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

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2 Heuristic Operation Strategy

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1 Research Background

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

2 Recent Studies

charging strategies

- Economic and environmental impacts of charging strategies
- Optimization methods based on forecasting

energy management

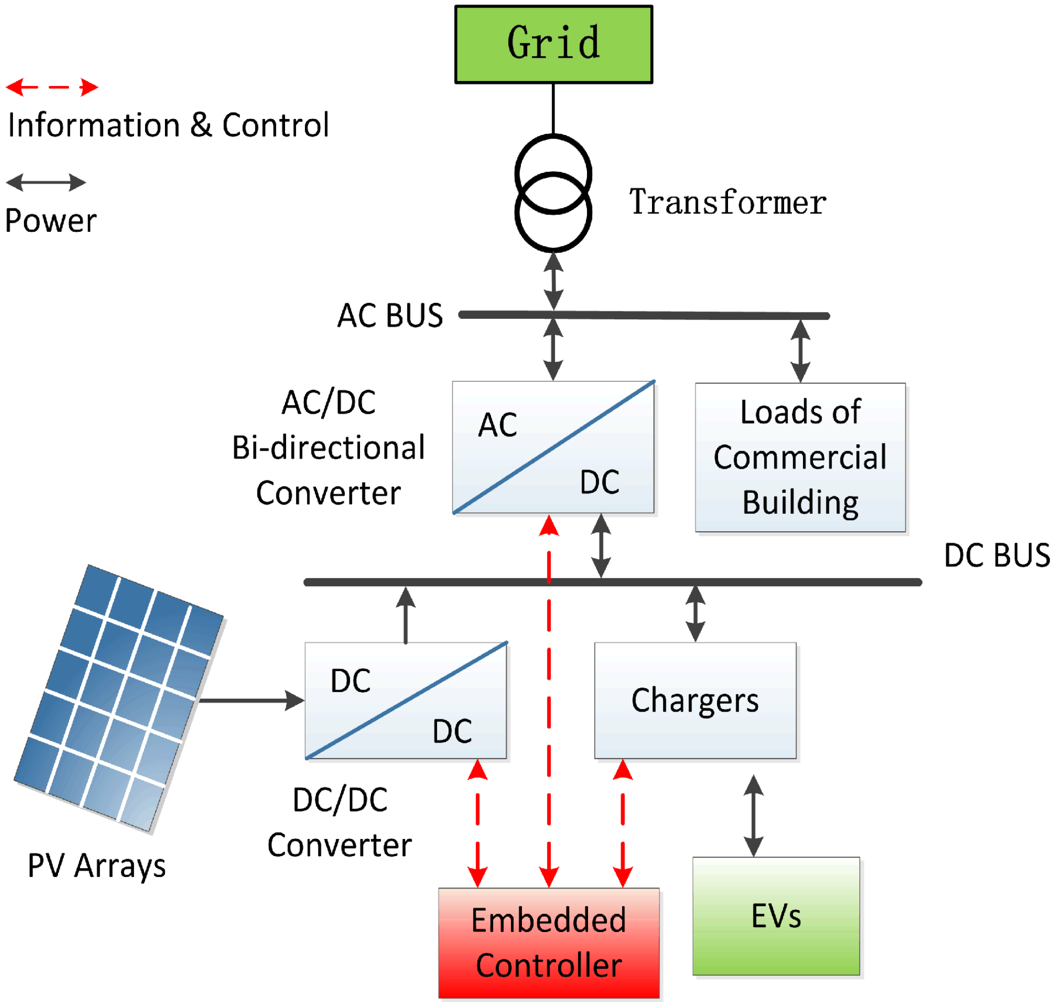
- Minimize the operating cost of micro-grid system
- Maximize customers' comfort with minimum power consumption

In these researches, most of the methods are based on day-ahead optimization, the forecasting for PV power and user load are required.

3 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.

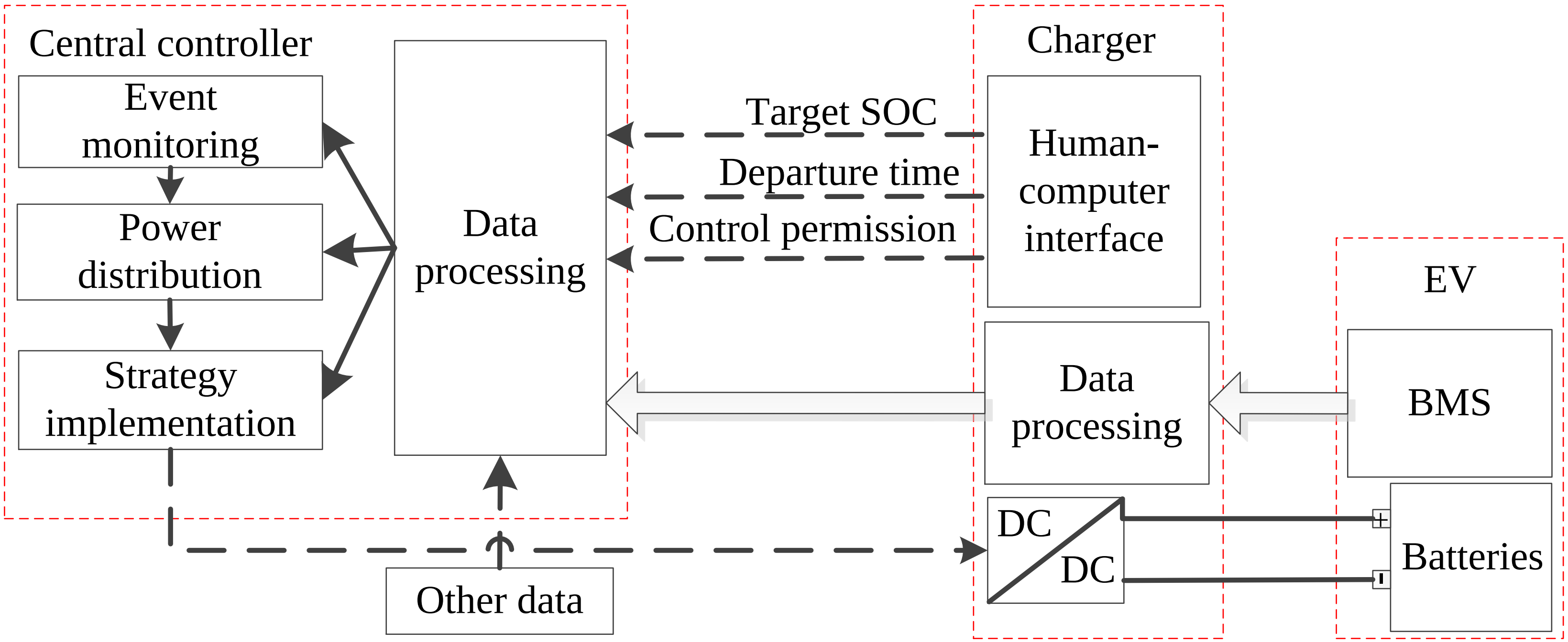
1 Typical structure of commercial building micro-grids



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

1 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

Real-time Decision

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

$$ECCD(t) = \frac{1}{N_{EV}(t)} \sum_{i=1}^{N_{EV}(t)} \left(\frac{SOC^i(t) + C^i(t) \cdot \left(t_d^i - t\right)}{SOC_{obj}^i} \right)$$

The first principle: maximize the ECCD.

