Intelligent Grid Interfaced Vehicle Eco-charging - iGIVE

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Queen's University Belfast

energy, power
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Project overview

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igive

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EP/L001063/1 NSFC51361130153

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RESEARCH COUNCILS UK

Research Councils UK Energy For a Low Carbon Future

EPSRC Engineering and Physical Sciences Research Council

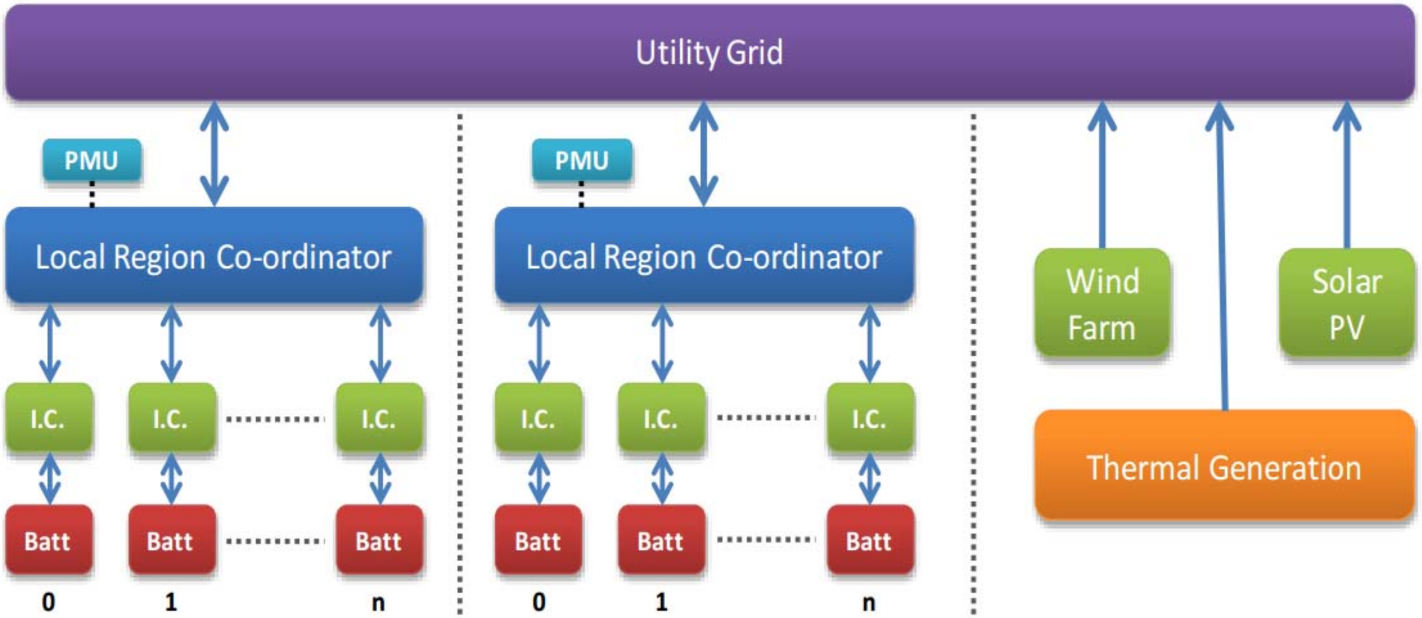
Project overview

Aim: to develop an intelligent grid interfaced vehicle eco-charging (iGIVE) system for more reliable, more flexible and efficient, and more environmental friendly smart gird solutions for seamless integration of distributed low-carbon intermittent power generation and large number of EVs.

Challenges:

- ✓ Real-time estimation of SOC, SOH, etc
- ✓ On-board charging apparatus piecemeal and non-systematic
- ✓ Environmental acceptance: harmonics, EMI, etc.
- ✓ Dispatch for coordinated EV charging/discharging
- ✓ Behaviours of different actors affect whole system, e.g. reliability
- ✓ Information platform

Project overview

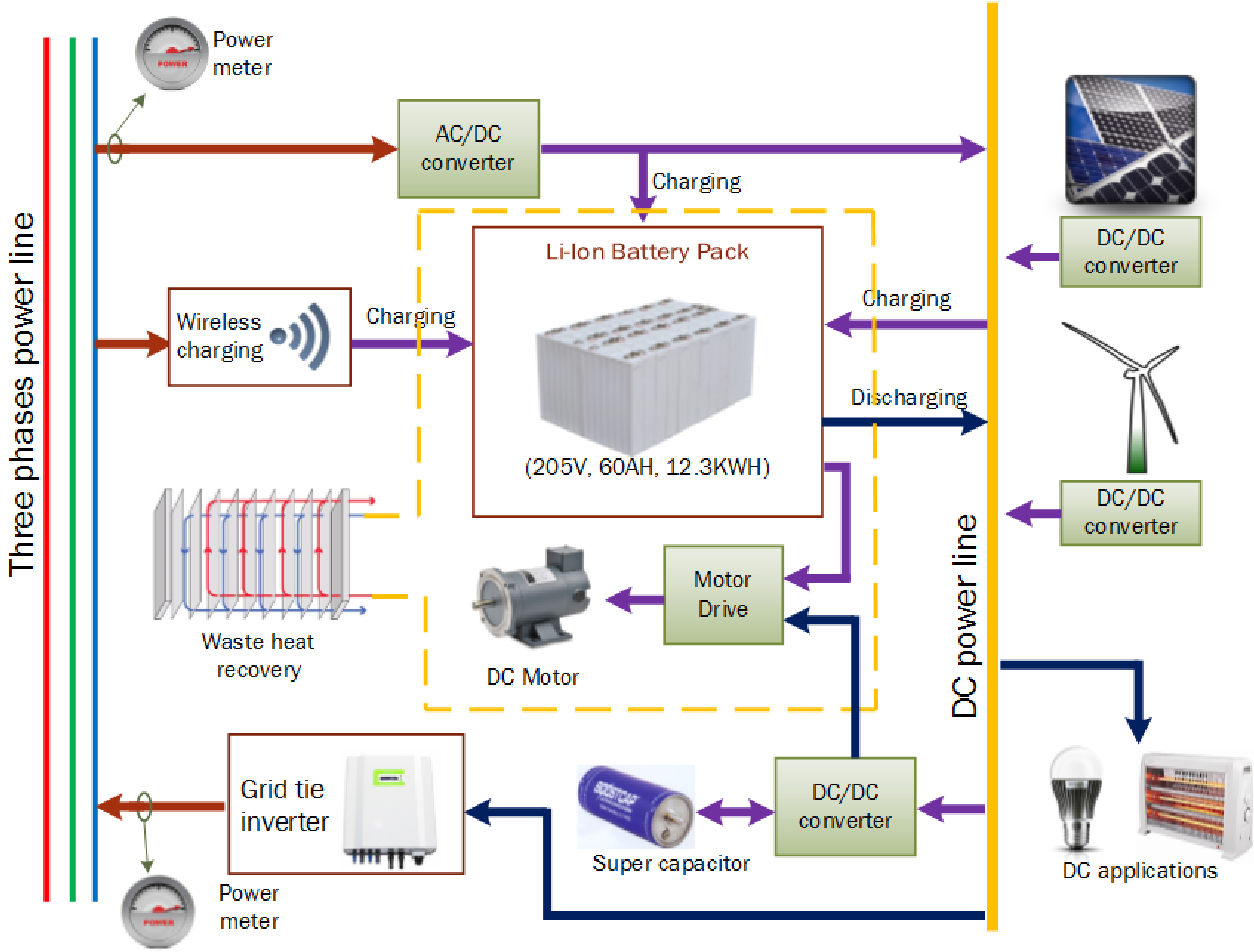


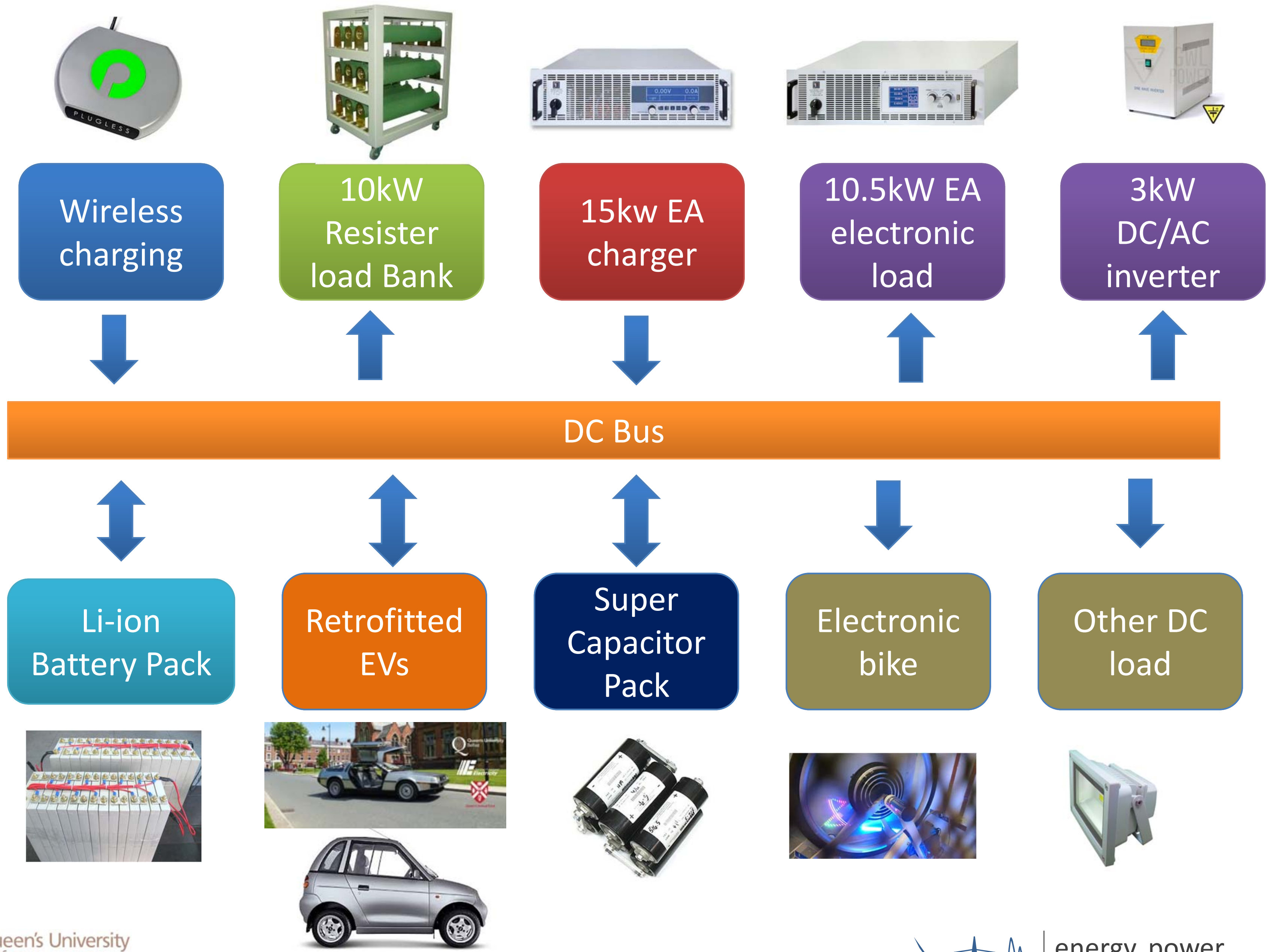
WP1) Development of energy and information flow framework for iGIVE
WP2) Power flow control-based battery model
WP3) Bi-directional traction drive charging system
WP4) Model for environment friendly EV battery charging
WP5) Optimal dispatching strategy for EV charging and discharging
WP6) Holistic system model for the impact of EV actors

Output Summary

- ✓ 48 journal papers, 35 conference papers, 1 special issue, 2 conference proceedings
- ✓ 2 conferences (LSMS2014 & ICSEE2014 and Control 2016), and 3 workshops
- ✓ 8 project meetings, 11 invited seminars, 2 keynotes
- ✓ 1 new joint EV lab
- ✓ 3 follow-on grants
- ✓ Industrial collaborations: Wrightbus, Yutong, Nari

Joint EV lab at QUB




Wireless charging
10kW Resister load Bank
15kw EA charger
10.5kW EA electronic load
3kW DC/AC inverter
DC Bus
Li-ion Battery Pack
Retrofitted EVs
Super Capacitor Pack
Electronic bike
Other DC load

