网络化能源系统的分布式能源管理
- 混合储能系统与微网
Distributed Energy Management of Networked Energy Systems - Hybrid Energy Storage Systems and Micro Grids

- 闫东翔，博士生
- 马澄斌，博士，副教授
上海交通大学密西根学院

- Dongxiang Yan, RA
- Chengbin Ma, PhD, Associate Professor
Univ. of Michigan-SJTU Joint Institute,
Shanghai Jiao Tong University,
Shanghai, P. R. China

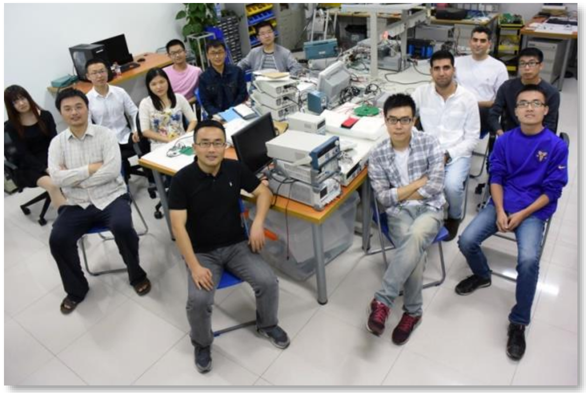
2017年7月7日 北京
July 7th, 2017, Beijing, China

JOINT INSTITUTE
交大密西根学院

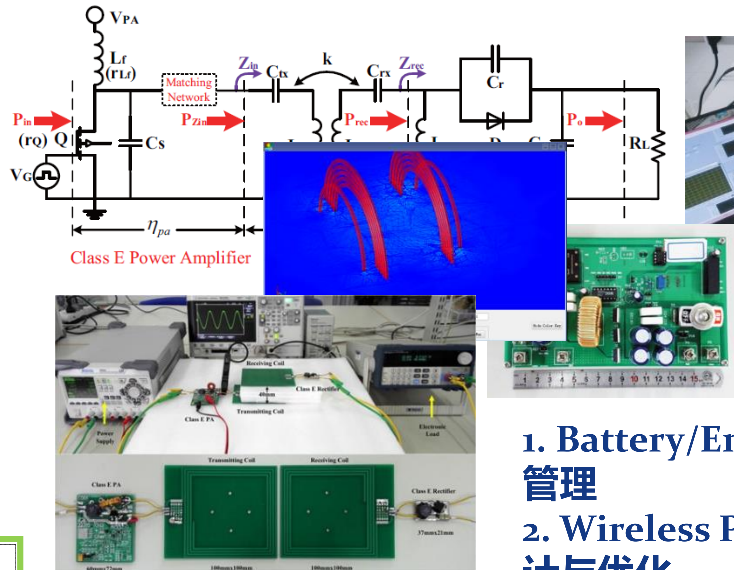
Outline/概要

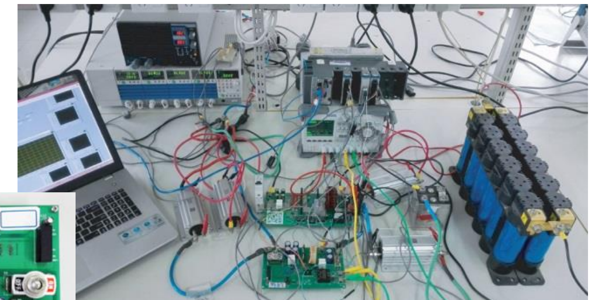
- Introduction/简介
- Multi-Agent Based Control/多代理人分布式控制
  - Battery/UC/Engine-Generator HES/电池-超级电容-发电机组混合系统
  - Single Micro Grid/单一微网
  - Multiple Micro Grids/多个微网
- Conclusions and Future Works/结论与工作计划

Dynamic Systems Control Lab (2010~Pre.)
动态系统控制实验室（2010年至今）

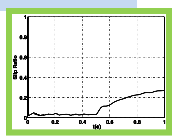


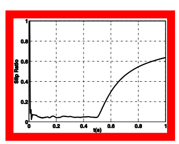
1 Postdoc, 5 Ph.D., 6 M.S.
1 博士后；5 博士生；6 硕士生

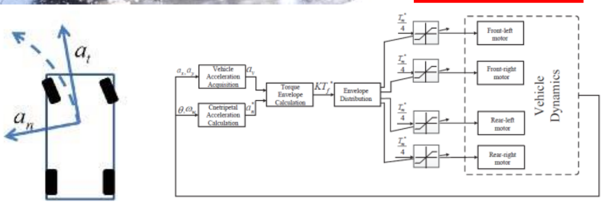


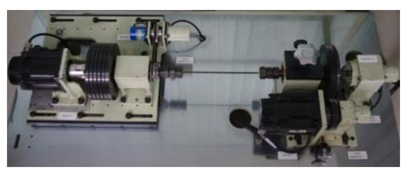


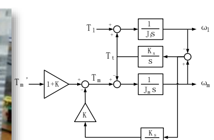
1. Battery/Energy Management/电池与能源管理
2. Wireless Power Transfer/无线电能传输设计与优化

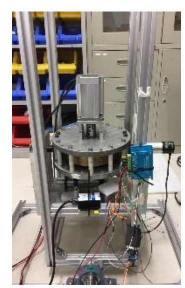












- Control Engr./控制工程
- Optimization/系统优化
- Power Electron./电力电子
- Mechatronics/机电系统

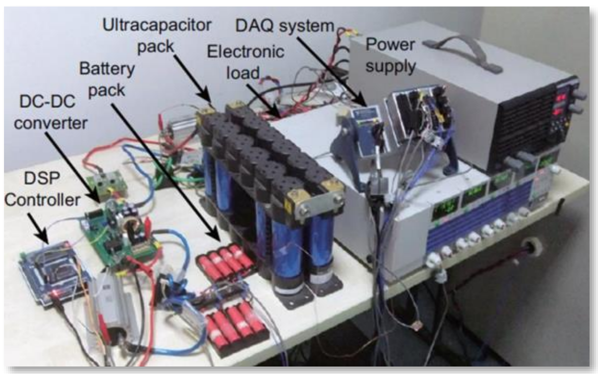
3. Electric Vehicle Dynamics/车辆动力学 4. Servo/Motion Control/伺服与运动控制