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

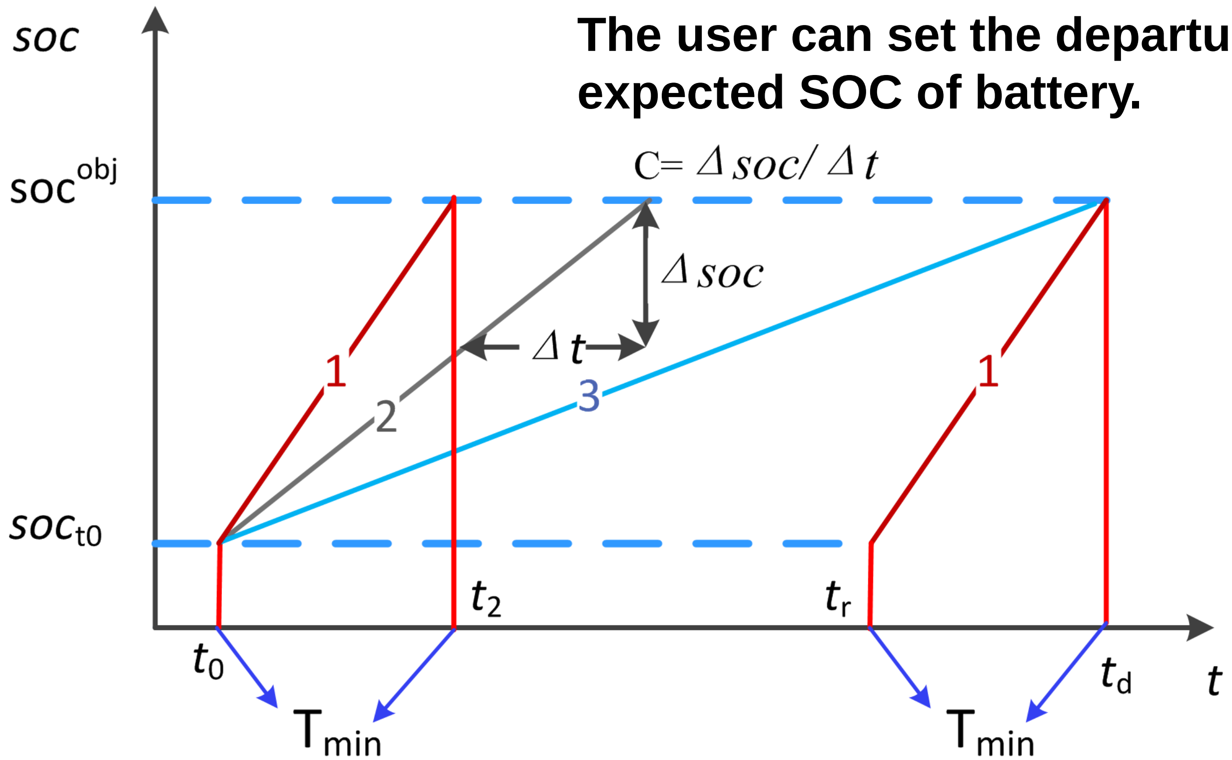
$$DPCE(t) = \left| P_{pv}(t) - \sum_{i=1}^{N_{EV}(t)} P^i(t) \right|$$

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

3 Strategy for Real-time Operation of Commercial Building Micro-grids

- **Model of EV Feasible Charging Region (FCR)**

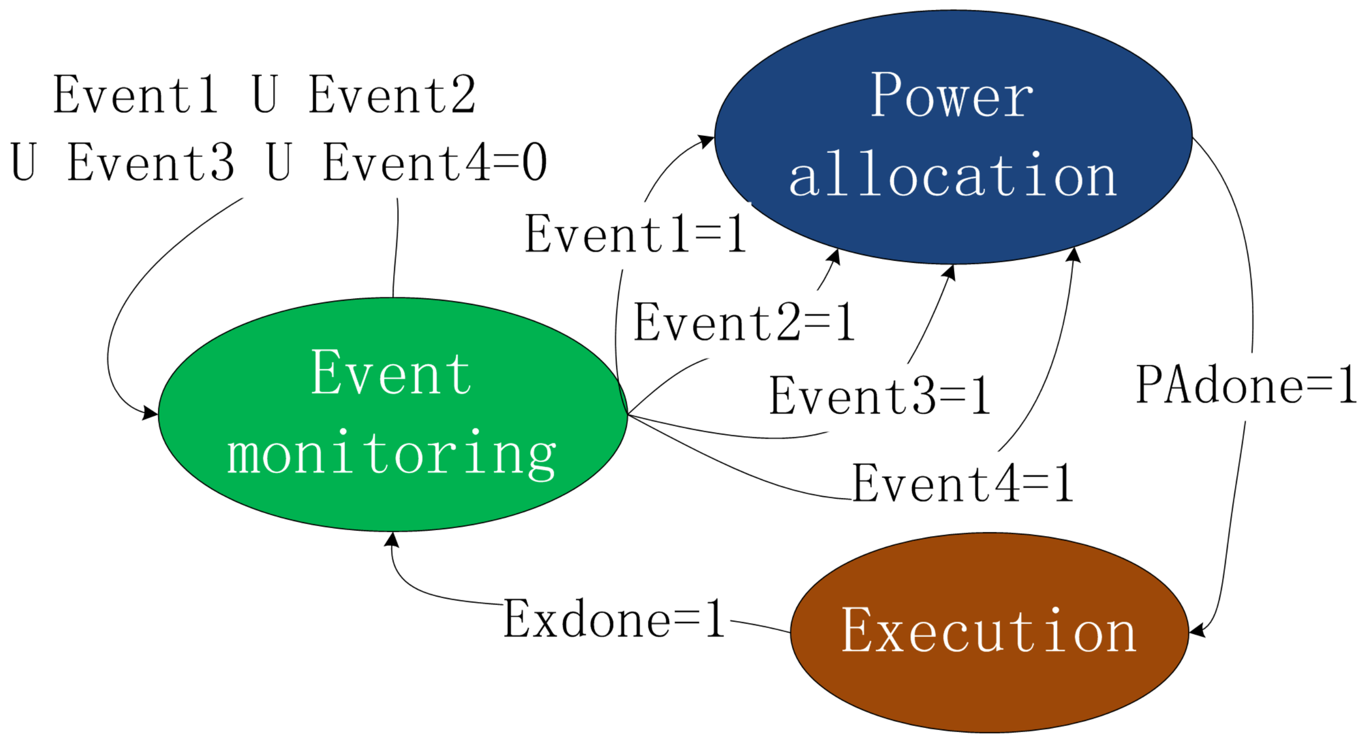
The user can set the departure time and expected SOC of battery.