Retrofitted EVs in EV lab

G-Wiz electric car

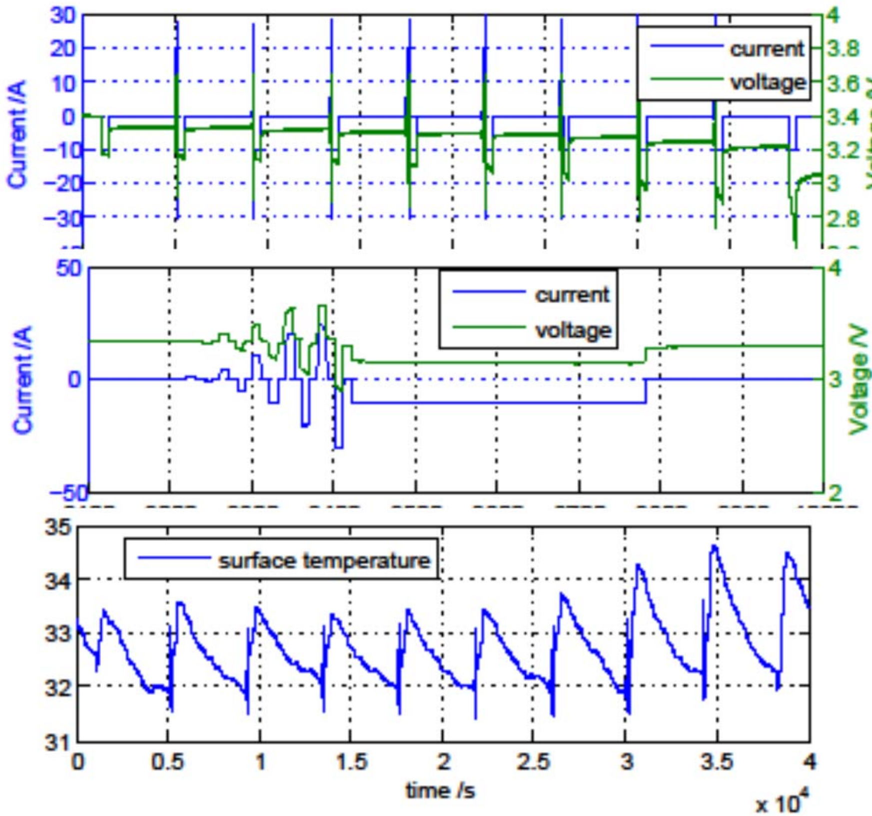
- DimensionsL 2.6m, W 1.3m, H 1.6m
- Motor power: 6kW continuous
- Weight: 400 kg excl batteries
- Battery: 200AH, 48V, Lead-acid
- Range: 48 miles

Retrofit: Li-ion battery, BMS, wireless communication, standard charging plug

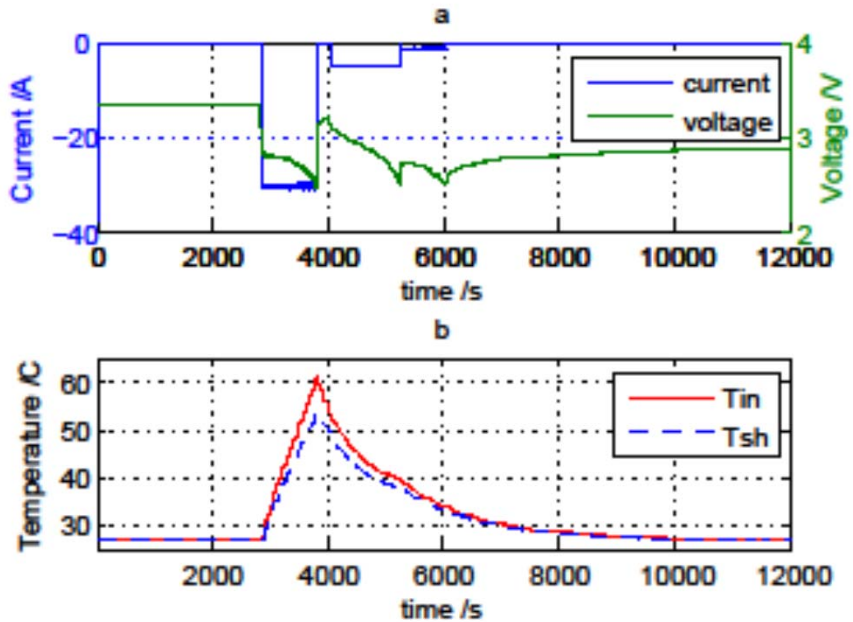
Electric DeLorean

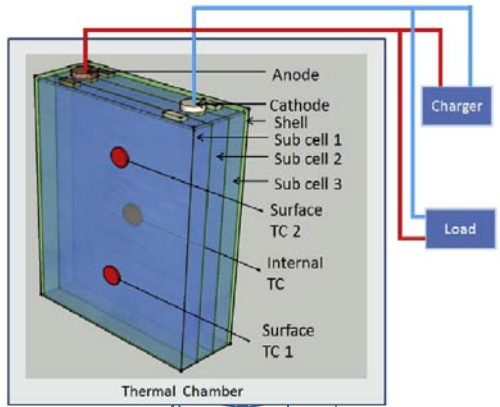
Test data

HPPC tests at different temperatures:
[0, 10, 23, 32, 39, 52]℃ on LiFePO4
(10Ah)

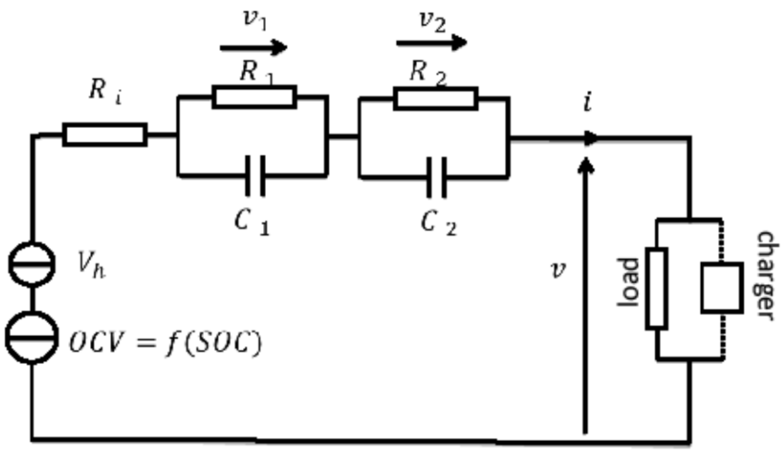


Thermal test





Simplified Thermoelectric Battery Model



Battery electrical model and SOC estimation.

[1] **Cheng Zhang**, Kang Li, Lei Pei, Chunbo Zhu. "An integrated approach for real-time model-based state-of-charge estimation of lithium-ion batteries." Journal of Power Sources 283 (2015): 24-36

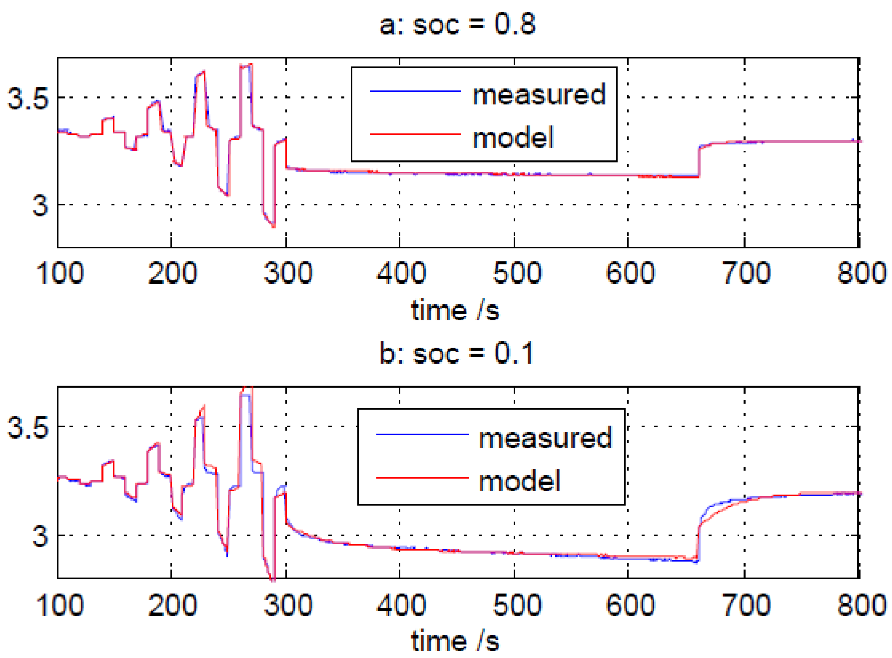
$$C_1 * \dot{T}_{in} = Q - k_1 * (T_{in} - T_{shell})$$
$$C_2 * \dot{T}_{shell} = k_1 * (T_{in} - T_{shell}) - k_2 * (T_{shell} - T_{env})$$

C_1: battery internal thermal capacity
C_2: battery shell thermal capacity
T_{in}: internal temperature
T_{shell}: shell temperature
T_{env}: environment temperature
Q: heat generation rate
k_1, k_2, heat conductive coefficients

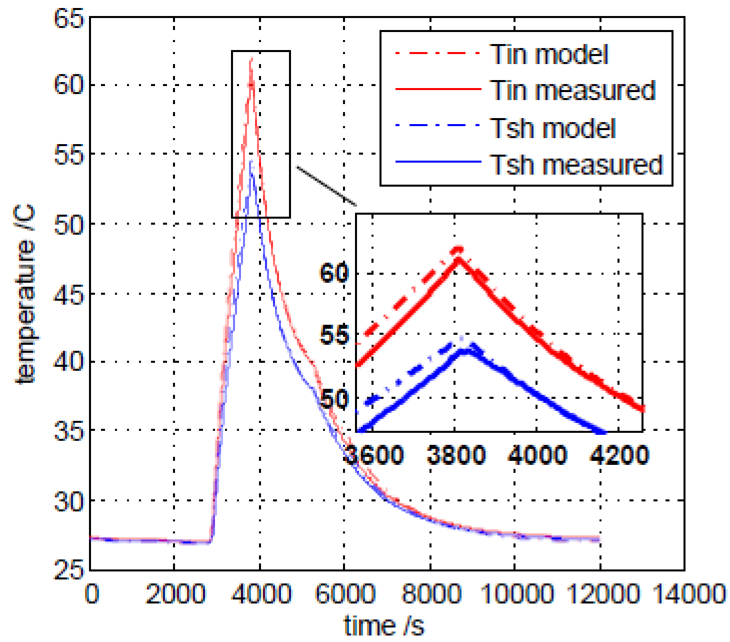
Battery thermal model and internal temperature estimation.

[2] **Cheng Zhang**, Kang Li, Jing Deng. "Real-time estimation of battery internal temperature based on a simplified thermoelectric model." Journal of Power Sources 302 (2016): 146-154

