$LiFePO_4$ battery performances testing and analyzing for BMS

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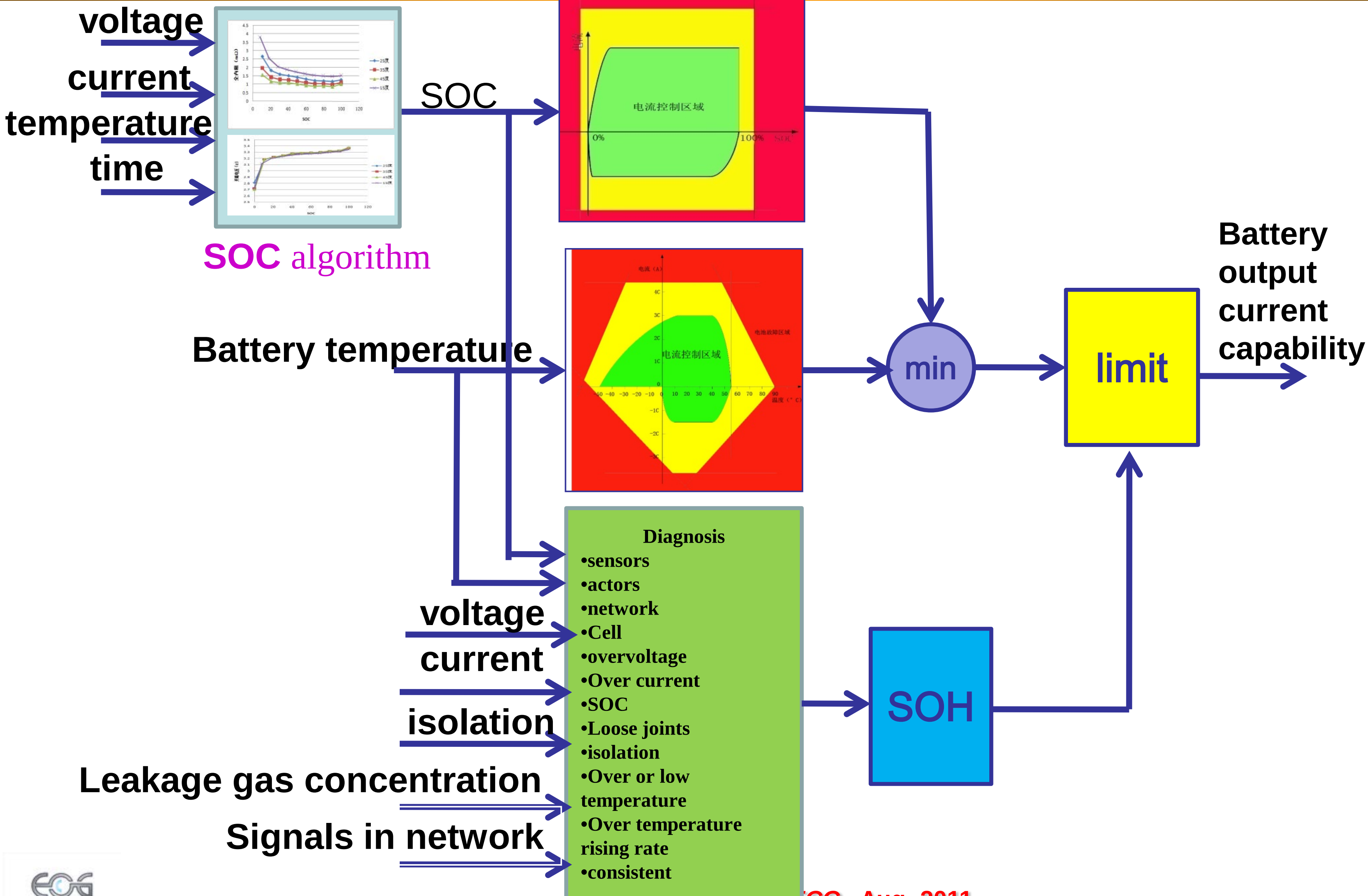
BMS requirements



SOC algorithm

Discharge method, Amp-hour integration estimation, Open circuit voltage estimation, resistance method, load-voltage method, Neural Networks, Kalman estimation et. al

The method based on Ah integration estimation and compensated other methods is more comment in practical engineering :

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

SOC_0 ：

- **OCV compensate（testing the relationship of OCV with SOC, temperature and standing time）**
- **load-voltage compensate（ testing the relationship of operating voltage with SOC, temperature and current， Internal resistance testing ）**