$$FCR:\{(t_s, C) \mid t_s \in [t_0, t_r], \mathrm{C} \in [\mathrm{C}_{\min}, C_{\max}]\}$$

3 Strategy for Real-time Operation of Commercial Building Micro-grids

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

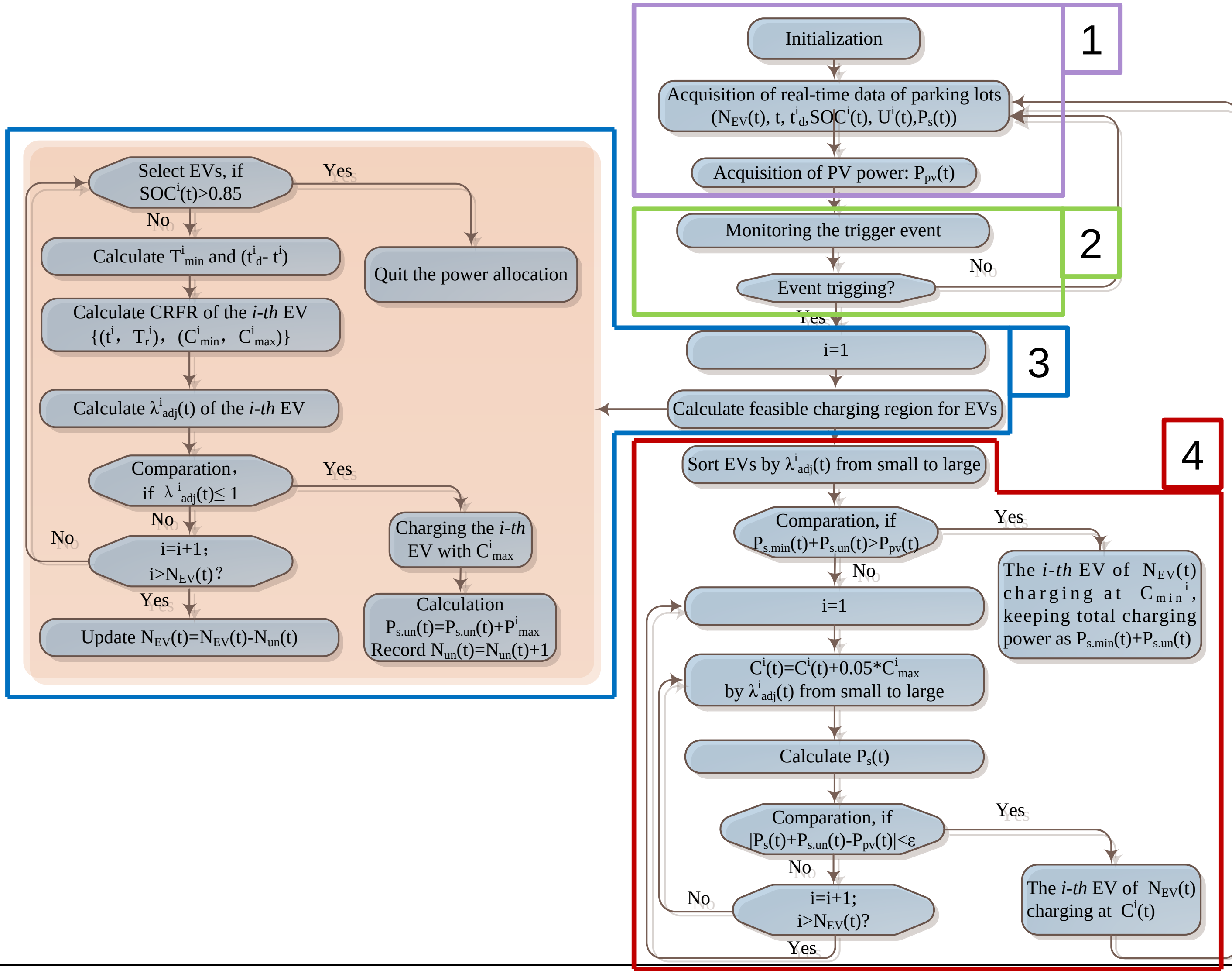


3 Strategy for Real-time Operation of Commercial Building Micro-grids

- **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 : $\left|P_{pv}(t)-P_{pv\_base}\right| \geq 0.05 \cdot P_S(t-\Delta t)$
  - The variation of the total charging power exceeds the accepted extent : $\left|P_S(t)-P_{S\_base}\right| \geq 0.05 \cdot P_{S\_base}$

Algorithm of Real-time power allocation (RTPA)



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

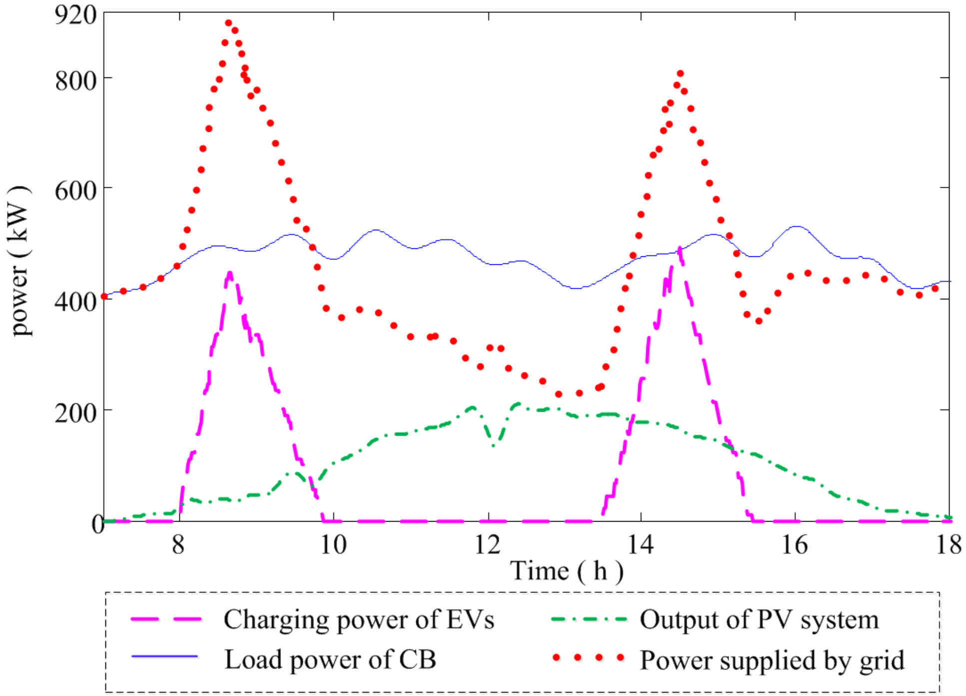
- **Experiment cases**

  - 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.