Battery modelling results



Part of the electrical modelling results

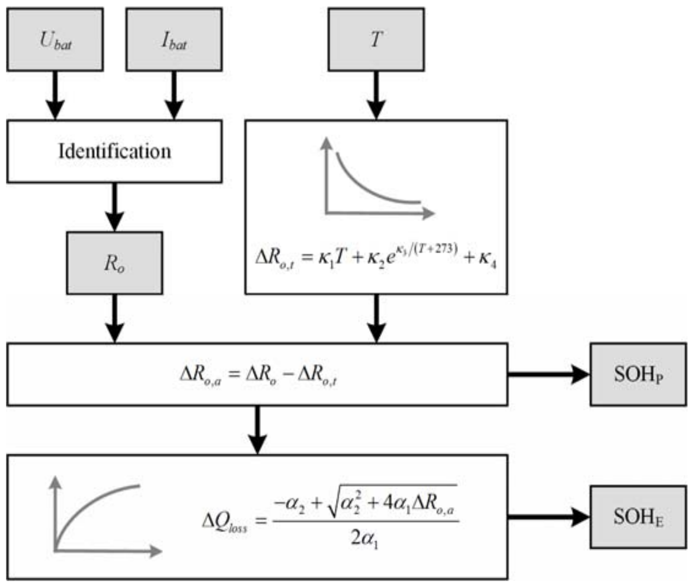


Thermal modelling results

SOH estimation

$$Q_{loss} = Q_{LLI} + Q_{LAM\_liNE}$$

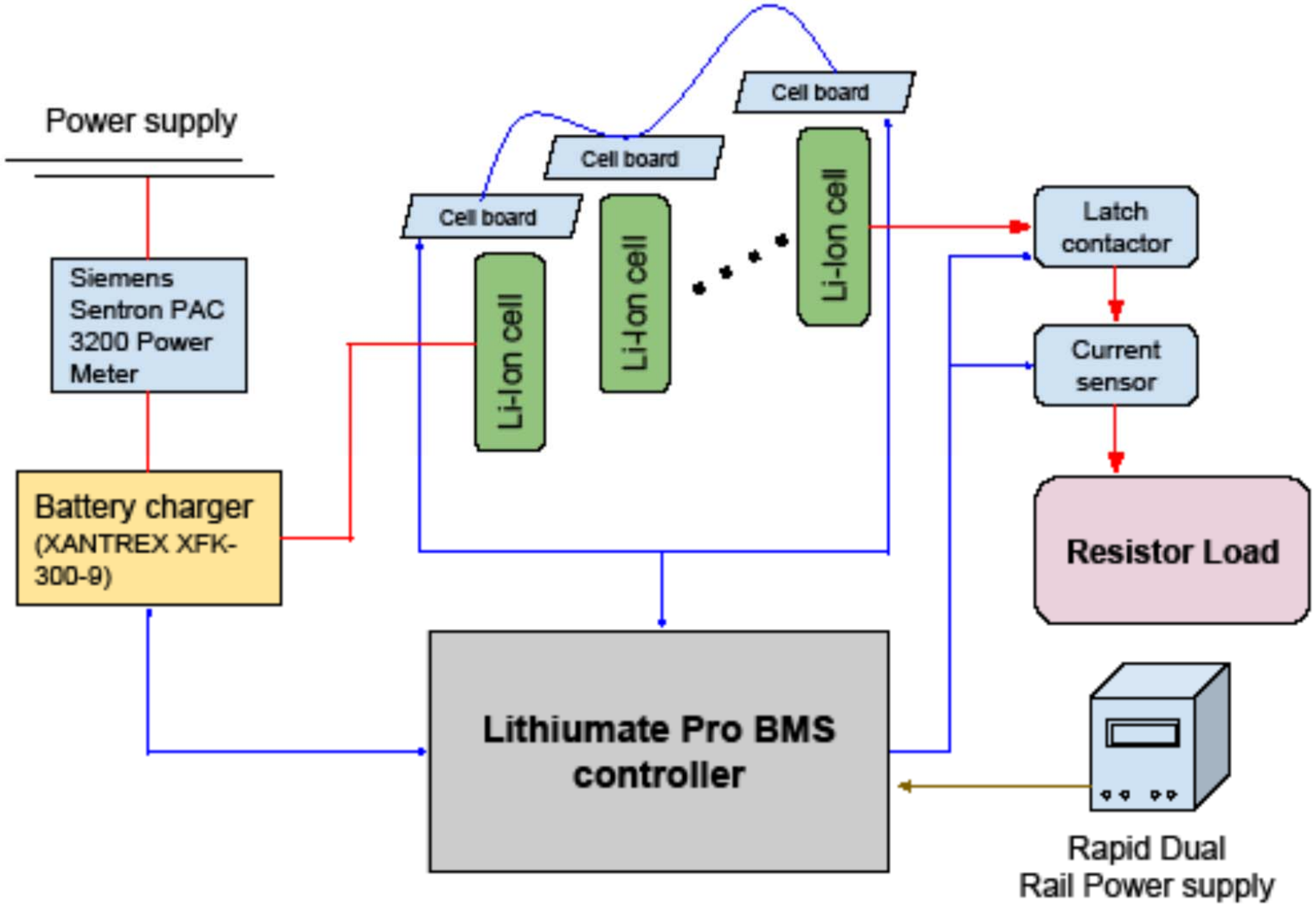
$$Q_{loss} = k_1 \cdot e^{\frac{-k_2}{273+t_{amb}}} \cdot \left(\frac{Q_{Ah\_thr}}{|I_{cell}|} \right)^{k_3} + k_5 \cdot (U_{EOD} + U_{EOC}) \cdot \left(1 - e^{k_6 \cdot \left(\frac{k_4}{I_{dis}^2} - \frac{Q_{Ah-thr}}{2Q_{cap,0}} \right)} \right) \cdot e^{k_7 \cdot I_{dis}^2 \cdot \left(\frac{Q_{Ah-thr}}{2Q_{cap,0}} \right)} \cdot \varepsilon \left(\frac{Q_{Ah-thr}}{2Q_{cap,0}} - \frac{k_4}{I_{dis}^2} \right)$$



Degradation cycle	Temp (°C)	Measured SOH_P (%)	Est. SOH_P (%)	Measured SOH_E (%)	Est. SOH_E (%)
0	50	100.0	100.6	100.0	100.6
100	30	98.4	99.8	95.4	98.7
200	10	92.2	94.7	87.7	91.8
300	−10	71.3	70.9	75.2	76.7

State of Health (SOH) estimation method

Battery management system



A battery management system has been setup to control

charging and discharging of lithium-ion battery pack

Battery Temperature Control

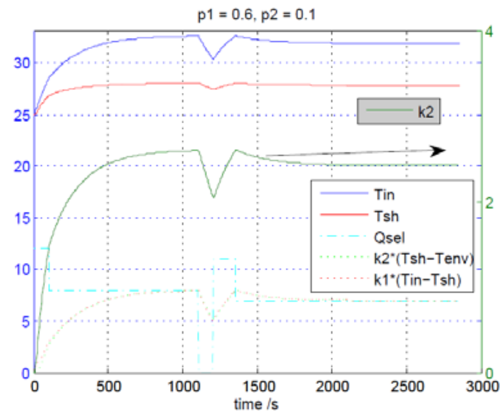
Consider the developed battery thermal model, an objective function is proposed

$$J = \alpha * \int_{t=t_0}^{t=t_f} f_2(v)dt + (1-\alpha) * \int_{t=t_0}^{t=t_f} exp(-c_2/T_{in})dt$$

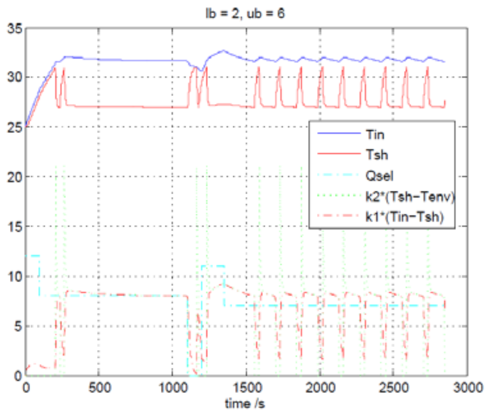
which is a trade-off between cooling performance (characterized by battery aging), and cooling parasitic energy consumption, i.e., $f_2(k_2)$

Then different controller can be designed and optimized.

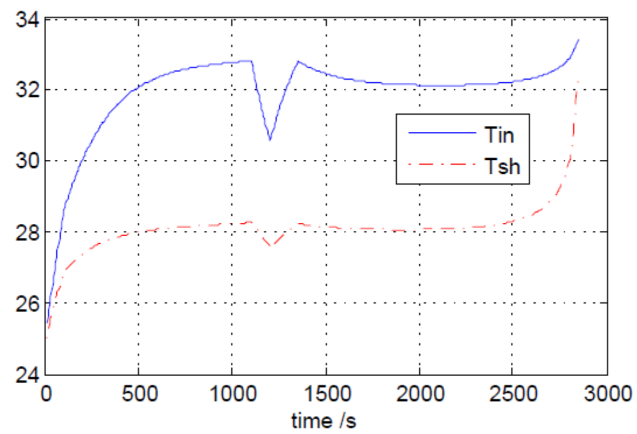
PID controller



Bang-Bang controller



optimal controller.



Battery fast charging control

Based on the developed battery thermoelectric model, new objective function is proposed for battery fast charging control

$$J_1 = (1-\alpha_1-\alpha_2)*t_f + \alpha_1 * \int_{t=t_0}^{t=t_f} (v-OCV)*i dt + \alpha_2 * \int_{t=t_0}^{t=t_f} exp(-c_2/T_{in}) dt$$

subject to

$$the \quad battery \quad model \quad equations$$

$$-I_{max} < i < I_{max}$$

$$V_{max} < v < V_{max}$$

$$T_{in} < T_{max}$$

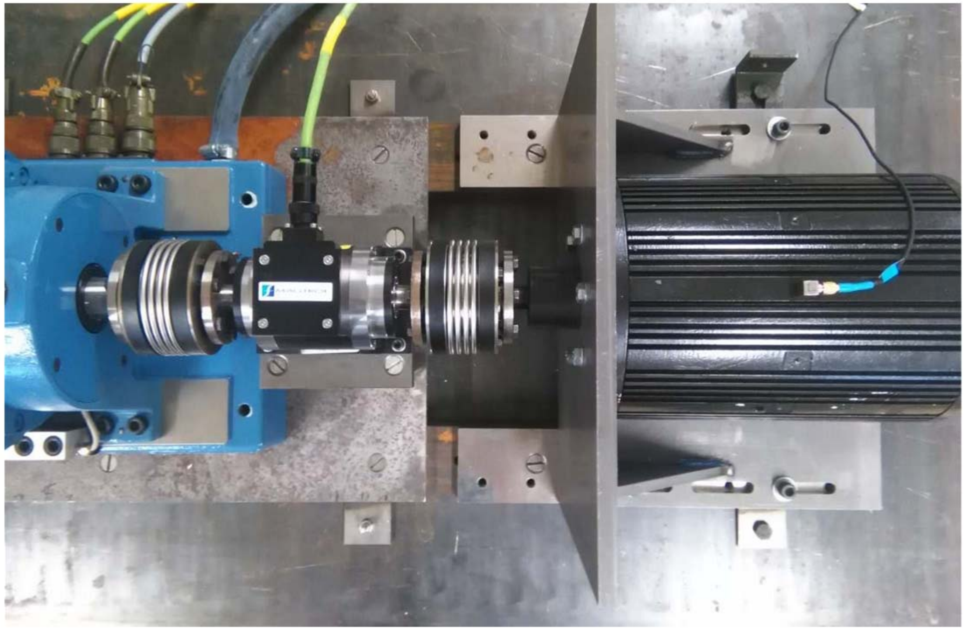
$$soc_{min} < soc < soc_{max}$$

This objective function is a trade-off between charging time, efficiency, and battery aging.

Different charging patterns can be compared.

V2G Charging - Cranfield University

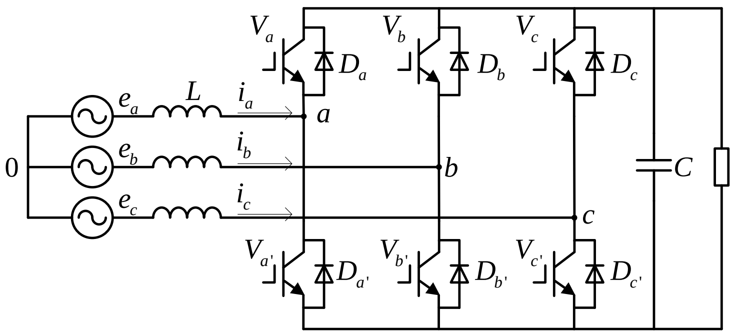
Novel V2G Charging-Traction PM motor technology



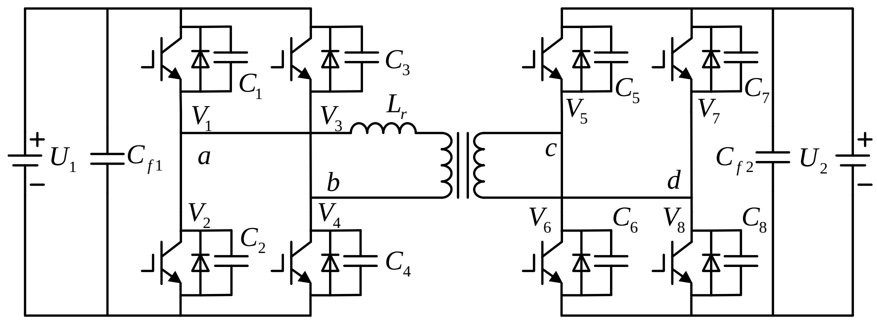
Dual-use traction-charging PMSM motor

- ✓ The vector control with sensorless algorithm developed based on DSP 28335.
- ✓ Open circuit tested.
- ✓ No-load condition tested with the maximum speed at 1280rpm (the designed value is 1250rpm, very close agreement to the test result).
- ✓ Load-condition with 10Nm at 1000rpm tested.

