Battery Management System

ECG of Tsinghua University

Dr. Languang Lu

2010-9-1

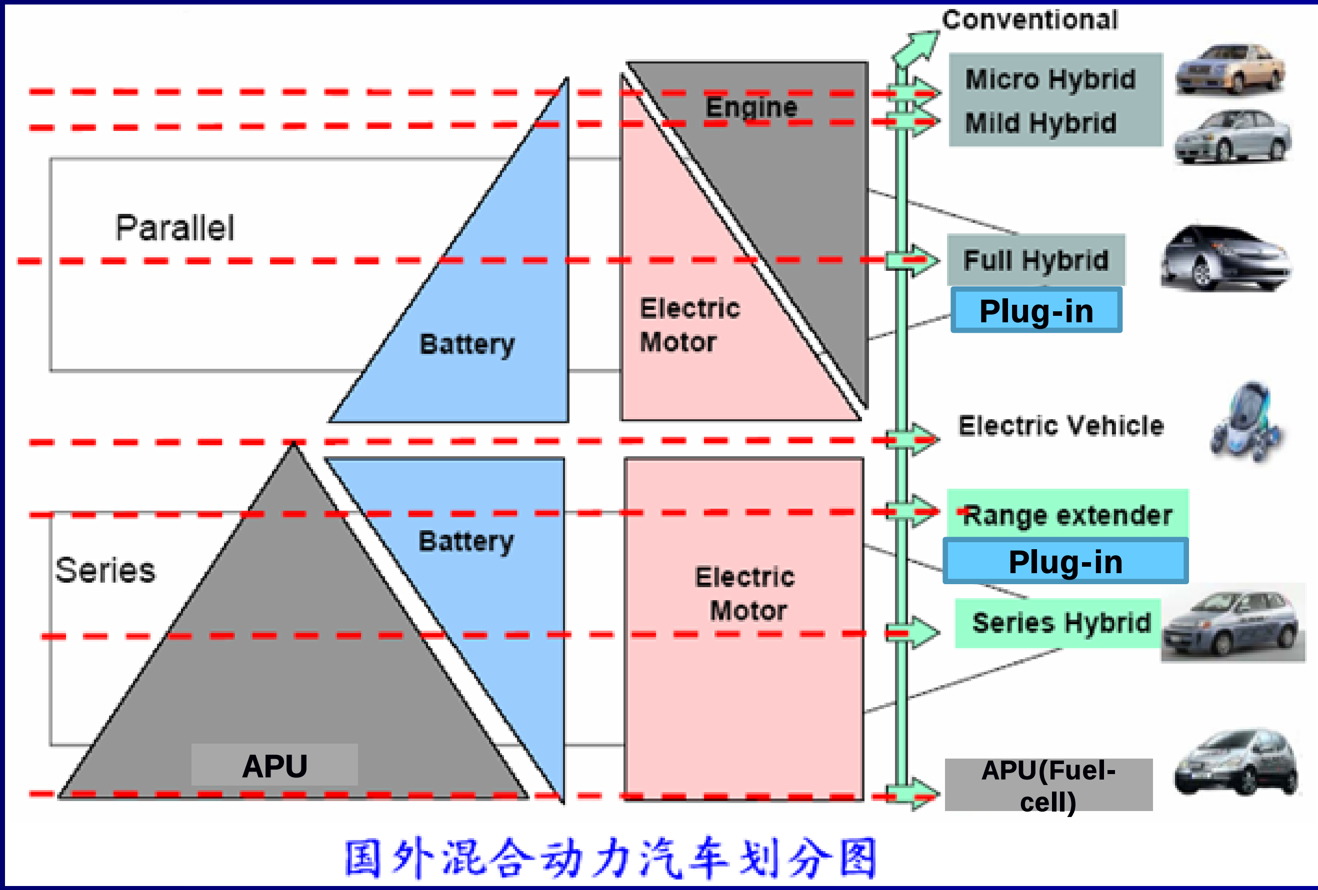
Contents

- Automotive battery status and development trend
- Battery current major problems
- Key Technology of battery management system
- Battery management System in Tsinghua University

Vehicle battery power system and its requirements

Green Power-train System

Divided by topology： parallel, Series
Divided by deep of hybrid: start/stop, micro, mild, strong, plug-in, BEV. **The Key component of the Green Power-train is Battery.** For different deep of hybrid system, the battery performance requirements (specific energy, specific power) are different .



characters	Start-Stop	M-HEV	P-HEV	Power-Assist (Minimum)	Power-Assist (Maximum)	Power Assist	Dual Mode	Minimum PHEV Battery (10miles)	Maximum PHEV Battery (40miles)
Peak discharge pulse power (kW/kg)	0.6 (2s)	0.52 (2s)	0.51 (18s)	0.625 (10s)	0.67 (10s)	0.625 (18s)	0.45 (12s)	0.83/0.75 (2s/10s)	0.38/0.32 (2s/10s)
peak charge pulse power (kW/kg)	N/A	0.32 (2s)	0.51 (18s)	0.5 (10s)	0.58 (10s)	0.75 (2s)	0.35 (10s)	0.5 (10s)	0.21 (10s)
available (Wh/kg)	25	12	20	7.5	8.3	7.5	15	85	97
production price 100k units/yr ($/kWh)				1667	1600			500	293

◆Series Hybrid Bus (60Ah)： the maximum discharge C rate is 8C， the rated discharge rate is about 5C

◆Parallel Hybrid Bus （40Ah）： the maximum discharge C rate is5C， the rated discharge rate is about 2.3C

◆Plug-in（30km）Hybrid Bus（140Ah）： the maximum discharge C rate is 3C， the rated discharge rate is about 2C

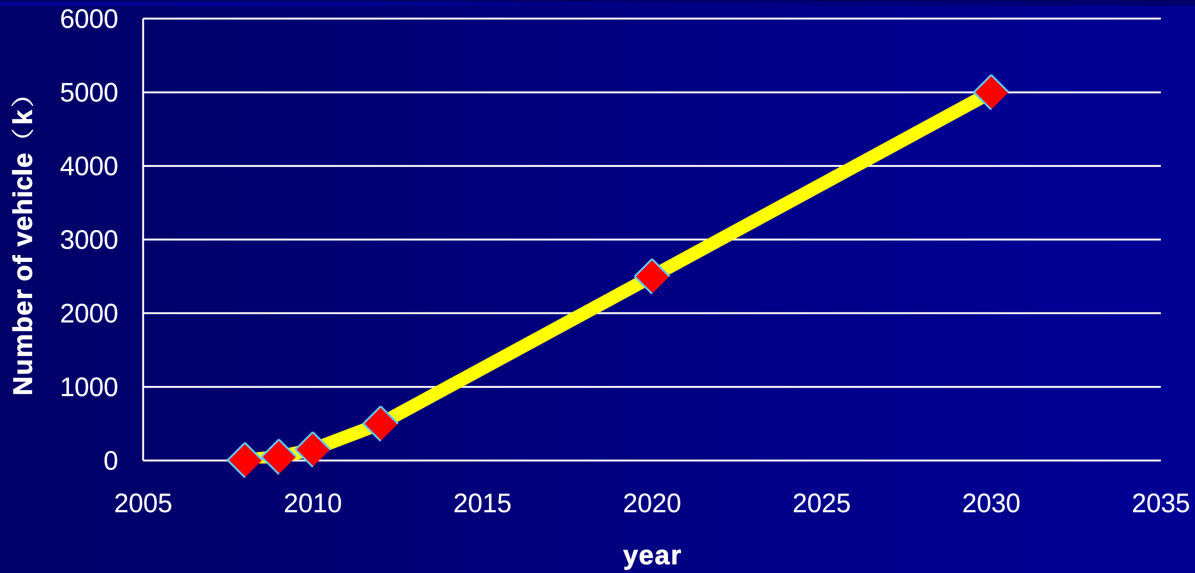
◆Plug-in（60km）Hybrid Bus（280Ah）： the maximum discharge C rate is 1.7C， the rated discharge rate is about 1.1C

◆Hybrid passenger car： the maximum discharge rate is greater than 10C， the rated discharge rate is greater than 5C

◆Short low-speed urban micro-car （<60km/h)： the maximum discharge rate is about 1C

◆Short high-speed urban micro-car（>80km/h): the maximum discharge rate is about 3C

HEV-year goal of Chinese

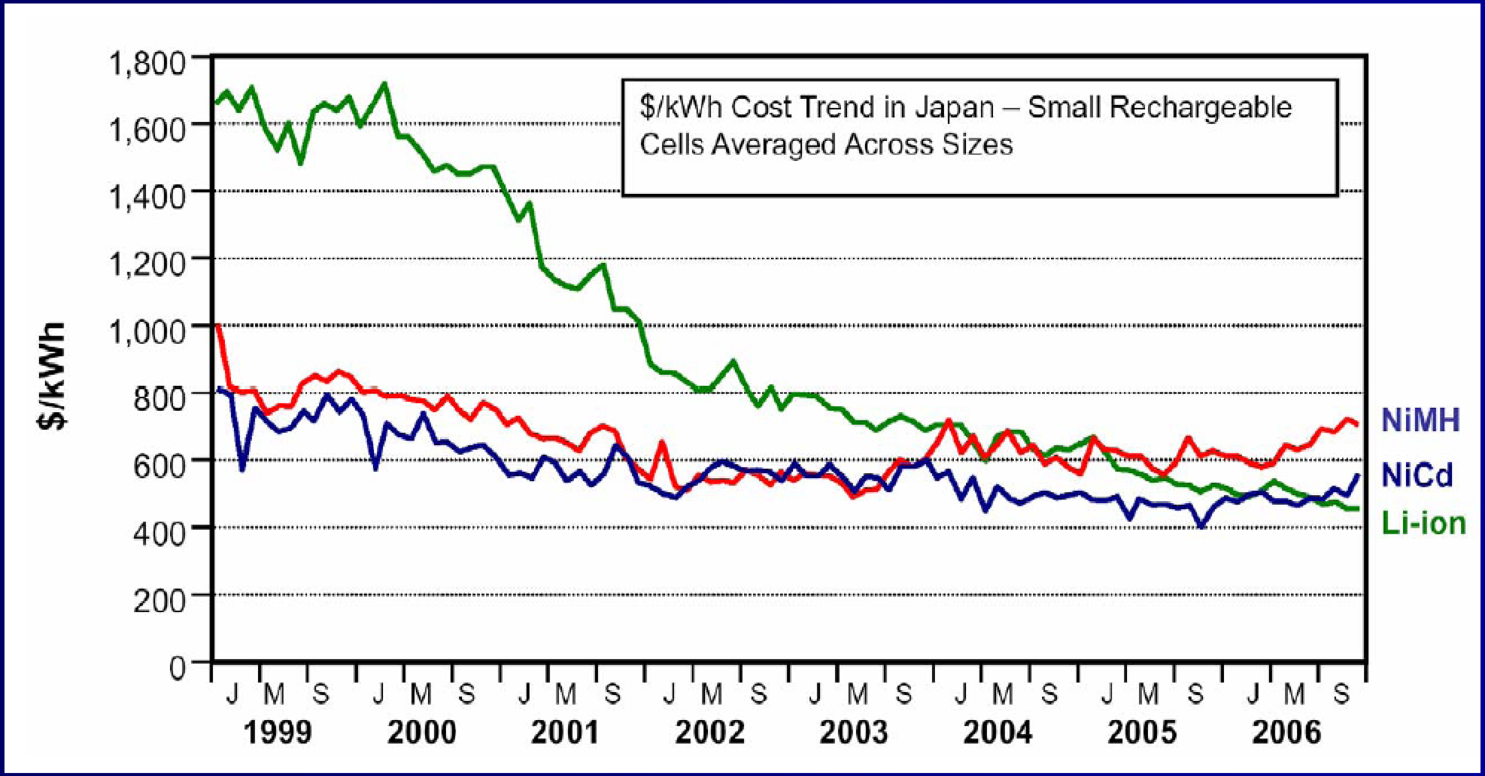


year	2008	2009	2010	2012	2020	2030
Annual ownership in hybrid vehicles	5000	50000	150000	500000	2500000	5000000
Annual alternative fuel （thousand tons）	5	46	175	488	3832	7663
Annual CO2 reduced emissions （thousand tons）	15	145	549	1526	11993	23986

from： International hybrid electric vehicle technology development and application of large-scale seminars，2008-12-9~10

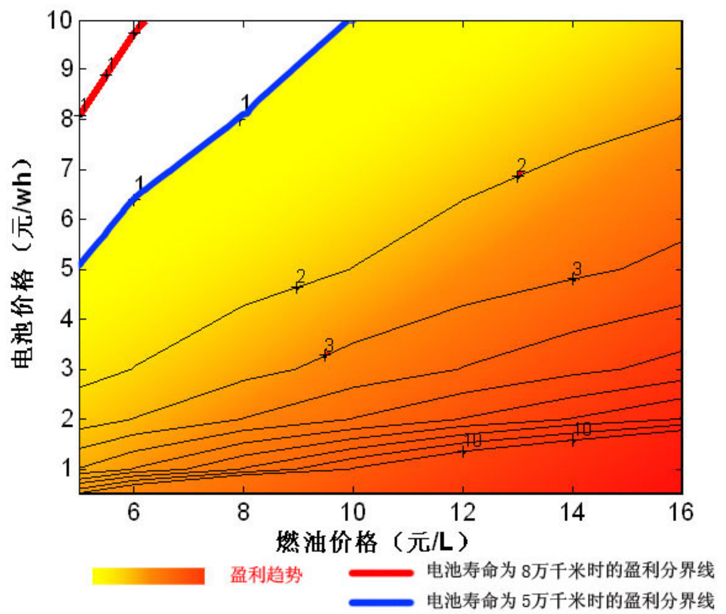
Rechargeable batteries cost

- Nickel metal hydride, nickel cadmium batteries to stabilize the price
- Lithium ion battery prices decrease, the price has been lower than the nickel-metal hydride batteries, in future it will be able to reach 2RMB/wh（in china the price of energy LiFeP04 battery is 2.8 RMB/wh now）

