr>
<tr>
<td></td>
<td>/ Suppression of ΔVac ( \leq 2% )</td>
</tr>
<tr>
<td></td>
<td>/ Low voltage ride-through ( \geq 60%, \text{within 200ms} )</td>
</tr>
<tr>
<td></td>
<td>/ Suppression of low-order harmonics ( \leq 80%\text{of the guide-line} )</td>
</tr>
</tbody>
</table>
Operating system of PCS

Integrated operation system of PCS

Individual operation system of PCS
Table 2 Comparison of Po calculation considering PCS efficiency and PV generation distribution

<table>
<thead>
<tr>
<th>Operating system</th>
<th>Individual</th>
<th>Integrated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional PCS</td>
<td>PCS under development</td>
</tr>
<tr>
<td>Po (%)</td>
<td>91.7</td>
<td>95.6</td>
</tr>
</tbody>
</table>

Where \[ Po = \sum_k (\eta_k \times P_k) \]  \hspace{1cm} (1)

\( \eta_k \): Efficiency of PCS in band k
\( P_k \): Distribution in band k
\( k \): band of PV generation distribution

Selected due to Simple operation and configuration

Selected due to Simple operation and configuration

PV generation distribution in Kofu city
Detection method for DC grounding fault

ELB: Electric leakage breaker

420V/6.6kV

Grounding switch

Grounding resister
Voltage fluctuation suppression

AC grid

Connecting point

66kV/6.6kV

640kW feeder

6.6kV/420V

Evaluating point

M/M system

1200kW feeder

640kW PV system
(10kW PCS x 64)

/ Measuring V,P,Q at measuring point every 1s(Sampling time)
/ M/M: Measuring/Monitoring system

1200kW PV system
(400kW PCS x 3)

P, Q, V at evaluating point (18 Feb. 2010)

P(kW), Q(kVAr)

V

Q

P

ΔV due to PV ≤ 0.2%

Q/P ≈ 0.19

ΔP=55%
<table>
<thead>
<tr>
<th>Test conditions</th>
<th>Positive sequence voltage [pu]</th>
<th>PCS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Conventional</td>
</tr>
<tr>
<td>Extra high voltage line fault</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1LG</td>
<td>0.72</td>
<td>Stop</td>
</tr>
<tr>
<td>2LG</td>
<td>0.38</td>
<td>Stop</td>
</tr>
<tr>
<td>3LG</td>
<td>0.34</td>
<td>Stop</td>
</tr>
<tr>
<td>Distribution line fault</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2LS</td>
<td>0.50</td>
<td>Stop</td>
</tr>
<tr>
<td>3LS</td>
<td>0.47</td>
<td>Stop</td>
</tr>
</tbody>
</table>

LG: Line grounded fault, LS: Line shorted fault,
Fig. 3 PCS continuous operation test

(a) Digital simulation

(b) Miniature model

Phase voltage at connecting point of grid [pu]

Positive sequence phase voltage [pu]

PCS current [pu]

DC voltage [pu]

Decrease in current

2LG  $\div 200\text{ms}$

2LG  $\div 200\text{ms}$

0.45pu

1.36pu

0.42pu

200ms

200ms

Fig. 3 PCS continuous operation test
80% of permissible harmonics current of guideline

* Phase a, b, c
* 420kVA, 420V base

(a) Harmonics current of 420V AC line

(b) Harmonics voltage of 420V AC line

Fig. 4 Acceptance tests at the factory of harmonics of 400kW PCS
Harmonics current

No harmonics current occurrence can be seen from the PCS

(18 Feb. 2010)
Test in Shaded Module

- Make partial shadow to simulate module trouble in order of string No. 1 to No. 6.
- Measure a string current and voltage / PV generation.
- Compare it with a system of the same kind.

- Layout of Object array: Sanyo HIT 10kW system

  - No. of series: 9 modules/String
  - No. of parallel: 6 strings/Array

Modules and strings layout (below figure):

![Diagram of module layout](image)
### Test Result

**Without shading**

- **Shaded string 1:** Output \( \Rightarrow 0.78\% \)
- **Shaded string 2:** Output \( \Rightarrow 0.83\% \)
- **Shaded string 3:** Output \( \Rightarrow 0.89\% \)

**With shading**

- **2 modules shaded:**
  - Series No. of modules: \((7/9 \times 310) \times 5 \times 6\)
  - PCS input voltage: \(310 \times 5 \times 5\)
  - String current: \(310 \times 5 \times 5\)
  - Output: \((8/9 \times 310) \times 5 \times 6\)

### Graphs

**Graph 1:**
- **PCS input power**
- **The same PCS input for with and without shading**
- **With shading:**

**Graph 2:**
- **PCS input voltage**
- **One module shading**
- **Shaded string:**

### Table

<table>
<thead>
<tr>
<th>Series No. of modules</th>
<th>PCS input voltage</th>
<th>String current</th>
</tr>
</thead>
<tbody>
<tr>
<td>((7/9 \times 310) \times 5 \times 6)</td>
<td>(310 \times 5 \times 5)</td>
<td>(310 \times 5 \times 5)</td>
</tr>
</tbody>
</table>
**Selected advanced type PV modules and system**

