An Engineering Approach to the Optimal Design of Distributed Energy Systems in China

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Outline

- Introduction
- Background
- Super-Structure Representation of the Optimization Model
- Scenario Analysis
- Conclusion
Introduction

- **Definition**
  - Distributed Energy Resource (DER): *Small-scale power generation technologies (typically in the range of 3 kW to 10,000 kW) used to provide an alternative to or an enhancement of the traditional electric power system* (From Wikipedia)
  - Distributed Energy System (DES): *An integration of many modular energy generation, conversion and storage units in small scale to provide cooling, heating and power to the customers*

<table>
<thead>
<tr>
<th>Distributed Energy System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distributed Energy Resources</strong></td>
</tr>
<tr>
<td>Gas Turbine</td>
</tr>
<tr>
<td>Solar PV</td>
</tr>
<tr>
<td>Wind Turbine</td>
</tr>
</tbody>
</table>
Introduction

- Potential benefits of DES compared with Centralized Energy Systems
  - Distributed energy systems can avoid the difficult planning and construction processes associated with large plants and long distance transmission
  - In the case that the power grid accidentally fails, distributed energy systems can continuously supply energy to customers, thereby enhancing energy security
  - Various scattered renewable energy, such as solar, wind and geothermal, can be integrated into the system, providing energy collectively
Background

- **Laws and Regulations**
  - The National Energy Administration (NEA) of China issued a draft document on “guidance on the development of natural gas distributed energy systems” in April, 2010, which suggests to install up to fifty thousand megawatts distributed energy systems by the year of 2020.
  - “The administrative measures on distributed generation” is expected to be released by the NEA in 2011.
  - “The 12th five-year plan on cogeneration and distributed energy” drafted by China Electricity Council (CEC) is also near completion.

The laws and regulations with regard to DES indicate that the government is more interested in the distributed natural gas CCHP system.
Background

- Demo Projects

Some of the demonstration projects of distributed energy systems in China and their system configuration:

<table>
<thead>
<tr>
<th>No.</th>
<th>Location</th>
<th>Main devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pudong International Airport, Shanghai</td>
<td>Gas turbine, Waste heat boiler</td>
</tr>
<tr>
<td>2</td>
<td>Huangpu Central Hospital, Shanghai</td>
<td>Gas turbine, Waste heat boiler</td>
</tr>
<tr>
<td>3</td>
<td>Minhang Central Hospital, Shanghai</td>
<td>Gas turbine, Waste heat boiler</td>
</tr>
<tr>
<td>4</td>
<td>Shanghai Institute of Technology, Shanghai</td>
<td>Micro-turbine, Absorption Chiller, Waste heat boiler</td>
</tr>
<tr>
<td>5</td>
<td>Shuya Liangzi Ministry of Health, Shanghai</td>
<td>Diesel engine, Waste heat boiler</td>
</tr>
<tr>
<td>6</td>
<td>Zizhu Science-based Industrial Park, Shanghai</td>
<td>Micro-turbine, Absorption Chiller</td>
</tr>
<tr>
<td>7</td>
<td>Shanghai Jinqiao Sports Center, Shanghai</td>
<td>Gas engine, Waste heat boiler</td>
</tr>
<tr>
<td>8</td>
<td>Shanghai Global Financial Hub, Shanghai</td>
<td>Gas engine, Waste heat boiler</td>
</tr>
<tr>
<td>9</td>
<td>Beijing Gas Group Monitoring Center, Beijing</td>
<td>Gas engine, Absorption Chiller</td>
</tr>
<tr>
<td>10</td>
<td>Ciqumen Station Building, Beijing</td>
<td>Micro-turbine, Absorption Chiller</td>
</tr>
<tr>
<td>11</td>
<td>Zhongguancun Software Square, Beijing</td>
<td>Gas turbine, Absorption Chiller</td>
</tr>
<tr>
<td>12</td>
<td>International Trade Center, Phase 3, Beijing</td>
<td>Gas turbine, Waste heat boiler</td>
</tr>
<tr>
<td>13</td>
<td>International Business Center, Beijing</td>
<td>Gas turbine, Waste heat boiler</td>
</tr>
<tr>
<td>14</td>
<td>Olympic Energy Exhibit Center, Beijing</td>
<td>Micro-turbine, Absorption Chiller</td>
</tr>
</tbody>
</table>

The current demonstration projects are all distributed natural gas CCHP systems.
Background

A typical natural gas Combined Cooling, Heating and Power (CCHP) system

Gas Engine -> Electricity
Waste heat -> Space heating
Heat Recovery
Absorption chiller

Cooling
Hot water
We believe that adding more energy resources and technologies can improve the performances of distributed energy system.
Background

- Challenges towards the design of a distributed energy system
  - Fluctuation in energy demands and supply
  - The large number of available distributed energy technologies
  - The infinite number of possible combinations of distributed energy technologies

An energy systems engineering framework towards the optimal design of distributed energy systems is needed
Super-Structure Representation of the Optimization Tool

Energy Resources
- Grid power
- Natural Gas
- Wind
- Solar
- Biomass

Energy Generation Technologies
- ICE
- GT
- NG boiler
- Wind turbine
- Solar PV
- Solar hot water
- Biomass boiler

Secondary Energy Carriers and Storage
- Battery storage
- Electricity
- Hot water storage
- Heat

Energy Conversion Technologies
- Electric heater
- Electric HP
- Electric chiller
- Heat coil
- Absorption HP
- Absorption chiller
- Heat Exchanger