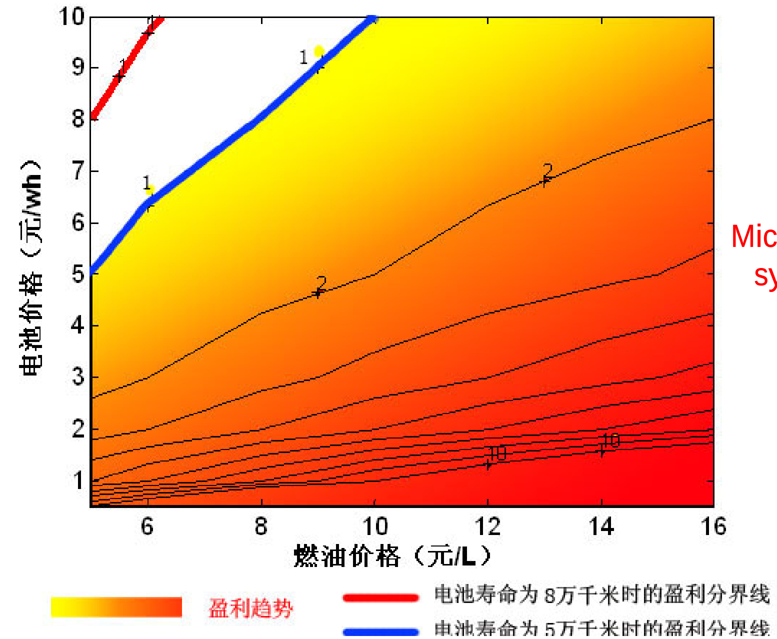


Cost analysis of different power-systems

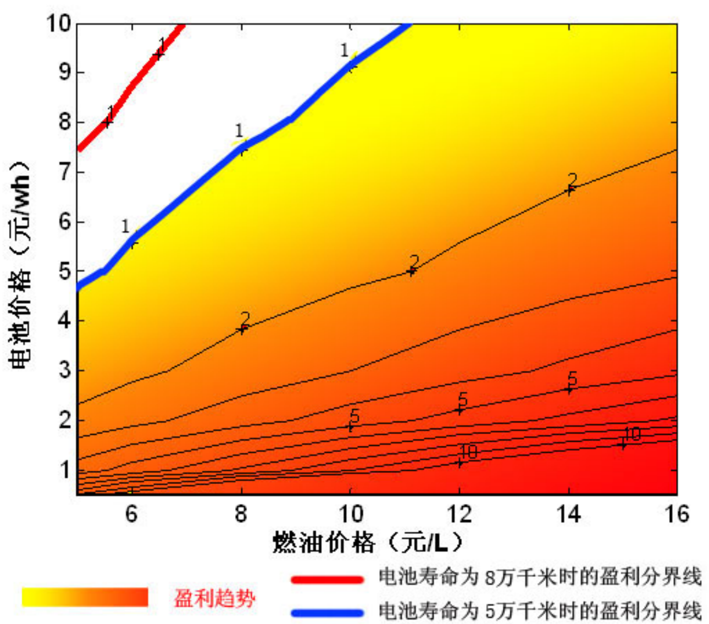
Start/stop system



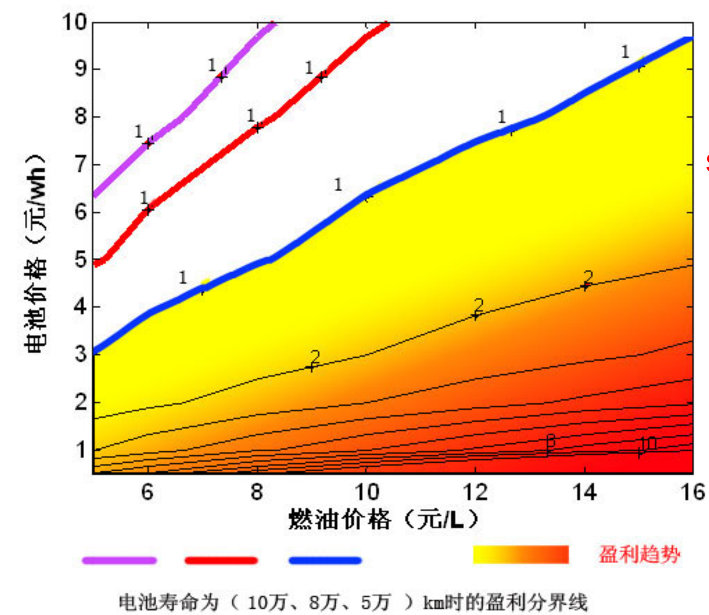
Micro-HEV system

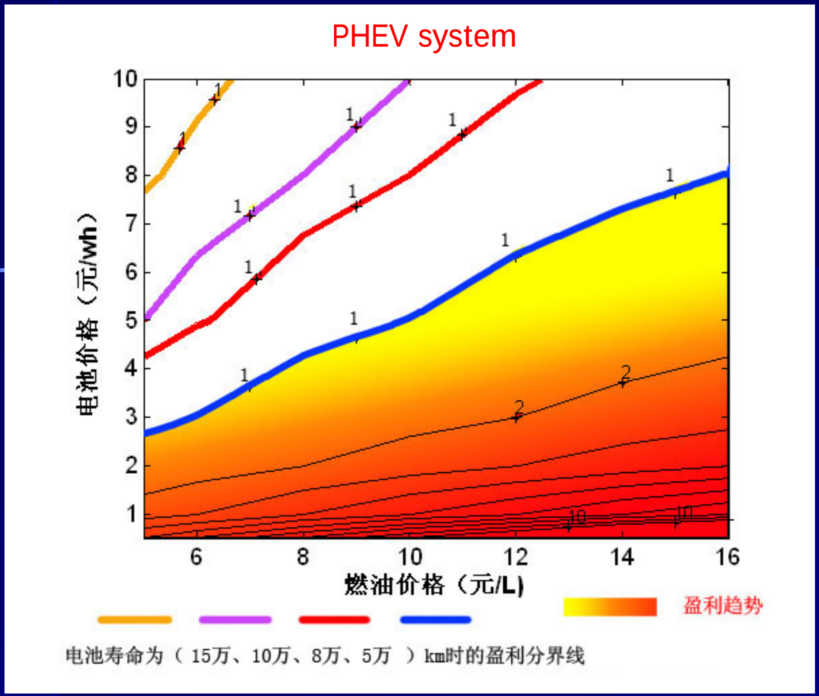


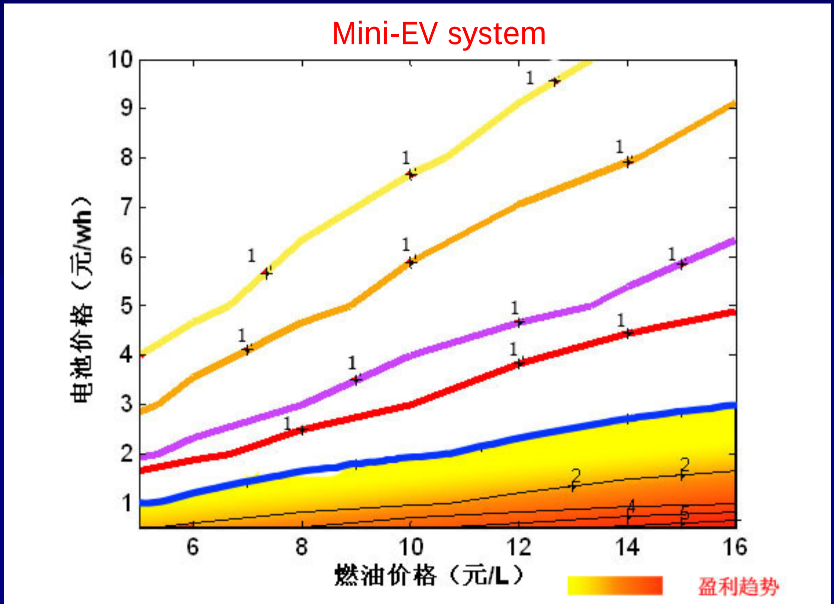
Mild-HEV system



strong-HEV system







Analysis showed that：

In the current oil prices, battery price . With the lithium-ion batteries

•Start-stop、Micro-HEV and Mild-HEV are Profit，

Therefore, the industrialization of these kind hybrid could be undertaken

• Strong-HEV、PHEV are in the state of Maintain principal

•Mini-EV Is still not profitable

Depends on the extension of battery life, the price reduction
and oil prices rise

(but the mini-EV base on Lead-acid batteries is profit.

• Full-EV profit is depends on the battery technology leap

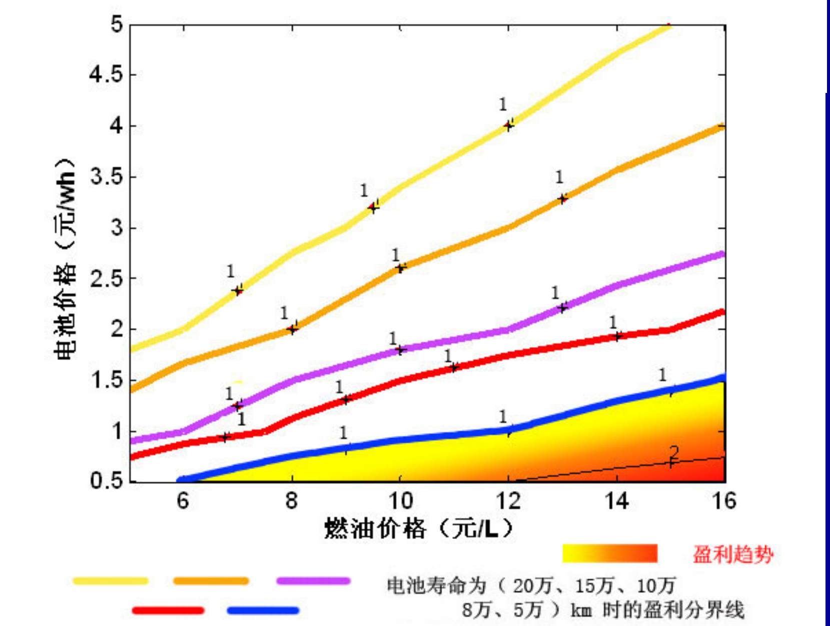
Analysis base on the following supposes：

（1） Vehicle service life of 200,000 kilometers

（2）the start-stop、micro-HEV、Mild-HEV、strong-HEV、PHEV、Mini-EV、Full-EV fuel saving is 6%、12%、15%、20%、60%、100%、100% respectively

（3） Conventional vehicle fuel consumption is 6L/(T*100km）

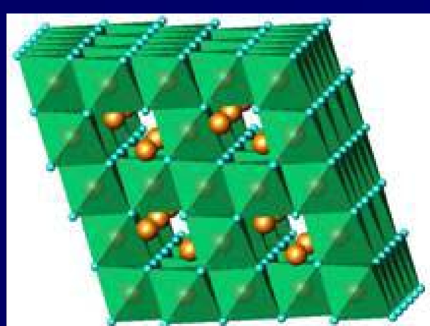
（4） the battery capacity of start-stop、micro-HEV、Mild-HEV、strong-HEV、PHEV、Mini-EV、Full-EV is：0.18、0.36、0.5、1、3.6、16、36kWh/T respectively



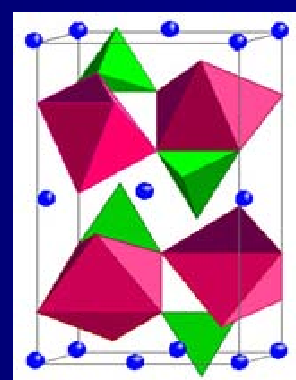
Full-EV system

Commonly used car power lithium ion battery at present

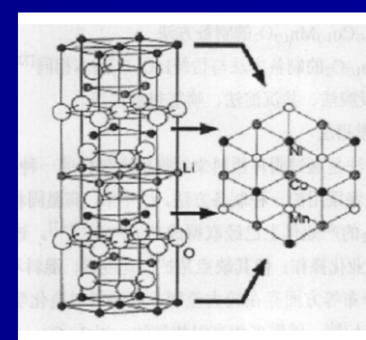
- ◆**Three elements （$LiCo_xNi_yMn_{1-x-y}O_2$）Li-ion Battery(the United States, Europe and Japanese)**
- ◆**Lithium manganese（$LiMn_2O_4$ ） battery（ Japanese, Chinese）**
- ◆**Lithium iron phosphate （$LiFePO_4$）battery （Chinese, the United States, Europe ）**



Lithium manganese
（ Spinel structure）



Lithium iron phosphate
（ olivine structure）

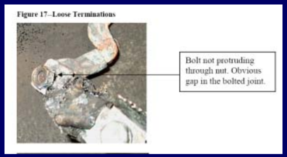


Three elements
（layer structure）

Contents

- Automotive battery status and development trend
- Battery current major problems
- Key Technology of battery management system
- Battery management System in Tsinghua University

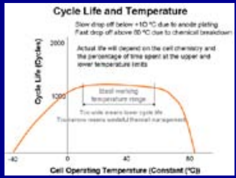
The main issues of current lithium ion battery

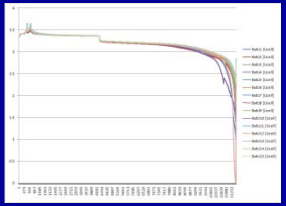


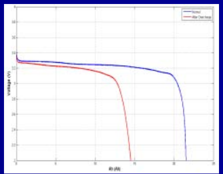
The key problems

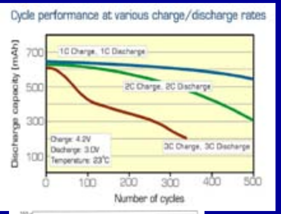
- safety
  - abuse

- durability
  - •High temperature,
  - •overcharge
  - •Over discharge
  - •High rate charge or discharge









- Cell to Cell variation (capacity, Impedance)
  - Material
  - manufacture
  - Integration and management

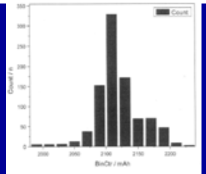


图 3.1 2Ah 软包装电池同批次电池的容量分布
Fig.3.1 Capacity distribution of same type batteries

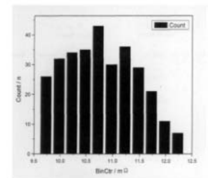


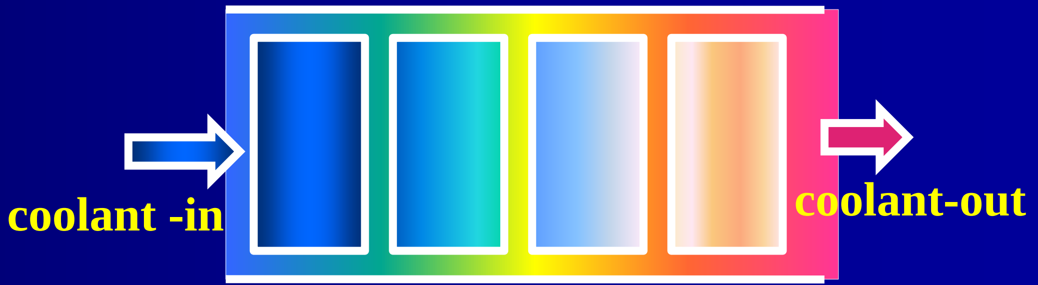
图 3.2 2Ah 软包装电池同批次电池的内阻分布
Fig.3.2 Impedance distribution of same type batteries

