A Heuristic Operation Strategy for Commercial Building Microgrids Containing EVs and PV System

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Micro-grid technology can integrate Electric Vehicle Charging Stations and Distributed Photovoltaic system, which helps to improve the overall economic and environmental benefits.

- PV generation could reduce the dependence of EVs on fossil fuel and improve the utilization of renewable and clean energy.
- EVs could help solve the intermittent of renewable energy and reduce the cost of energy storage system.
- Micro-grids realize the self-consumption of renewable energy on EVs and promote the combination of EVs and renewable energy generation.
In these researches, most of the methods are based on day-ahead optimization, the forecasting for PV power and user load are required.
the main contribution

- For the daytime charging demand of EVs, the operation aim to improve the self-consumption of PV energy and reduce the dependence on the power grid.
- According to the SOC of EV batteries and variation of PV output, the charging rate of EVs is adjusted dynamically in the real-time event triggering mechanism.
- The optimization process is simplified that either the statistical data or the forecasting of PV output and EV charging demand is not needed.
- This method can be applied at very low cost. The algorithms can be self-operating in an embedded system without any need for operators or be directly embedded into the control system of converters.
Introduction

Case Study

Operation Strategy

Conclusion

1. Typical structure of commercial building micro-grids

- PV arrays
- DC/DC converter
- Bidirectional AC/DC inverter
- Chargers
- EVs
- Loads of commercial building
- Embedded controller
Typical structure of commercial building micro-grids

Intercommunication among Central Controller, Charger and EVs

- Information of EV batteries (such as SOC, voltage, etc.) can be transmitted to the chargers and embedded controller.
- The charging power is feasible to be regulated by chargers in a smooth way.
- Users can set some information on the panel of the charger by themselves, such as the departure time.
2 Basic Operation Principles

- **Expected Completeness of Charging Demand (ECCD)**

  \[
  ECCD(t) = \frac{1}{N_{EV}(t)} \sum_{i=1}^{N_{EV}(t)} \left( \frac{SOC^i(t) + C^i(t) \cdot (t^i_d - t)}{SOC^i_{obj}} \right)
  \]

  The first principle: maximize the ECCD.

- **Deviation of PV Energy Consumed by EVs (DPCE)**

  \[
  DPCE(t) = \left| P_{pv}(t) - \sum_{i=1}^{N_{EV}(t)} P^i(t) \right|
  \]

  The second principle: minimize the DPCE = improve self-consumption rate of PV energy for EVs.

- Model of EV Feasible Charging Region (FCR)

The user can set the departure time and expected SOC of battery.

\[ FCR : \{ (t_s, C) \mid t_s \in [t_0, t_r], C \in [C_{\min}, C_{\max}] \} \]
Strategy for Real-time Operation of Commercial Building Micro-grids

- Mechanism of Dynamical Event Triggering (DET)
3 Strategy for Real-time Operation of Commercial Building Micro-grids

- **Mechanism of Dynamical Event Triggering (DET)**

  - New EV arrives at the parking lot
  - EV finishes the charging
  - The output of PV system varies more than the accepted extent:
    \[
    |P_{pv}(t) - P_{pv\_base}| \geq 0.05 \cdot P_S(t - \Delta t)
    \]
  - The variation of the total charging power exceeds the accepted extent:
    \[
    |P_S(t) - P_{S\_base}| \geq 0.05 \cdot P_{S\_base}
    \]
Algorithm of Real-time power allocation (RTPA)

1. Initialization
   - Acquisition of real-time data of parking lots: \( (N_{EV}(t), t, t_{id}, SOC(t), U(t), P_s(t)) \)
   - Acquisition of PV power: \( P_{pv}(t) \)
   - Monitoring the trigger event
     - Event triggering?
       - Yes
         - \( i = 1 \)
       - No
         - \( i \) = \( i + 1 \)