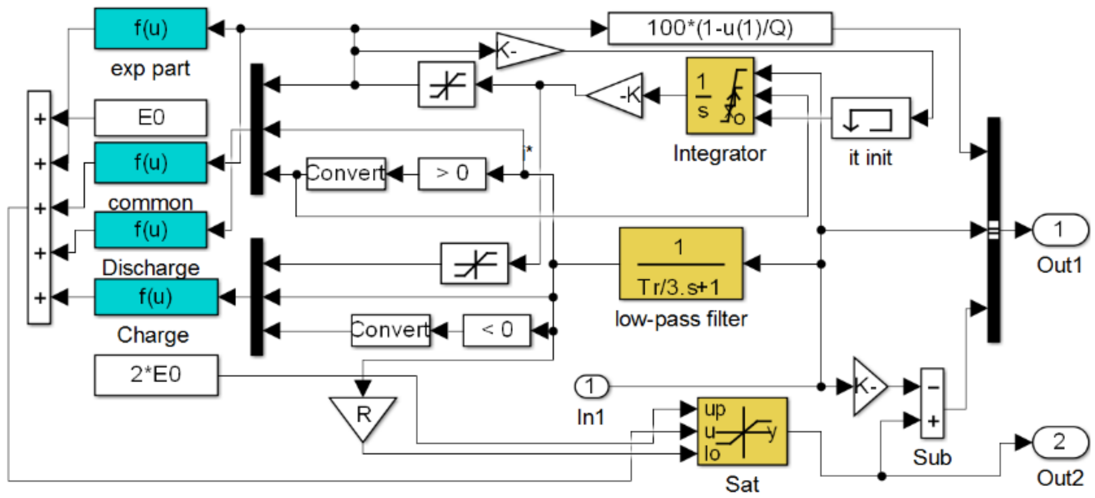
V2G Charger Design in Parking Lots and Impacts



3 Phase PWM AD/DC

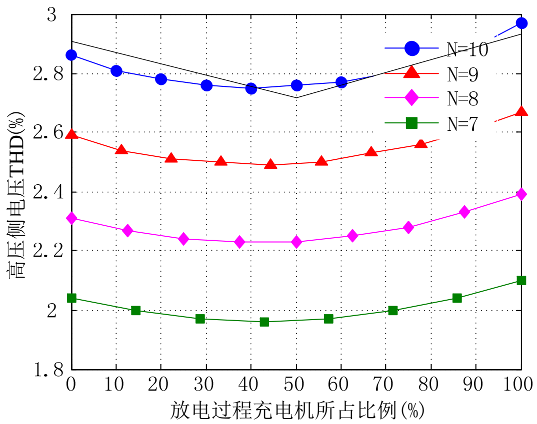


Bi-directional DC/DC Converter

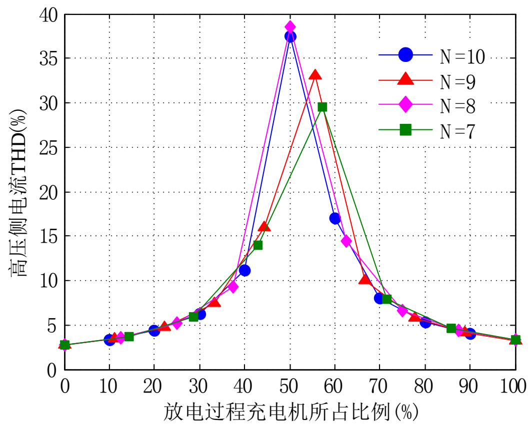


Li-ion battery modelling

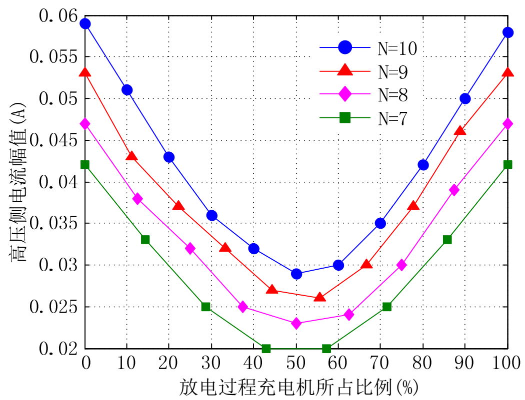
V2G Charger Design in Parking Lots and Impacts



High Voltage Side Voltage THD



High Voltage Side Current Harmonics THD



High Voltage Side Current

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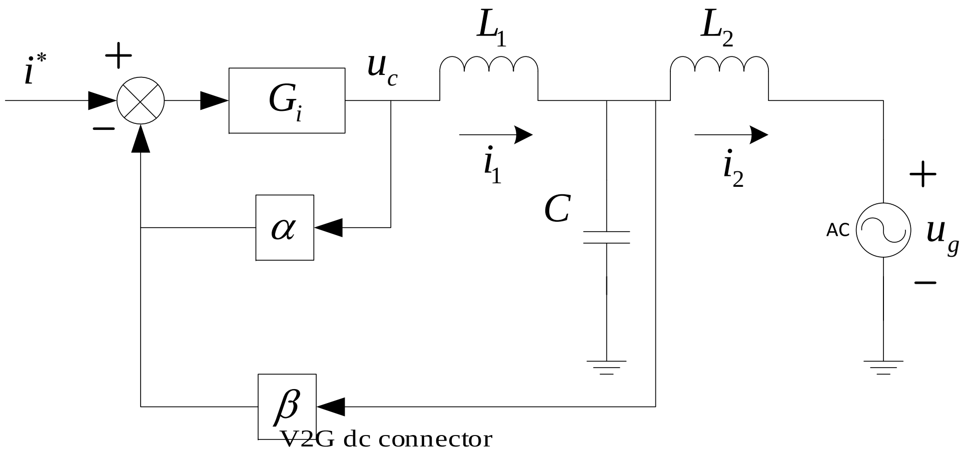
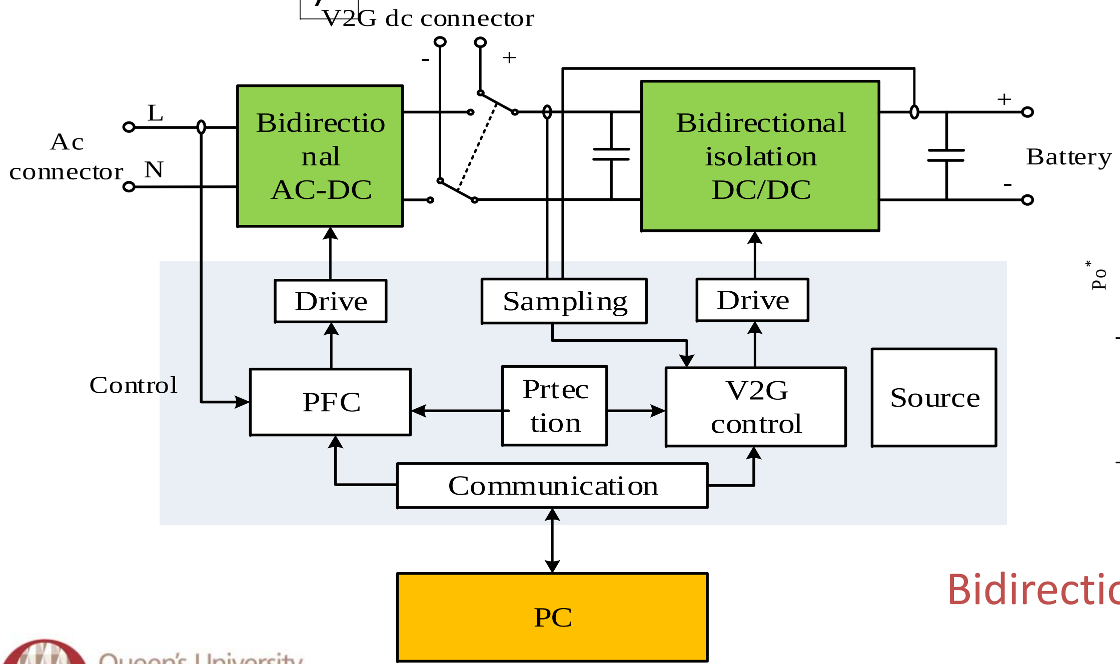
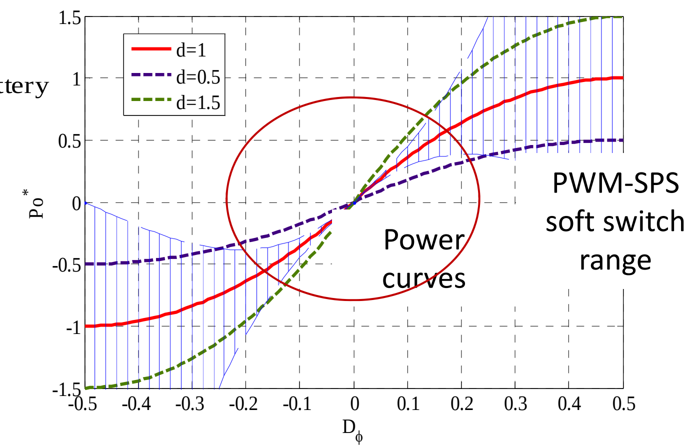
V2G Charger Design in Parking Lots and Impacts

Development of wide power range and high performance bi-directional charger



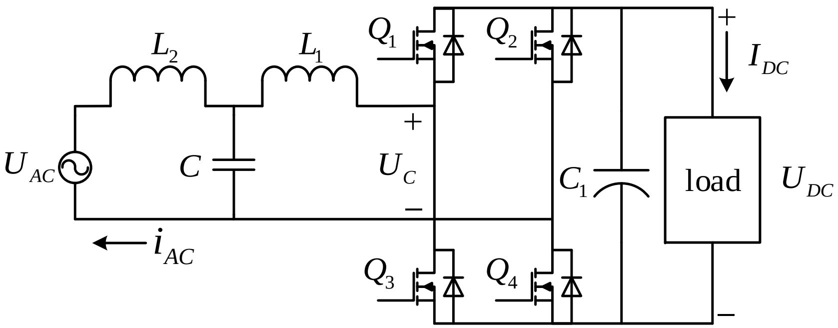
Current weighting control structure based on LCL filter



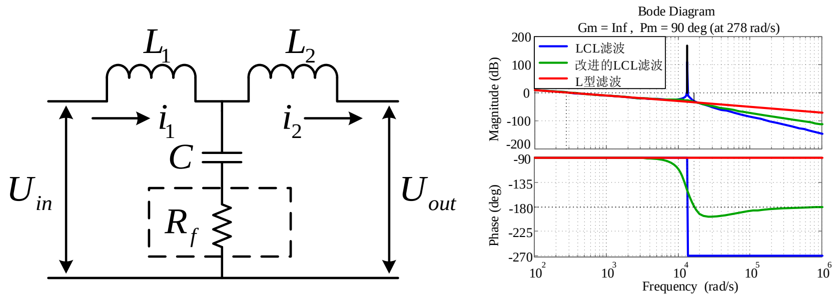


Bidirectional V2G control system

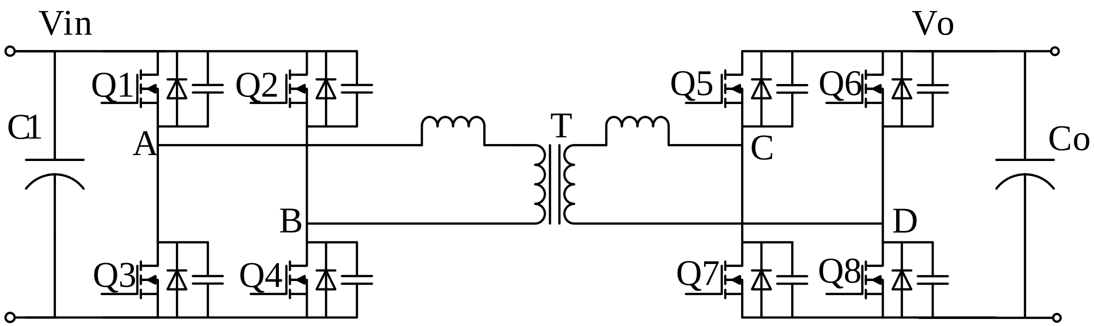
V2G Charger Design for Vehicles and Impacts