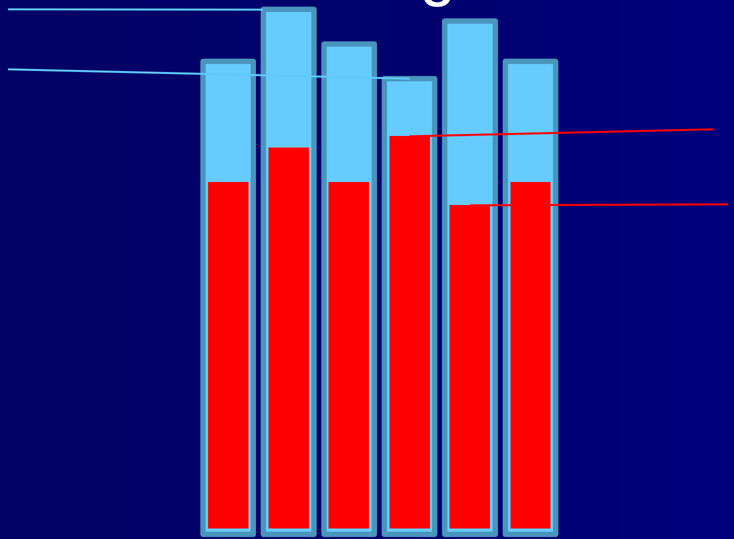
- cost

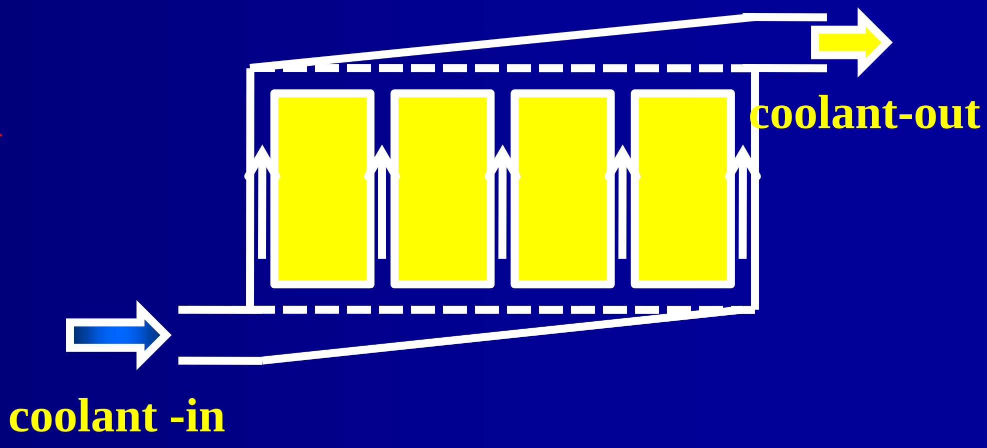
Battery pack Cell to Cell variation

Coulomb efficiency different of cell to cell

- temperature difference of cell to cell environment
- Capacity different
- Resistant different
- SOC different
- Shelf discharge different







Lithium-ion battery safety operating window

Lithium-ion battery safety operating window is narrow

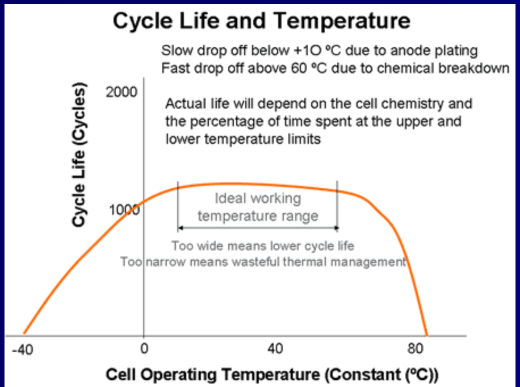
$LiFePO_4$ operating voltage：

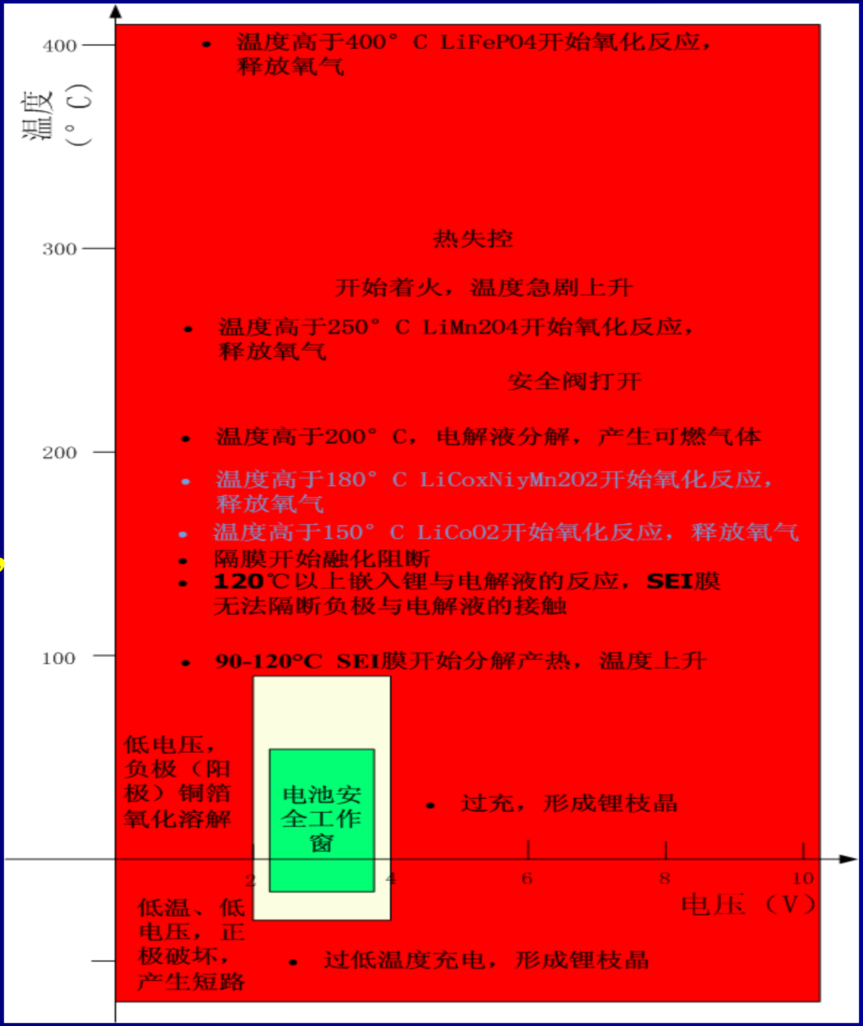
2.5~3.6V

operating temperature：

-20~55 ℃

Battery technology is the core of the 3 key technology of EV(battery, motor, and control)





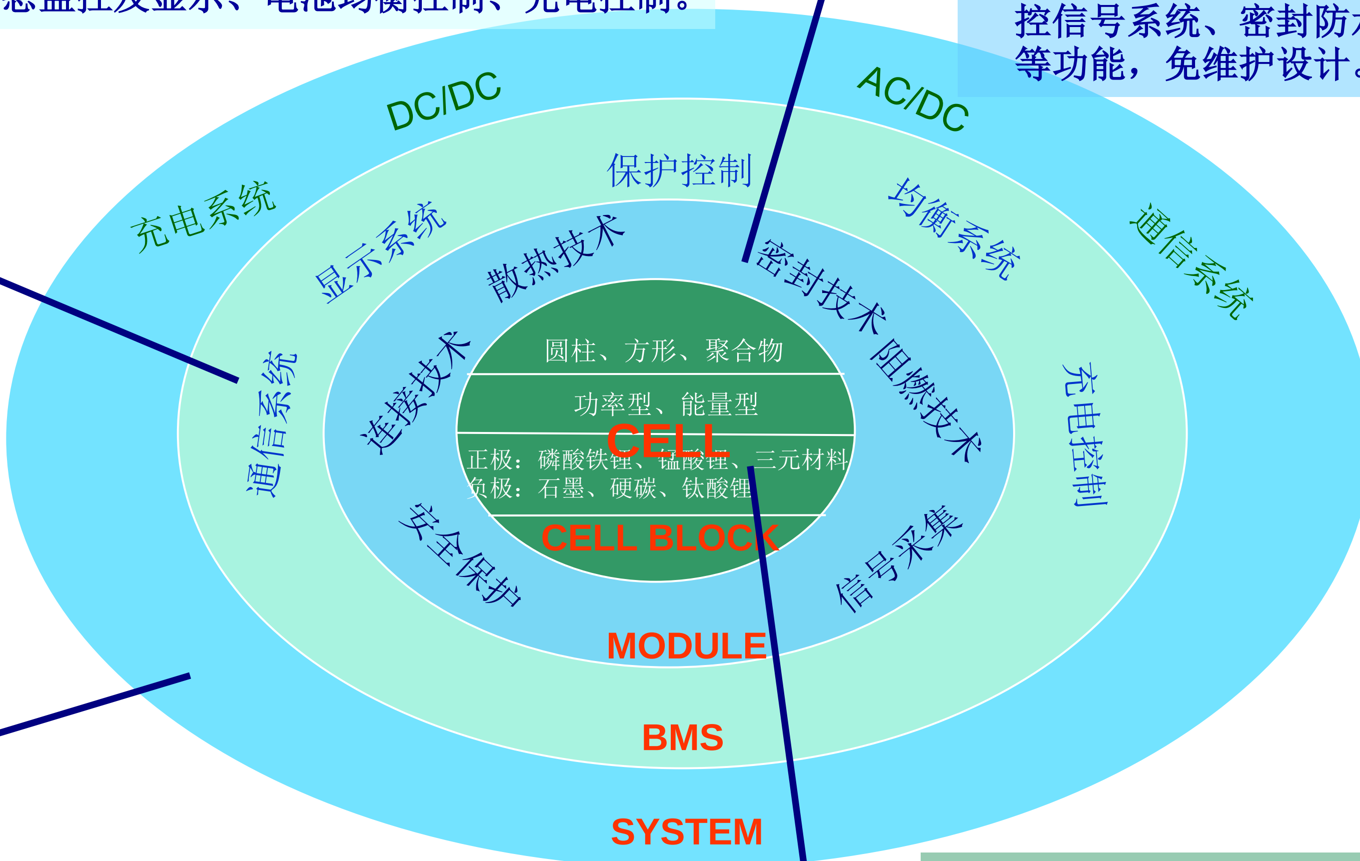
Contents

- Automotive battery status and development trend
- Battery current major problems
- Key Technology of battery management system
- Battery management System in Tsinghua University

Key Technology of battery

BMS：电源管理系统，对各电池或电池模块进行管理，包括安全保护、电量及电池状态监控及显示、电池均衡控制、充电控制。

Module: 电源模块，包括电池组、电池热管理系统，电池监控信号系统、密封防水、阻燃等功能，免维护设计。



Power Systems：包括电源管理系统、充电机及充电管理系统、电池组模块等。

Cell : 单体电池

Cell Block: 单体电池串并连接体，设计上考虑电池连接的可靠性，

Specifications and standards for Electric vehicle battery

- SAE J2344,
- EN1987-1
- EN1987-2
- EN1987-3
- GB/T 18384. 1, Safety requirements for electric vehicle, part I: Vehicle energy storage
- GB/T 18384. 2, Safety requirements for electric vehicle, part II: Safety and fault protection functions
- GB/T 18384. 3, Safety requirements for electric vehicle, part III: Danger of electric shock protection
- QC/T 743-2006, Lithium-ion batteries for electric vehicle
- GB 4208-93, Enclosure protection class (IP Code)

Specifications and standards for Electric vehicle battery

- GB/T XXXXX-XXXX, Electric vehicle with lithium-ion battery pack and system testing procedures (draft)
- GB/T XXX , The communication protocol Electric vehicle battery management system with non-vehicle charger (draft)
- SAE J1742, Road vehicles wiring harness to connect high-voltage test methods and general performance requirements
- SAE J2380, Vibration test electric vehicle batteries
- SAE J2464, Electric vehicle battery abuse tests
- ETA-HTP008, Battery Charging
- JEVS TG Z002, High voltage components for electric vehicle-related identity guidelines
- JEVS TG Z001, Operation of electric vehicle charging guidelines identify the relevant

BMS Function defined

- EMC
- Parameters Detection
- Information storage
- TTCAN
- balance
- Charge control
- Security alarm and control
- SOC
- SOH
- SOF
- OBD

BMS Function defined

In addition to diagnostic performance, the contact resistance can be diagnosed and found loose joints

- Parameters Detection

  included: bus-voltage, current, cell voltage, temperature, leakage gas, Insulation , Collision and Impedance

- SOC (State of charge) estimation

  based on the discharge current, temperature and voltage conditions

- SOH (State of Health) estimation

  based on the battery degradation and abuse

- SOF (State of Function) estimation

  According to the SOC, SOH and the environment, estimated the output capacity of the battery

BMS Function defined

- On-board diagnosis （OBD） and prediction

  include： Sensor failure, actuator failure, network failure, the battery itself fault, overvoltage (overcharging), undervoltage (through put), over-current, ultra high temperature, ultra-low temperature, joints loose, flammable gas concentration in excess of, insulation failure, consistent failure , temperature rise too fast, etc.

- Security alarm and control

  Including thermal control, fault diagnosis to inform the vehicle controller or charger through the network, required vehicle controller or charger to process (BMS can also cut off power supply output if over a certain limit), in order to protect the battery or person form high temperature, overcharge, over discharge, over current, electric leakage.

- Charge control

  BMS according to the characteristics of its own battery and charger power rating, by controlling the charger to recharge the battery.

BMS Function defined

- Battery balance

According to the battery cells information, using a balanced charge, or dissipation, or energy transfer, and so on , in order to keep each cell SOC consistent as far as possible .

- Network

For the convenience of On-line calibration, monitor, automatic code generation and on-line program download, the network is needed.

- Information storage

used to store the key data, such as SOC, SOH, accumulated charge and discharge capacity, failure code, consistent information etc.

- Electromagnetic compatibility (EMC)

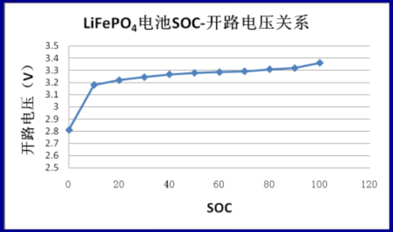
BMS must have good resistance to electromagnetic interference（EMS）, because of the poor conditions of electric vehicles.

The 3 key technologies of BMS

- High precision detection of cell differential voltage under high common-mode voltage

  Cumulative voltage can reach more than 300 V, accuracy level is a few mV

  methods: Resistor divide, Optocoupler isolation amplifier , Discrete Transistor , Distributed measurement, Coupler relay etc.



- **Precision SOC estimation**

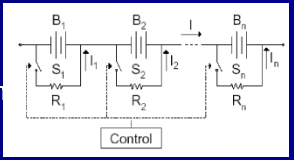
  Many factors that affect SOC , such as the accuracy of the measurement (current, voltage, temperature etc.), the load ,the operating temperature and the degradation of the battery etc.

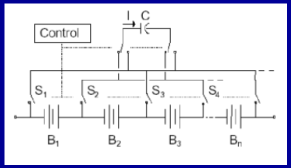
Method： Current integration, OCV, load-voltage, Resistance, Neural network modeling, Kalman filtering method etc.

