Economic Analysis and Policy Proposals for Island Microgrid in China

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Outline

Part I  Background

Part II  Characteristics of Island Microgrid
  ◆  Technical Characteristics
  ◆  Sizing Considerations

Part III  Case Study: Dawanshan Island
  ◆  Overview & System Structure
  ◆  Control Strategies & Microgrid Design
  ◆  Economic Evaluation & Policy Proposals

Part IV  Policy Proposals for Development of Island Microgrid in China

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Background

Status & Importance to develop island microgrid

- More than 7000 islands (> 500 m²)
- 450 islands with residents, 80,000 km²
- Most powered by diesels in limited hours

Island Microgrid can:

- Make use of renewable energy on islands such as wind, solar and sea energy
- Economical & Environmental friendly
- Improve power reliability for residents
- A new energy-utilization model

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Technical Characteristics

1. **Operation Mode**
   - Islanded Mode:
     - Independent of the bulk power grid
     - Standalone mode
     - Supplied by local power sources

2. **Energy Source**
   - The renewable:
     - Solar Energy
     - Wind Energy
     - Sea/Tidal Energy
     - Biomass Energy
     - ... ... ... ...

3. **Power Cost**
   - Much Higher:
     - Higher than urban micro-grid
     - Expensive transportation
     - Expensive install cost
     - Expensive construction cost

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Sizing Considerations

Wind Turbines

- Abundant wind energy on islands but not in accordance with load demand
- Consider the system cost and excess wind energy
- Use pitch control (variable-pitch blades)

Photovoltaic Arrays

- Abundant solar energy on islands and often in accordance with load demand
- Installed capacity depends on the specific conditions
- Install PV as much as possible due to its simple control
Sizing Considerations

Energy Storage System

- Act as main power source when diesel generator is off, providing power regulation and voltage/frequency control
- Support power fluctuation independently
- Depends on control strategies

Diesel Generators

- Act as back-up power supply
- Large capacity leads to low efficiency
- Depends on load demand
- Consider using several small diesel generators instead of a large one

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**Overview**

**Dawanshan Island**

- Located to the southeast of Guangdong, China.
- The area of the island is $8.1 \text{ km}^2$, and the population is 300.
- Main industries: fishing and tourism
- Relied on diesel generation with high cost and low reliability

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## Resources & Demand

### Load Demand

- Mainly at: Wanshan, southwest and northwest of the island
- Load changes with tourism:
  - High-season: May – Oct;
  - Low-season: Jan-April, Nov-Dec
- Peak load: 810kW; 59% of load is 200kW-400kW

## Wind Resource

<table>
<thead>
<tr>
<th>Abundant</th>
<th>Average wind speed: 6.89 m/s ~ 7.58 m/s at the height 10m ~ 70m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average wind power density: 426.1 W/m² ~ 444.3 W/m²</td>
</tr>
<tr>
<td></td>
<td>Average wind speed: Winter &gt; Summer</td>
</tr>
</tbody>
</table>

## Solar Resource

<table>
<thead>
<tr>
<th>Medium</th>
<th>Average annual solar radiation: 4996.25 MJ/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Typical year solar radiation: 4975 MJ/m²</td>
</tr>
<tr>
<td></td>
<td>Solar radiation is high from May to October</td>
</tr>
</tbody>
</table>

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System Design

**Objective Function:**

\[
\text{Net Income} = \max f = B_{\text{net}}^{\text{pre}} - C_{\text{TEI}}^{\text{pre}}
\]

\[
B_{\text{net}}^{\text{pre}} = \sum_{l=1}^{T} (B_{\text{ele},l} - C_{\text{fuel},l}) / (1 + r)^l
\]

\[
C_{\text{TEI}}^{\text{pre}} = C_1 + \sum_{l=1}^{T} (C_{D,l} / (1 + r)^l)
\]

**Constraints:**

<table>
<thead>
<tr>
<th>Device</th>
<th>Range/Alternatives</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE</td>
<td>1000kW, 500kW</td>
<td>Load Level</td>
</tr>
<tr>
<td>WT</td>
<td>500kW, 850kW</td>
<td>Cost &amp; Tech Readiness Level; Peak Load 810kW</td>
</tr>
<tr>
<td>PV</td>
<td>≤ 200kWp</td>
<td>Local Environment; Roof Space</td>
</tr>
<tr>
<td>ESS</td>
<td>2000kWh ~ 5000kWh</td>
<td>Consider the Worst Situation</td>
</tr>
</tbody>
</table>

System Structure of Dawanshan Microgrid

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Resource/Load Data

Solar/Wind/Load Data:
According to the solar and wind resources of Dawanshan Island, data needed in the optimization model was generated by HOMER.
Control Strategies

Load Following Strategy

◆ Use WT/PV/ESS first, and take ESS as main power source;
◆ When WT+PV+ESS > Load, ESS would be charged by WT/PV;
◆ When WT+PV+ESS < Load, DE would be started to supply load along with ESS;
◆ When WT+PV > Load, DE would be shut down, and load would be supplied by WT/PV/ESS.