1 Analysis and comparison of results

Case1: Uncontrolled operation strategy



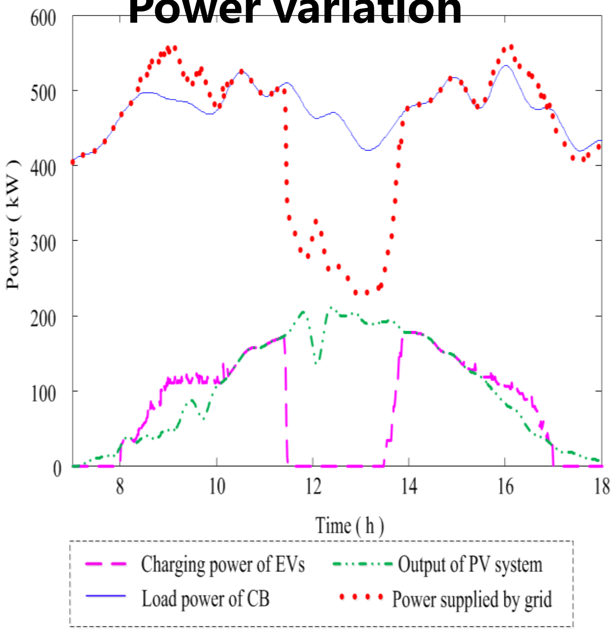
Power variation

During the peak hours, the charging power of EVs leads to about extra 420kW loads than the original peak loads.

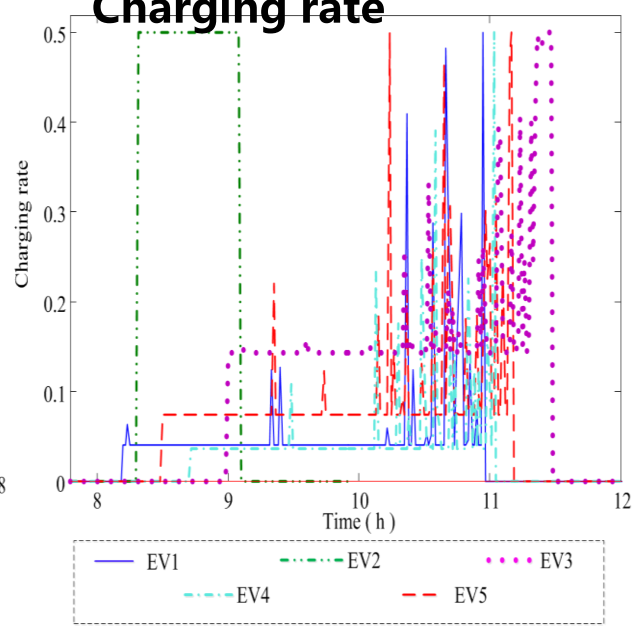
1 Analysis and comparison of results

Case2: FCR + PSO operation strategy

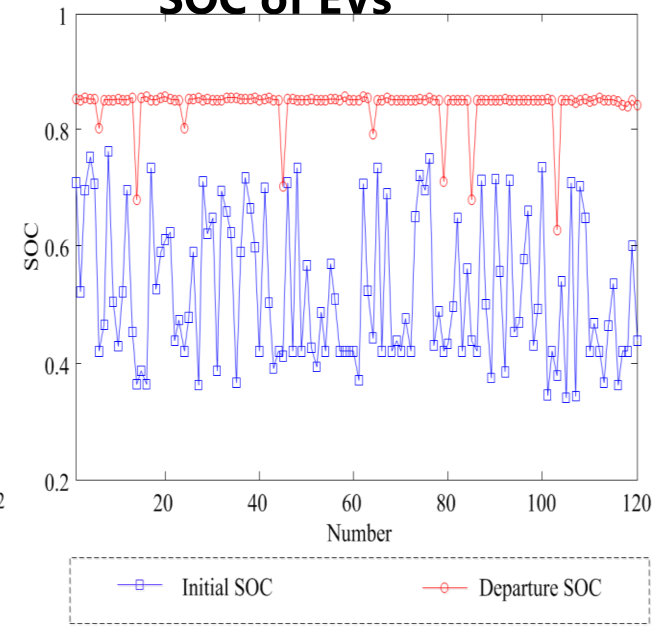
Power variation



Charging rate



SOC of EVs

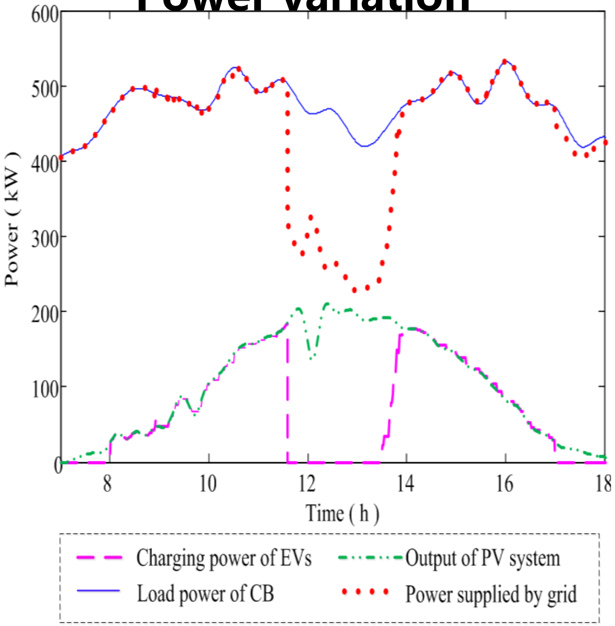


The extra load is only 70 kW and most of the EVs can leave with objective SOC successfully. However, the total charging power and the charging rate of EVs fluctuate frequently.