- **Balance of the battery**

  efficiency, cost

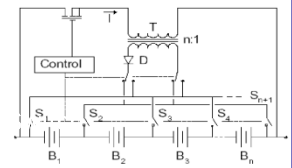
Resistor dissipation

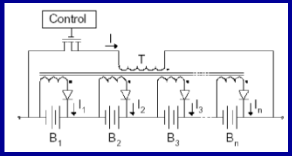




capacitor

Inductance
+
Combination



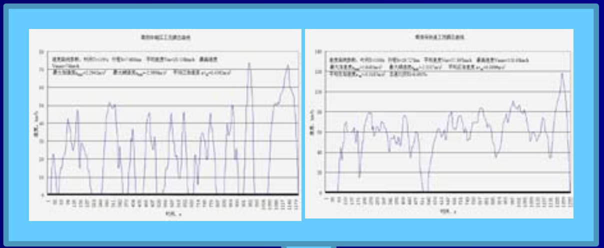


Coaxial
inductor

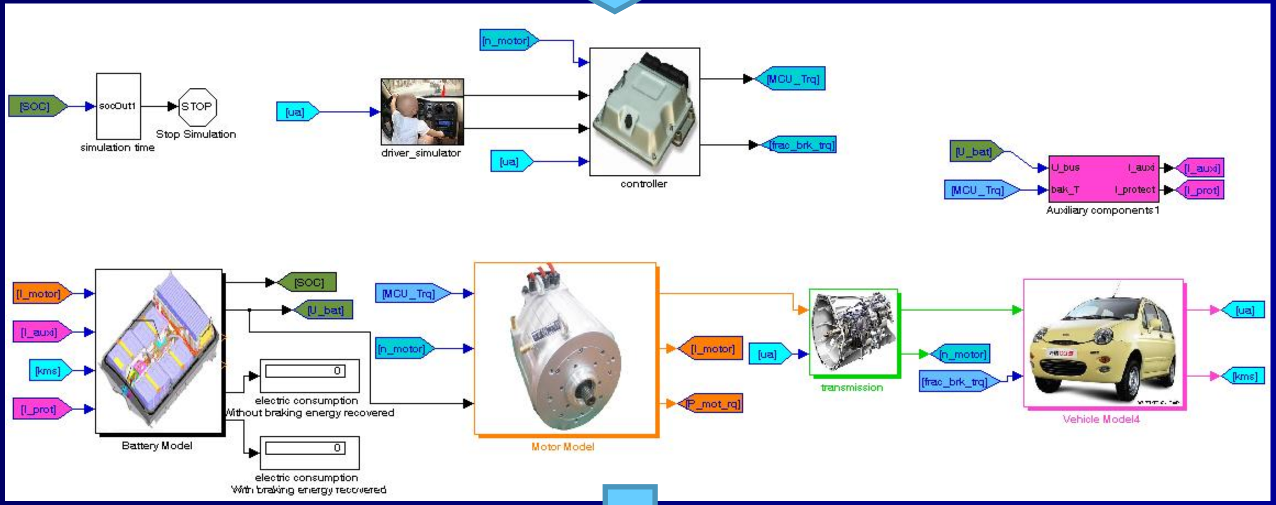
Contents

- Automotive battery status and development trend
- Battery current major problems
- Key Technology of battery management system
- Battery management System in Tsinghua University

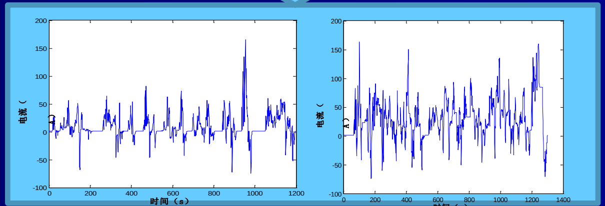
1. The simulation platform for EV



Driving cycle



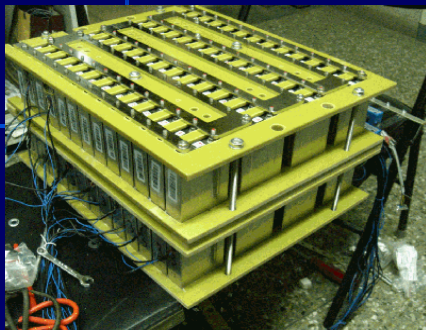
System model



Battery operating cycle

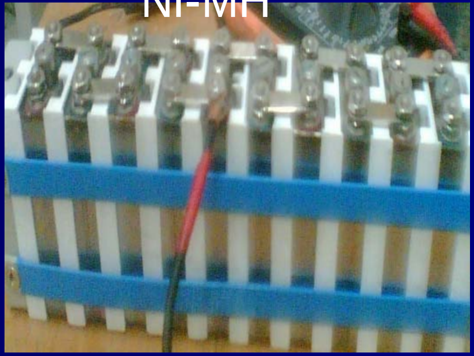
2. Battery performance testing and modeling

LiFePO4



Lithium **manganese**

Ni-MH



Improved lead-acid batteries

battery test equipment

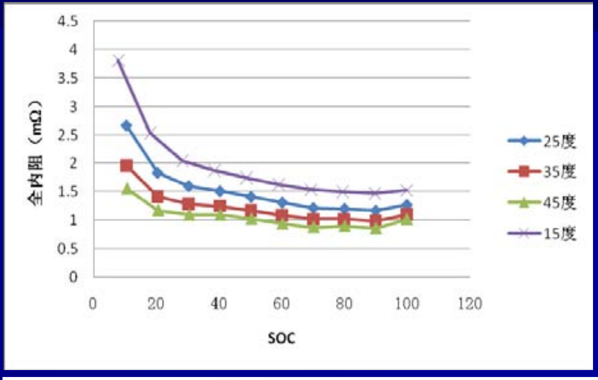
Battery performance testing and modeling

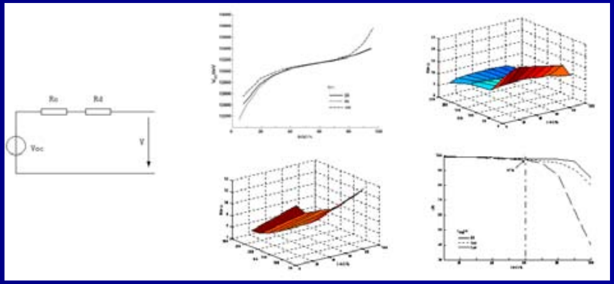
✓Single Cell Testing and Modeling

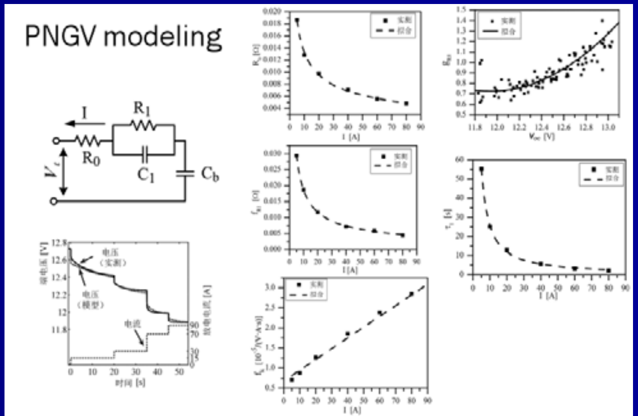
- Base performance test and analysis
- performance test and analysis under driving cycle
- Durability test and analysis
- Single cell modeling

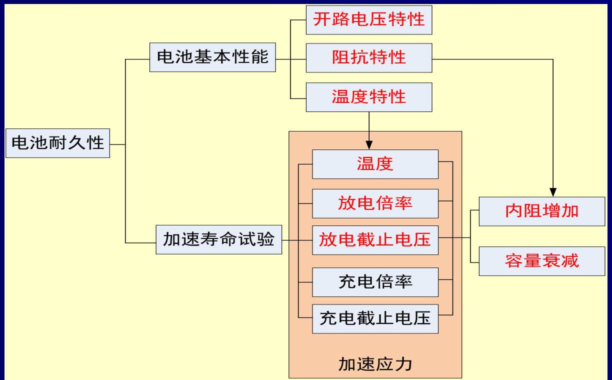
✓Pack Testing and Modeling

- Base performance test and analysis
- Cycle test and analysis
- Pack network Modeling

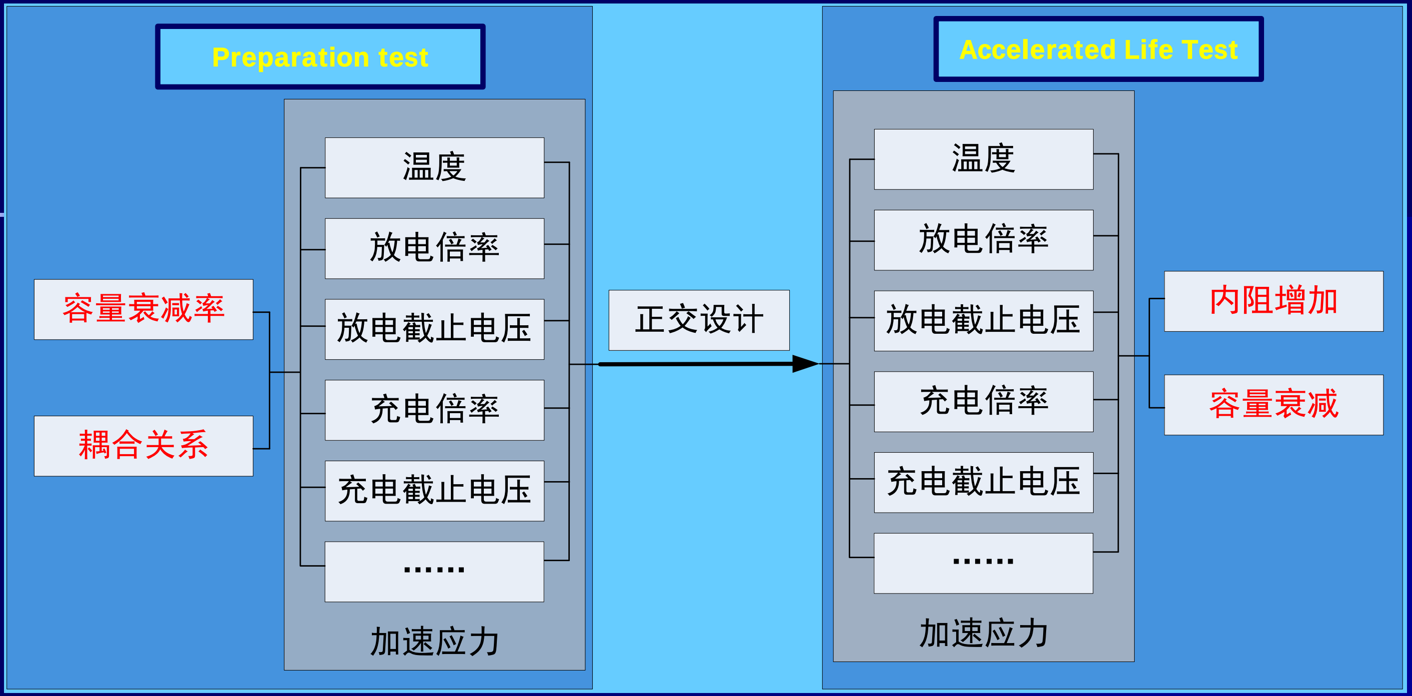




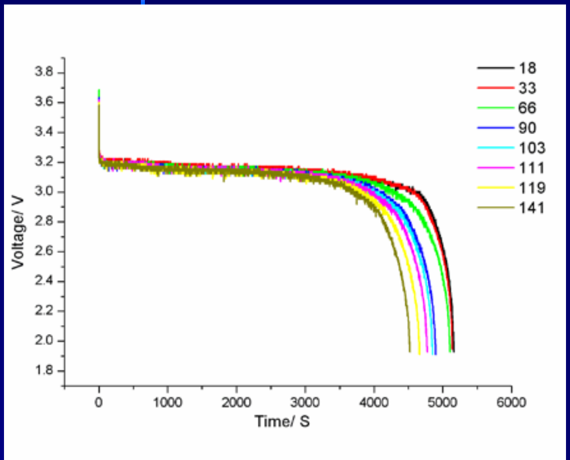




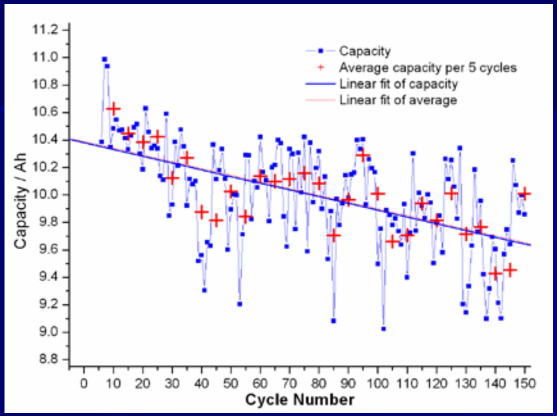
Durability test method (Orthogonal accelerated)

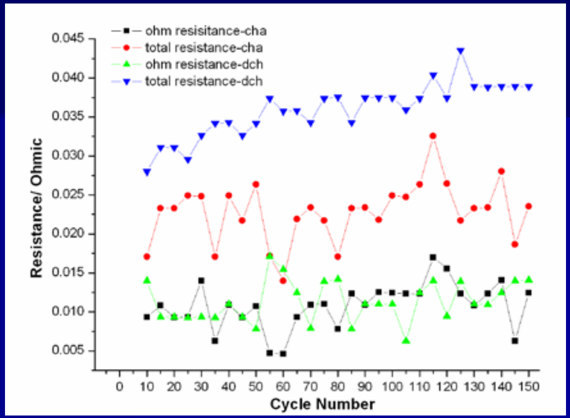


factors / levels	Temperature A	Discharge cut-off voltage B	Discharge current C	Charge cut-off voltage D	Charge current E
1	30℃	1.25V	5C	3.65V	1/3C
2	40℃	1.5V	3C	3.75V	1/2C
3	50℃	1.75V	1C	3.85V	1C
4	60℃	2V	1/3C	3.95V	1.5C

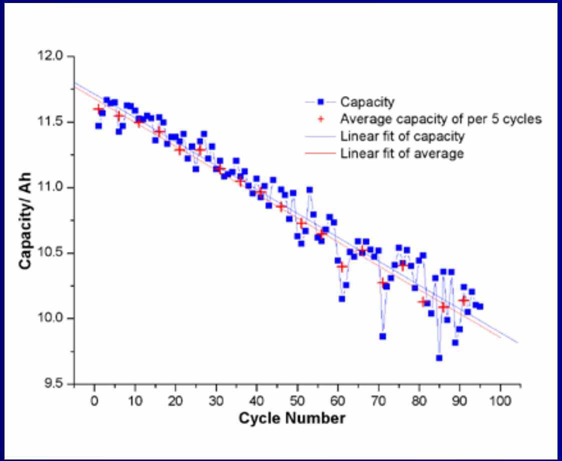


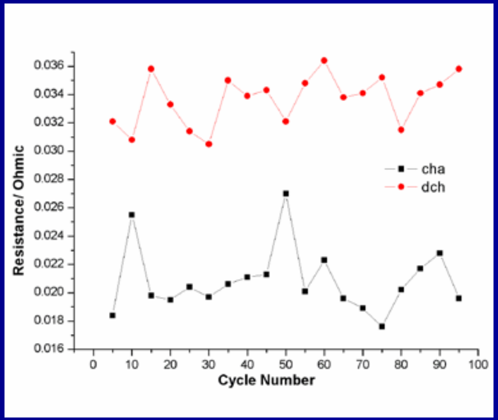
The degradation is almost 4 times in 50 ℃ than that in 30 ℃