2. Select EVs, if \( SOC_i(t) > 0.85 \)
   - Yes
     - Yes
     - No
   - No
     - Calculate \( T_{min}^i \) and \( (t_i^d, t_i^t) \)
     - Yes
     - No
     - Quit the power allocation
     - Calculate CRFR of the \( i \)-th EV \( \{ (t_i^d, T_i), (C_{min}^i, C_{max}^i) \} \)
     - Calculate \( \lambda_{adj}^i(t) \) of the \( i \)-th EV
       - Comparison, if \( \lambda_{adj}^i(t) \leq 1 \)
         - Yes
           - Charging the \( i \)-th EV with \( C_{max}^i \)
             - Calculation \( P_{cum}(t) = P_{cum}(t) + P_{max} \)
           - No
             - \( i = i + 1 \)
               - \( i > N_{EV}(t) \)?
                 - Yes
                   - Update \( N_{EV}(t) = N_{EV}(t) - N_{un}(t) \)
                 - No
                   - Quit the power allocation
   - No
     - Charging the \( i \)-th EV with \( C_{max}^i \)
       - Calculation \( P_{cum}(t) = P_{cum}(t) + P_{max} \)
     - Record \( N_{adj}(t) = N_{adj}(t) + 1 \)

3. Comparation, if \( P_{min}(t) + P_{cum}(t) > P_{pv}(t) \)
   - Yes
     - Sorting EVs by \( \lambda_{adj}^i(t) \) from small to large
       - The \( i \)-th EV of \( N_{EV}(t) \) charging at \( C_{min}^i \)
         - Keeping total charging power as \( P_{cum}(t) + P_{cum}(t) \)
     - No

4. Comparation, if \( |P_d(t) + P_{cum}(t) - P_{pv}(t)| < \varepsilon \)
   - Yes
     - The \( i \)-th EV of \( N_{EV}(t) \) charging at \( C(t) \)
   - No
     - \( i = i + 1 \)
       - \( i > N_{EV}(t) \)?
1. Analysis and comparison of results

- **Parameters of simulation**
  - Peak value of regular load: 500kW
  - Rated capacity of the PV system: 240kW
  - Number of EVs: 60

- **Experiment cases**
  - Case1: Uncontrolled operation strategy
  - Case2: FCR + PSO operation strategy
  - Case3: DET + PSO operation strategy
  - Case4: FCR + DET + PSO operation strategy
  - Case5: FCR + DET + RTPA operation strategy

PSO algorithm is widely used in optimization for charging strategy of EVs.
Analysis and comparison of results

Case 1: Uncontrolled operation strategy

During the peak hours, the charging power of EVs leads to about extra 420kW loads than the original peak loads.
The extra load is only 70 kW and most of the EVs can leave with objective SOC successfully. However, the total charging power and the charging rate of EVs fluctuate frequently.
The charging rate varies dramatically and randomly. Besides, the charging demand of many EVs cannot be satisfied before leaving.
Analysis and comparison of results

Case 4: FCR + DET + PSO operation strategy

The DET mechanism makes the charging rate of EVs varies more smoothly than above cases.
Analysis and comparison of results

Case5: FCR + DET + RTPA operation strategy

- **Power variation**
  - The extra load is cut down to 70 kW and most of the EVs can leave with objective SOC. Moreover, the charging rate of EVs is obviously the smoothest one of the five cases.
## 2 Comparison of efficiency