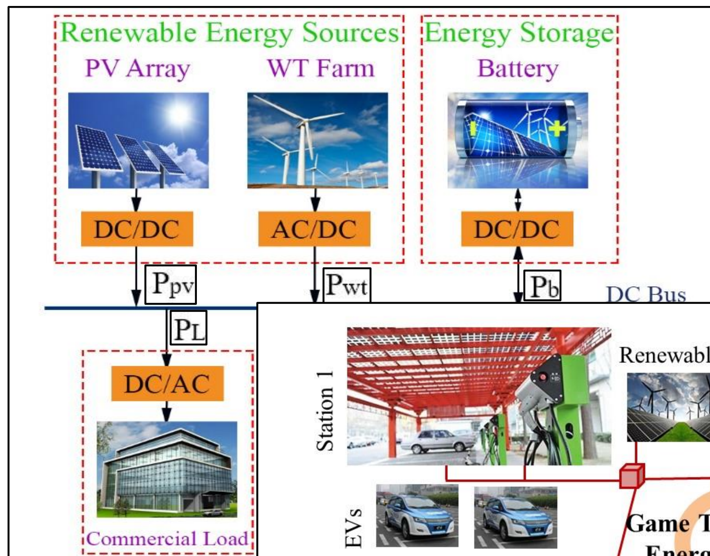
Research Interests/研究兴趣

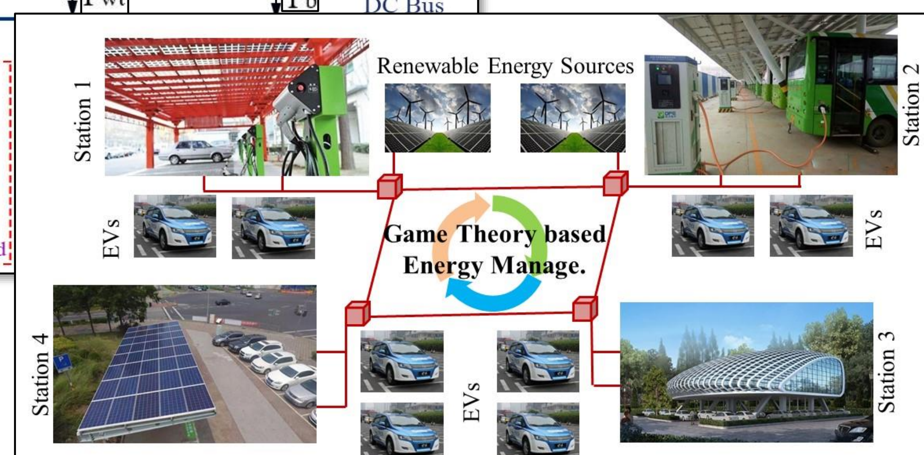
Hybrid Storage System
（混合储能系统）

Micro Grids and Smartgrids
（微网与智能电网）

Resilient Control
（弹性控制）





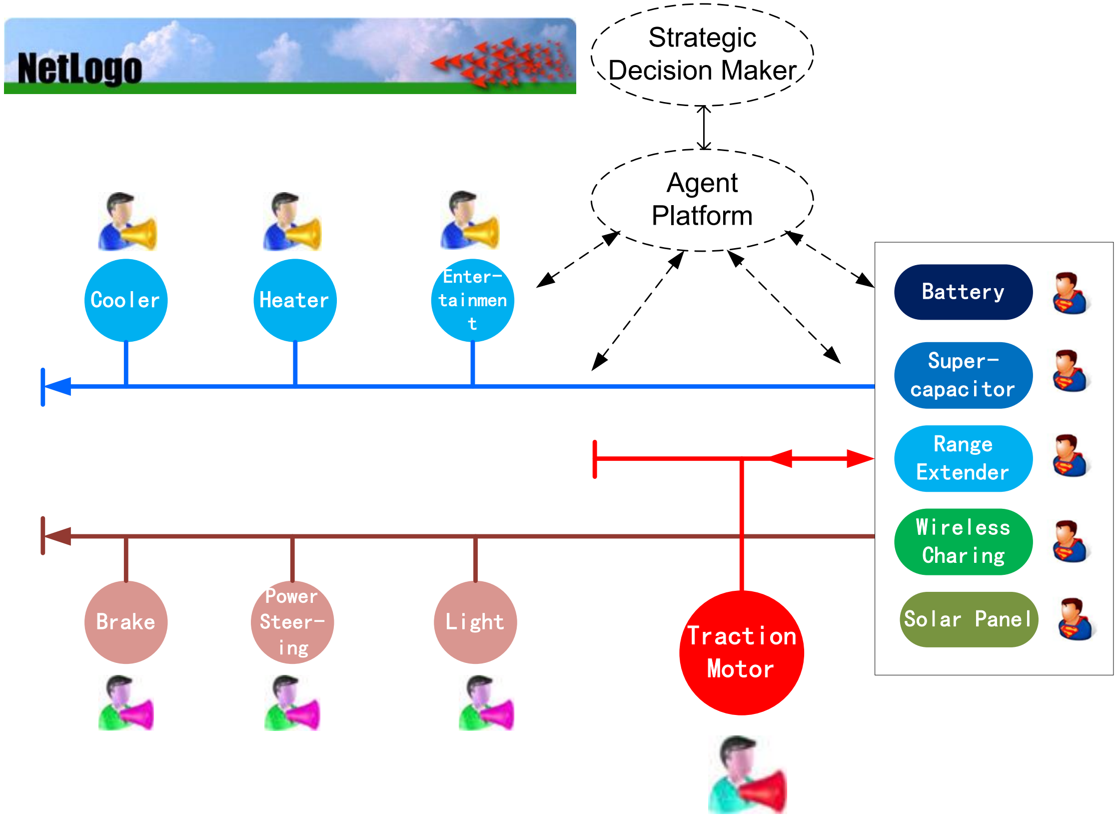


- Flexibility/灵活性
- Scalability/可扩展性
- Reliability/可靠性
- Resilience/自适应弹性

Control of Networked Energy Systems

网络化能源系统的控制

- Flexibility, Fault-tolerance, Scalability, Reliability/灵活性、容错性、可扩展性、可靠性
- Intelligent "Plug & Play" in a dynamic environment/在复杂动态环境中的"即插即用"



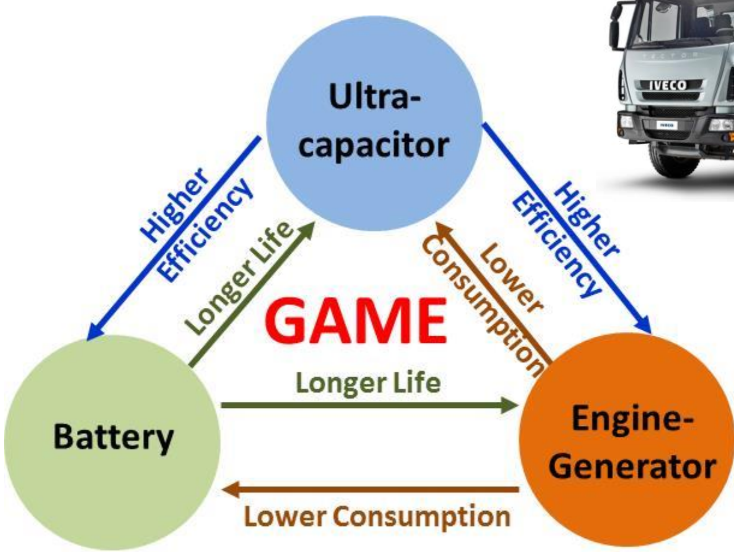
Multi-agent Interaction Modeling
基于多代理人的建模

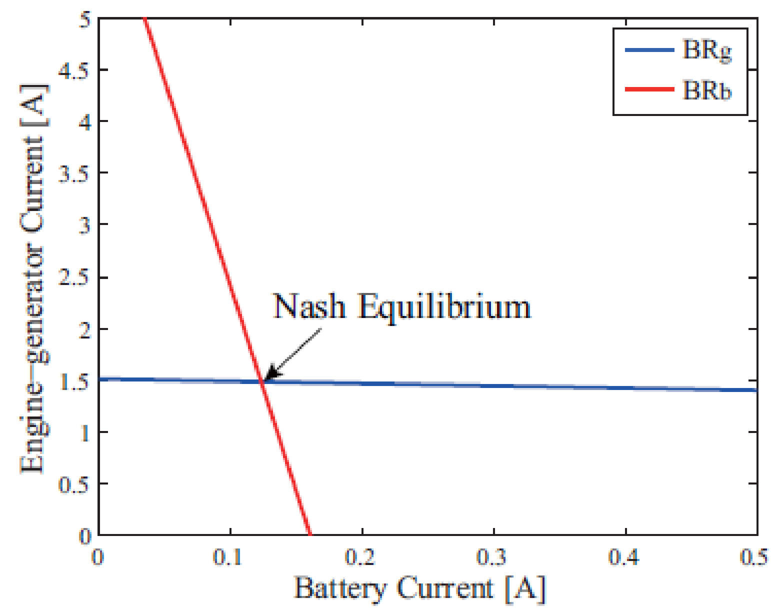
Strategic Interaction Analysis
策略层面的交互分析