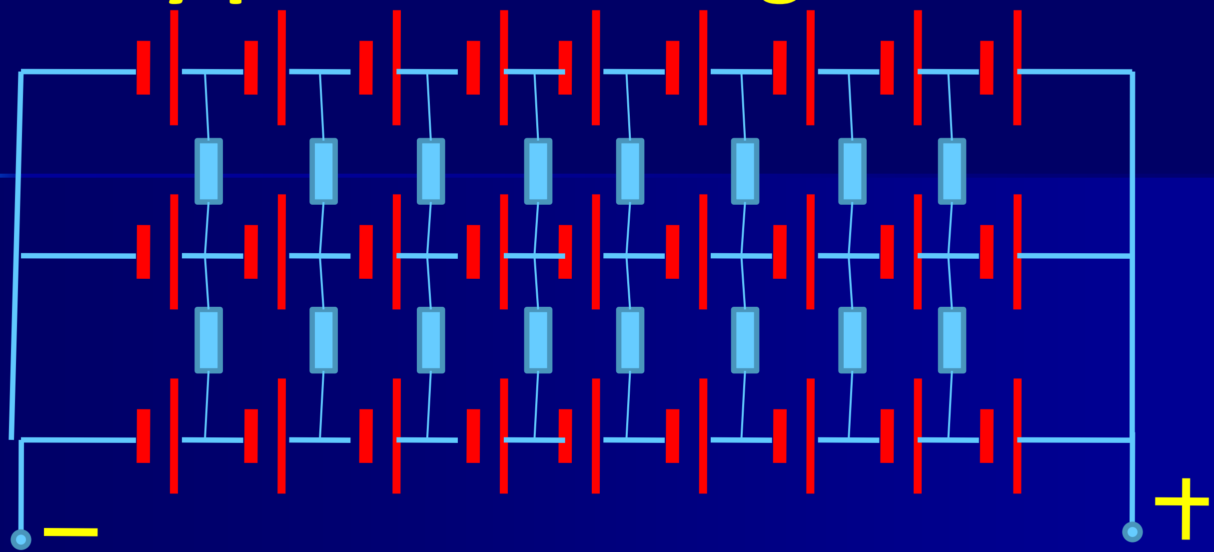
30 ℃

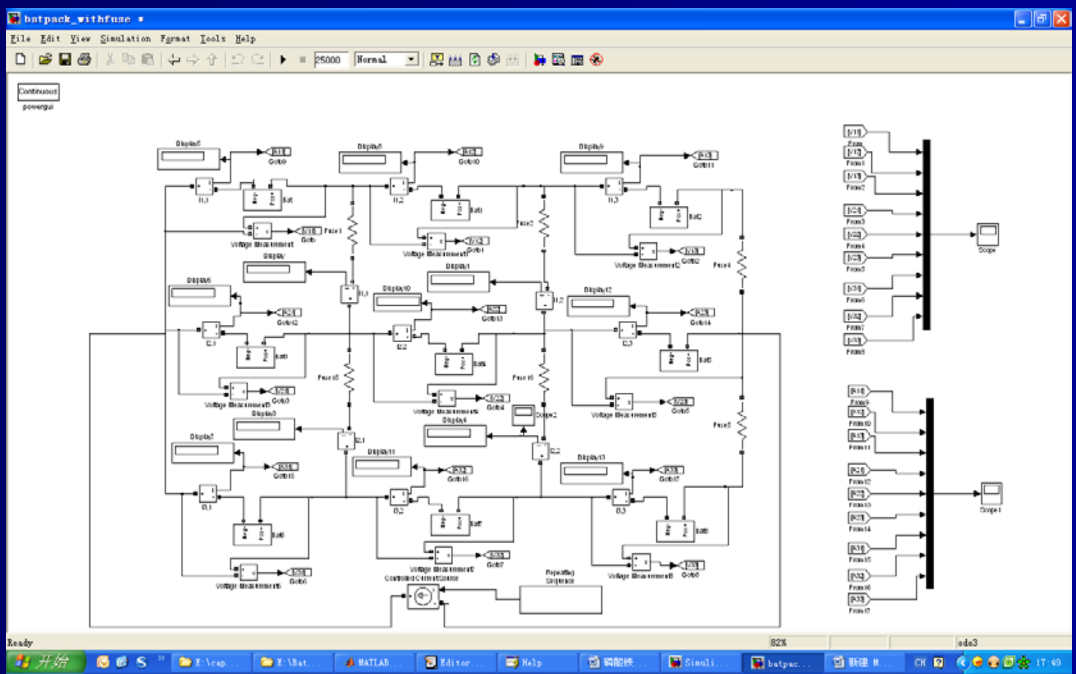




50 ℃

Battery pack modeling





Battery network modeling

Testing procedures in Tsinghua University

电池测试试验流程

清华大学汽车工程系
发动机控制组(ECG)

2010

一、 要求厂家提供电池参数

见附件

二、 来货检查

记录厂家电池出厂参数，包括：单体编号、单体容量、内阻、出厂单体开路电压等。
测量各个单体的开路电压，并与厂家数据比较。

三、 试验

■ **单体电池试验**

（一） 电池剩余电量测试（3h）
25℃下，以0.3C放电至2.5V，记录剩余电量。
（二） 标准测试（36h）
25℃，0.3C充电，0.3C放电，至少连续充放电4次。
（三） 标准温度HPPC测试
（四） 标准温度Peakpower测试
（五） 35℃、45℃、15℃、0℃、-10℃、-20℃ 0.3C放电倍率、HPPC、PP测试
（六） 25℃、35℃、45℃、0℃、-10℃、-20℃ 其他倍率(0.5C、1C、1.5C)放电测试
（七） 自放电测试
（八） 电池耐久性测试

■ **电池组测试**

（一） 常温标准测试
室温下，0.3C充电，0.3C放电，至少连续充放电3次。
（二） 常温HPPC测试
（三） 常温PP测试
（四） 常温恒功率测试（10kW、20kW、30kW）
（五） 车用工况循环测试
（六） 电池组一致性、耐久性测试

单体倍率放电测试

● **温度为15℃~45℃时倍率放电**

步骤
（1） 保持电池于测试温度，以测试的倍率放电至截止电压（2.5V）；
（2） 以0.3C进行充电至截止电压（3.6V），然后以截止电压恒压充电至电流0.05C
（3） 静置1h
（4） 以测试倍率进行放电至截止电压（2.5V）
（5） 静置1h
（6） 重复（2）~（5）4次

记录：电压、电流、Ah、温度
计算：容量、库伦效率

● **低温（0、-10、-20℃）倍率放电**

步骤：
（1） 保持25℃ 4h以上
（2） 以0.3C充电至截止电压（3.6V），然后以截止电压恒压充电至电流0.05C
（3） 静置1h
（4） 将温度调至测试的低温，保持4h以上
（5） 以测试的倍率放电至截止电压（0℃以上2.5V，0℃以下为2.0V）
（6） 重复（1）~（5）3次

记录：电压、电流、Ah、温度
计算：容量、库伦效率

单体电池HPPC测试方法

● **温度为15℃~45℃时的HPPC测试**

1. 确定I_{HPPC}

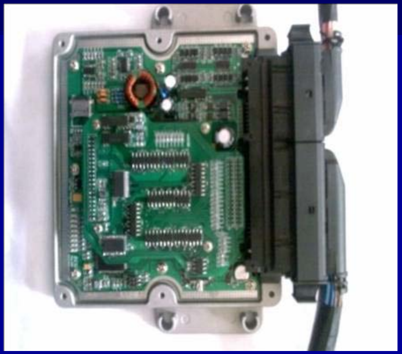
$$I_{HPPC} = \frac{P_{char}}{V_{oc} \times BSF}$$

其中：I_{HPPC}为脉冲电流间的持续电流

P_{char}为车辆常用功率，取10kW

BSF为比例因子。

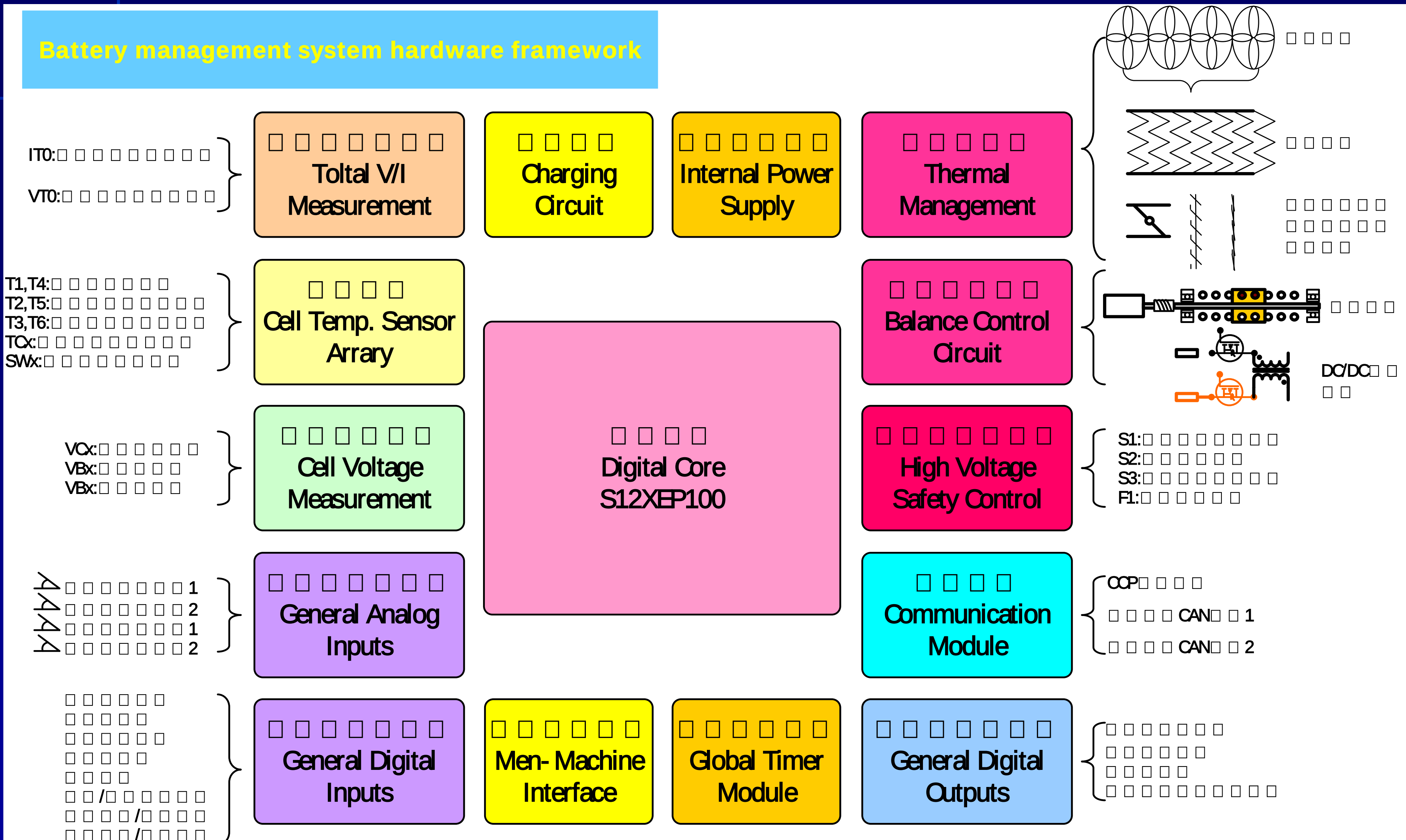
3、 Battery management system hardware and software development



- ✓EMC Technology
- ✓Signals Collection and storage module
  according to the function in section 2
- ✓TTCAN network technology
  Communication protocol (included the protocol with charger), on-line calibrate and monitor, automatic code generation and on-line program
- ✓Underlying software based on OSEK
- ✓Thermal Management Module
  (cooling and heating)
- ✓High voltage management module
  (leakage, isolate, control)
- ✓SOC（each cell）,SOH, SOF and OBD

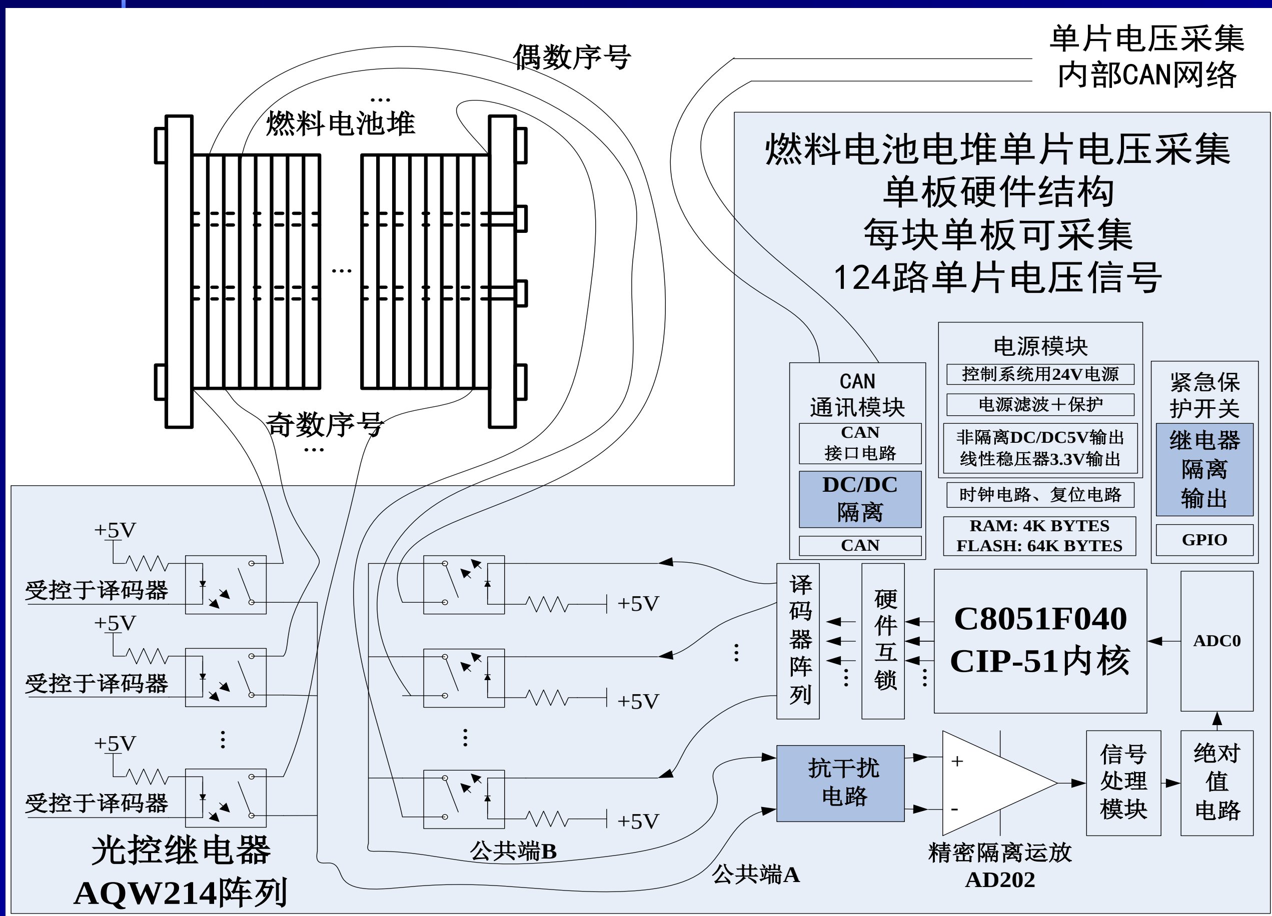
Each cell has its own ID and its own data file

