Overview of Renewable Energy & Electric Vehicle Development in China

Zechun Hu
Tsinghua University
zechhu@tsinghua.edu.cn

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Smart Grid Operation and Optimization Laboratory
1. Renewable Power Generation
2. Electric Vehicle Development
3. Electric Vehicle Charging Infrastructure
4. Our EV Related Research Work
Renewable Power Generation

- Installed capacity of wind and solar power generation increased very fast in the past six years
- **Wind power** ranks number one from year 2012
- Installed **solar power capacity** outnumbers Germany from year 2015
- Fast increasing renewable generation poses great challenges to power system operation, especially in the “Three North Parts” of China
Total accumulated installed capacity 2016
Serious wind spillage problem

<table>
<thead>
<tr>
<th>Year</th>
<th>Curtailment (billion kWh)</th>
<th>Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>20.8</td>
<td>17</td>
</tr>
<tr>
<td>2013</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>2014</td>
<td>13.3</td>
<td>8.5</td>
</tr>
<tr>
<td>2015</td>
<td>33.9</td>
<td>15</td>
</tr>
<tr>
<td>2016</td>
<td>49.7</td>
<td>17.1</td>
</tr>
</tbody>
</table>

2015 average curtailment rate = 15%
- >30% curtailment rate
- >20–29% curtailment rate
- >10–19% curtailment rate
- >1–9% curtailment rate

Source: http://www.nature.com/articles/nenergy201676/figures/1

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Serious wind spillage problem

- Amount of wind energy spilled

<table>
<thead>
<tr>
<th>Year</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spilled energy (billion kWh)</td>
<td>20.8</td>
<td>15.0</td>
<td>13.3</td>
<td>33.9</td>
<td>49.7</td>
</tr>
<tr>
<td>Percentage (%)</td>
<td>17</td>
<td>11</td>
<td>8.5</td>
<td>15</td>
<td>17.1</td>
</tr>
</tbody>
</table>

Wind spillage in several provinces (2016)

<table>
<thead>
<tr>
<th>Province</th>
<th>Spilled energy (billion kWh)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gansu</td>
<td>10.3</td>
<td>43.1%</td>
</tr>
<tr>
<td>Xinjiang</td>
<td>13.7</td>
<td>38.4%</td>
</tr>
<tr>
<td>Ningxia</td>
<td>1.9</td>
<td>13.1%</td>
</tr>
<tr>
<td>Shaanxi</td>
<td>0.2</td>
<td>6.6%</td>
</tr>
</tbody>
</table>
Contents

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Background for EV development

• Environment
  – Air pollution is serious, esp. in big cities

• Energy Security
  – More than half of the oil consumed is imported
  – Renewable energy generation

• Auto Industry
  – China is the biggest auto market
  – Promote the implementation of new technology
Efforts by Government and Results

- In Nov 2007, NRDC released “rules on the production admission administration of new energy automobiles”
- In Jan 2009, several departments and NRDC launched “Ten Cities and One Thousand EVs” program
- In June 2010, subsidy is provided for private EV buyers.
- In Feb, 2014, Beijing initiated a vehicle plate program for EVs only.
- Over 300% increase of EV vehicle registration in 2015 compared to 2014.

![Graph showing EV sales in thousands from 2013 to 2016.]

**Sales/Thousand**

<table>
<thead>
<tr>
<th>Year</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17.6</td>
<td>83.9</td>
<td>331.1</td>
<td>507</td>
</tr>
</tbody>
</table>

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EV production and sale

<table>
<thead>
<tr>
<th>Pure EV Passenger car</th>
<th>Sale/thousand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 2015</td>
<td>147</td>
</tr>
<tr>
<td>Year 2016</td>
<td>263</td>
</tr>
</tbody>
</table>

Sales in 2015

Sales in 2016

Source: China Association of Automobile Manufactures

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<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Pure EV</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2013-15</td>
<td>3.5</td>
<td>3.325</td>
<td>3.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016-2020</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.5</td>
<td>2</td>
<td>2</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>150≤R&lt;250</td>
<td>5</td>
<td>4.75</td>
<td>4.5</td>
<td>4.5</td>
<td>3.6</td>
<td>3.6</td>
<td>2.7</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>R≥250</td>
<td>6</td>
<td>5.7</td>
<td>5.4</td>
<td>5.5</td>
<td>4.4</td>
<td>4.4</td>
<td>3.3</td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td><strong>PHEV</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R≥50</td>
<td>3.5</td>
<td>3.325</td>
<td>3.15</td>
<td>3</td>
<td>2.4</td>
<td>2.4</td>
<td>1.8</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td><strong>FCEV</strong></td>
<td>-</td>
<td>20</td>
<td>19</td>
<td>18</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>
## Cost comparison PHEV, BEV and conventional vehicle in Shanghai 2016