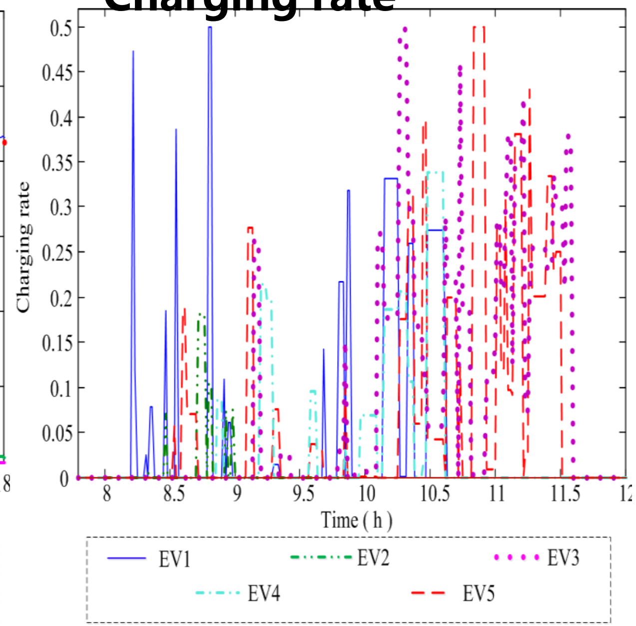
1 Analysis and comparison of results

Case3: DET + PSO operation strategy

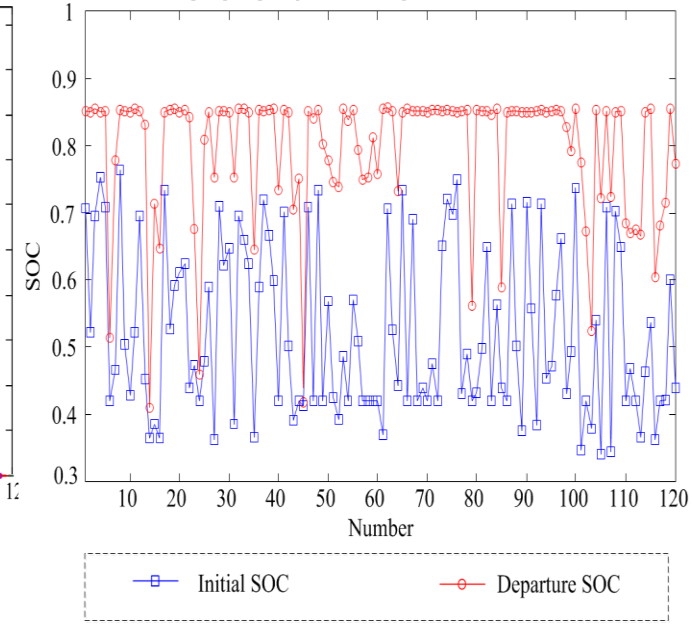
Power variation



Charging rate



SOC of EVs

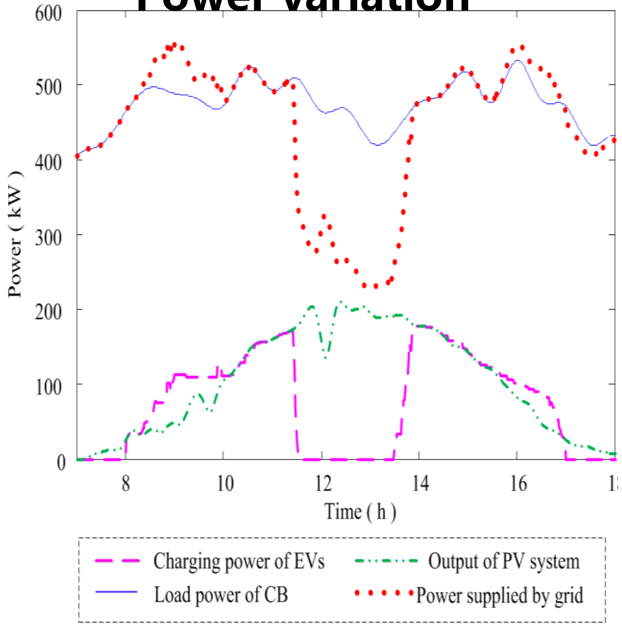


The charging rate varies dramatically and randomly. Besides, the charging demand of many EVs cannot be satisfied before leaving.

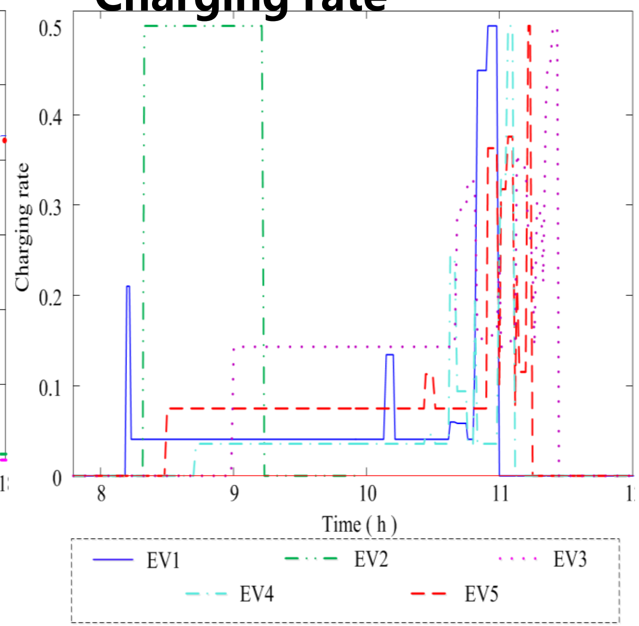
1 Analysis and comparison of results

Case4: FCR + DET +PSO operation strategy

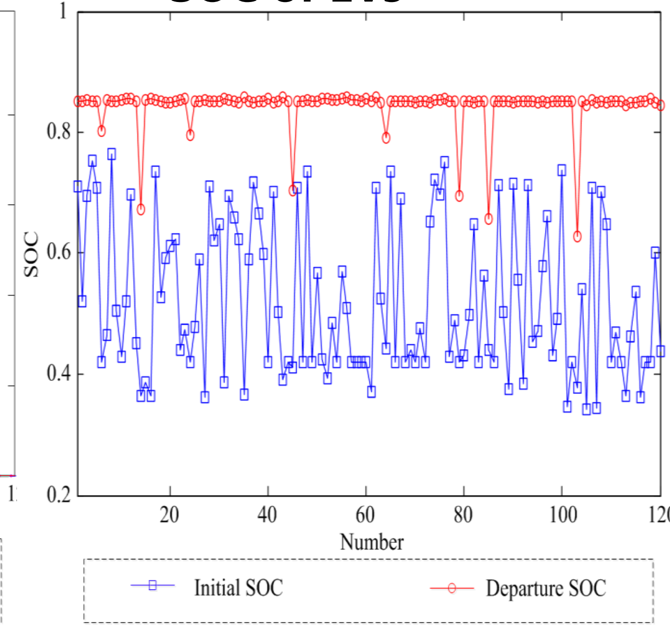
Power variation



Charging rate



SOC of EVs

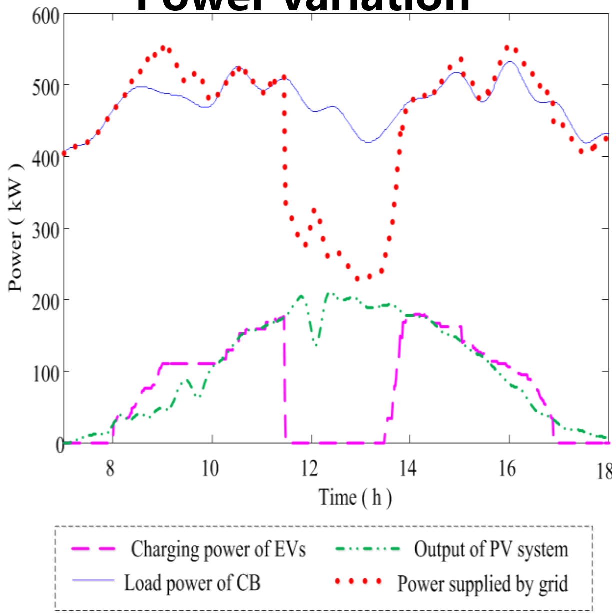


The DET mechanism makes the charging rate of EVs varies more smoothly than above cases.