Technical Committee (TC) on "Energy Storage " (TCES)
IEEE工业电子储能系统技术委员会

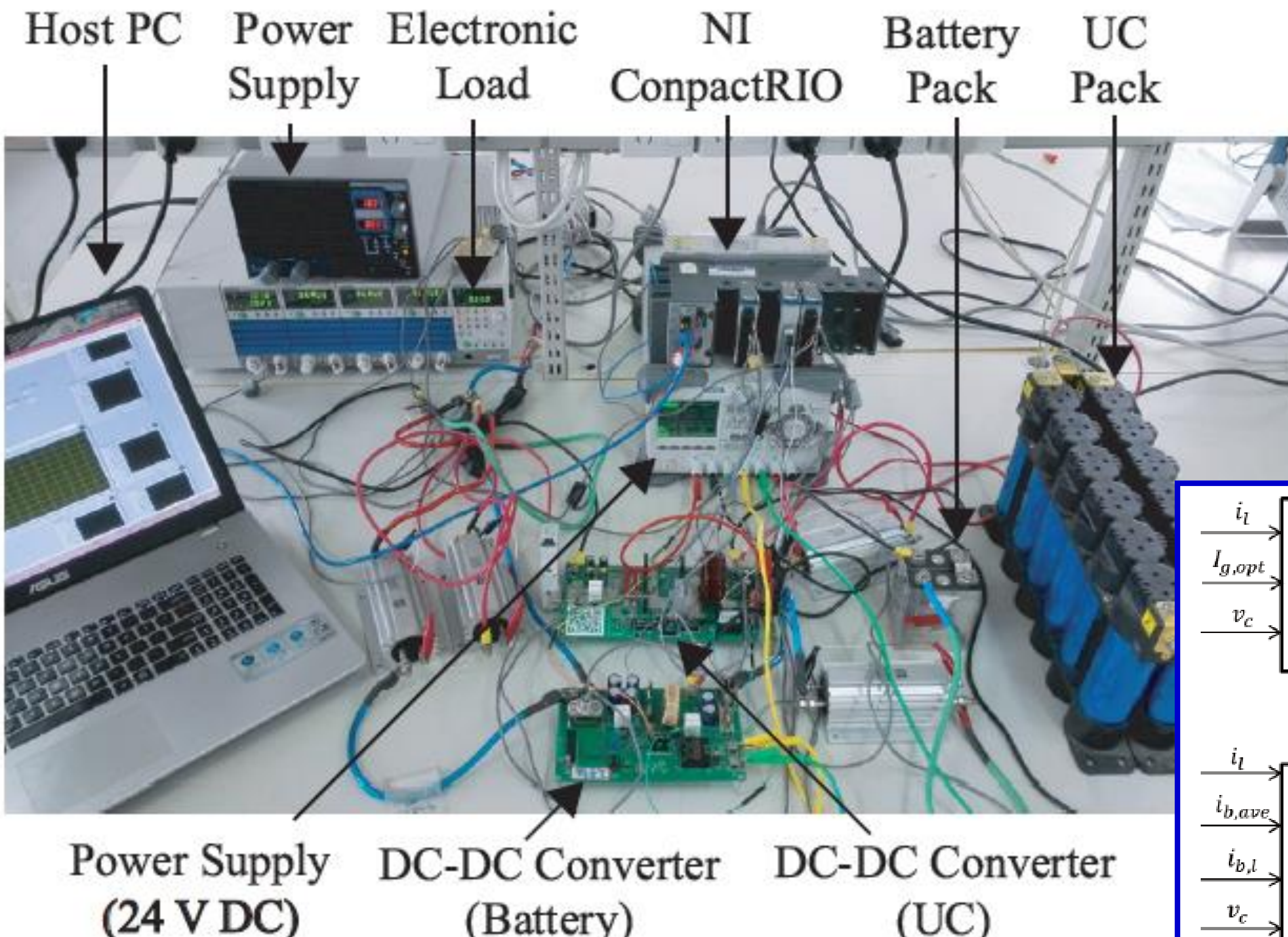
Three-Source Hybrid Energy System
三能源混合系统

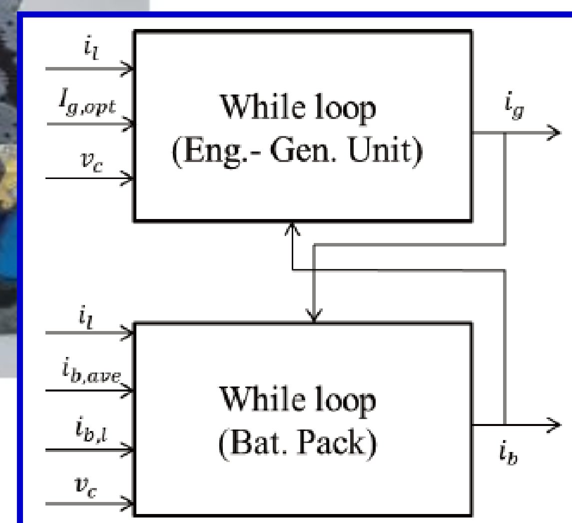
- Three energy devices act as agents to play a game（三个装置分别被表达为独立的代理人）
  - Engine-generator: lower the **fuel consumption** （发电机组：最小化燃油消耗）;
  - Battery pack: extend the **cycle-life** （电池包：延长其循环寿命）;
  - UC pack: maintain the **charge/discharge capability** （超级电容包：保持其充放电能力）.
- Ultracapacitor is an assistive energy storage device （超级电容是辅助储能装置）.
- Two degree-of-freedoms: battery and generator （两个自由度：电池包与发电机组）





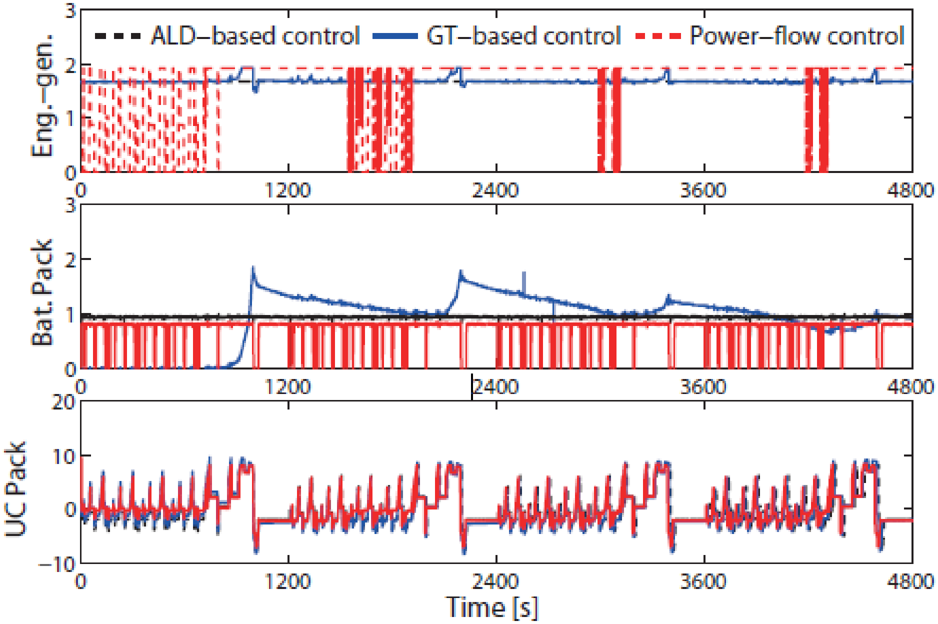
Test bench/小型实验系统



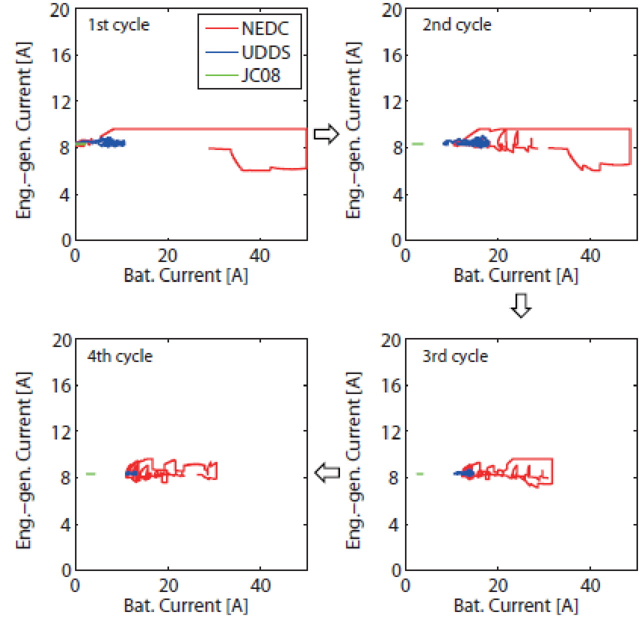


Results under Real Test Cycles

基于实际工况下的结果

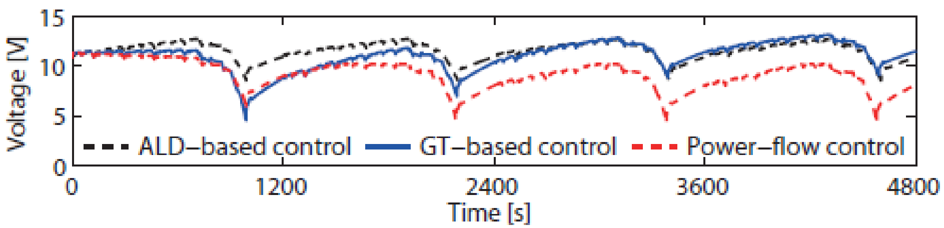


(a)



IMPROVEMENTS (%) IN EXPERIMENTS.