Energy Demands
- Electricity Demand
- Heating Demand
- Cooling Demand
- Hot water Demand

Abbreviations:
- NG = Natural gas
- ICE = Internal combustion engine
- PV = Photovoltaic
- GT = Gas turbine
- HP = Heat Pump
Scenario Analyses

- Targeted Site
  - A residential community in Beijing (10 buildings)

- Energy Supply System Options
  - Centralized Energy System
  - Distributed natural gas CCHP System
  - Complex Distributed Energy System
Scenario Analyses

- Energy Demands

- Electricity load, kW

- Heat load, kW

- Cooling load, kW

- Hot water load, kW

- Graphs showing the energy demands for different months.
**Scenario Analyses**

- **Technological and Economic Data 1**

The technological and economic data of energy generation technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Investment, yuan/kW</th>
<th>O&amp;M cost, yuan/kWh</th>
<th>Efficiency</th>
<th>Heat</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal combustion engine</td>
<td>1245</td>
<td>0.072</td>
<td>0.35</td>
<td>0.5</td>
<td>30</td>
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<tr>
<td>Gas turbine</td>
<td>1975</td>
<td>0.0683</td>
<td>0.25</td>
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<tr>
<td>Natural gas boiler</td>
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<td>0.00216</td>
<td>0</td>
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<td>20</td>
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<td>Wind turbine</td>
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<td>0.05</td>
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<td>0</td>
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<tr>
<td>Solar PV</td>
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<td>0.01</td>
<td>0.12</td>
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<td>30</td>
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<tr>
<td>Solar Heat</td>
<td>900</td>
<td>0.01</td>
<td>0</td>
<td>0.4</td>
<td>15</td>
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<tr>
<td>Biomass boiler</td>
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<td>0.85</td>
<td>15</td>
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<tr>
<td>Transmission</td>
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<td>0</td>
<td>1</td>
<td>0</td>
<td>20</td>
</tr>
</tbody>
</table>
Scenario Analyses

- Technological and Economic Data 2

<table>
<thead>
<tr>
<th>Technology</th>
<th>Investment, yuan/kW</th>
<th>O&amp;M cost, yuan/kWh</th>
<th>Efficiency (or COP)</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric heater</td>
<td>1000</td>
<td>0</td>
<td>0</td>
<td>20</td>
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<tr>
<td>Electric heat pump</td>
<td>3960</td>
<td>0.0097</td>
<td>0</td>
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<tr>
<td>Electric chiller</td>
<td>2778</td>
<td>0.0097</td>
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<tr>
<td>Distribution</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Heat coil</td>
<td>201</td>
<td>0.00216</td>
<td>0</td>
<td>20</td>
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<tr>
<td>Absorption chiller</td>
<td>1473</td>
<td>0.008</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Absorption heat pump</td>
<td>1473</td>
<td>0.008</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Heat Exchanger</td>
<td>201</td>
<td>0.00216</td>
<td>0</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technology</th>
<th>Investment, yuan/kW</th>
<th>O&amp;M cost, yuan/kWh capacity</th>
<th>Efficiency</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery</td>
<td>831</td>
<td>8.3</td>
<td>0.7</td>
<td>13.5</td>
</tr>
<tr>
<td>Hot water storage</td>
<td>90</td>
<td>0.18</td>
<td>0.9</td>
<td>20</td>
</tr>
</tbody>
</table>
Results

- **Optimal Design**
  - The optimal DES is a complex system with various technologies rather than a simple distributed natural gas CCHP system

### Abbreviations:

- **NG** = Natural gas
- **ICE** = Internal combustion engine
- **PV** = Photovoltaic
- **GT** = Gas turbine
- **HP** = Heat Pump

### Energy Resources

- Grid power
- Natural Gas
- Wind
- Solar
- Biomass

### Energy Generation Technologies

- **Transmission**
  - ICE: 41kW
  - GT: NG Boiler: 175kW
  - NG boiler
  - Wind turbine
  - Solar PV: Solar Hot Water: 128kW
  - Solar hot water
  - Biomass boiler

### Secondary Energy Carriers and Storage

- Battery storage
- Hot water storage
  - Hot Water Tank: 128kW

### Energy Conversion Technologies

- **Distribution**
  - Electric heater
  - Electric Heat Pump: 20.8kW
  - Electric HP
  - Electric Chiller: 116kW
  - Electric chiller
  - Heat Coil: 282kW
  - Heat coil
  - Absorption HP: 341kW
  - Absorption HP
  - Absorption Chiller: 40kW
  - Absorption chiller
  - Heat Exchanger: 291kW
  - Heat exchanger

### Energy Demands

- Electricity Demand
- Heating Demand
- Cooling Demand
- Hot water Demand
Results

- **Economics and Efficiency**
  - Economics: Annual cost
  - Efficiency: Equivalent natural gas consumption $E_{NG_{equivalent}} = E_{NG} + E_{GP} / 58%$

Distributed natural gas CCHP can have a better economics and efficiency than the centralized energy system, however, DES is a better solution.
Conclusion

- This paper provides a generic energy systems engineering framework towards the optimal design of distributed energy systems in China.
- The superstructure based modeling and optimization framework can address issues related to the design of distributed energy systems such as technology selections and integration among these technologies.
- Computational results show that the optimal configuration of distributed energy systems is a complicated system with internal combustion engines, natural gas boilers, solar hot water, electric heat pumps, electric chillers absorption chillers being the core technologies.
- The distributed energy system proposed by the optimization model of this study reveals better economic and energetic performances than both the conventional energy system and the typical distributed CCHP systems that the government is promoting.