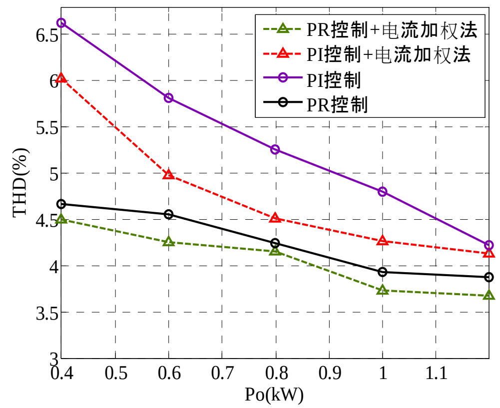
Single Phase PWM AD/DC



LCL Filter with a small resistor



Bi-directional DC/DC Dual Active Bridge



THD using different control

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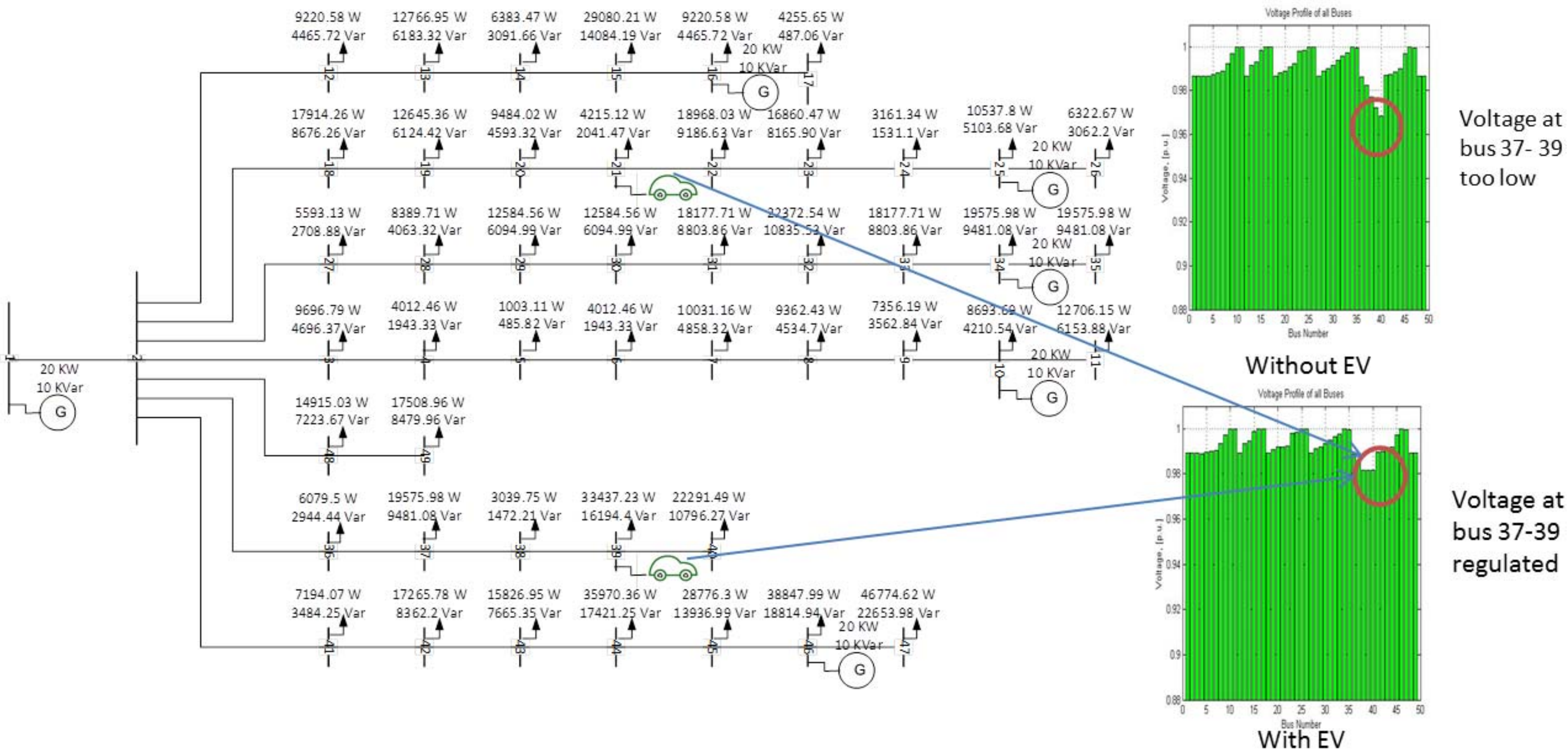
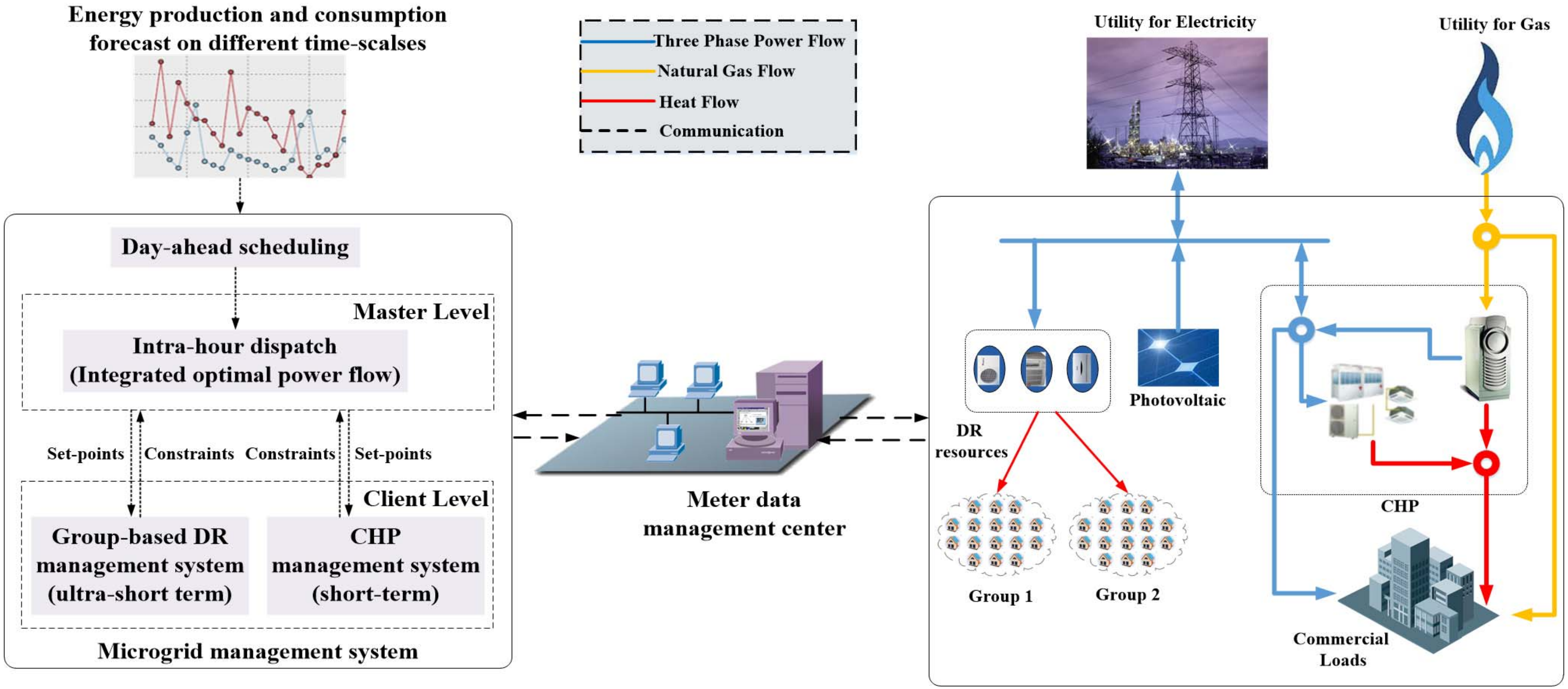
Interface and Integration of Microgrid and EVs



Microgrid voltage regulation by dispatching of EVs as mobile storage

Hierarchical Management for Integrated Community Energy System



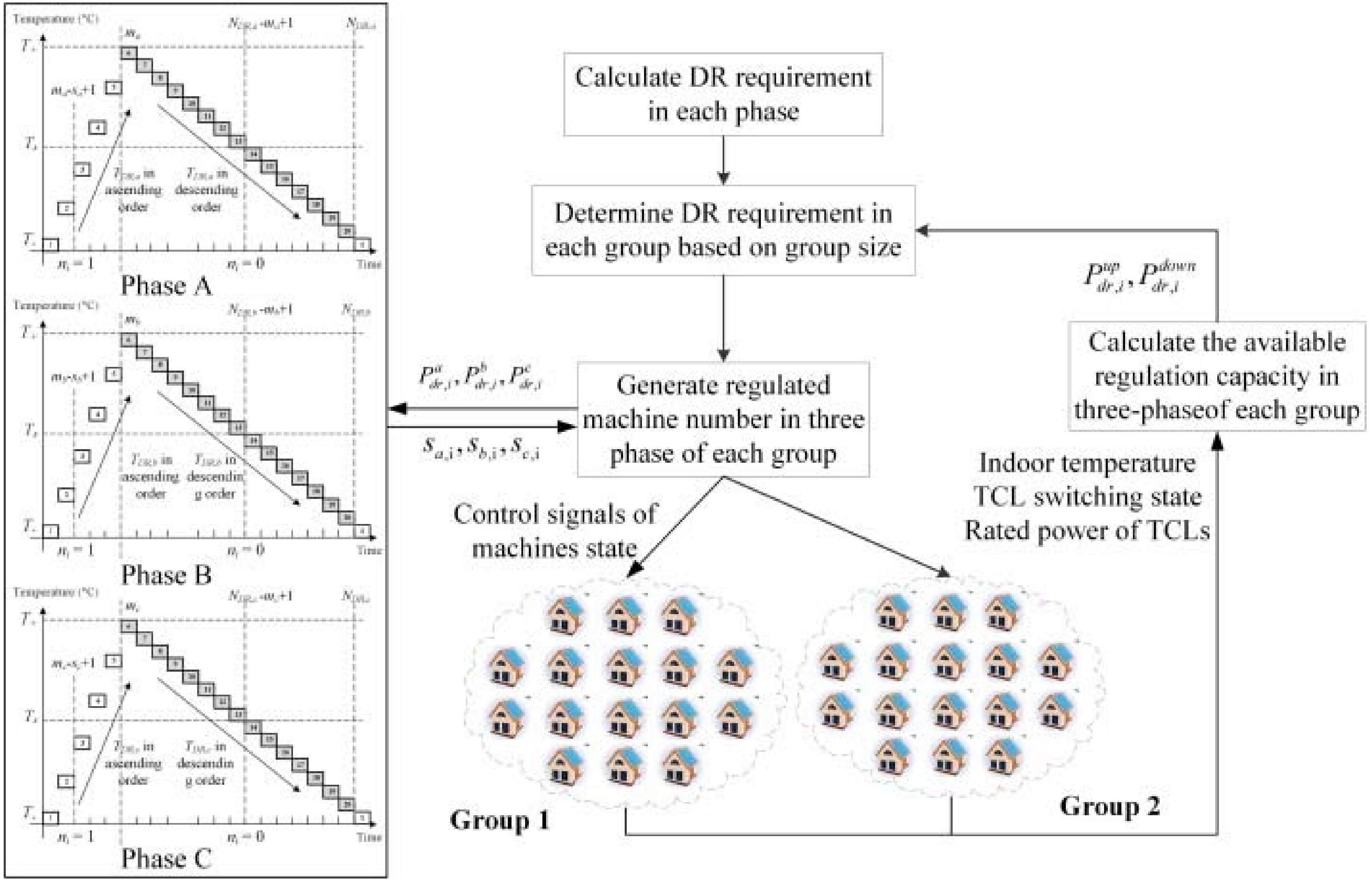
Group-based DR management

- Thermostatically controlled loads
- EVs considering eco-charging
- EVs and TCLs coordination.

Integrated optimal power flow

- Heat, gas, and electricity flows
- Three-phase electrical system
- Microgrids and distribution networks.

Three-phase Demand Response Dispatch

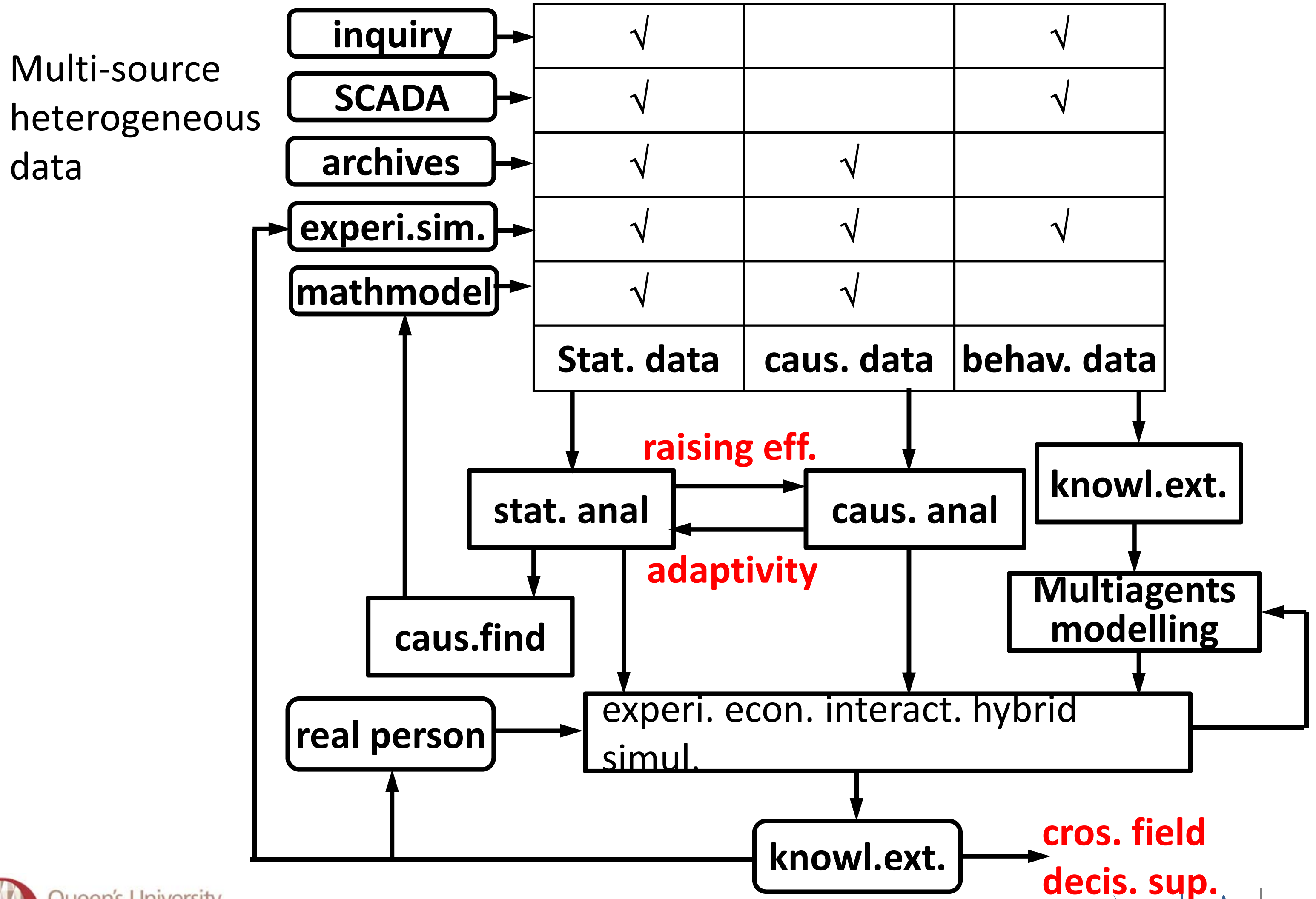


Flowchart of the three-phase DR.