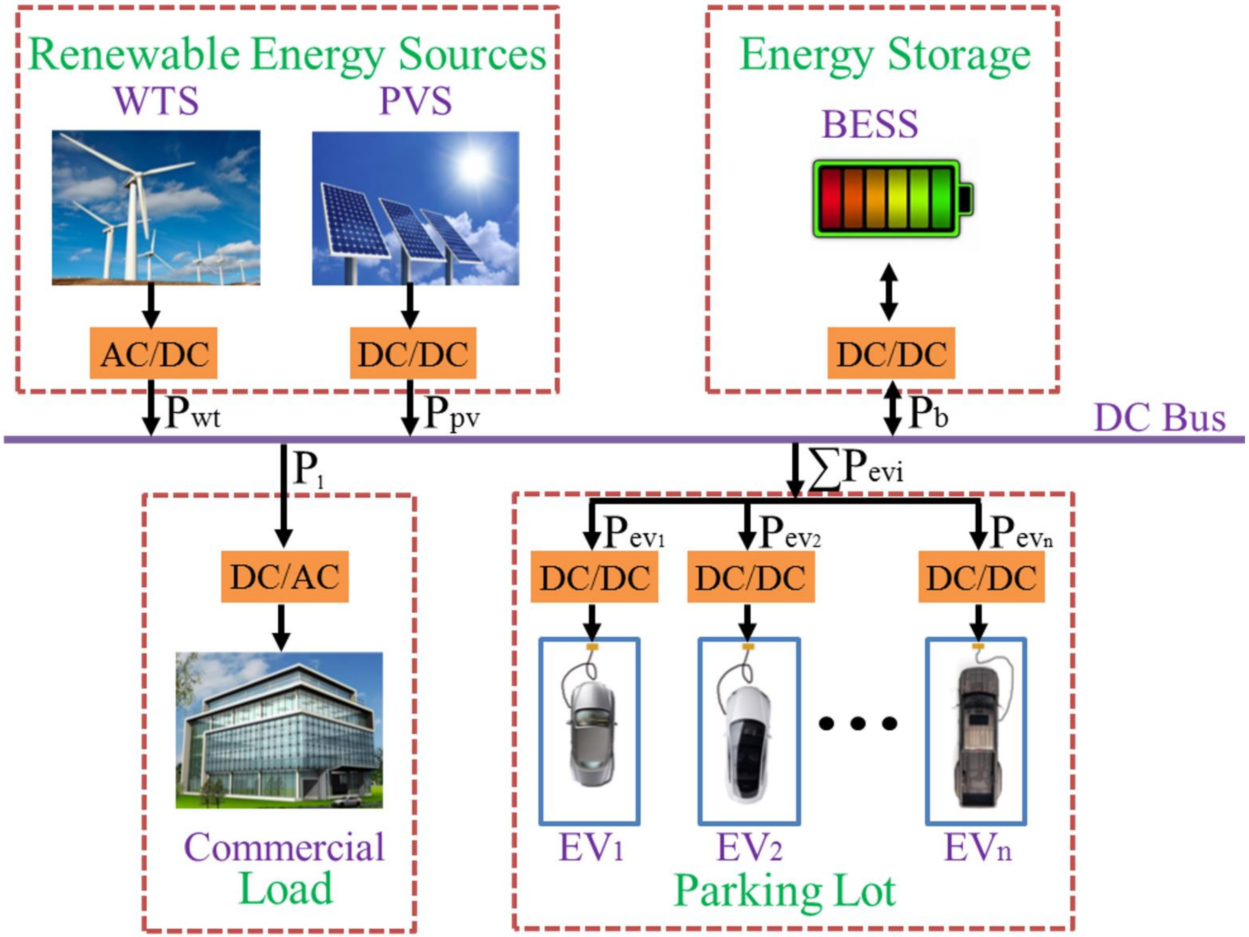
Cycles	$C_{g,ave}$	$I_{b,var}$	$\lvert\Delta E_{c,ave}\rvert$
NEDC	4.10% ↓	54.17% ↓	75.62% ↓
UDDS	5.95% ↓	59.90% ↓	74.15% ↓
JC08	17.21% ↓	67.67% ↓	62.24% ↓



- H. Yin, C. Zhao, M. Li, C. Ma, M. Chow: "A Game Theory Approach to Energy Management of An Engine-Generator/Battery/Ultracapacitor Hybrid Energy System", IEEE Trans. Industrial Electronics, Vol. 63, No. 7, pp. 4266-4277, July 2016.