Battery management system hardware framework



Hardware framework of CM (cell monitor)

patent：ZL200510086690.8



Solve the following 3 key issues

① High Cumulative voltage

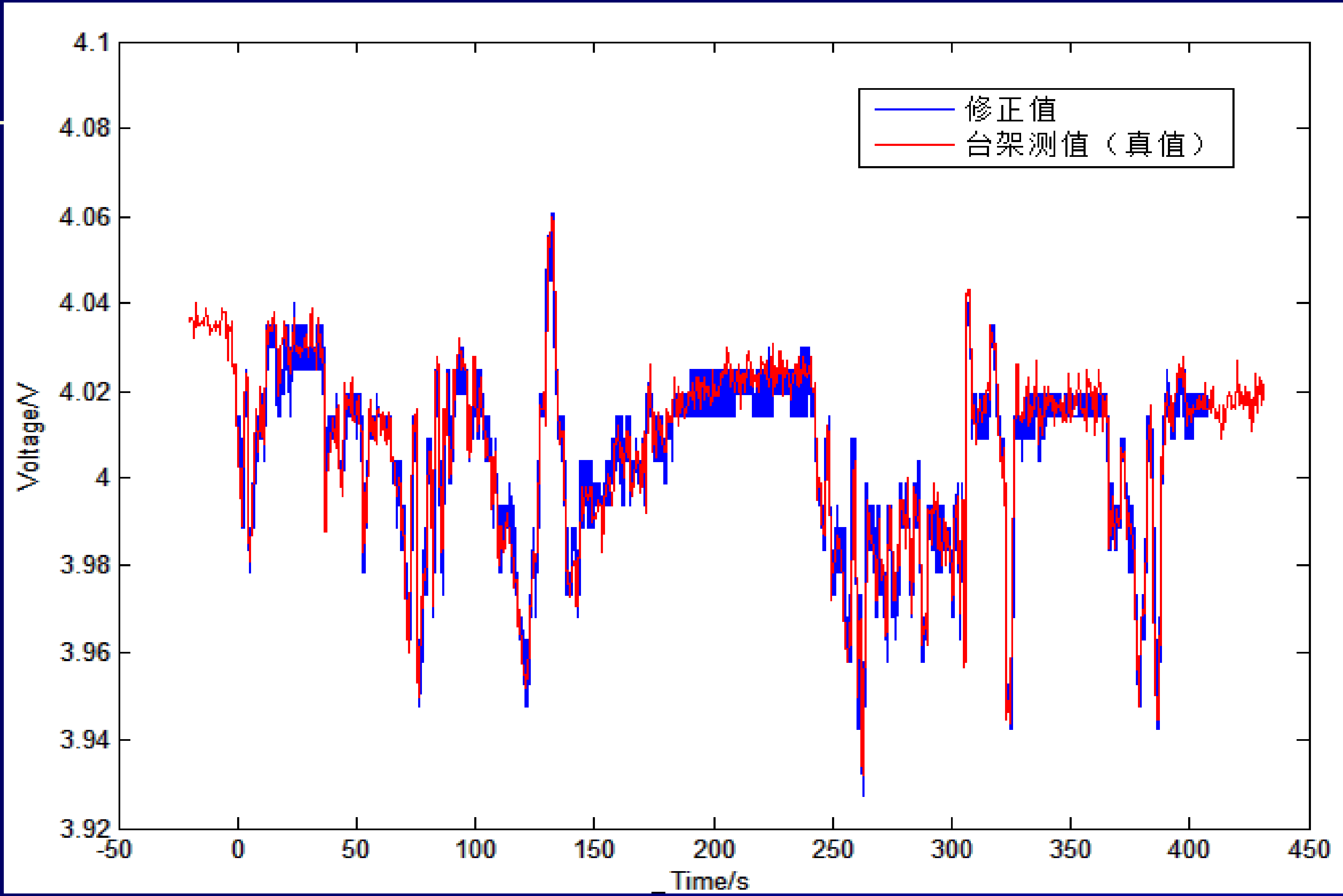
② “common earth”

③ The absolute value of the signal

✓Error <5mV

✓Number of channels meet each cell detected

Cell voltage test



Battery management system software copyright V1.0，2009SRBJ5098

soc

- Ah integrate
- OCV
- Load-Voltage
- Resistance
- Linear model
- Neural network

Modeling

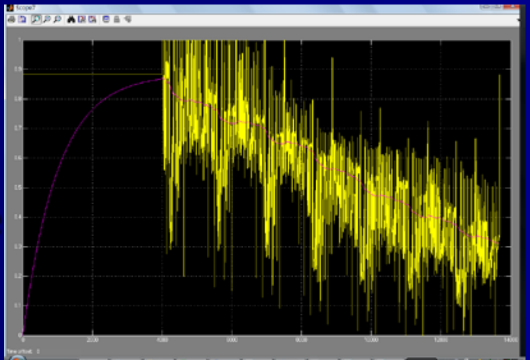
- Kalman filtering

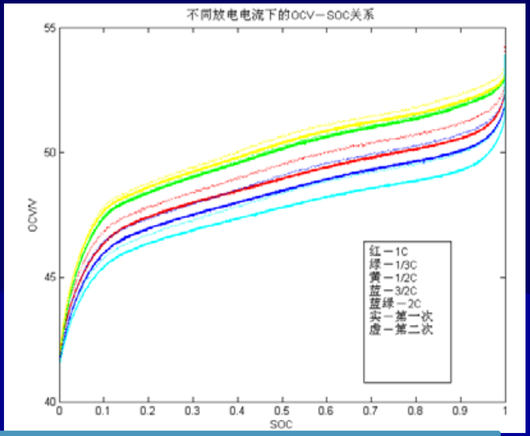
solutions

- compensated by different models
- Current Sensor Compensation
- Improve the accuracy of input by using the voltage difference
- Regularity Maintenance（balance charge）

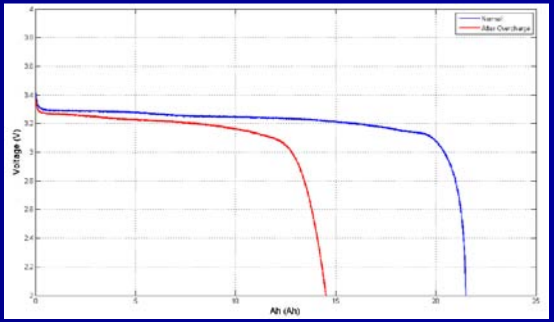
reason

- The flat voltage of Li-ion battery, especially LiFePO4
- Highly nonlinear （ Ion diffusion is about $10^{-9} cm^2/s$)
- Accuracy of the sensors (especially the current sensors and cell voltage detect)
- Self discharge

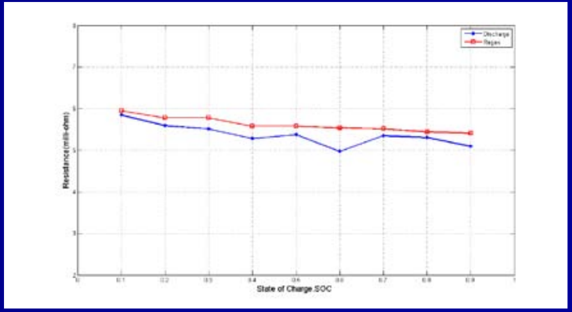




Lithium manganese



LiFePO4 battery



Resistance of LiFePO4 battery

$SOC = SOC_0 + \frac{\eta \int I dt}{C}$

SOC

- SOC estimation base on Practical Engineering test（ Large amounts of data MAP）

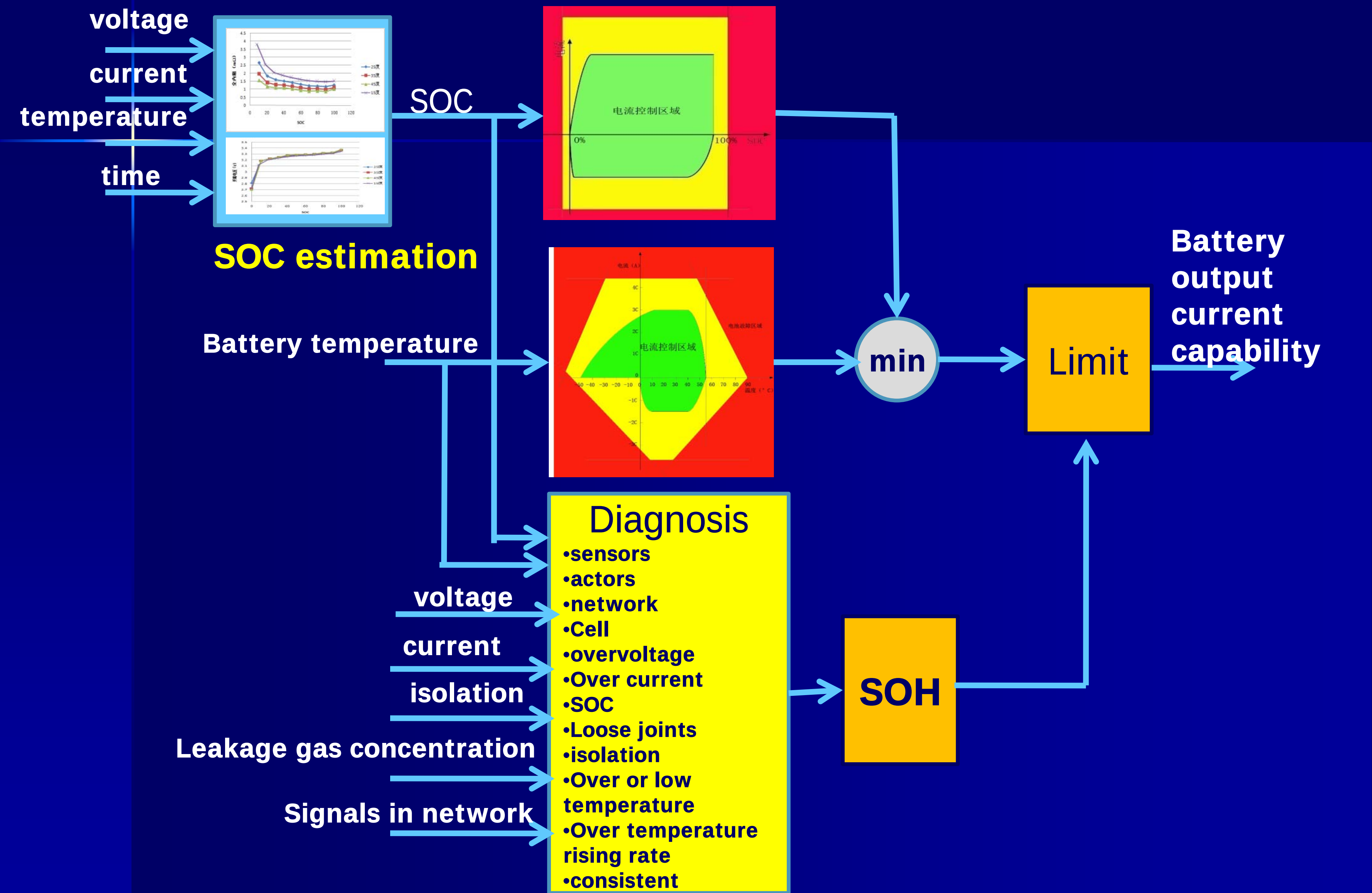
Based on Ah integration

$$SOC = SOC_0 + \frac{\eta \int I dt}{C}$$

Compensated by the following methods

- Degradation of capacity（map）
- Self discharge（map）
- Coulomb efficiency
- Full charge
- OCV（map）

SOF Algorithm



Battery balance technology in Tsinghua

Battery balance technology

✓**Balance charge** (for plug-in, EV using in battery maintain)

✓**Dynamic balance**

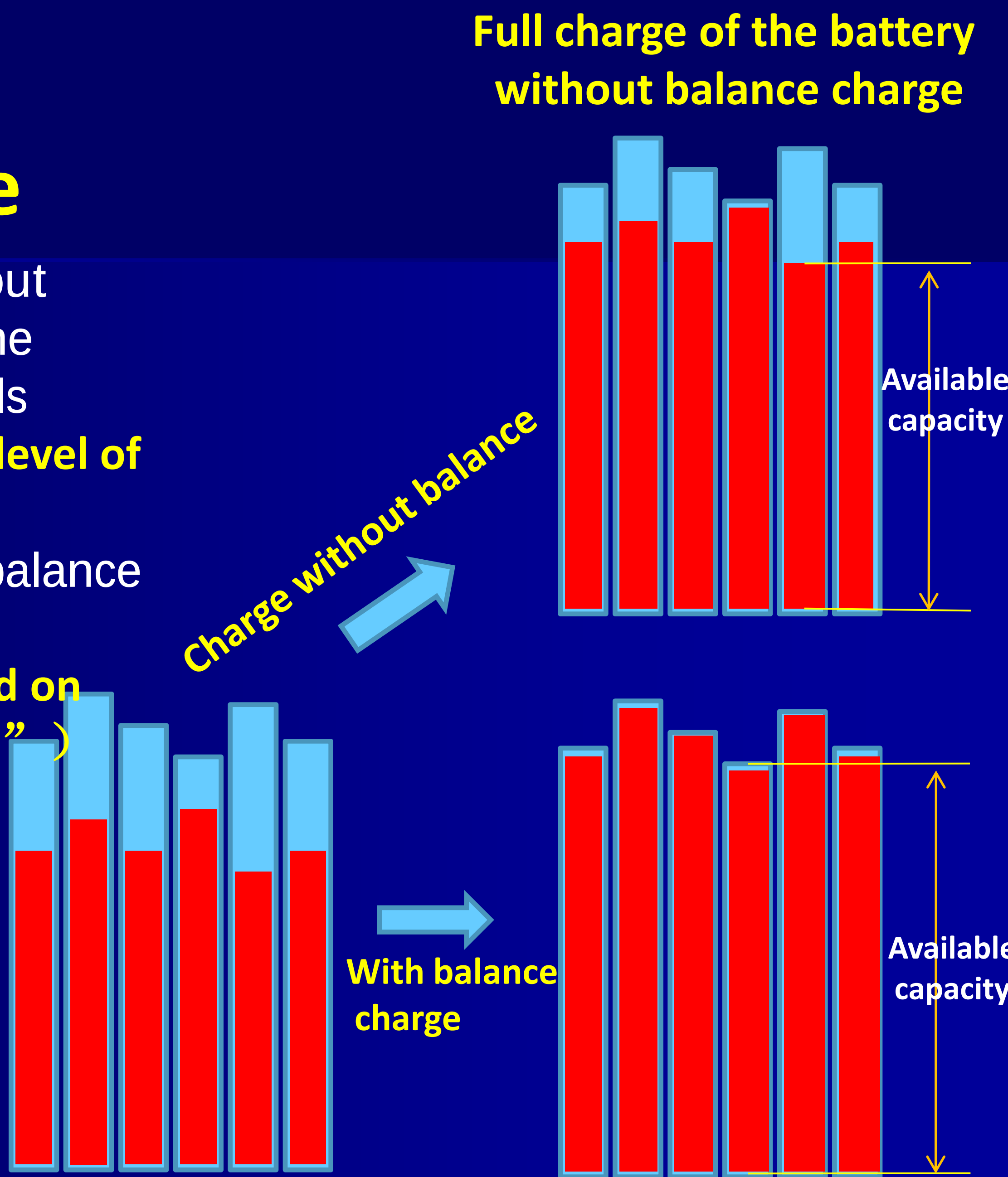
Worm gear + stepping motor to choose the cell to be balanced, and to achieve balanced of the battery by directly control of two-way DCDC through a micro-controller

Balance charge

■ the available capacity without balance charge depends on the smallest capacity of single cells **(depend on “the lowest water level of the glass cup”)**

■the available capacity with balance charge depends the minimum capacity of single cells **(depend on the “Minimum volume of glass”)**

After maintaining by a balanced charge, it do not need to balance in each charge, because the inconsistency is to deterioration over a period of time.