A hybrid experimental-economics-based simulation platform

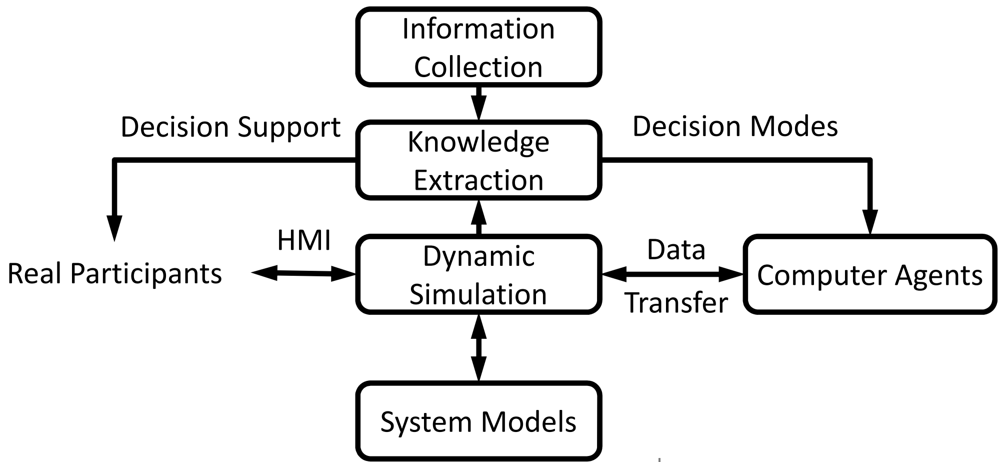
- ✓ A questionnaire design method proposed. Probabilistic characteristics of potential EV users' purchase and travel decisions extracted from questionnaires
- ✓ A multi-agent model was built to reflect multi-dimensional joint probability distribution of the respondents' willingness
- ✓ A verification method designed – potentially used for modeling of other group decision behaviors
- ✓ A framework to study the Interactivity of EV and power grid operation proposed

Collection, analysis, knowledge extraction and decision support of big data

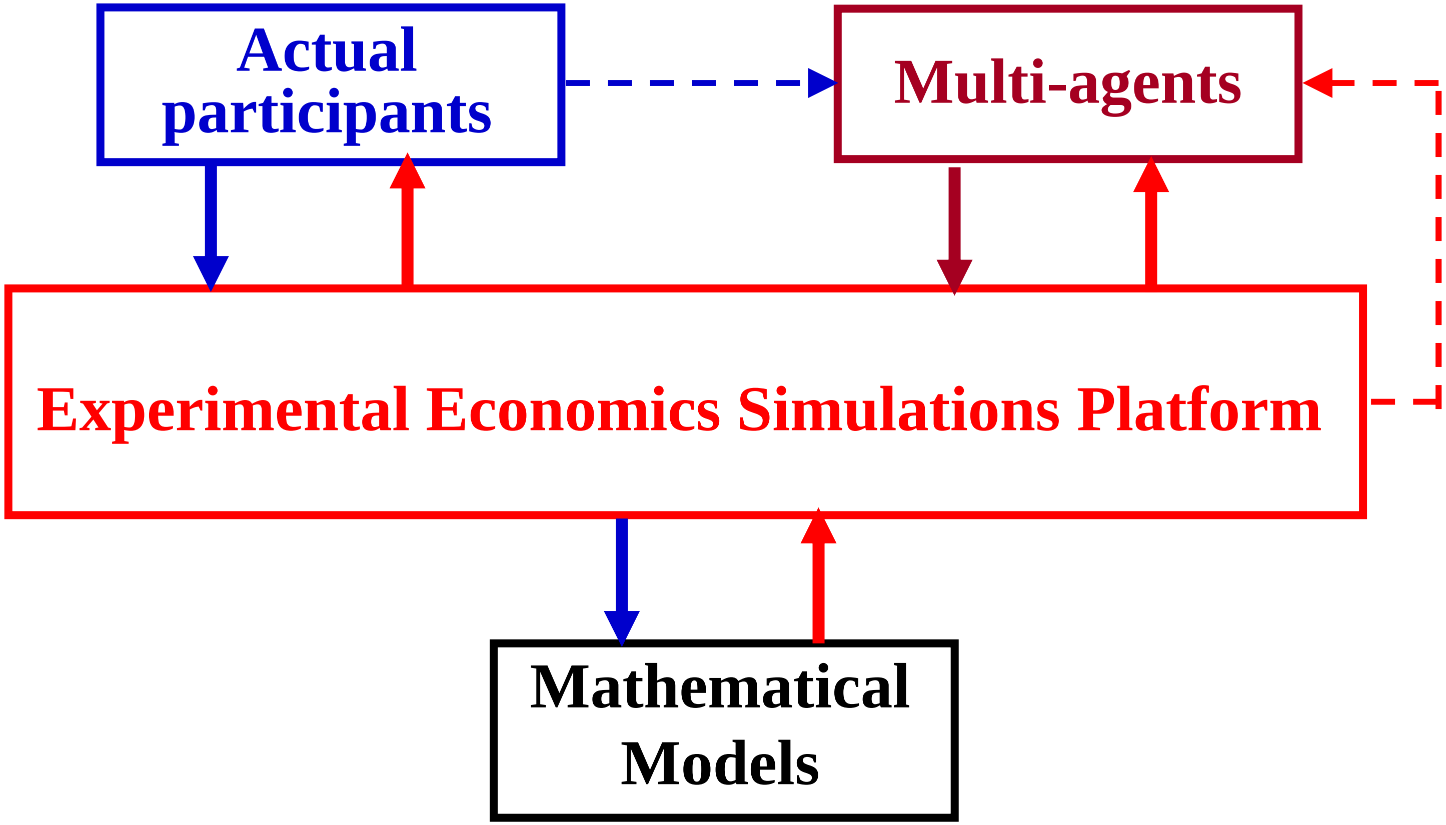


Modeling and Simulation Methods of EV Users' Behaviors

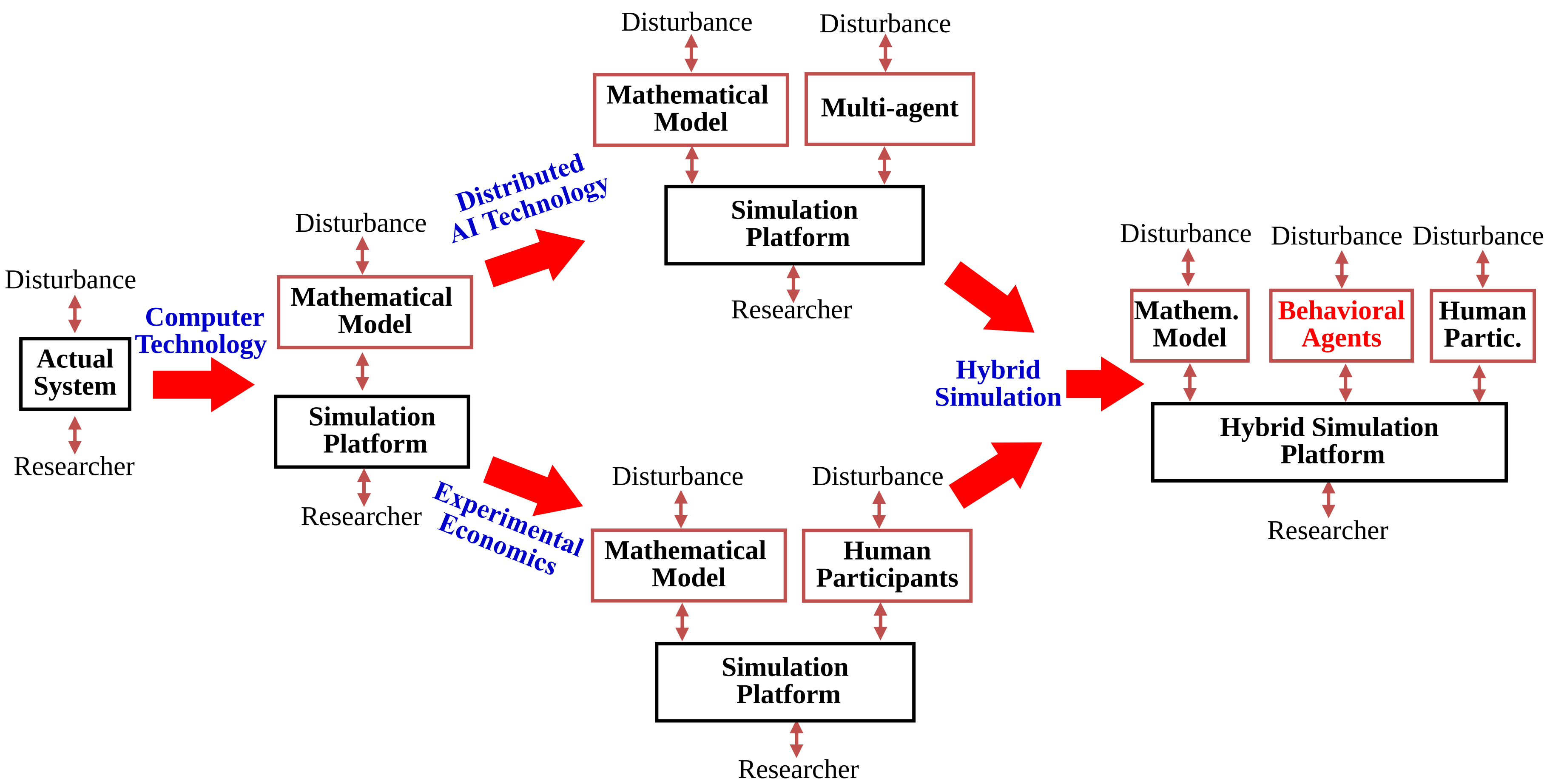
- Difficulties of experimental economics to study group behaviors
  - The number of participants is limited
  - Repeated trials may be poorly comparable with each other
- Extracting correlation inf. from big data to model group behavior
  - Historical data, real-time data acquisition, questionnaire
  - Matching probability distribution of respondents' behaviors
  - Verifying the validity of multi-agent by comparing the multi-agent Monte-Carlo simulation results and the questionnaire results
- A hybrid experimental-economics-based simulation
  - Using computer agents to replace a certain group of experts
  - Using real participants to play several key roles



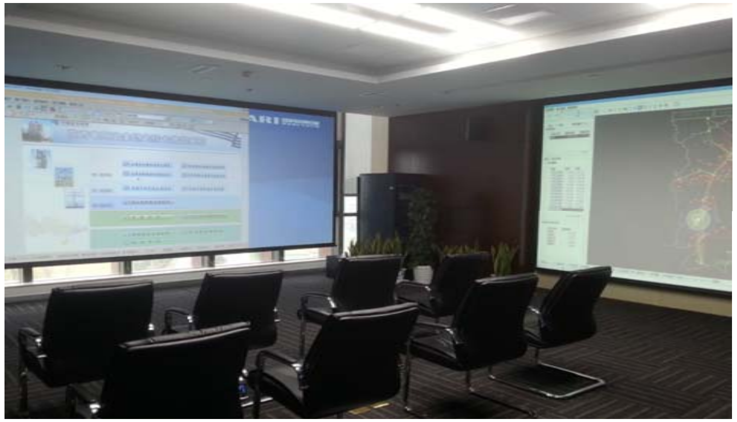
Behavior-involved Projects
Studied by Using Hybrid Simulations