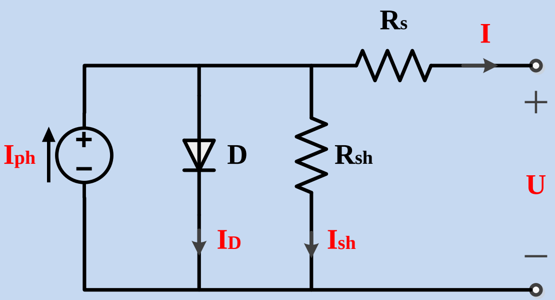
Islanded Micro Grid
孤岛模式微网

- An example of application （应用示例）

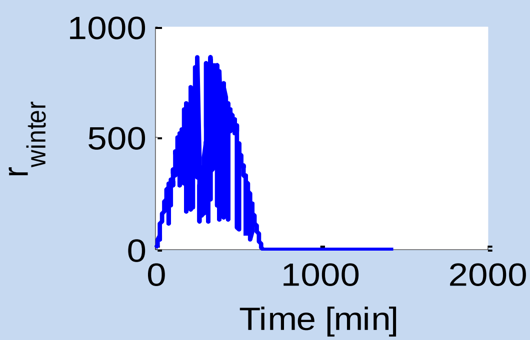


Physical Models
物理模型

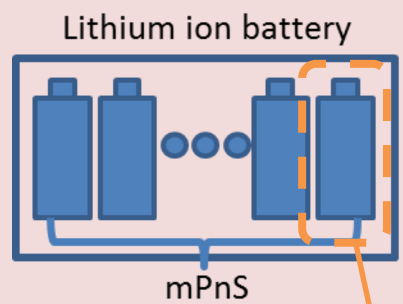
PV Model
PV模型



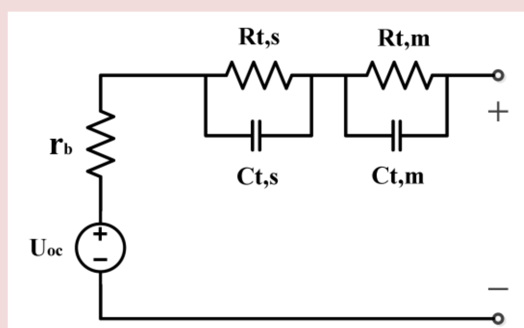
Radiation model/日照模型



Storage Battery Model
储能电池模型

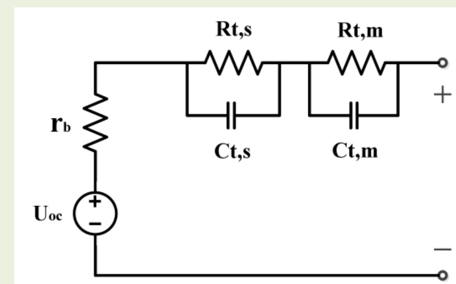


Equivalent circuit model
等效电路模型



EV Model
电动汽车模型

Equivalent circuit model
等效电路模型

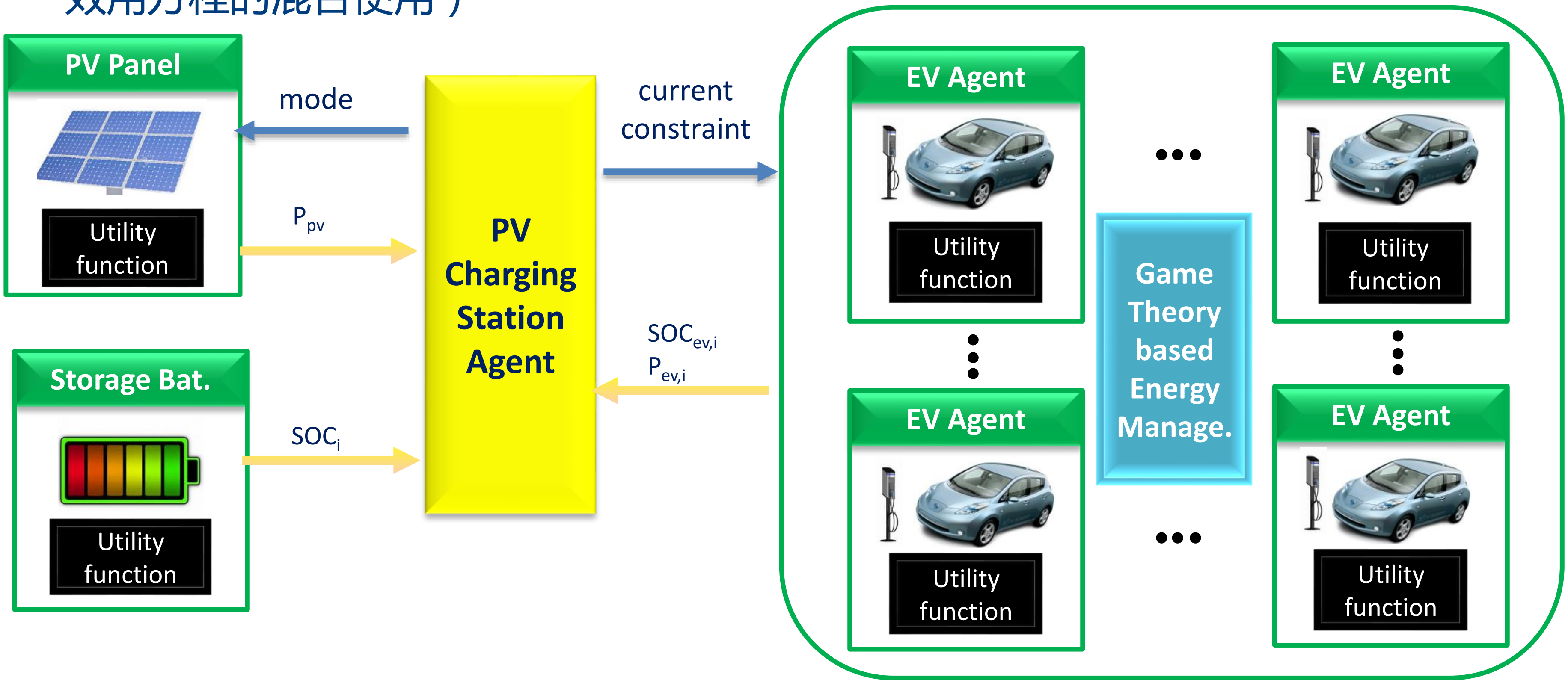


Included uncertainties/导入不确定性

- Capacity/容量
- SOC/荷电状态
- Starting time of charging/充电开始时间

Multi-Agent Modeling
多代理人建模

- Agents: PV charging station and electric vehicles（代理人：太阳能充电站与电动汽车）
- Models: combination of physical models and utility functions（模型：物理模型和效用方程的混合使用）



Distributed Energy Management

分布式能量管理

- Utility function-based charging power distribution（基于效用方程的充电功率分配）

Multi-object optimization（多目标优化）:

$$\text{OBJ 1: } \max u_{ev1}$$

...

$$\text{OBJ n: } \max u_{evn}$$

$$u_{evi} = \frac{P_i^*}{SOC_i} ln(p_i + 1)$$

$$\sum_{i=1}^{n} p_i \le p_{total} \le p_{max}$$

Direct solution 直接求解

Socially stable condition（稳定条件）:

$$\lambda_1 := \lambda_2 := \cdots := \lambda_n := \bar{\lambda} \neq 0$$

$$\mathrm{p_i} = \frac{a_i}{\lambda_i} - 1$$

Non-cooperative game/非合作博弈

Centralized control（集中式控制）:

$$\mathrm{p_i} = \frac{a_i(p_{total} + n) - \sum_{i=1}^{n} a_i}{\sum_{i=1}^{n} a_i}$$

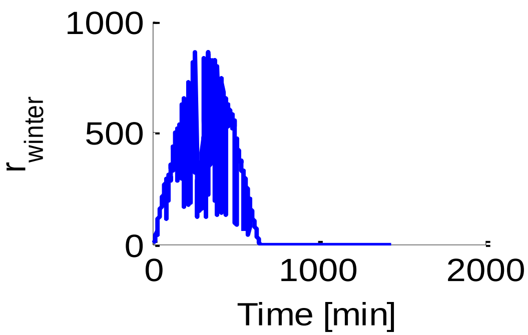
Decentralized control via（分布式控制）:

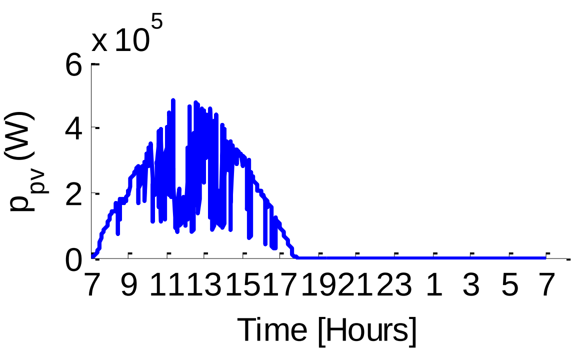
- Best response functions /最优响应方程
- Consensus network/一致性网络

$$\lambda_i(k+1) = \lambda_i(k) + \sum_{j=1}^{N} \omega_{ij}(\lambda_j(k) - \lambda_i(k))$$