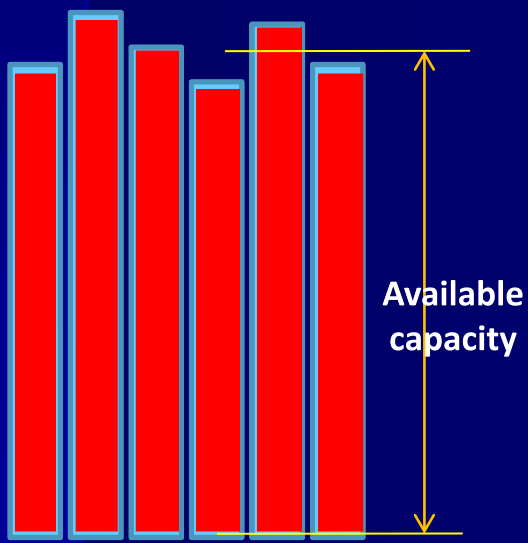


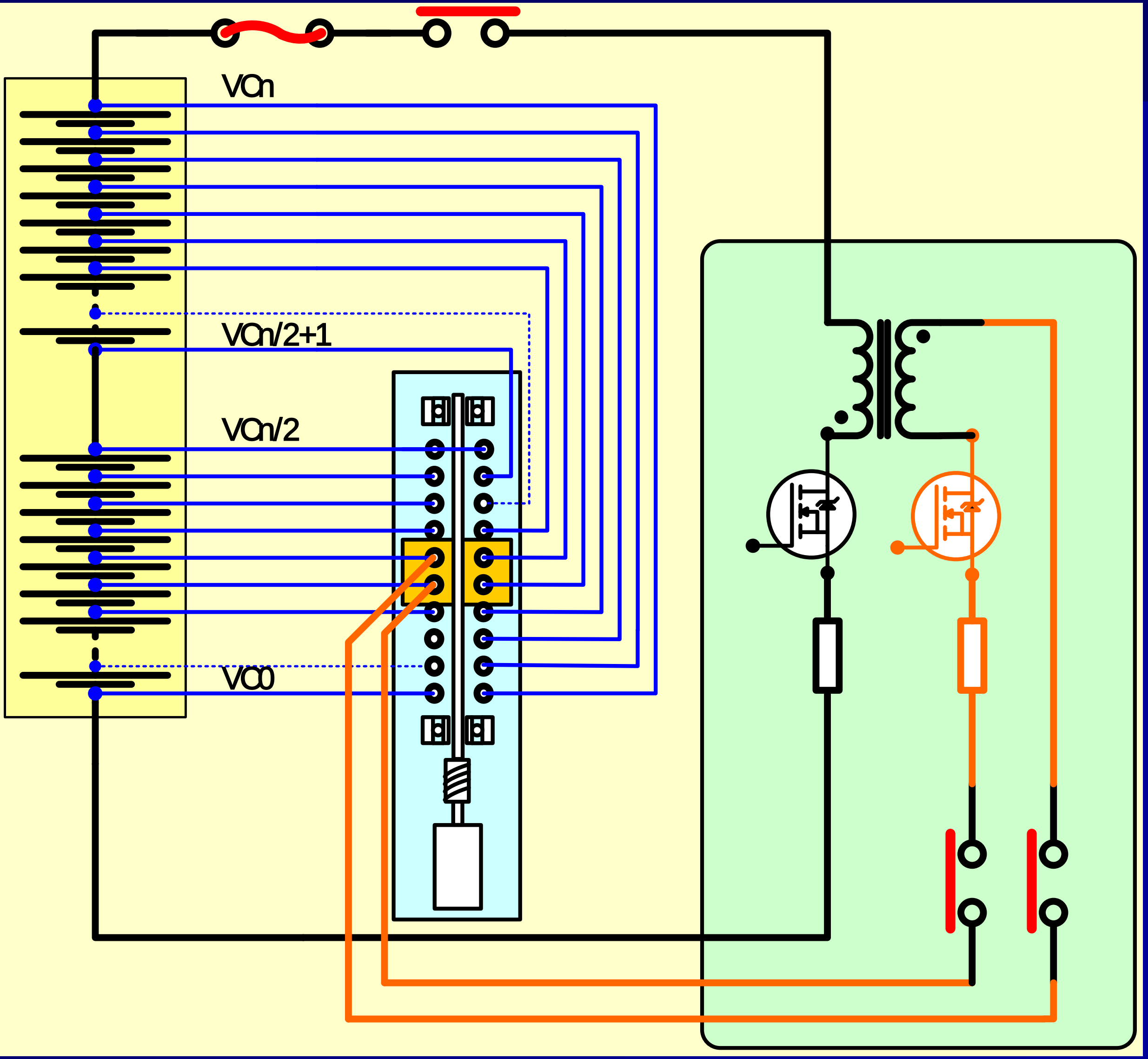
Active balanced subsystem

Patent:
200910092039.x
200910092039.x

Balance current is large

Balance depend on each cell SOC





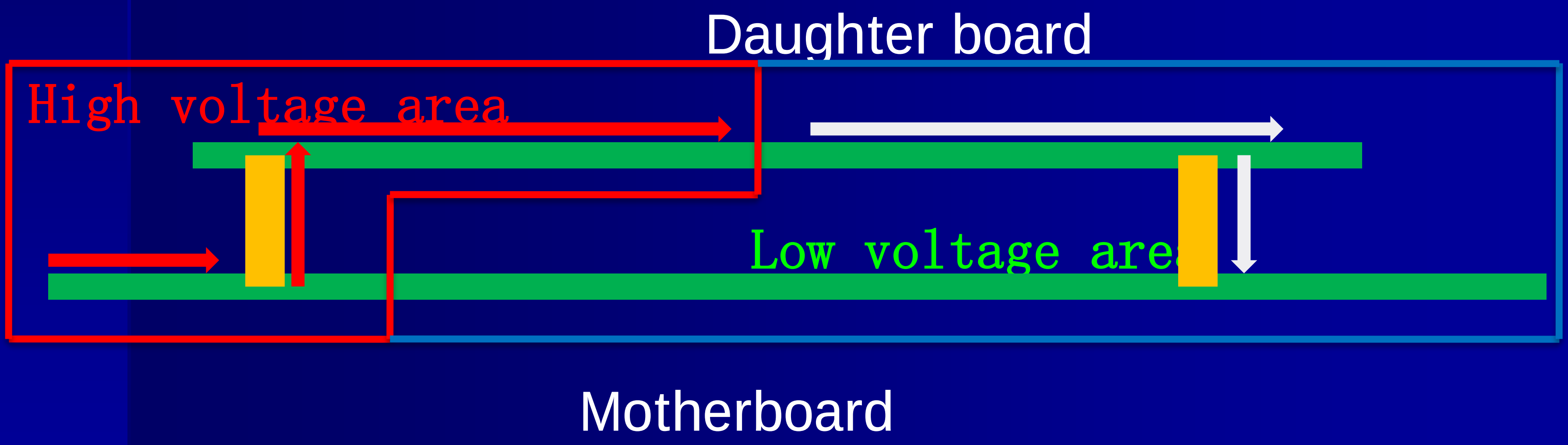
Charge control in BMS

Fast Charge or Slow charge depend on
The customer and the conditions of the battery

BMS Charge control processing：
1.Communication with charger
2. According to the battery charger power class,
the battery condition as well as the driver request
To determine the charge method
3. Pre-charge
4.Normal charge（CCCV）