C ：bearing on current, temperature and aging

- **Testing the capacity under different T and C-rate**
- **Testing the capacity degradation under different conditions**

η ： Coulombic efficiency related with T, C-rate

- **Testing theηunder different T, C-rate**
- **Testing the self-discharge under different T**

SOF calculation

SOF (State of Function)

（1）consider the low-voltage and high-voltage limit，Avoiding local over-discharge or over-charge

$$V_{\min} = V_{ocv} - I_{\max} \times r$$

$$I_{\max} = (V_{ocv} - V_{\min}) / r$$

- **testing the OCV with SOC**

(2) Consider the high operating temperature

$$I^2 \times r \times t = C_{bat} \times m_{bat} \times (T_{\max} - T_{bat})$$

Understanding Battery thermal parameters C_{bat}

- **testing the temperature rising under different temperature and different C-rate**

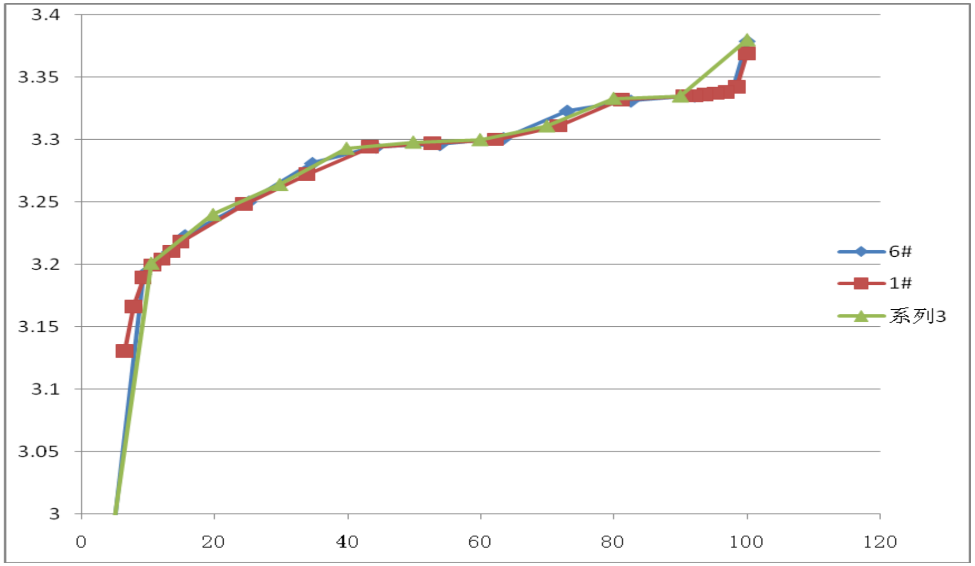
Contents

Test method

- **Modified HPPC test** (Reference: Battery Test Manual For Plug-In Hybrid Electric Vehicles, 2008,The Idaho National Laboratory is a U.S. Department of Energy National Laboratory ,Operated by Battelle Energy Alliance)

In order to get accurate OCV, the test points must be increased, especial in SOC<40% , 60% <SOC <80% and SOC>90%

In temperature <0℃, charge pulse is canceled



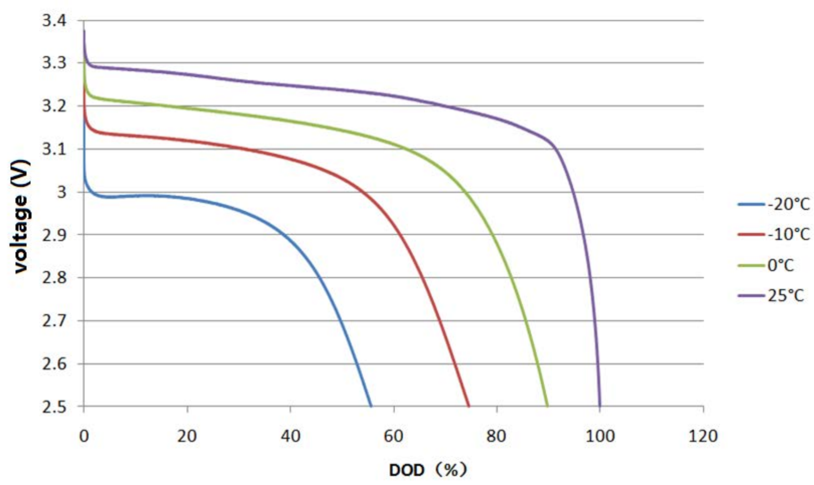
- **Modified Peak-power test** (reference: ELECTRIC VEHICLE BATTERY TEST PROCEDURES, 1996,by USABC)