<table>
<thead>
<tr>
<th>Classification</th>
<th>Manufacture</th>
<th>Installed Capacity (kW)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mono-crystal Si</td>
<td>Sharp</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sanyo</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Isofoton</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GE-Energy</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sun Power</td>
<td>50/10</td>
<td>Back contact(210W/315W)</td>
</tr>
<tr>
<td></td>
<td>Suntech</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Poly-crystal Si</td>
<td>Sharp</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kyocera</td>
<td>110/10</td>
<td>Normal/Back contact</td>
</tr>
<tr>
<td></td>
<td>Mitsubishi</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sun tech</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Day4Energy</td>
<td>30</td>
<td>No bus-bar</td>
</tr>
<tr>
<td>a- Si</td>
<td>Kaneka</td>
<td>30/10</td>
<td>Single layer/Tandem</td>
</tr>
<tr>
<td></td>
<td>Fuji Electric</td>
<td>10</td>
<td>Film</td>
</tr>
<tr>
<td>Spherical</td>
<td>SST</td>
<td>20</td>
<td>Spherical concentrating</td>
</tr>
<tr>
<td>Ribbon Type</td>
<td>Schott Solar</td>
<td>30</td>
<td>Ribbon processing</td>
</tr>
<tr>
<td>Cl(G)S</td>
<td>Showa Shell</td>
<td>30</td>
<td>Compound Semiconductor</td>
</tr>
<tr>
<td>Tracking</td>
<td>Sharp</td>
<td>3</td>
<td>Concentrating &amp; tracking</td>
</tr>
</tbody>
</table>
Supporting structure of PV module

- Steel pipe
- Screwed pipe
- Joint fitting

Input energy ⇒ -20%
CO2 emission ⇒ -40%
Configuration of measuring/monitoring system

- Partly dual system
- Separation of measuring sys. and monitoring sys.
- Local and remote operation
- Time synchronization

Characteristics

**Tokyo terminal**

**Yamanashi terminal**

**Mobile PC**

**Internet**

**TCP/IP**

**Monitoring server**

**Measuring server**

**PCS monitoring server**

**Individual PV measuring server**

**Hokuto site**

**Weather measurement**

**GPS**

**NW camera**

**PVs**

**PCS**

**Module evaluation terminal**
# Items of measuring/monitoring system (1\textsuperscript{st} stage)

<table>
<thead>
<tr>
<th>Measuring/monitoring items</th>
<th>Number of M/M points</th>
<th>Sampling time (s)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC voltage of PV array</td>
<td>70</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>DC current of PV array</td>
<td>70</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Generation output power of PV array</td>
<td>70</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>PCS input/output power</td>
<td>2x70</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Harmonics voltage/current</td>
<td>2x70</td>
<td>60</td>
<td>Fundamental - 63\textsuperscript{rd}</td>
</tr>
<tr>
<td>AC voltage/current</td>
<td>2x4</td>
<td>6</td>
<td>210V/420V/6.6kV/66kV</td>
</tr>
<tr>
<td>Active /reactive power</td>
<td>2x4</td>
<td>6</td>
<td>↑</td>
</tr>
<tr>
<td>Frequency</td>
<td>1</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Power factor</td>
<td>1</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Irradiation</td>
<td>14</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>1</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Direction and velocity of wind</td>
<td>2</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Fault detection signal</td>
<td>7</td>
<td>-</td>
<td>Real time</td>
</tr>
</tbody>
</table>
Evaluation of adaptability to the large-scale PV system construction for various advanced PV modules from a module in real environment and in generation characteristic of each system.

**Indoor measurement**
- STC Condition
- I-V curve
  - Irradiation, modules temp
  - Spectral irradiance

**Module Evaluation**
- Fundamental Characteristics
  - Kind of module
  - Installation method
  - Weather & season distinction
  - Spectral irradiance
- LINEX-IV method

**System Evaluation**
- System generation characteristics evaluation
  - Kind of module
  - Installation method
  - Weather & season distinction
- Generation loss evaluation
  - System layout
  - Configuration of string
  - Configuration of PCS
  - Needed energy for tracking
- SV method

**Examination of evaluation standard from a generation characteristic in construction**
- Quantity of sunlight (A horizontal plane, a tilt, pursuit side)
- Installed capacity
- Needed area, etc.