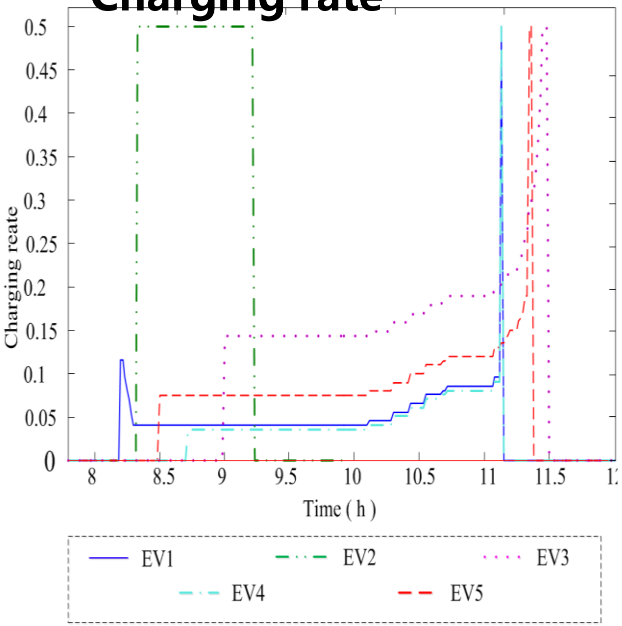
1 Analysis and comparison of results

Case5: FCR + DET + RTPA operation strategy

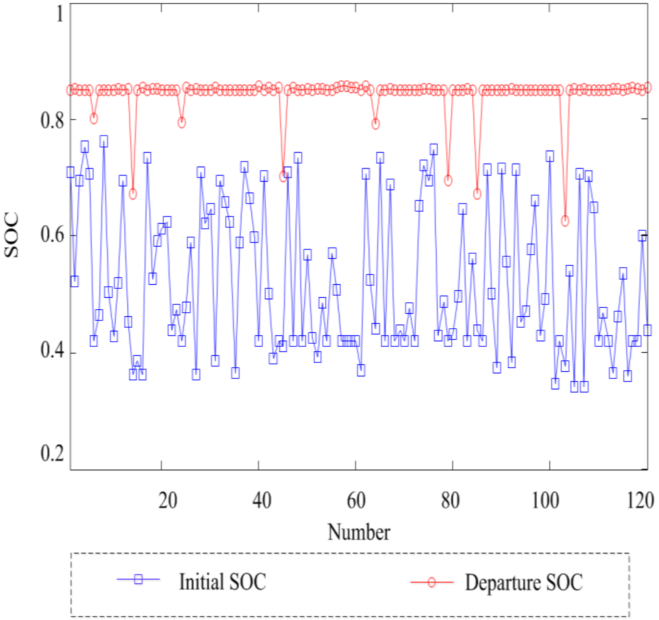
Power variation



Charging rate



SOC of EVs



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

Name	FCR+PSO	DET+PSO	FCR+DET+PSO	FCR+DET+RTPA
Time cost on calculation with different number of EVs	23.87 s/1	23.92 s/1	23.97 s/1	**0.27 s/1**
	26.47 s /10	26.22 s/10	26.56s/10	**1.125 s/10**
	30.53 s/20	29.34 s/20	30.49 s/20	**0.708 s/20**
	35.11 s/30	34.36 s/30	35.03 s/30	**0.567 s/30**
	41.72 s/40	39.69 s/40	41.53 s/40	**0.567 s/40**
	46.14 s/50	45.05 s/50	46.08 s/50	**0.432 s/50**
	55.26 s/60	54.98 s/60	55.3 s/60	**0.432 s/60**
Calculation times per day	450	180	168	**172**
Occupancy time on processor per day	**17411.73 s**	**5966.27 s**	**6079. 75s**	**54.53s**

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)

✓ A Hybrid Forecasting Model with Parameter Optimization for Short-term Load Forecasting of Micro-grids. Applied Energy, 2014, 129: 336-345.

✓ Multi-objective Optimization for Component Capacity of the Photovoltaic-based Battery Switch Stations: Towards Benefits of Economy and Environment. Energy, 2014, vol. 64, no.1, pp. 779-792.

✓ Optimal Operation Method for Microgrid with Wind/PV/Diesel Generator/Battery and Desalination. Journal of Applied Mathematics, 06/2014.

✓ 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.

✓ 可再生能源与电动汽车充放电设施在微电网中的集成模式与关键问题[J]. 电工技术学报，2013，28(2)：1-14.

✓ 含光伏发电系统的电动汽车充电站多目标容量优化配置方法[J]. 电工技术学报，2013，28(6)：238-248.

✓ 含光伏发电系统的电动汽车充电站多目标容量优化配置方法[J]. 电工技术学报. 2014，29(8)：46-56.

✓ 电动汽车光伏充电站的多目标优化调度方法[J]. 电工技术学报. 2014, 38(14):77-83.

✓ 考虑换电储备的电动汽车光伏换电站动态功率分配方法[J]. 电工技术学报，2014，29(4)：306-315.

✓ 计及服务可用性的电动汽车换电站容量优化配置[J]. 电力系统自动化. 2014, 38(14):77-83.