Flow Chart of Load Following Strategy
## Design Results

### Sizing Plan

<table>
<thead>
<tr>
<th>Device</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Generators</td>
<td>$1 \times 850kW$</td>
</tr>
<tr>
<td>PV Arrays</td>
<td>200kWp</td>
</tr>
<tr>
<td>Lead-Acid Battery</td>
<td>2000kWh</td>
</tr>
<tr>
<td>PCS</td>
<td>1000kW</td>
</tr>
<tr>
<td>Diesel Generators</td>
<td>$2 \times 500kW$</td>
</tr>
</tbody>
</table>

### Initial Investment

<table>
<thead>
<tr>
<th>Device</th>
<th>Cost (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Generators</td>
<td>1,400,000</td>
</tr>
<tr>
<td>PV Arrays</td>
<td>325,000</td>
</tr>
<tr>
<td>Diesel Generators</td>
<td>130,000</td>
</tr>
<tr>
<td>Battery &amp; BMS</td>
<td>600,000</td>
</tr>
<tr>
<td>PCS</td>
<td>325,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2,780,000</td>
</tr>
</tbody>
</table>
Operation Evaluation

SOC of batteries was set within \([0.5, 0.9]\). Therefore, SOC was kept above 0.8 during 37.35% time of the year to improve the power reliability especially when there is fault for diesel generators.

**Generation of All Power Sources**

<table>
<thead>
<tr>
<th></th>
<th>Generation (MWh)</th>
<th>Percentage (%)</th>
<th>Utilization Hours (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WT</td>
<td>1427</td>
<td>53.35</td>
<td>1680</td>
</tr>
<tr>
<td>PV</td>
<td>150</td>
<td>5.60</td>
<td>750</td>
</tr>
<tr>
<td>DE</td>
<td>1098</td>
<td>41.05</td>
<td>[)</td>
</tr>
</tbody>
</table>

**SOC Statistics of ESS of One Year**

- SOC of batteries was set within \([0.5, 0.9]\). Therefore, SOC was kept above 0.8 during 37.35% time of the year to improve the power reliability especially when there is fault for diesel generators.

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**Operation Evaluation**

### Annual Renewable Energy Abandoned

<table>
<thead>
<tr>
<th>Device</th>
<th>Energy Abandoned (MWh)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WT</td>
<td>694</td>
<td>32.72</td>
</tr>
<tr>
<td>PV</td>
<td>72</td>
<td>32.43</td>
</tr>
</tbody>
</table>

- In summer, load level is high but wind resource is poor. Therefore diesel generator is used a lot in summer.
- In winter, load level is low but wind resource is abundant. Therefore excess wind energy is abandoned a lot in winter.

**Renewable Energy Abandoned During the Year**

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# Economic Evaluation

<table>
<thead>
<tr>
<th>Basic Information</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Cycle</td>
<td>year</td>
<td>25</td>
</tr>
<tr>
<td>Discount Rate (Interest Rate)</td>
<td>%</td>
<td>8</td>
</tr>
<tr>
<td>User Electricity Price</td>
<td>USD/year</td>
<td>0.33</td>
</tr>
<tr>
<td>Initial Investment*</td>
<td>USD</td>
<td>2,780,000</td>
</tr>
</tbody>
</table>

*(30% from investors, 70% loaned from banks)*

<table>
<thead>
<tr>
<th>Economic Indices</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Operation Cost</td>
<td>USD</td>
<td>560,000</td>
</tr>
<tr>
<td>Annual Income Selling Elec.</td>
<td>USD</td>
<td>850,000</td>
</tr>
<tr>
<td>Annual Net Income</td>
<td>USD</td>
<td>290,000</td>
</tr>
<tr>
<td>Net Present Value of Total Income</td>
<td>USD</td>
<td>-200,000</td>
</tr>
<tr>
<td>Internal Rate of Return</td>
<td>%</td>
<td>5.925</td>
</tr>
<tr>
<td>Payback Period</td>
<td>year</td>
<td>&gt;25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operation Results</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifetime of ESS</td>
<td>year</td>
<td>6.33</td>
</tr>
<tr>
<td>Times of ESS Replacement</td>
<td>time</td>
<td>3</td>
</tr>
<tr>
<td>Times of DE1 Replacement</td>
<td>time</td>
<td>4</td>
</tr>
<tr>
<td>Times of DE2 Replacement</td>
<td>time</td>
<td>0</td>
</tr>
</tbody>
</table>
Economic Analysis

Only the replacement of batteries and diesel generators were considered. The replacement of wind turbines and PV arrays were not considered.

The internal rate of return of this project is low, and the cost cannot be recovered in the project cycle. Therefore, this example cannot commercially operate without subsidies from the government.

For islanded microgrid, central government should offer the initial investment. Subsidies can be provided through appealing electricity price for long-term operation of microgrid.
Policy Proposal

For Dawanshan Case:

◆ **Subsidy Principles:** With subsidies, the internal rate of return should be no less than 8%, and years of investment recovery should be around 7 to 8 years. According to this principle, subsidy regulation and level can be made.

◆ Subsidies can be provided in forms of **initial investment** or **electricity price**.

◆ **Subsidy Level:**

<table>
<thead>
<tr>
<th>Subsidy Level</th>
<th>Initial Investment</th>
<th>Electricity Price</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Subsidy Level</strong></td>
<td>70% of initial investment</td>
<td>0.065 USD/kWh</td>
</tr>
<tr>
<td><strong>Years of Investment Recovery (With Subsidies)</strong></td>
<td>8.15 years</td>
<td>8.31 years</td>
</tr>
<tr>
<td><strong>Subsidy Period</strong></td>
<td>\</td>
<td>10 years</td>
</tr>
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Policy Proposal

For Future Development of Island Microgrid in China:

◆ Provide subsidies for initial investment of island microgrid

◆ Provide subsidies for electricity price of areas supplied by island microgrid

◆ Encourage more stakeholders to participate in the construction and operation of island microgrid

◆ Provide integrated energy service to satisfy users’ demand for electricity, heating and cooling, to improve the energy efficiency.

◆ Offer subsidies to device manufacturers, especially to those who produce wind turbines and batteries of medium/small capacity