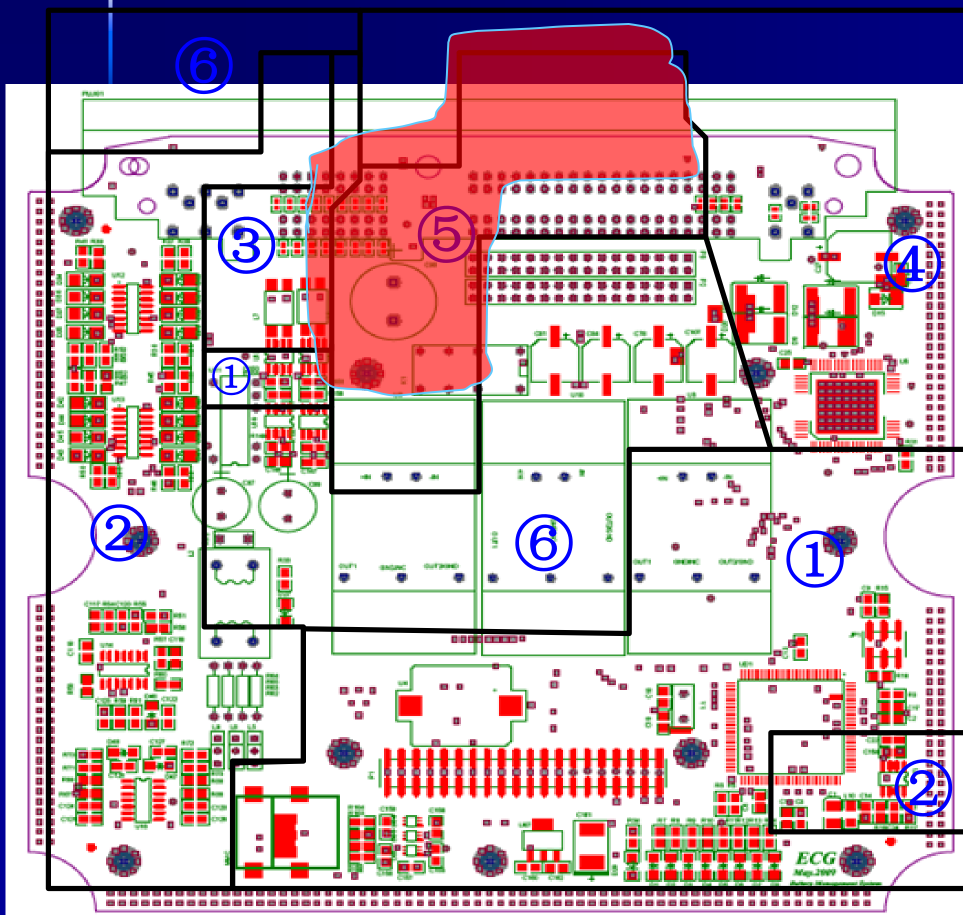
- EMC design of the hardware

layout

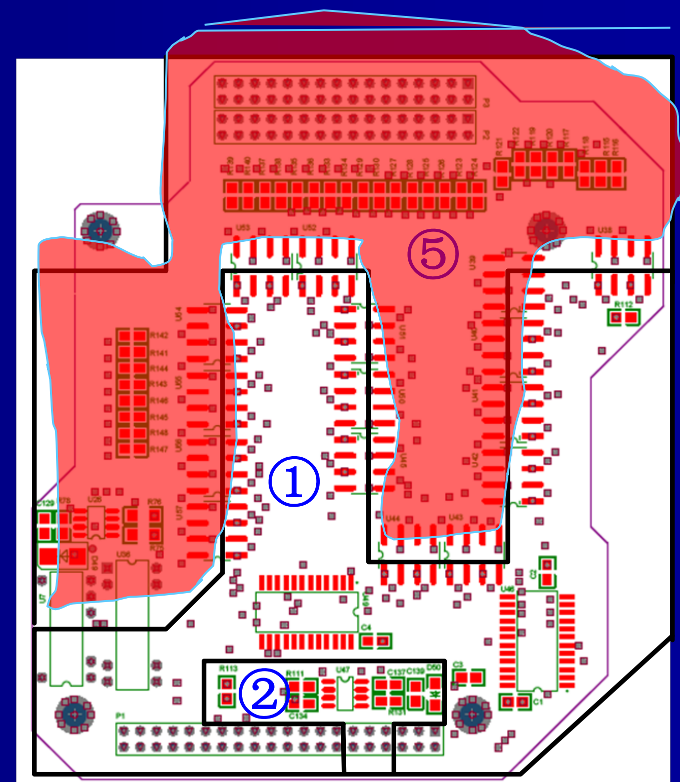


- layout

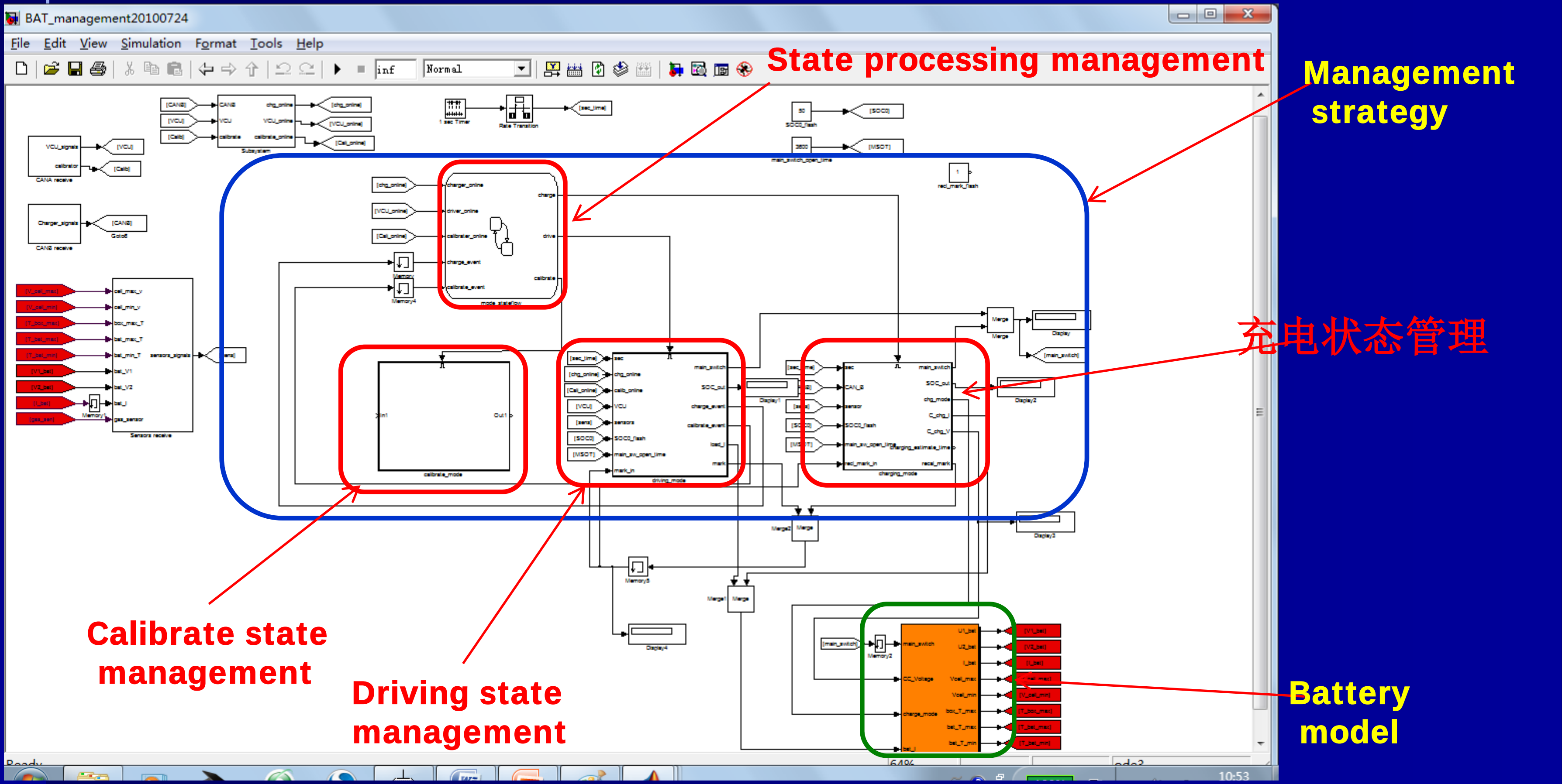
Motherboard



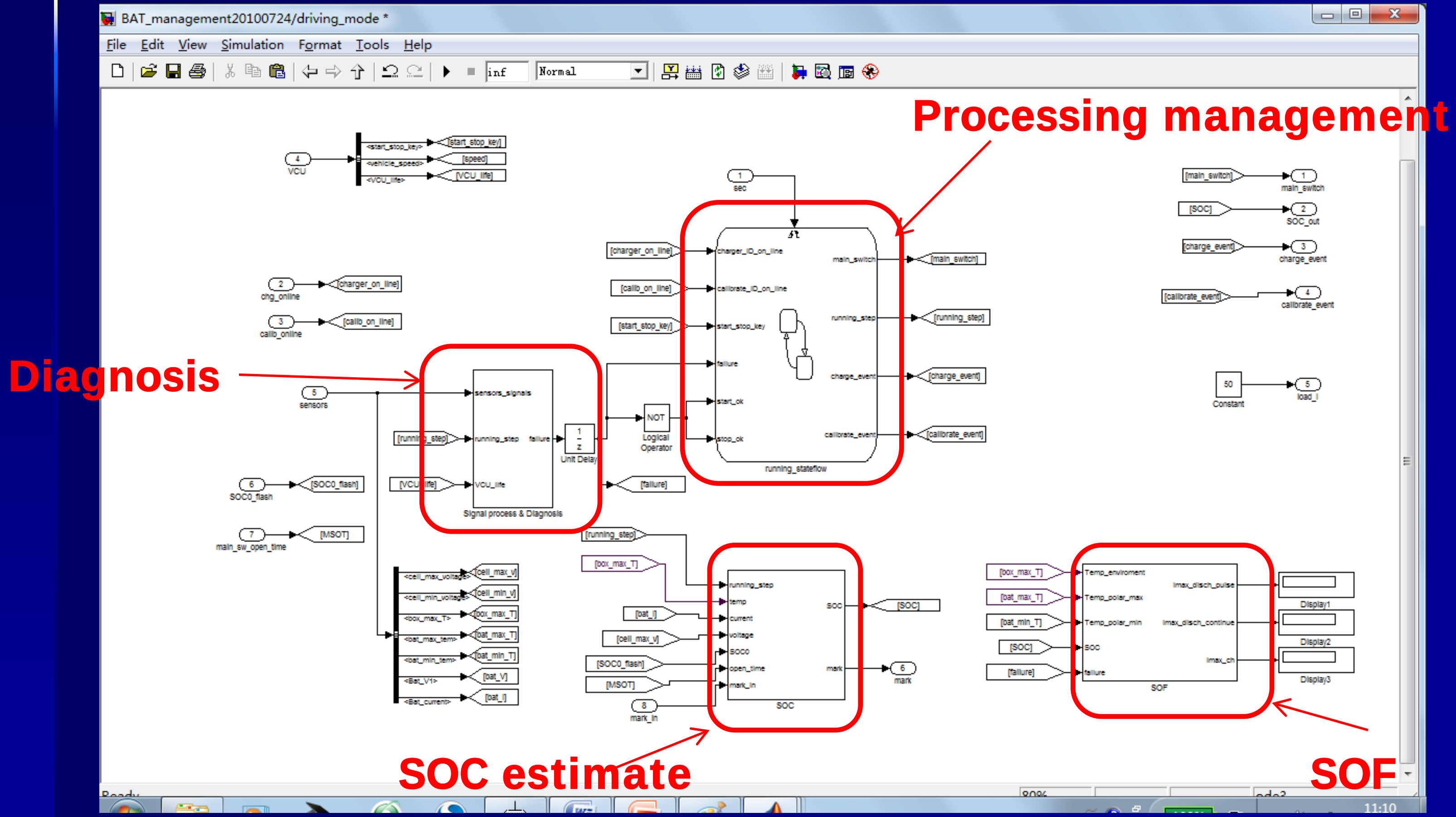
Daughter board



Battery management system modeling and automatic code generation



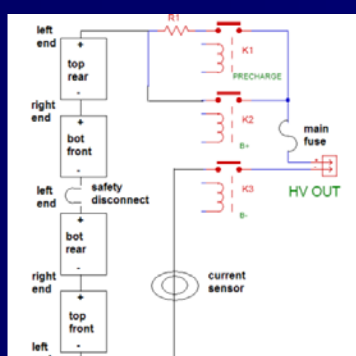
Battery management system modeling and automatic code generation (continuous)

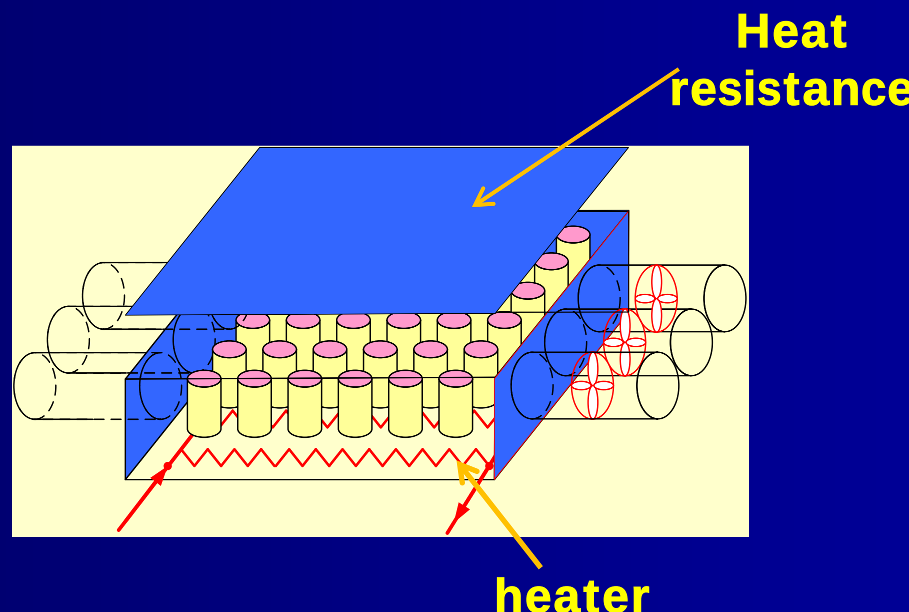


Battery packing technology

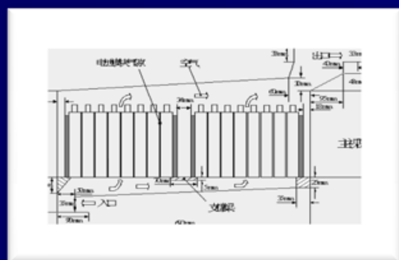
✓Analysis of the consistency of the battery pack (Variation change, for matching and maintenance of battery)

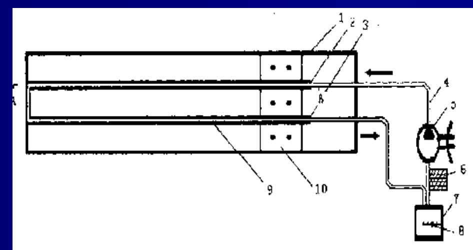
✓Research on the Series-parallel and the thermal management of the battery

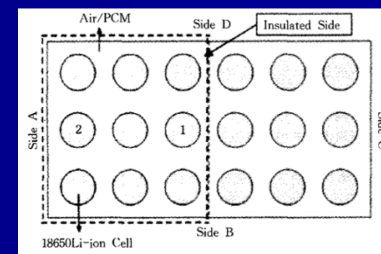




■cooling： air cooling, liquid cooling, Phase Change cooling







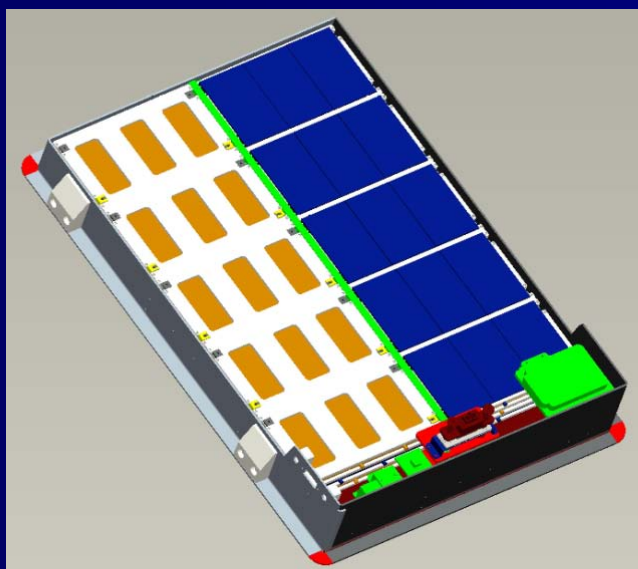
评价指标	空气	液体	相变材料（PCM）
系统复杂程度	一般	较复杂	简单
散热效率	一般	高	较高
功耗	较低	高	零
成本	一般	高	较高

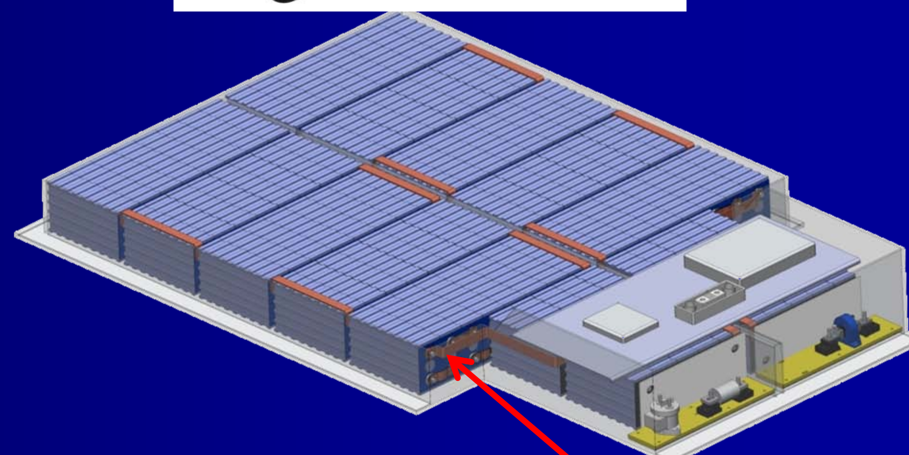
■Air-in selection： √parallel, series

■Air selection： compartment air，outside air, conditioner air

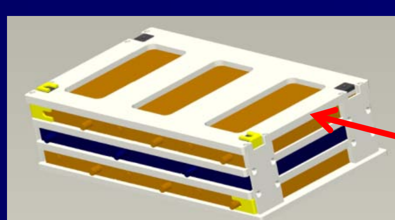
The battery for battery quick-change

- High integration, each battery has unique ID and interchangeable
- Battery information data record for each module, following the battery to the end of life.



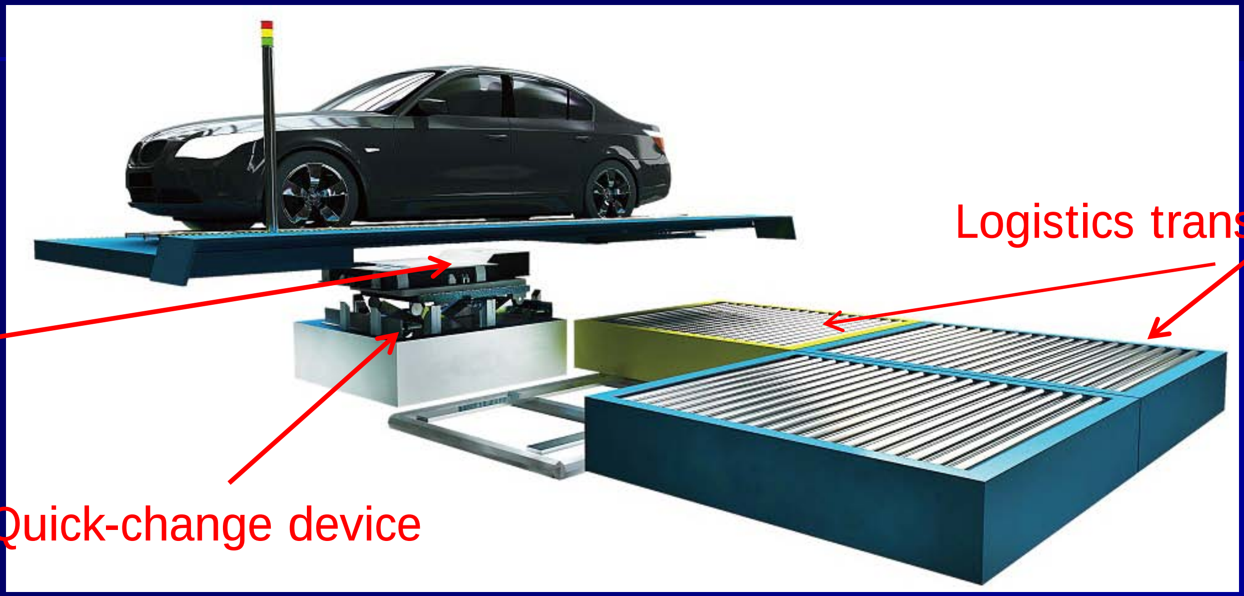


Cell monitor and balance



module

The battery quick-change system operating in Tsinghua University



•Universal： Standardized by the battery box, quick-change device intelligence, to achieve interoperability of various type of vehicle.
•Fast： Replace the battery less than three minutes , rapidly than conventional vehicle to fuel
•Automatic replace： Battery replacement to complete the entire process automatically, without human aid.
•Reliability： Designed had considered fully the frequent replacement and the vehicles vibration in bad conditions.

Thank you for your attention!