Hybrid simulations including game behaviors

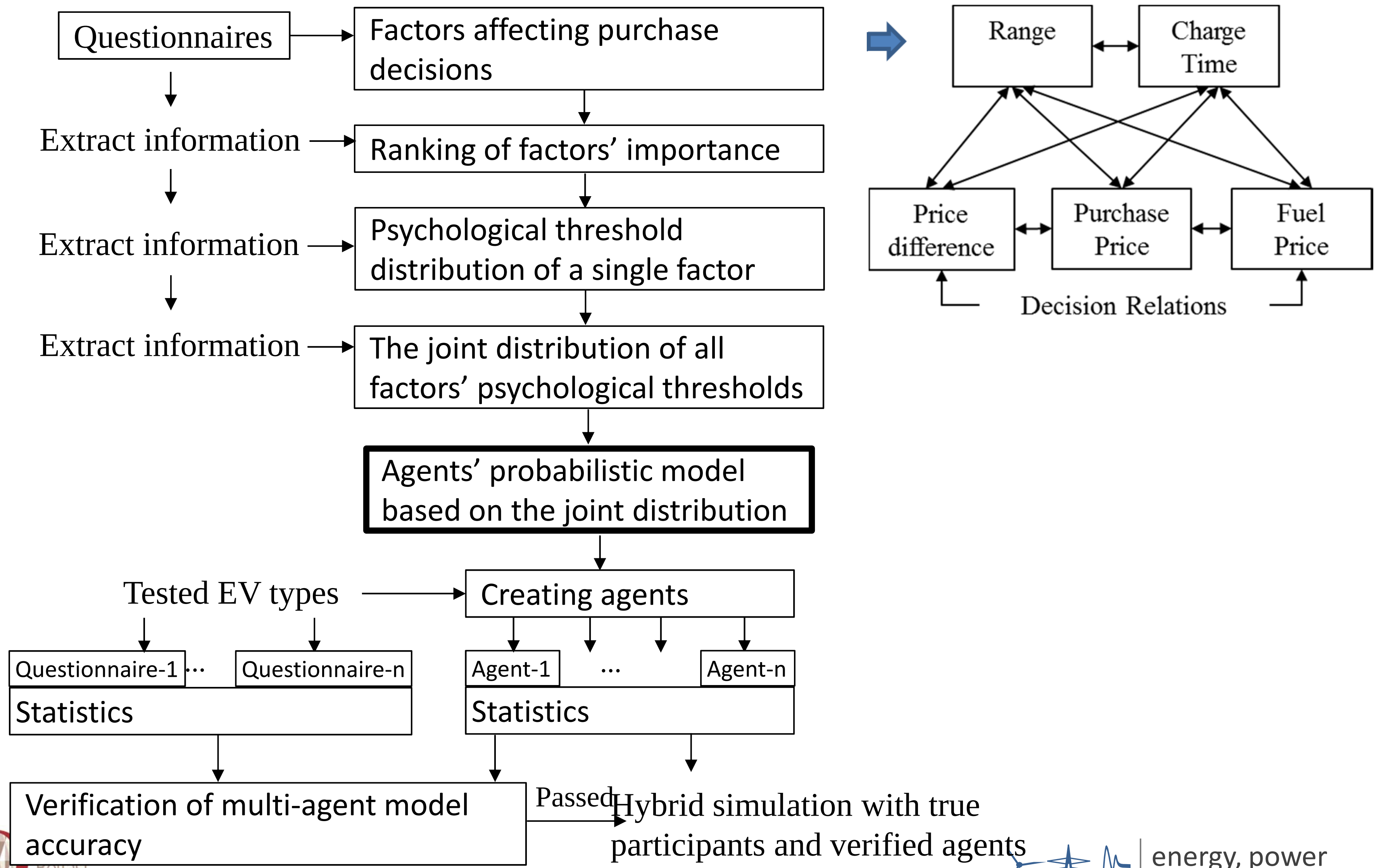


Dynamic Simulation platform for Macro-Energy Systems (DSMES)

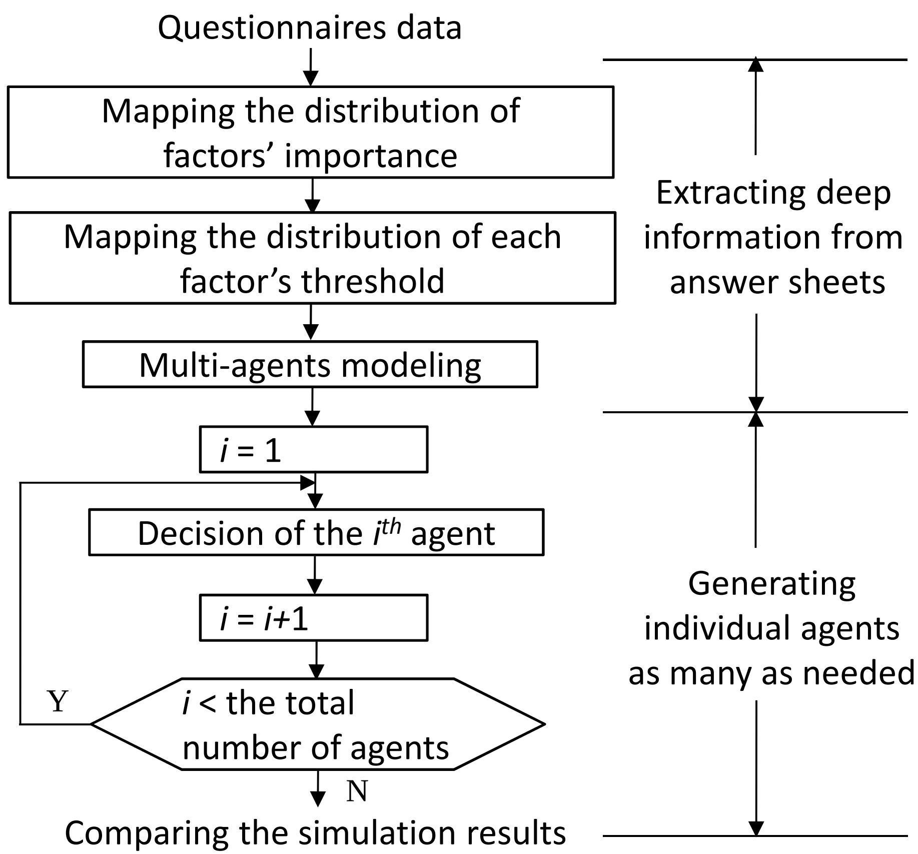


DSMES supports dynamic interactive simulations of cross-domain to study interactions among physical power system, power market, emission trading, etc.

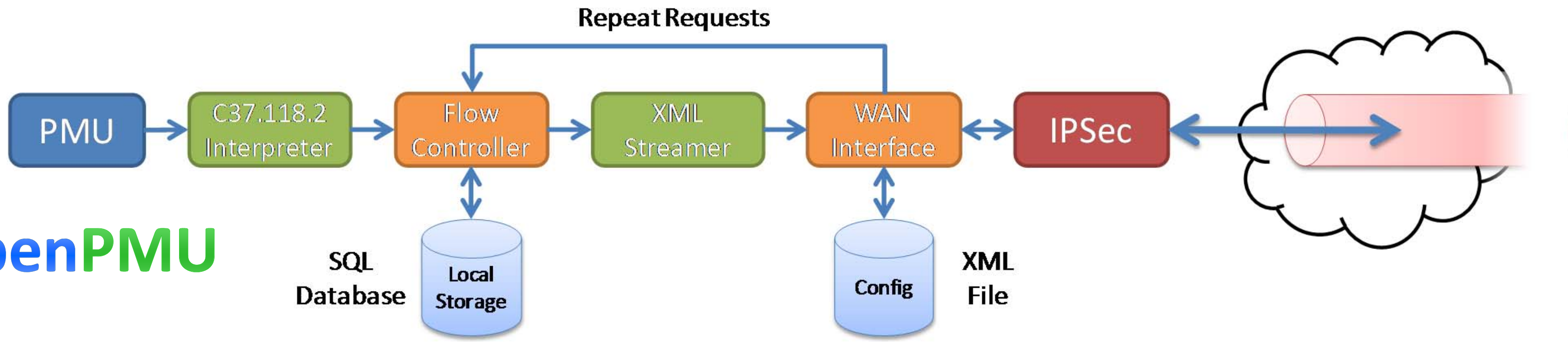
Experimental Economics Research on EV Purchase Willingness



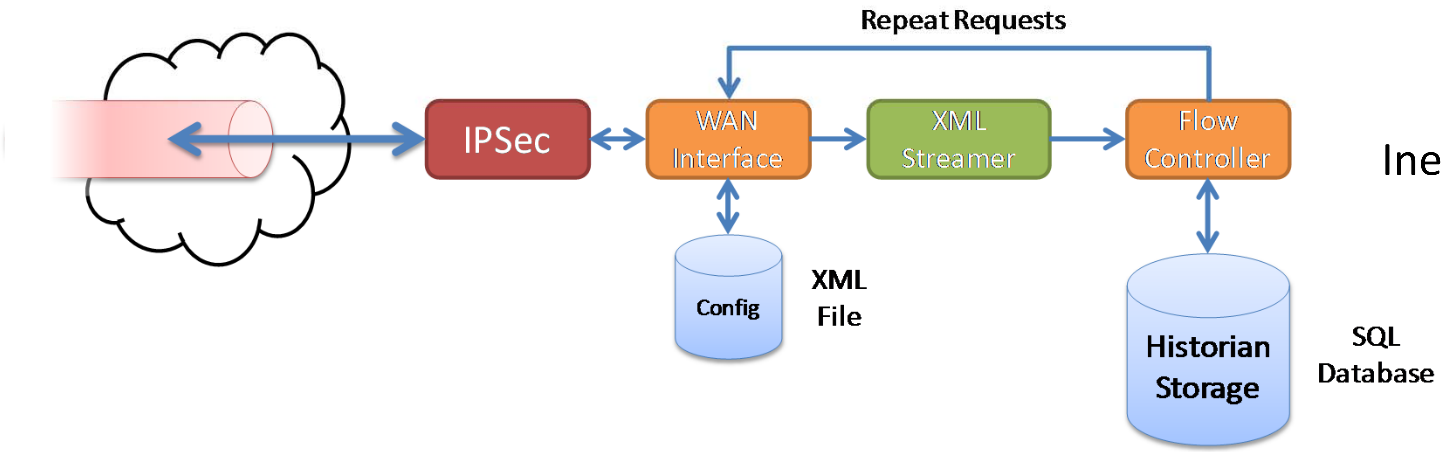
Flow Chart for Generating Multi-Agents Reflecting the Purchase Willingness of EV Potential Users