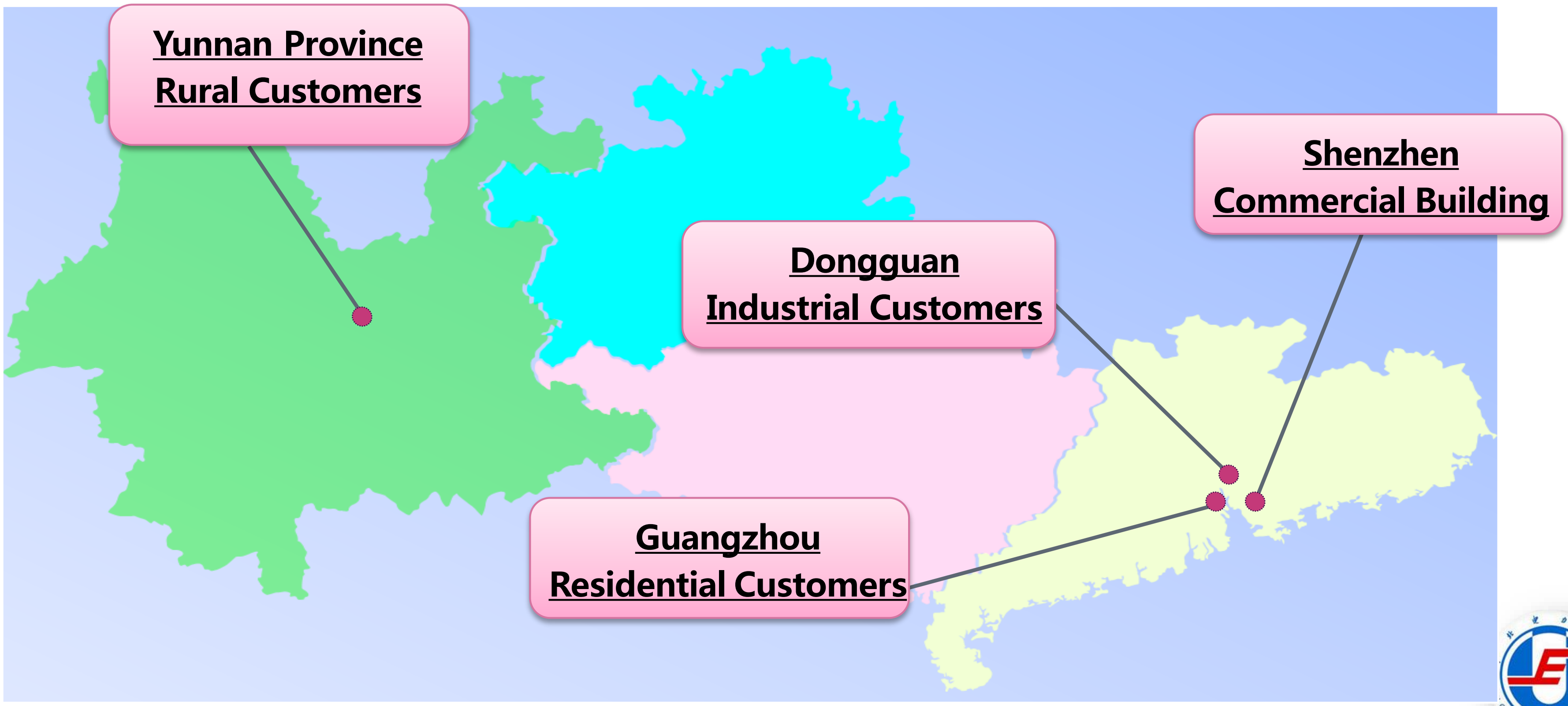
✓ 配网故障情况下电动汽车换电站V2G运行的主动控制策略[J]. 电网技术.

Related Work

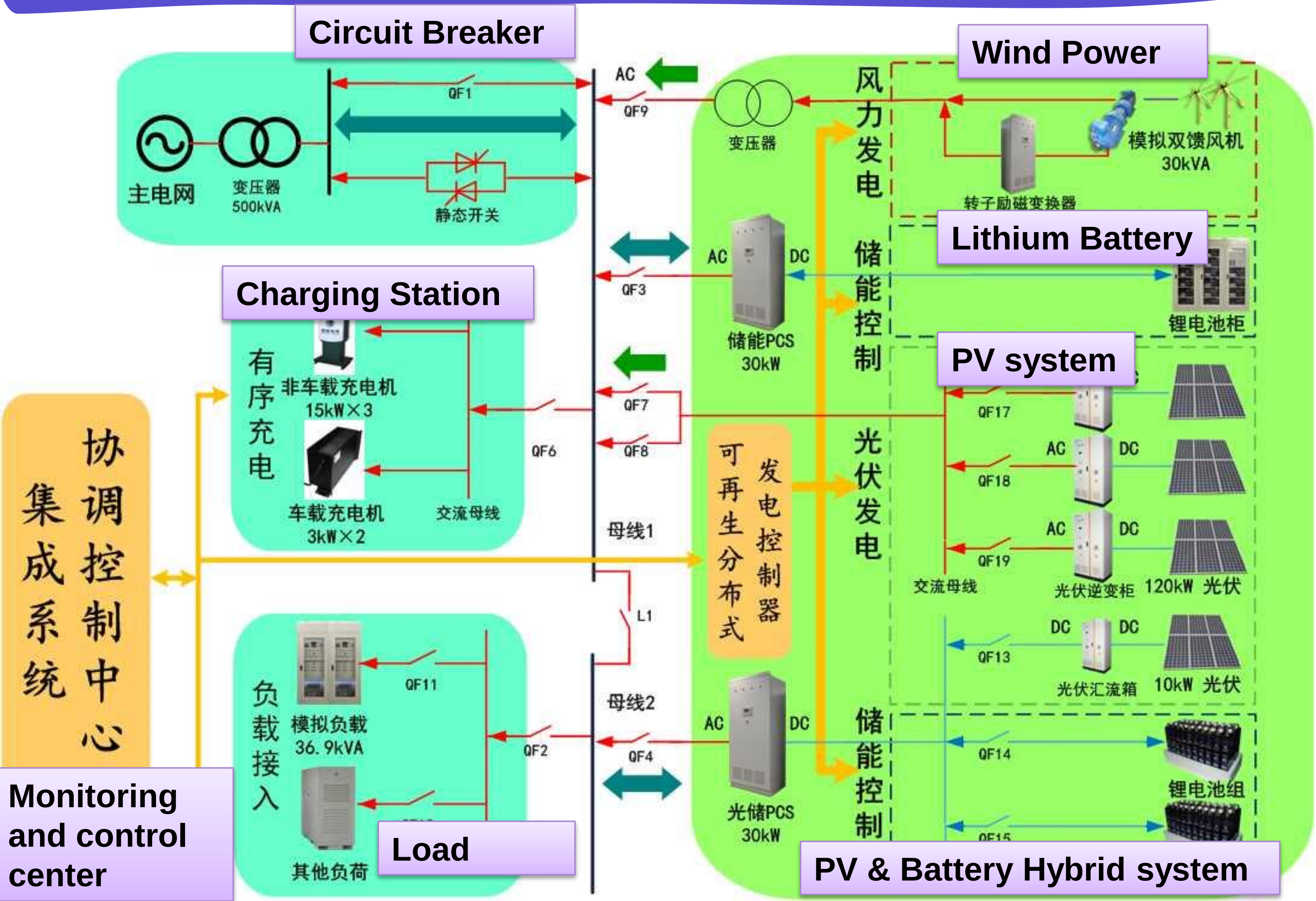
Demonstration and Key Technologies for User-side Smart Microgrid with Distributed Energy Resources. National High-tech R&D Program of China (863 Program) (No. 2014AA052001)