**Continuous monitoring of PV generation**
- Aging deterioration

**Evaluation from generation characteristics in real environment for adaptability**
15° are higher than 30°

45° are higher than 30°

Characteristics of inclination angle of array

Generation ratio [%] = \( \frac{\text{Cumulated generation of } 15° \text{ or } 45° \text{[kWh]}}{\text{Cumulated generation of } 30° \text{[kWh]}} \times 100 \)

Cumulated generation of 15° or 45° [kWh]

Cumulated generation of 30° [kWh]
Generation characteristics of tracking system
(Measured Jun. 17 2008)

- Generation energy of tracking system = 1.23
- Generation energy of fixed angle type 30 = 0.30
  (Jun.-Aug. 2008)
Average PV generation and tracking efficiency

- Average PV generation [kWh/day]
- Tracking efficiency [%]

- PV system condition: 3kW

- Tracking system:
  - Fixed angle (30 deg.)
Measured performance ratio and generation energy density of PV modules (Measured data from Apr. to Dec. 2008)
Installation availability in 2008 = 15.16%

Installation availability [%] = \( \frac{\text{PV generation (kWh/month)} \times 10^4}{\text{Installation capacity (kW)} \times 24 \text{[hr]} \times 30 \text{[day/month]}} \times 100\% \)

Cumulative PV generation and installation availability
Calculated energy input and EPT of PV modules

<table>
<thead>
<tr>
<th>Type</th>
<th>Energy Input [GJ/kW]</th>
<th>EPT [year]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mono-crystalline</td>
<td>38.1</td>
<td>3.6</td>
</tr>
<tr>
<td>HIT</td>
<td>30.4</td>
<td>2.8</td>
</tr>
<tr>
<td>Multi-crystalline</td>
<td>27.5</td>
<td>2.6</td>
</tr>
<tr>
<td>Amorphous/microcrystal</td>
<td>32.4</td>
<td>3.0</td>
</tr>
<tr>
<td>Amorphous</td>
<td>24.5</td>
<td>2.3</td>
</tr>
<tr>
<td>CIS</td>
<td>22.8</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Others: Cable, plumbing, Support structure, PV module

Diagram showing energy input and EPT for different types of PV modules.
LCA evaluation of supporting structure based on 10kW PV array

<table>
<thead>
<tr>
<th></th>
<th>Conventional Concrete type</th>
<th>Developed Screw pipe type</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input Energy [GJ]</strong></td>
<td>51.6 (29.9+22.4)*</td>
<td>41.8 (23.9+17.8)*</td>
</tr>
<tr>
<td><strong>CO2 emission [kg-C]</strong></td>
<td>1586 (678+908)*</td>
<td>919 (556+414)*</td>
</tr>
</tbody>
</table>

* (supporting stand + base)
The outline in Hokuto mega-solar project was introduced.

Some results provided so far were discussed.

The construction of the 2nd stage was over and evaluation started. The results are reported in the future.

We thank to NEDO for research supports.
System configuration of Wakkanai site

- Solar Forecast System
- Control System
- Meas. System

Communication Network 1
- M.T. C.T.
- O.T.
- O.T.

Communication Network 2
- M.T. C.T.
- O.T.
- O.T.

C.T.: Control Terminal
M.T.: Measurement Terminal

- NAS battery 1.5MW
- 33kV/6.6kV
- 6.6kV/420V
- PV

5MW

Wakkanai site overview

PV output: 5,020kW (Approx. 1,700 homes; About 10% of household in Wakkanai)
Area: About 1 ha (About 3 times of Tokyo-dome)
No. of modules: About 28,500
No. of strings: About 1,800
No. of arrays: 50 + 1 (Tracking system)
Grid stabilization technology

- Suppression test results of PV output fluctuation

- Sunny day with a little cloud
- FRR 2-600 90.2%
- FRR 60-600 92.3%

Fluctuation Reduction Factor (FRR)
FRR=(Spv-So)/Spv

$Spv = \sqrt{\sum_{i=t_1}^{t_2} (c_i^{PV})^2}$

$So = \sqrt{\sum_{i=t_1}^{t_2} (c_i^{O})^2}$

Ci: Frequency component of output fluctuation

Maximum fluctuation
About 2.0 MW (PV output)
⇒ about 0.3 MW (PV station output)
- **Scheduled operation in PV station**

<table>
<thead>
<tr>
<th>Schedule</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00～11:00 1500kW</td>
<td>• Peak hour (11:00～13:00): 2500kW (PV)<em>{max} − NAS (c</em>{max})</td>
</tr>
<tr>
<td>11:00～13:00 2500kW</td>
<td>• Rest hour: 1500kW (PV)<em>{min} + NAS (d</em>{max})</td>
</tr>
<tr>
<td>13:00～16:00 1500kW</td>
<td></td>
</tr>
</tbody>
</table>

- **Output of station**
  - **PV output**
  - **NAS output**

- **Time of the day**

- Discharge of NAS in AM because of cloudy
- Scheduled operation was achieved through a day
■ Isolation operation test  (22\textsuperscript{nd} March, 2009)

Small of Frequency variation, Voltage fluctuation and Harmonics voltage in isolation operation

- Frequency [Hz]
- Voltage [kV]

Active power of NAS(500kW)  
PV output  
Active power of NAS(1000kW)  
Grid-tie operation  
Isolation operation