PMU Telecoms Framework

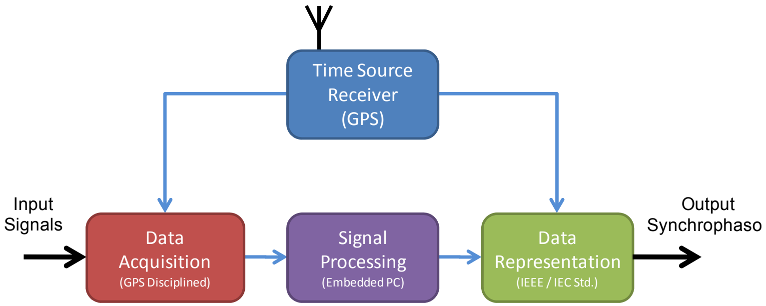


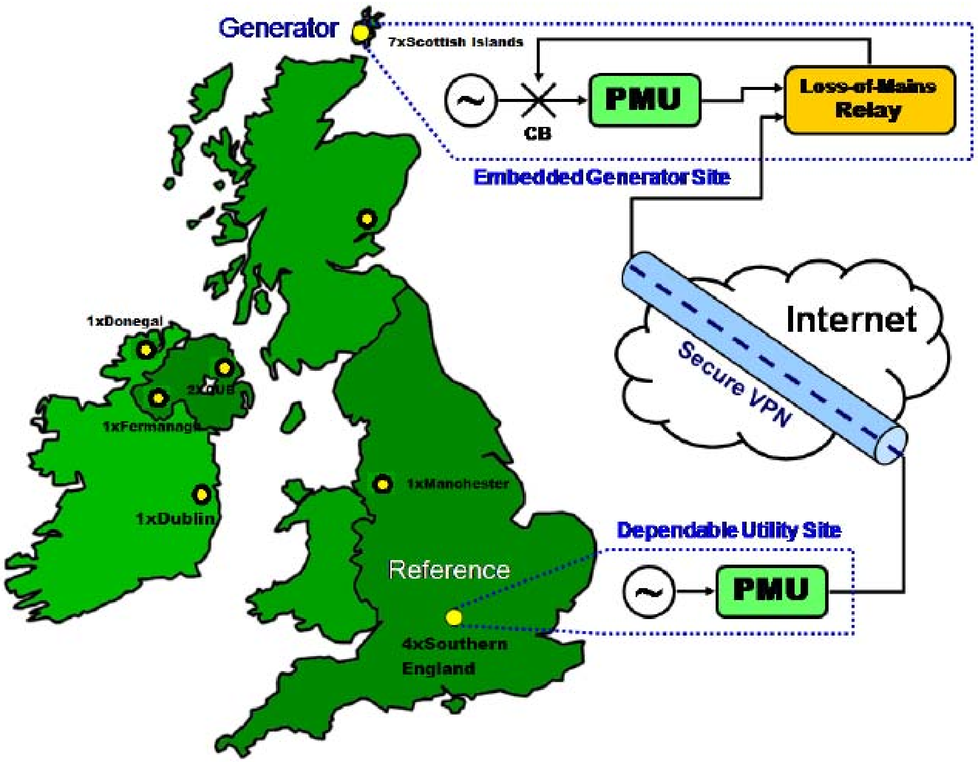
OpenPMU



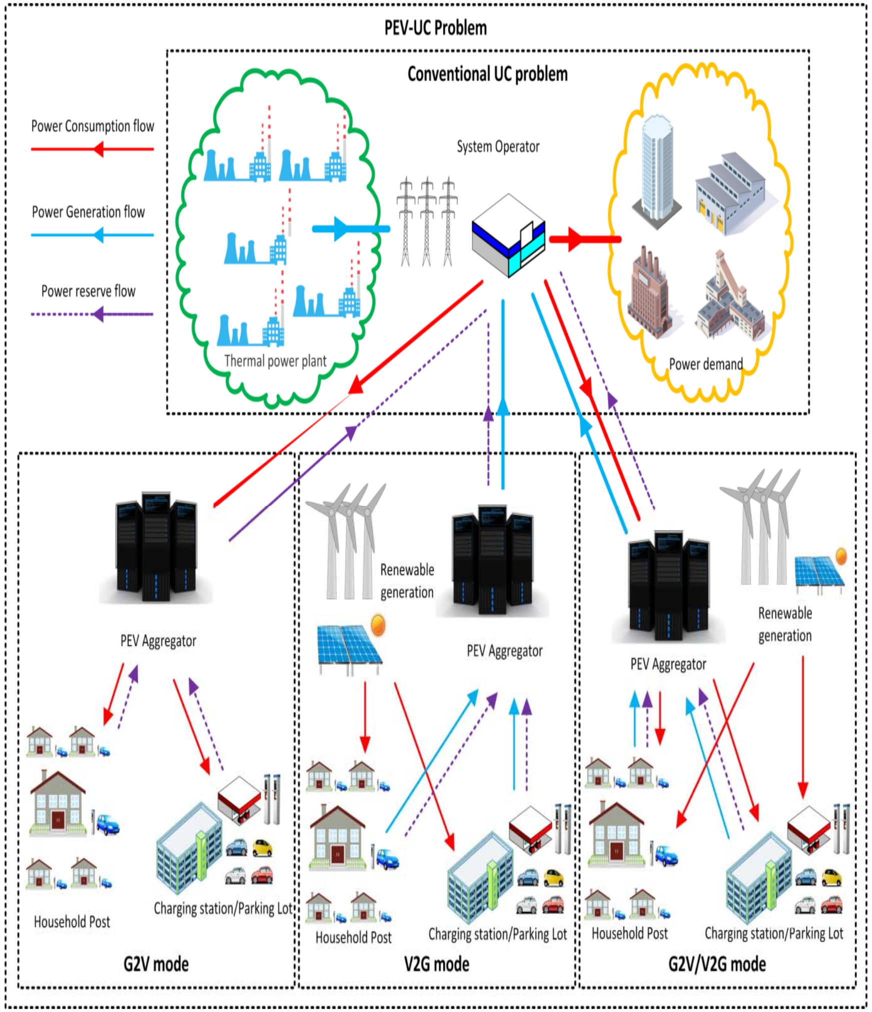
Application
Inertial EV response

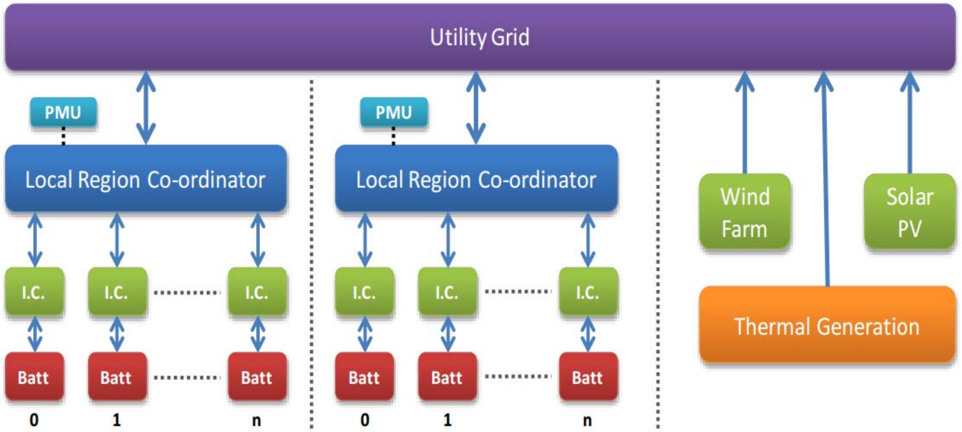
Wind Power Integration

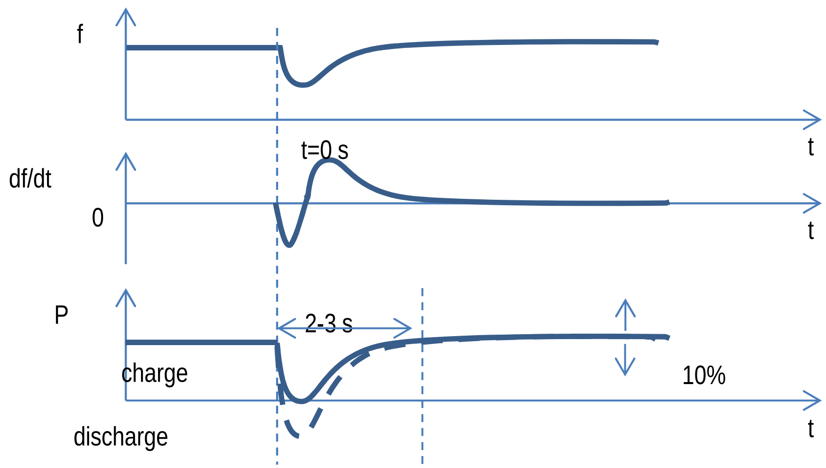




Electric Vehicles with Smart Grid



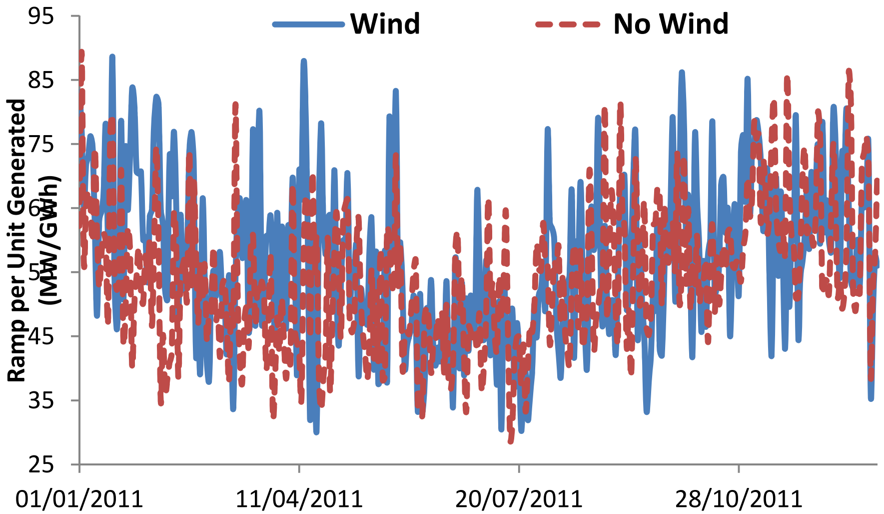


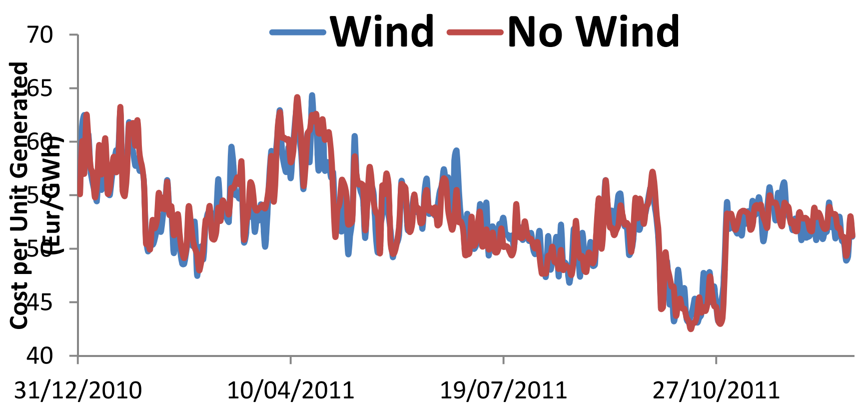


Simulation of inertial response

Wind and Gas Integration

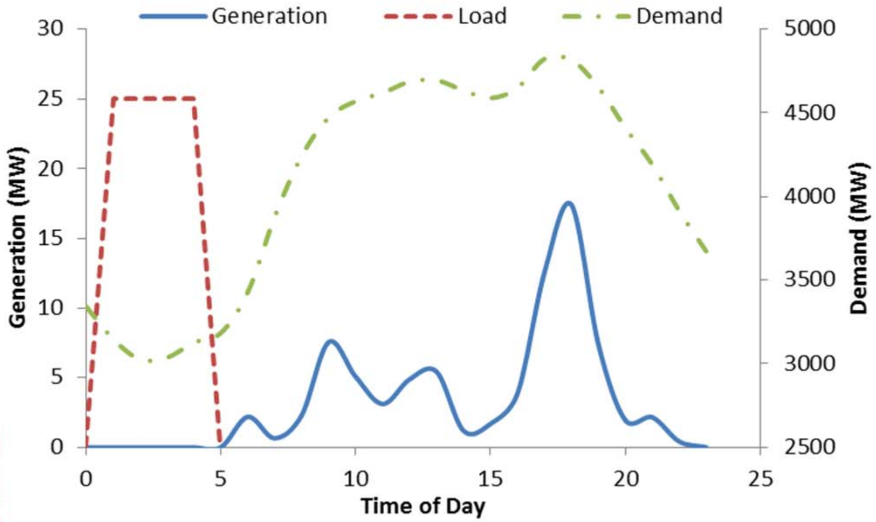
- Ramping carried out per unit generated
- Wind resulted in an increase from 54 MW/GWh to 57 MW/GWh
- Flexibility is key for the future generation portfolio
- Overall total gas generation costs fell 13% with the inclusion of wind
- This fall is masked by less generation
- Similar costs on a per unit basis

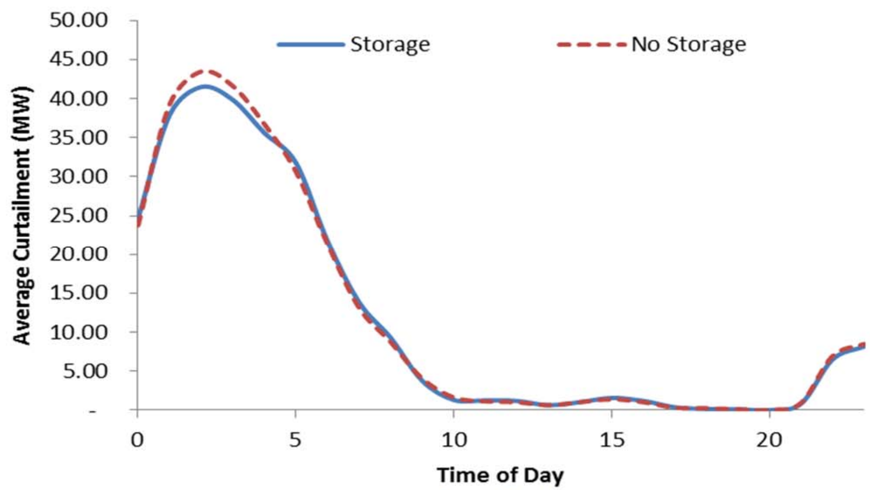




Wind and storage

- Counters wind variability
  - Reduces the requirement of thermal generation to fulfil residual demand
- Increases system flexibility
  - Fast acting response to system status
- Can provide arbitrage opportunities
  - Peak Load Shaving
  - Charge low, Discharge High
  - Unit given a SRMC of 150 €/MWh
- Reduce wind power curtailment
  - Reduction of 6 GWh to 1.7% of total available capacity





& intelligent control

UK-China workshop on

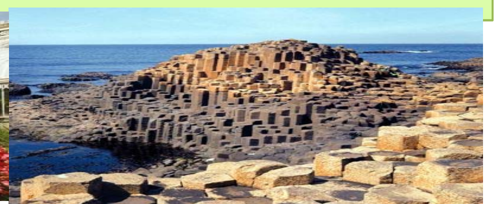
"Shaping low carbon energy future"

28-31 August 2016, Great Hall, Lanyon Building, Belfast, UK

This 3-day workshop is featured with keynote speeches, industrial exhibitions and knowledge transfer training, technical presentations and posters, panel discussions, break-out brain-storming, academic visits, formation of consortium and specific task groups, and networking events and social visits

Keynotes

1. Energy efficiency in intelligent manufacturing - **Prof Cheng Wu**
2. Smart grid and integration with electric vehicles - **Prof Yusheng Xue**
3. Battery management and wireless charging - **Prof Chunbo Zhu**
4. Modelling and analysis of integrated energy systems **- Prof Kang Li**
5. Planning, governance, and low carbon economy **- Prof Geraint Ellis**
6. Cyber security - **Prof Maire O'Neill**,



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