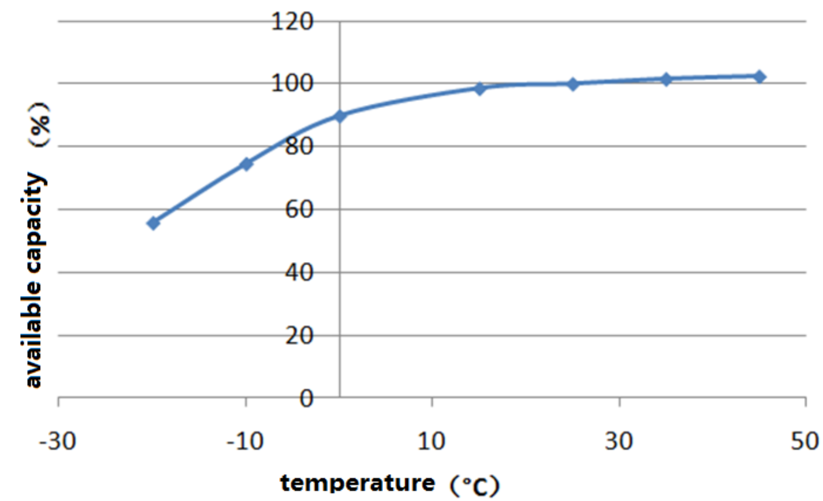
Test results and analyzing

- **The relationship between battery capacity and temperature**

The lower temperature the less available capacity, but when the temperature is more than 15 °C, the available capacity is essentially the same. At 15°C the available capacity is 98% of that at 25°C. The capacity remain 90% at 0°C. The capacity remain 74.5% (cut off voltage 2.5V) and 87% (cut off voltage 2.0V) at -10°C . The capacity remain 56% (cut off voltage 2.5V) and 72% (cut off voltage 2.0V) at -20°C .

Analyzing：The lower temperature, the higher resistance of the battery (reference to the slide in resistance analyzing) , so that in the same cut off voltage, the lower available capacity.