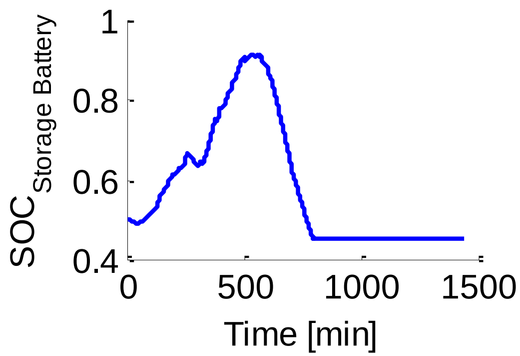
Simulation Results
仿真结果

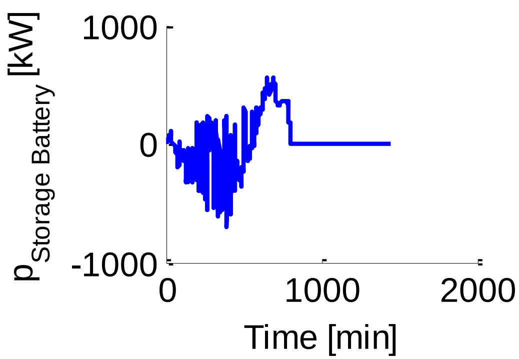
PV panel/PV板



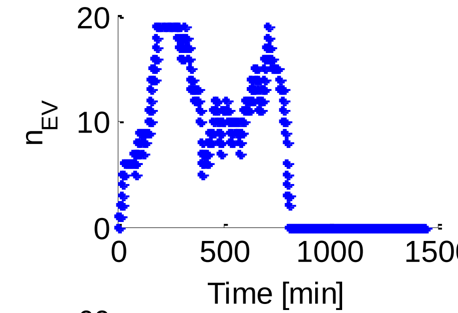


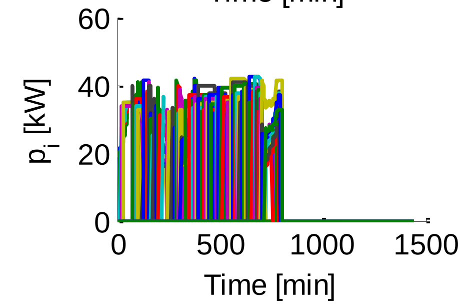
Storage Battery/储能电池

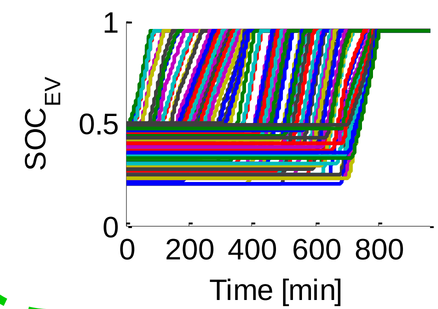




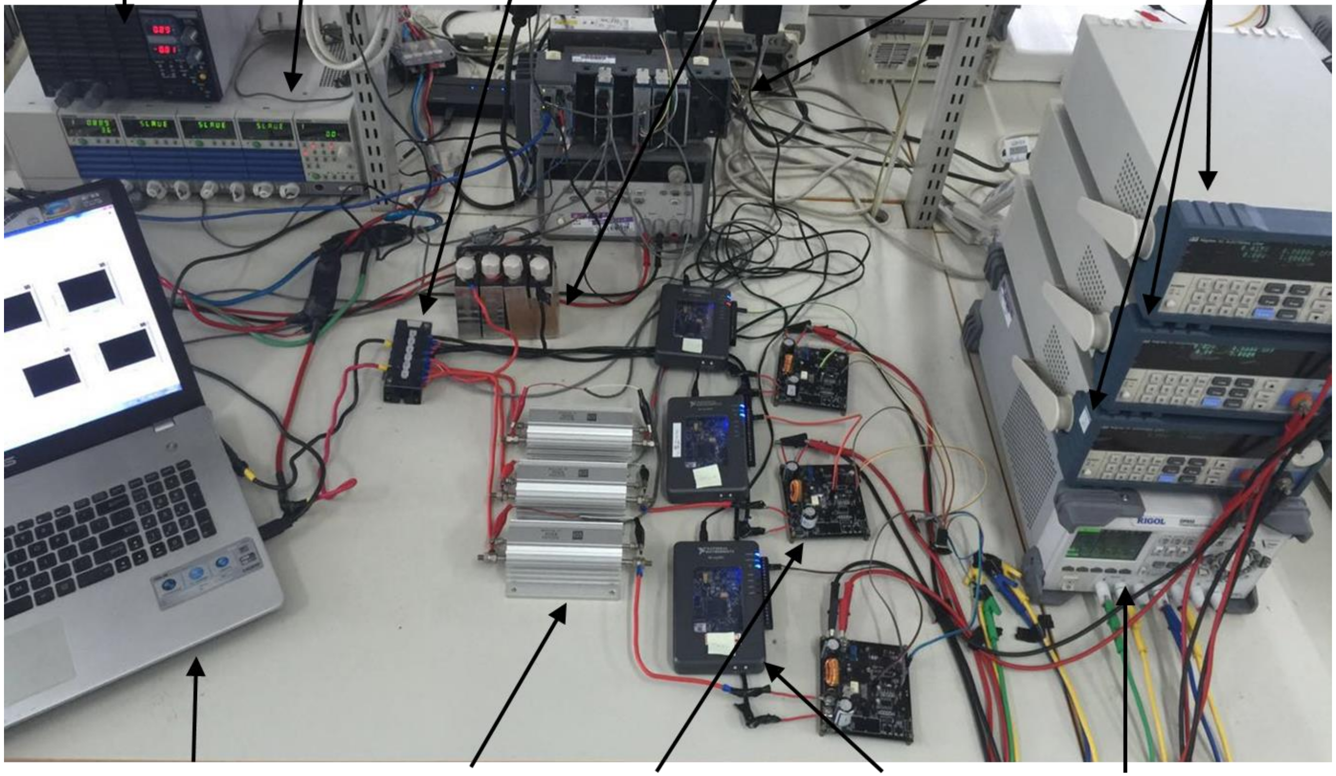
EVs/电动汽车







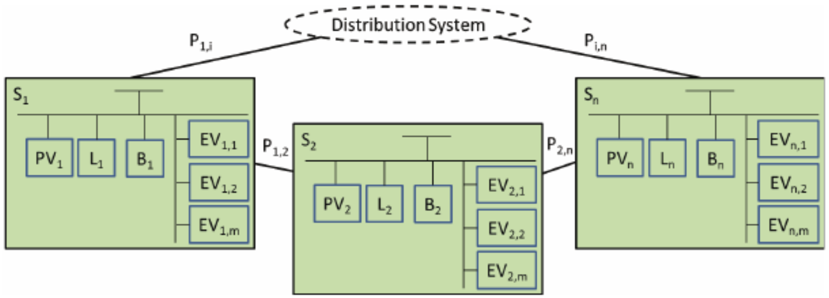
Experimental Setup
实验模拟系统



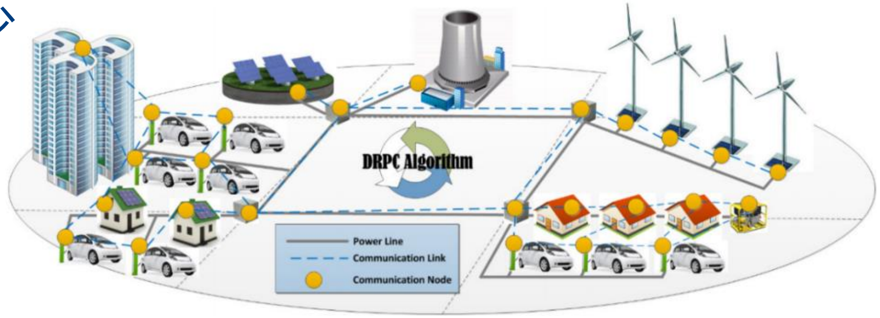
Multiple Micro-Grid Network
多微网网络

- **Large** scale micro grid/大规模微网
  - Complex and flexible topology/复杂灵活的拓扑 (**Modeling** tool/建模工具)
  - Distributed energy management/分布式管理 (**Decision Making** strategy/决策策略)
- **Multi-agent** modeling/多代理建模
- **Hierarchical distributed** energy management/分层分布式能量管理
  - **No centralized** control center/非集中式控制
  - Less required computational power/计算资源少
  - Robust against **uncertainties/**鲁棒性
  - Resilient against single point of failure/ **reconfigurability** /弹性可自恢复
- Applications/应用
  - Multiple PV-based charging station/多个充电站
  - Smart community/智慧社区