- 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



Microgrid Laboratory Platform of NCEPU

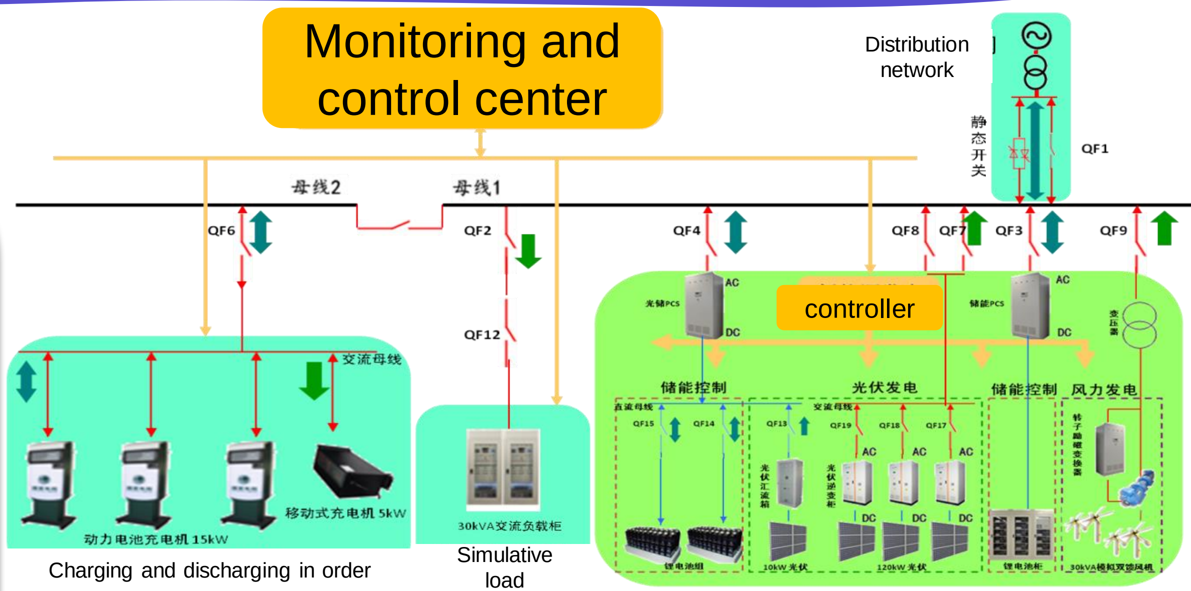


Microgrid Laboratory Platform of NCEPU

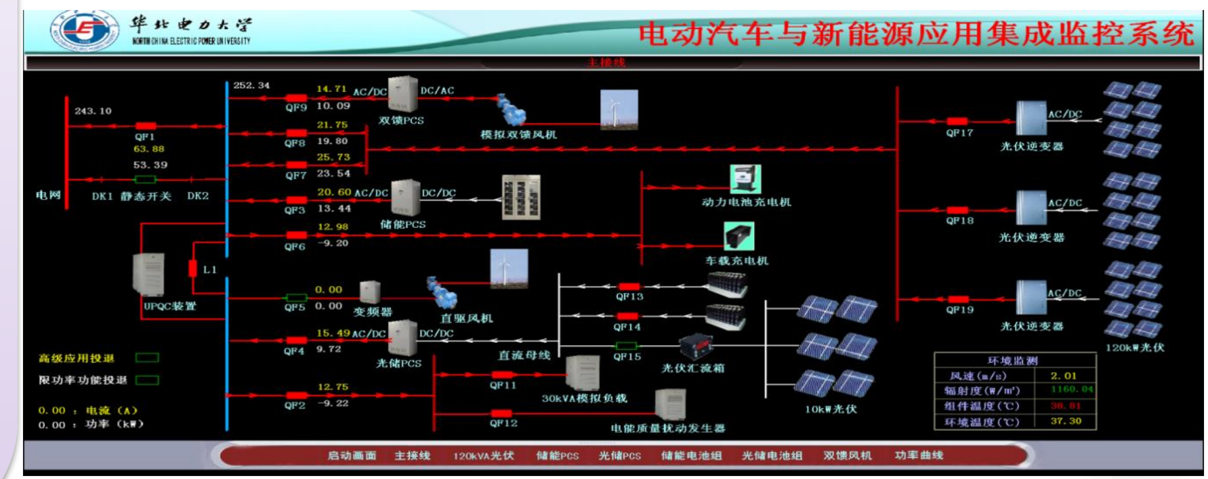
• Main Structure

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

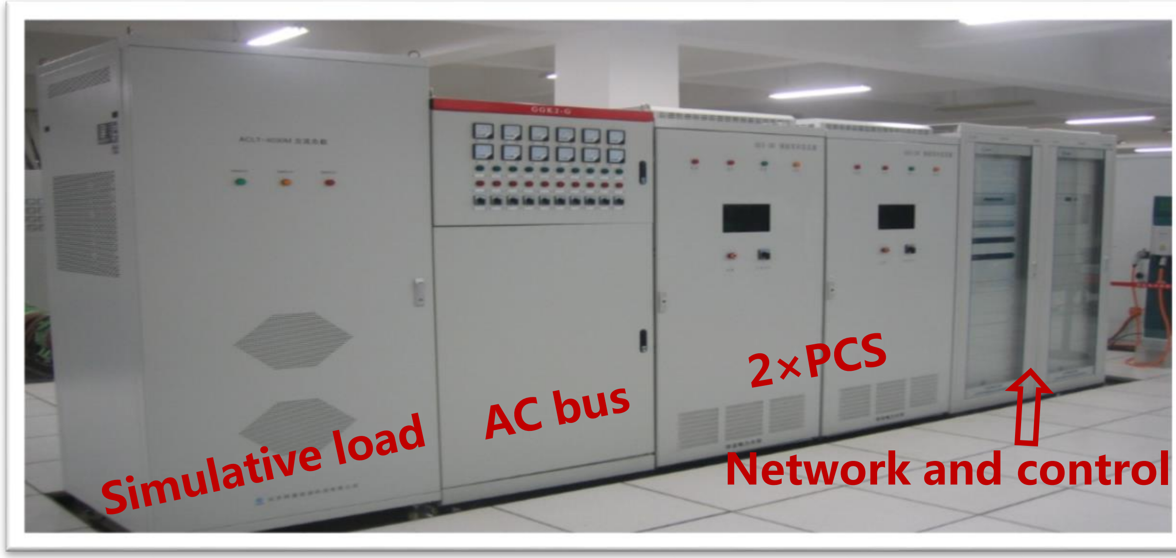


Main interface of software for monitoring and control center



Microgrid Laboratory Platform of NCEPU

- **Laboratory Equipment**



Thank you !

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