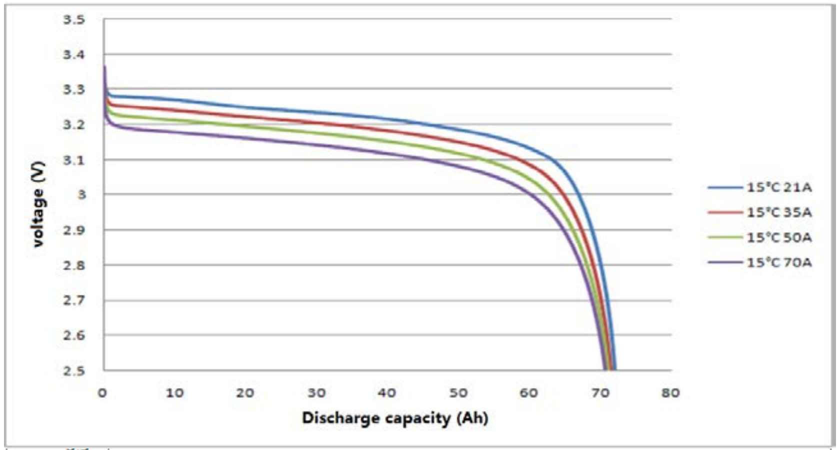


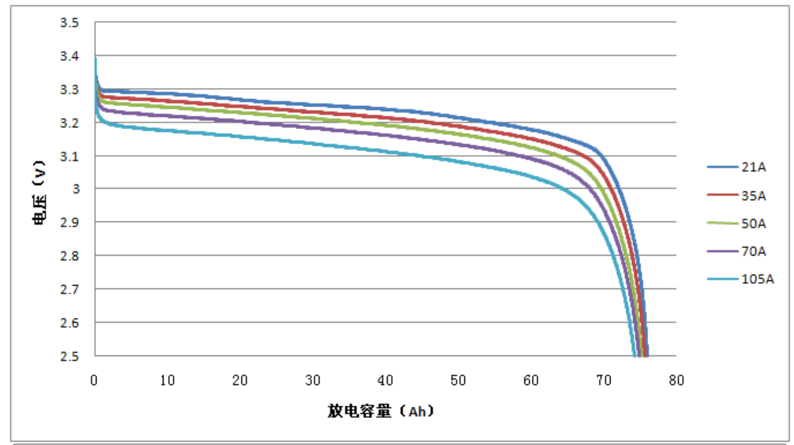


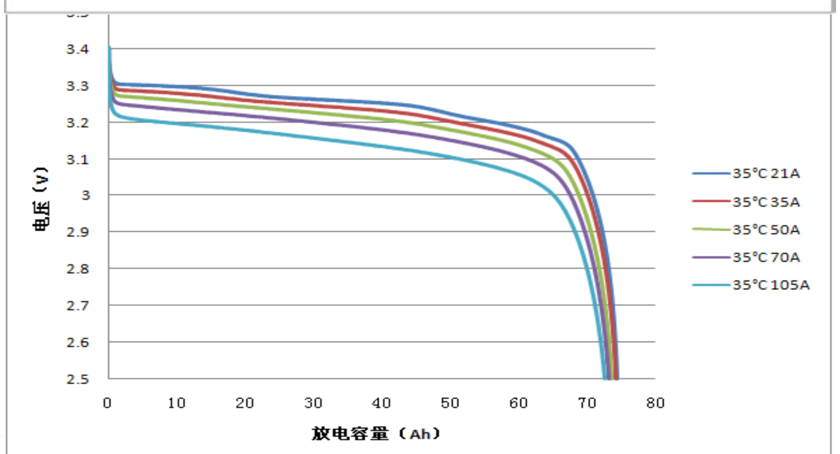
Test results and analyzing

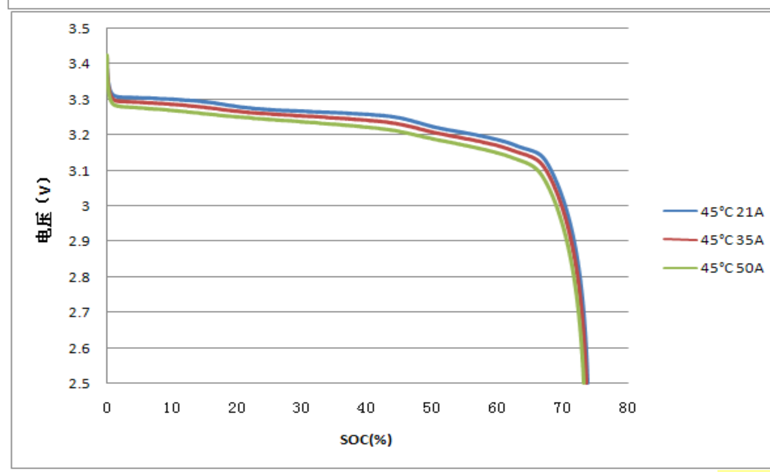
- **The relationship between battery capacity and C-rate**

when operating temperature is great than 15℃, the available capacity of energy LiFePO4 battery is less depend on the C-rate（0.3~1.5C）