Multiple PV-based Charging Station
多个光伏发电充电站



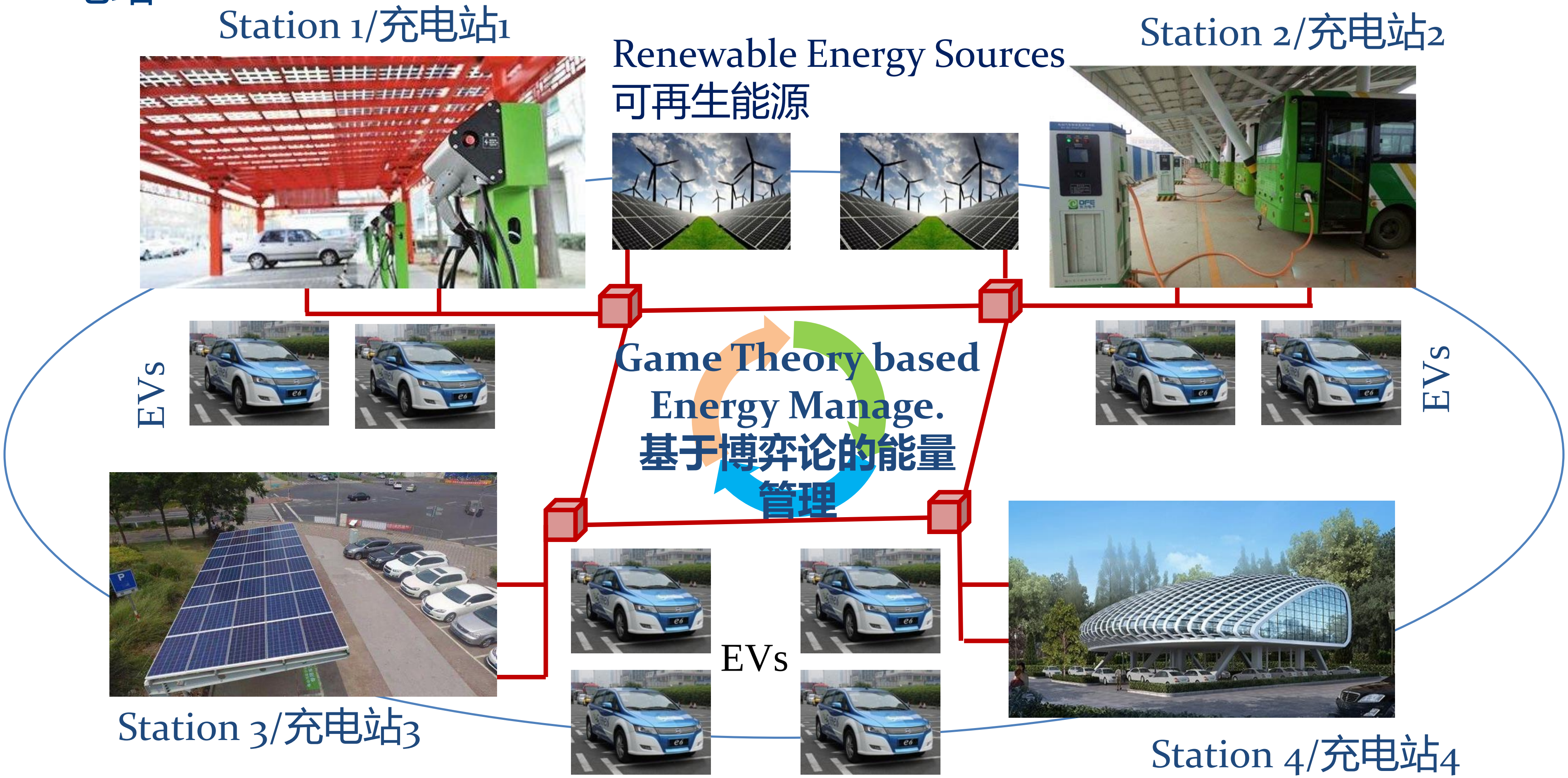
Smart Community/智慧社区



Rahbari-Asr N, Chow M Y, Chen J, et al. Distributed Real-Time Pricing Control for Large-Scale Unidirectional V2G With Multiple Energy Suppliers[J]. IEEE Transactions on Industrial Informatics, 2016, 12(5): 1953-1962.

Multiple Charging Stations/多充电站

- **Four Stations** with PV panels, storage batteries, and EVs/4个光伏发电充电站



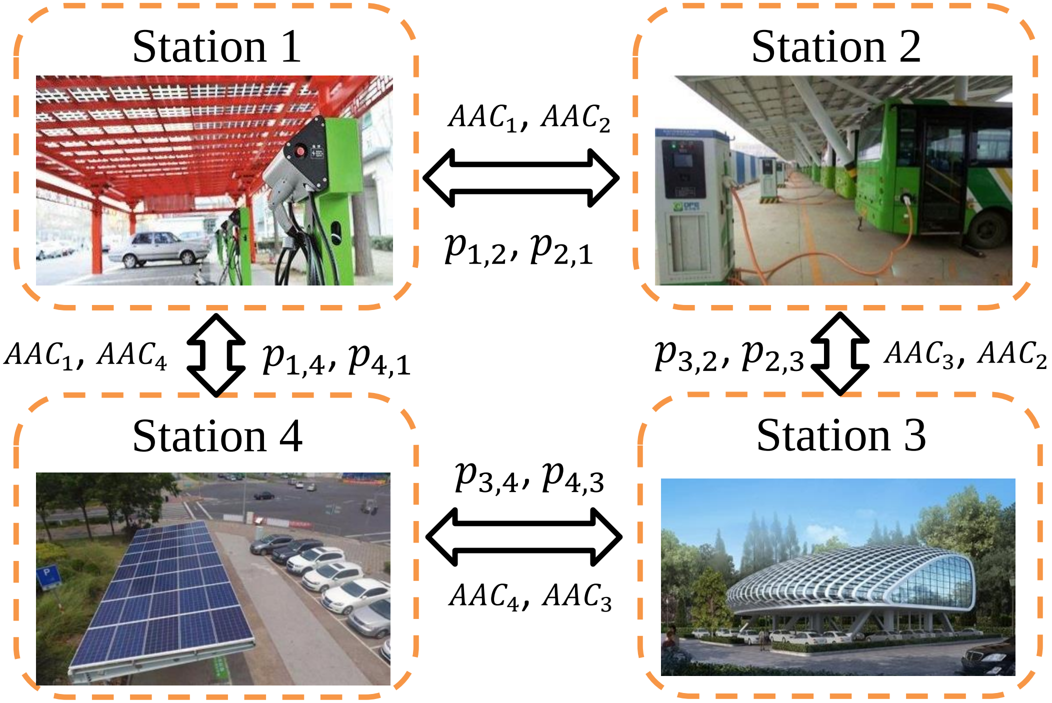
Game Theory-Based Solution

基于博弈论的解决方案

- Solution: two stage game theory-based energy management

  方案：基于两阶段博弈论的能量管理

  - **Station level**: Average remaining capacity control/平均剩余容量控制
    - OBJ: $AAC_1 = AAC_i = K \ (AAC_i = \frac{SOC_i}{n_i} C_i)$/目标函数
    - Learning algorithm/算法
  - **EV level**: Generalized non-cooperative Stackelberg equilibrium/广义非合作stackelberg均衡



Algorithm 1 Consensus Network Based Learning Algorithm

Station Level

For each PV-CS

$p_{i,j}(k+1) = P_{max} \frac{AAC_i - AAC_j}{max(AAC_i, AAC_j)}$ 一致性网络算法

EV Level

1.Initialization

$\lambda_{ij}(0) = \frac{a_{ij}}{P_{ij}^* + 1}$

$\delta p = \sum p_{ij} - p_{total,i}$

2.Consensus phase

while variation of $\lambda_{ij}(k) > 0.001$

$\lambda_{ij}(k+1) = \lambda_{ij}(k) + \sum_{j=1}^{n} w_{ij}(\lambda_{ij}(k) - \lambda_{ij}(k)) + \eta \delta p$