<table>
<thead>
<tr>
<th>Category</th>
<th>BYD Qin PHEV (NEV &gt;50km range)</th>
<th>BAIC EV200 BEV (NEV &gt;150km range)</th>
<th>Comparable conventional vehicle (BYD F3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price before subsidy</td>
<td>209,800 RMB (approx. 31200 USD)</td>
<td>208,900 RMB (approx. 28,000 USD)</td>
<td>65,900 RMB (approx. 9800 USD)</td>
</tr>
<tr>
<td>Purchase tax</td>
<td>0</td>
<td>0</td>
<td>3,295 RMB</td>
</tr>
<tr>
<td>National Subsidy</td>
<td>-24,000 RMB</td>
<td>-36,000 RMB</td>
<td>0</td>
</tr>
<tr>
<td>Local Subsidy</td>
<td>-12,000 RMB</td>
<td>-18,000 RMB</td>
<td>0</td>
</tr>
<tr>
<td>Number plate auction</td>
<td>0</td>
<td>0</td>
<td>Approx. 84,500 RMB</td>
</tr>
<tr>
<td><strong>Total customer costs</strong></td>
<td><strong>173,800 RMB</strong> (approx. 25800 USD)</td>
<td><strong>154,900 RMB</strong> (approx. 23100 USD)</td>
<td><strong>153,695 RMB</strong> (approx. 23,000 USD)</td>
</tr>
</tbody>
</table>

Source: NDRC et al., 2015; MOF et al., 2015; SMPG, 2016.

(Exchange rate RMB/EUR=0.136)
To Jan. 2016, the total number of public charging ports is 58,758 (AC 38,312, DC 12,101, Combo 8,345); private owned number is 50,241 (AC 50,233, DC 8).
Centralized charging and swapping stations

- **12,000** centralized charging and swapping stations are planned by 2020.

Category and target

- 3,850, public transportation charging
- 2,500, e-taxi services charging
- 2,450, sanitary and logistics charging
- 2,400, urban public charging
- 800, Intercity fast charging

Intercity fast charging network

Source: NDRC et al., 2015.
Distributed charging pillars

- **4.8 million** distributed charging pillars are planned by 2020.

Category and target

- 2.8 million, residential compounds
- 1.5 million, commercial areas
- 0.5 million, public parking areas

Source: NDRC et al., 2015.
Charging infrastructure implementation

Newly-built constructions rules (2016)

- **100%** parking lots in compounds should be enabled for charging installations (parking lot).
- **10%** parking lots in public constructions (larger than 20,000m²) have to equip with charging devices.

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Short term solution

- Co-use power supply of illumination equipment, such as street light.

Long term goal

- Develop mechanical and multi-storey parking garages with charging facilities.

Source: MOHURD, 2015.
Nationwide development and provincial targets are planned.

- Deployment of charging infrastructure in Beijing:
  - The “public-private partnerships” is encouraged and subsidized with maximum 30% of total investment.
  - Regulated charging service fee is introduced and directly related to 92 octane gasoline price.

<table>
<thead>
<tr>
<th>Region</th>
<th>No. of province</th>
<th>Charging station target by 2020</th>
<th>Charging pillar target by 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration area</td>
<td>12</td>
<td>7,400</td>
<td>2.5 million</td>
</tr>
<tr>
<td>Demonstratio area</td>
<td>14</td>
<td>4,300</td>
<td>2.2 million</td>
</tr>
<tr>
<td>Promotion area</td>
<td>5</td>
<td>300</td>
<td>0.1 million</td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>12,000</td>
<td>4.8 million</td>
</tr>
</tbody>
</table>

Source: GOSC, 2015; NDRC et al., 2015; BMCDR, 2015.
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Research work overview

Integration of EVs into power system

Charging demand forecast

Temporal distribution

Temporal & spacial distribution

On system operation

On system planning

Impacts of EV charging on power systems

Coordinated charging strategies

Control strategies of V2G

Control Objectives

- Peak shaving and valley filling
- Frequency regulation
- Providing reserve
- With renewable generation

Optimal planning of charging facilities

Urban area

Highway network

Operation of charging facilities and market mechanism

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Charging load forecast and facility planning

Spatial and temporal distribution of PEV charging load forecast

Charging load forecast

Charging station planning

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Research work on coordinated charging
• Charging stations or parking lots with charging piles for PEVs
• The charging load and base load are connected to the distribution transformer
• Charging process of each EV is optimized to flatten the load profile and make more profit for the charging station while capacity constraint of the transformer is held
Smart Charging – multiple stations

- A schematic illustration of the distributed charging system in an urban area
- Proposed hierarchical control framework for PEV charging coordination across multiple stations or aggregators
- A charging load aggregation method is put forward considering real-world PEV charging and distribution transformer constraints
Smart Charging – Three Levels

- **Day-ahead Transmission**
  - Transmission Operator
  - Input:
    - Base load profile prediction
    - TOU electricity tariffs
  - Output: day-ahead referential charging curve

- **Distribution**
  - Municipal charging load aggregation
  - Distribution Operator
  - Input:
    - Distribution base load profile
    - TOU electricity tariffs
  - Output: Preferred charging power
  - Station charging load aggregation
  - Station Operator
  - Input: Customer’s demand

- **Real-time Station**
  - Station Operator
  - ...
V2G for Primary Frequency Control

- Objective and Constraints
  - Smoothing frequency fluctuation
  - Meeting Charging demands
    - Charging EVs
    - Holding battery SOC

- Our Solution Method
  - Frequency droop control
    - Responding frequency signal
    - Considering SOC level
  - Tradeoff between achieving charging demands and frequency droop control


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Coordination of EV and renewables

- Coordinate with wind farm/PV plant, reduce the wind/solar curtailment
- Coordinate with distributed generation resources
- Application of EV in micro-grids (reduce the curtailment and secure system operation)

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Coordination of EV and renewables

- From charging station to charging network
- From planning to operation

Coordinated EV charging: A key to open two locks!
Thank You!