<table>
<thead>
<tr>
<th>Time cost on calculation with different number of EVs</th>
<th>FCR+PSO</th>
<th>DET+PSO</th>
<th>FCR+DET+PSO</th>
<th>FCR+DET+RTPA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23.87 s/1</td>
<td>23.92 s/1</td>
<td>23.97 s/1</td>
<td>0.27 s/1</td>
</tr>
<tr>
<td></td>
<td>26.47 s/10</td>
<td>26.22 s/10</td>
<td>26.56 s/10</td>
<td>1.125 s/10</td>
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<tr>
<td></td>
<td>30.53 s/20</td>
<td>29.34 s/20</td>
<td>30.49 s/20</td>
<td>0.708 s/20</td>
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<tr>
<td></td>
<td>35.11 s/30</td>
<td>34.36 s/30</td>
<td>35.03 s/30</td>
<td>0.567 s/30</td>
</tr>
<tr>
<td></td>
<td>41.72 s/40</td>
<td>39.69 s/40</td>
<td>41.53 s/40</td>
<td>0.567 s/40</td>
</tr>
<tr>
<td></td>
<td>46.14 s/50</td>
<td>45.05 s/50</td>
<td>46.08 s/50</td>
<td>0.432 s/50</td>
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<tr>
<td></td>
<td>55.26 s/60</td>
<td>54.98 s/60</td>
<td>55.3 s/60</td>
<td>0.432 s/60</td>
</tr>
<tr>
<td>Calculation times per day</td>
<td>450</td>
<td>180</td>
<td>168</td>
<td>172</td>
</tr>
<tr>
<td>Occupancy time on processor per day</td>
<td>17411.73 s</td>
<td>5966.27 s</td>
<td>6079.75 s</td>
<td>54.53 s</td>
</tr>
</tbody>
</table>

Our proposed charging strategy performs well in many aspects, such as small calculation scale, high efficiency and low occupancy rate of computation resource.
Heuristic operation strategy: FCR+DET+RTPA

The strategy is based on the real-time decision without forecasting of PV output or EV charging demand.

1. The FCR model ensures the EVs leave with objective or maximum SOC of EV batteries.

2. The DET mechanism can cut down the calculation frequency to avoid unnecessary calculation.

3. The RTPA algorithm proves to be excellent in calculation time, efficiency and occupancy time on micro-processor.
Related Work

- We have published over 30 papers on journals and conferences on the topic of optimization of microgrid and electric vehicles.

Selected Publications:

- A Heuristic Operation Strategy for Commercial Building Micro-grids Containing EVs and PV System. IEEE Transactions on Industrial Electronics. 10.1109/TIE.2014.2364553
- A Charging Strategy for PV-based Battery Switch Stations Considering Service Availability and Self-consumption of PV energy. IEEE Transactions on Industrial Electronics. (revised and under review)
- 考虑动力电池梯次利用的光伏换电站容量优化配置方法. 中国电机工程学报. 2013, 33(4) : 34-44.
- 配网故障情况下电动汽车换电站V2G运行的主动控制策略[J]. 电网技术.
Related Work

Demonstration and Key Technologies for User-side Smart Microgrid with Distributed Energy Resources. National High-tech R&D Program of China (863 Program) (No. 2014AA052001)

- Different Climate (solar, temperature)
- Different User type (Residential customers, Commercial customers, Industrial customers)
- Different electricity prices and incentives

Software Tools for Microgrid Planning, Design and Evaluation
Low cost EMS for User-side Microgrid

- Yunnan Province Rural Customers
- Guangzhou Residential Customers
- Dongguan Industrial Customers
- Shenzhen Commercial Building
Microgrid Laboratory Platform of NCEPU

- Circuit Breaker
- Wind Power
- Lithium Battery
- PV system
- PV & Battery Hybrid system
Microgrid Laboratory Platform of NCEPU

- **Main Structure**

A Platform includes PV, wind power, EVs, Energy Storage and simulative load.

- AC bus: 380V
- Simulative WPG: 30kW
- PV system: 130kW
- Energy storage system: 75Ah/352V, 25Ah/352V
- Bi-directional converter: 2×30kVA
- EV charger: 3×15kW
- Vehicular charger: 2×3kW
- Simulative AC load: 30kVA

Main interface of software for monitoring and control center
Microgrid Laboratory Platform of NCEPU

- Laboratory Equipment

photovoltaic arrays and inverters

Simulative load

AC bus

2×PCS

Network and control

Simulative wind turbines and converters
Thank you!

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