$p_{ij} = \frac{a_{ij}}{\lambda_{ij}(k+1)} - 1$

$\delta p = \sum_{j=1}^{n} p_{ij} - p_{total,i}$

end while

3.Check phase

if $|\delta p| < \varepsilon$ **then**

Terminate, **k++**

else

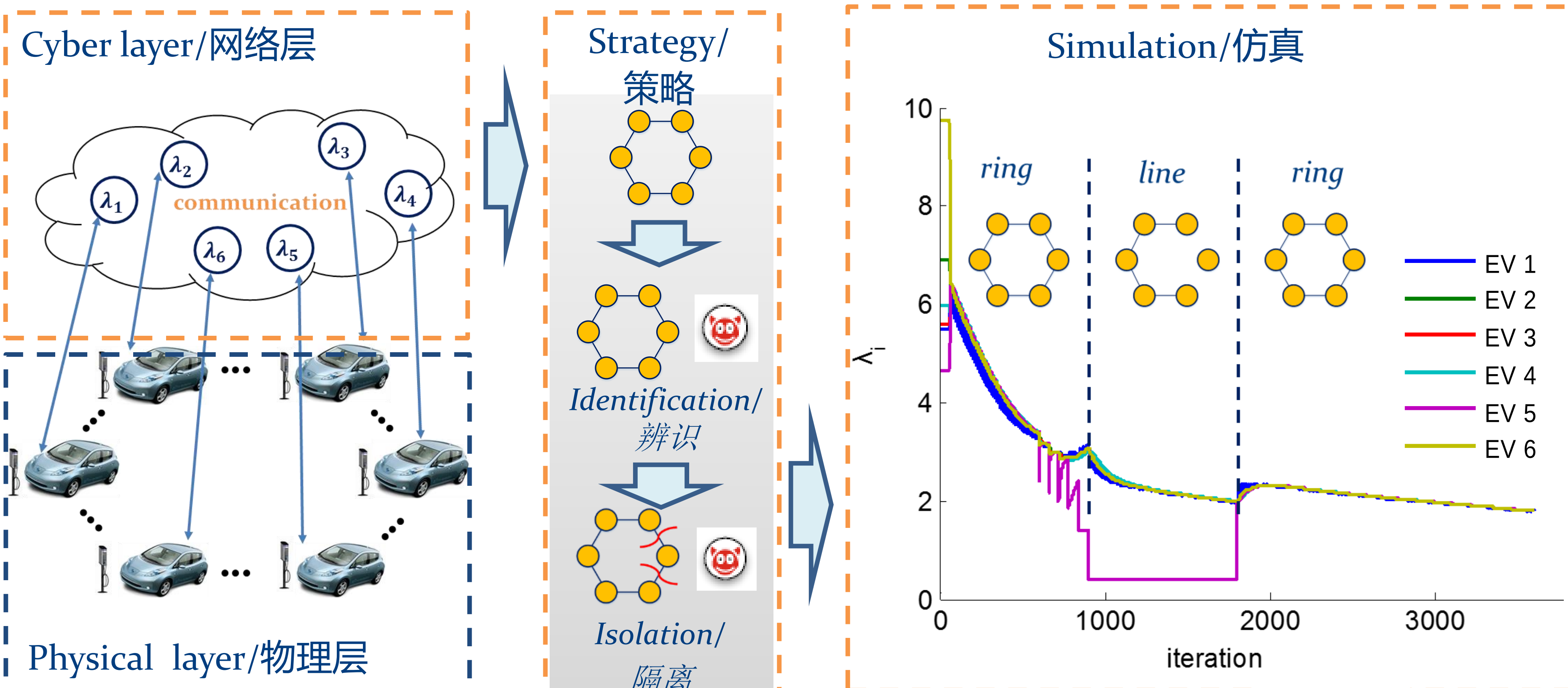
Continue

end if

4.Go back to step 2

Resilient Control/弹性控制

- A new control scheme that **handles and recovers** from **unpredictable** uncertainties such as extreme weather, cyber attack, failure of devices.
- 针对不可预测的不确定因素(极端天气、网络攻击、故障等)的系统自恢复弹性控制。



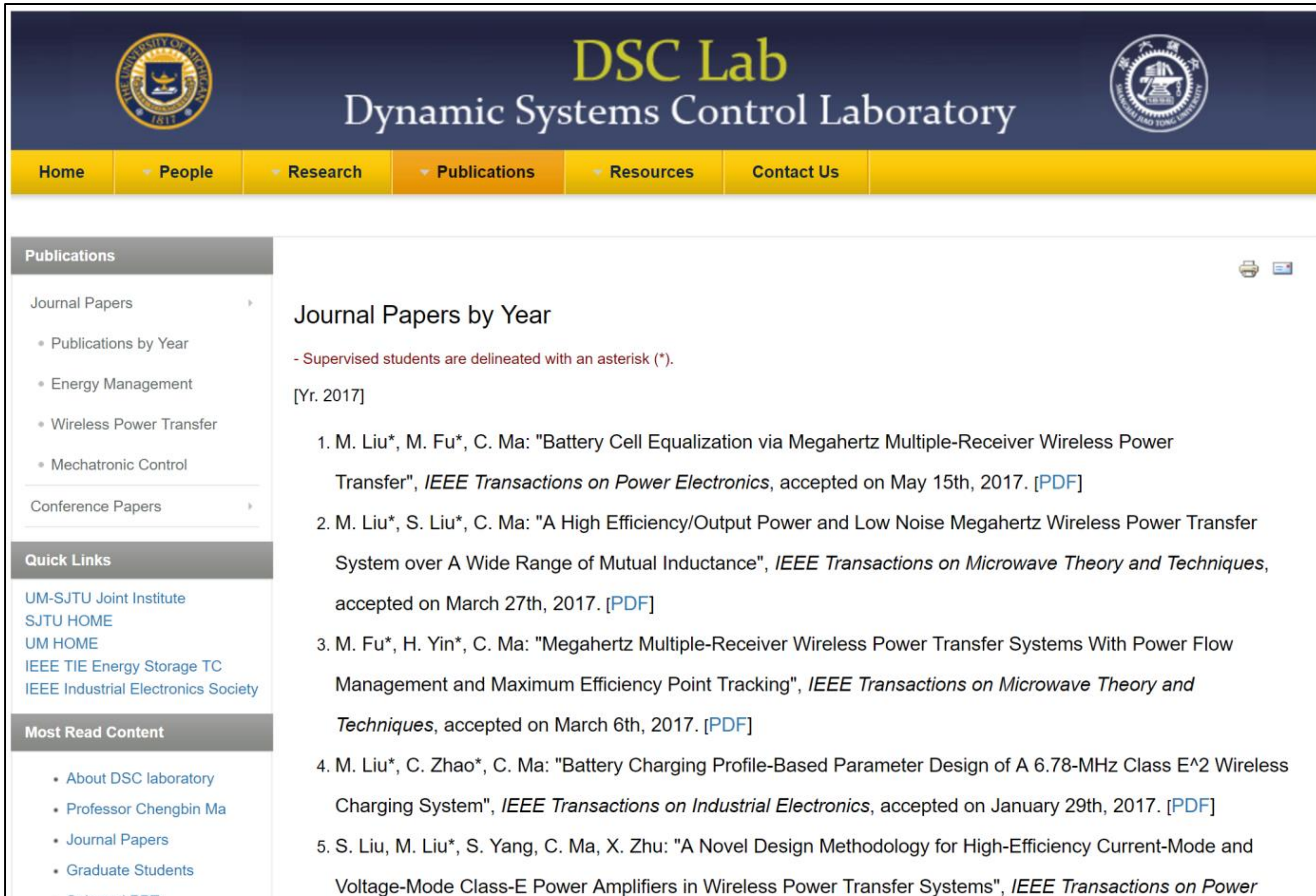
Conclusions and Future Works

- System-level analysis, optimization, and implementation of design and control are critically important/系统级跨学科的分析、优化与控制对提高系统的综合性能非常重要。
- Distributed control provides networked system improved flexibility, fault-tolerance, and scalability/分布式控制能够使网络化系统具有灵活性、容错能力和扩展性。
- Major interests/目前主要研究兴趣：
  - Self-recovery mechanism of networked energy systems via resilient control/网络能源系统自恢复弹性控制机理;
  - Advanced control of multiple autonomous vehicles/多辆自动驾驶车辆间的协调控制;
  - Optimized circuit topology and design strategy for multiple-receiver WPT systems/ “一对多”无线电能传输系统的拓扑与设计/控制策略优化。

Downloadable Publications

发表文献下载

- http://umji.sjtu.edu.cn/lab/dsc/index.php/publication/journal-papers



DSC Lab

Dynamic Systems Control Laboratory

Home | People | Research | Publications | Resources | Contact Us

Publications

- Journal Papers
  - Publications by Year
  - Energy Management
  - Wireless Power Transfer
  - Mechatronic Control
- Conference Papers

Quick Links

UM-SJTU Joint Institute
SJTU HOME
UM HOME
IEEE TIE Energy Storage TC
IEEE Industrial Electronics Society

Most Read Content

- About DSC laboratory
- Professor Chengbin Ma
- Journal Papers
- Graduate Students
- Selected PPTs

Journal Papers by Year

- Supervised students are delineated with an asterisk (*).

[Yr. 2017]

1. M. Liu*, M. Fu*, C. Ma: "Battery Cell Equalization via Megahertz Multiple-Receiver Wireless Power Transfer", *IEEE Transactions on Power Electronics*, accepted on May 15th, 2017. [PDF]
2. M. Liu*, S. Liu*, C. Ma: "A High Efficiency/Output Power and Low Noise Megahertz Wireless Power Transfer System over A Wide Range of Mutual Inductance", *IEEE Transactions on Microwave Theory and Techniques*, accepted on March 27th, 2017. [PDF]
3. M. Fu*, H. Yin*, C. Ma: "Megahertz Multiple-Receiver Wireless Power Transfer Systems With Power Flow Management and Maximum Efficiency Point Tracking", *IEEE Transactions on Microwave Theory and Techniques*, accepted on March 6th, 2017. [PDF]
4. M. Liu*, C. Zhao*, C. Ma: "Battery Charging Profile-Based Parameter Design of A 6.78-MHz Class E^2 Wireless Charging System", *IEEE Transactions on Industrial Electronics*, accepted on January 29th, 2017. [PDF]
5. S. Liu, M. Liu*, S. Yang, C. Ma, X. Zhu: "A Novel Design Methodology for High-Efficiency Current-Mode and Voltage-Mode Class-E Power Amplifiers in Wireless Power Transfer Systems", *IEEE Transactions on Power*

谢谢您的聆听！

Thank you for your attention!

Prepared by Dr. Chengbin Ma (撰写人：马澄斌)
Presented by Dongxiang Yan (发表人：闫东翔)
Email/邮件: chbma@sjtu.edu.cn
Web/网址: http://umji.sjtu.edu.cn/faculty/chengbin-ma/
Lab/实验室: http://umji.sjtu.edu.cn/lab/dsc