Impact of waterworks pumps demand response to increase maximum photovoltaic integration capacity

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This research is supported by "Miyako-city island type smart community evaluation project".
**PV Influence to supply-demand balance**

Net demand curve change by increasing PV penetration

Demand is under minimum output of total power generations -> PV will be curtailed.

**Solution? Demand response of Waterworks pumps!**

By demand response (DR) of waterworks pumps, increase daytime demand and reduce curtailment.
**Target: Miyako island**

- Sub-tropical, Isolated grid, Population: 55000
- Electrical demand: 18MW~55MW
- PV: **22.2MW**, Wind: 4.8MW, Battery: 4.0MW
- Additional PV installation is restricted because of "power surplus".
- **Waterworks pumps: 5MW!**
- Pump DR tests has done to reduce peak and mitigate surplus.

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**Research object**

Evaluate the impact of demand response (DR) of waterworks pumps by shifting the time of pump operation

Constraint conditions
1. Tank water level is under 100%
2. Water usage is fixed

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Overview of simulation

Suppose that there is no real-time signal from power system operator to waterworks system operator.

Step 1: Calculate hourly PV surplus by “Power system model”
Step 2: Calculate hourly PV surplus consumption and pump power change by “Waterworks system model”
Step 3: Calculate the impact of Pump DR to Power System by “Power system model”

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Step 1: Power system model of the island

- Time resolution: 1 hour
- Time span: 2014/10~2015/3

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### Step1: Estimate actual load

0. Hourly Large PV output and net load data are got
1. Estimate existing FIT-PV output using Large PV data
2. Estimate “actual load”
   
   $\text{Actual load} = \text{Net load} + \text{Large PV} + \text{FIT-PV}$

3. Calculate net load with larger PV installation scenarios

### Step1: PV surplus and PV threshold

- “**PV surplus**” was defined as hourly PV output minus constant PV threshold.
- **Not** calculated by hourly net load itself

- **PV threshold** was defined as a value by which the minimum net load in half year was equal to minimum DG output.
**Step1: Calculation result of PV surplus**

- The amount of PV surplus increased dramatically when total capacity of PV increased.
- PV surplus was relatively small and less-frequent in Dec. and Jan..

Hourly PV surplus in the half year

![Hourly PV surplus graph]

Example of PV surplus in a day (Feb. 15)

![Example of PV surplus graph]

**Next: Step2**

Suppose that there is no real-time signal from power system operator to waterworks system operator.

- Step1: Calculate hourly PV surplus by “Power system model”
- Step2: Calculate hourly PV surplus consumption and pump power change by “Waterworks system model”
- Step3: Calculate the impact of Pump DR to Power System by “Power system model”

![Flowchart of system model]

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Step 2: Waterworks pump system model

- There are 5 farmponds and each water level is calculated.
- PV surplus is used as target of the total pump power.
- Water level of the farmpond is calculated using actual water usage data.

When "PV surplus" exists, Pump consume it

Step 2: Determination sequence of pump power

PV surplus
(from electrical model)

- Pump power target = PV surplus
- Farm pond 1
- Pump flow target
- Restrictions check: Max. flow, Water level
- Pump flow
- Water level
- Pump power

- Rest of Power target
- Farm pond 2
- Flow target
- Flow
- Flow level
- Pump water flow
- Control

- Rest of Power target
- Farm pond 5
- Flow target
- Flow
- Flow level
- Pump power

Leftover of PV surplus

Total pump power with DR = Total pump power without DR
= Net power change

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Step2: Results in half year

- The ratio of the leftover became higher in proportion to increase of PV installation,
  - In PV24MW case, almost all of PV surplus was consumed by pumps.
  - Even in the PV34MW scenario, half of PV surplus was consumed by pumps.

<table>
<thead>
<tr>
<th>PV scenario</th>
<th>24MW</th>
<th>29MW</th>
<th>34MW</th>
<th>39MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV surplus [GWh]</td>
<td>0.46</td>
<td>1.49</td>
<td>3.04</td>
<td>4.59</td>
</tr>
<tr>
<td>Leftover [GWh]</td>
<td>0.002</td>
<td>0.38</td>
<td>1.48</td>
<td>2.79</td>
</tr>
<tr>
<td>Leftover/ surplus</td>
<td>0.005</td>
<td>0.25</td>
<td>0.49</td>
<td>0.61</td>
</tr>
</tbody>
</table>

Step2: Result when total PV was 29MW

- From Oct. to Jan., most of the PV surplus was consumed because the PV surplus itself was relatively small.
- The PV surplus remained in February and March.
  - The water level reaches 100% frequently.

Hourly PV surplus and leftover
Hourly water level
Step 2: Example of pump power with and without DR

- Without DR, pump power is relatively flat.
- When there is large PV surplus, the pump power increases dramatically.

![Graph showing pump power with and without DR]

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Next: Step 3 (only result)

Suppose there is no real-time signal from power system operator to waterworks system operator.

Step 1: Calculate hourly PV surplus by “Power system model”
Step 2: Calculate hourly PV surplus consumption and pump power change by “Waterworks system model”
Step 3: Calculate the impact of Pump DR to Power System by “Power system model”
Step 3: Impact of Pump DR to Power System

- Fuel reduction by DR itself is not large.
- Curtailment reduction leads to more PV installation.

<table>
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<tr>
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<th>24MW</th>
<th>29MW</th>
<th>34MW</th>
<th>39MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel reduction rate [%]</td>
<td>w/o DR: 2.9</td>
<td>4.9</td>
<td>6.6</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td>With DR: 3.0</td>
<td>4.9</td>
<td>6.7</td>
<td>8.3</td>
</tr>
<tr>
<td>Curtailment energy [GWh]</td>
<td>w/o DR: 0.01</td>
<td>0.10</td>
<td>0.41</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>With DR: 0.00</td>
<td>0.06</td>
<td>0.33</td>
<td>0.82</td>
</tr>
<tr>
<td>Curtailment time [hour]</td>
<td>w/o DR: 10</td>
<td>58</td>
<td>143</td>
<td>229</td>
</tr>
<tr>
<td></td>
<td>With DR: 0</td>
<td>33</td>
<td>107</td>
<td>184</td>
</tr>
</tbody>
</table>

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Step3: Curtailment hour and energy

- When the PV installation was relatively small, most of the PV surplus could be consumed by the pumps.
- When PV installation became larger, the waterworks pumps could not consume all of the PV surplus power.
- About 2 MW PV can be installed additionally with same extent curtailment.
Summary

- This paper evaluated impact of DR of waterworks pumps to consume the PV surplus.
- Seasonal characteristics of water usage and PV surplus is important for analysis of pump DR.
- Fuel reduction by DR itself is not large, but the curtailment reduction leads to more PV installation.

Future work
- Forecast of PV generation and water usage and more sophisticated water level control.
- IoT sprinklers can control the water usage itself.

Thank you

- Please give me questions or comments!