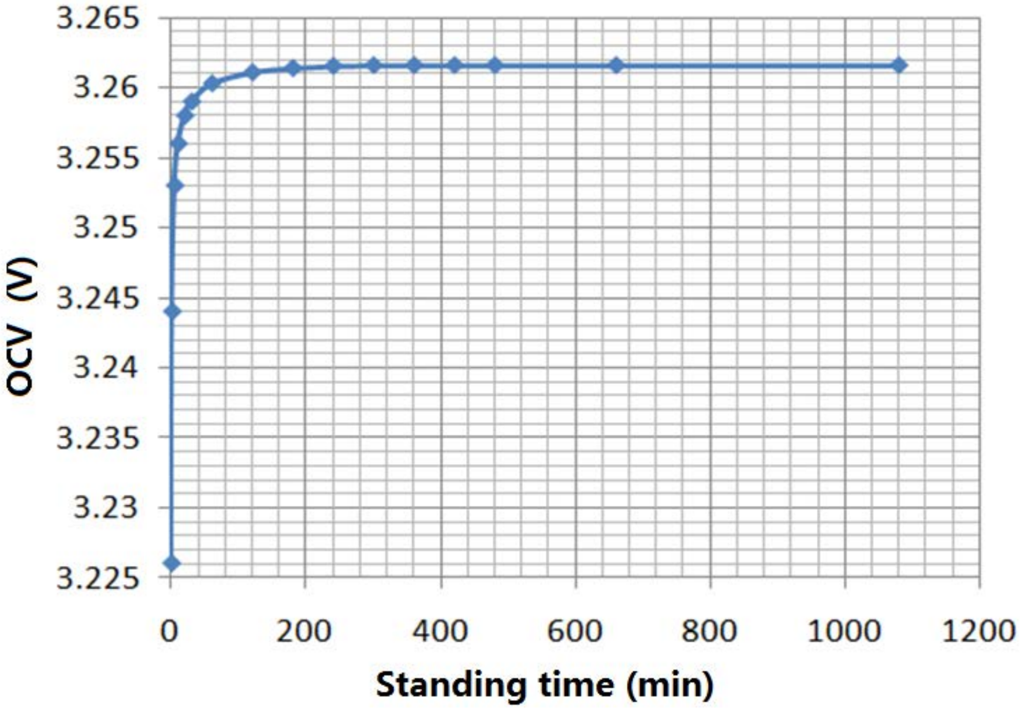




Test results and analyzing

- **The stable OCV**

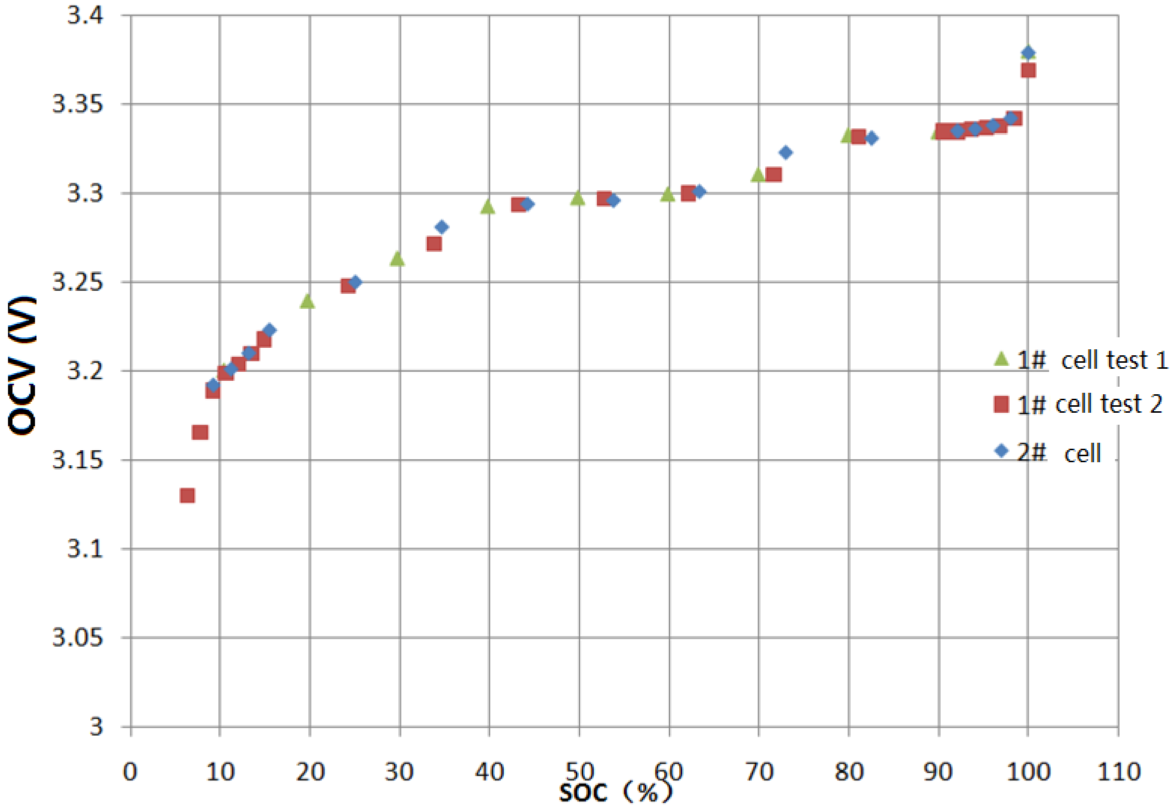
The OCV (about 30% SOC, 25 ℃) increases rapidly in the beginning of standing, then increases slowly, after 4h the OCV is keeping stable. The OCV difference is less than 1mV at 3h with the stable. So the OCV at 3h is considered stable in testing.



Test results and analyzing

- **The relationship between SOC and OCV**

the stable OCV is almost the same of different cells if the previous charge/discharge is the same

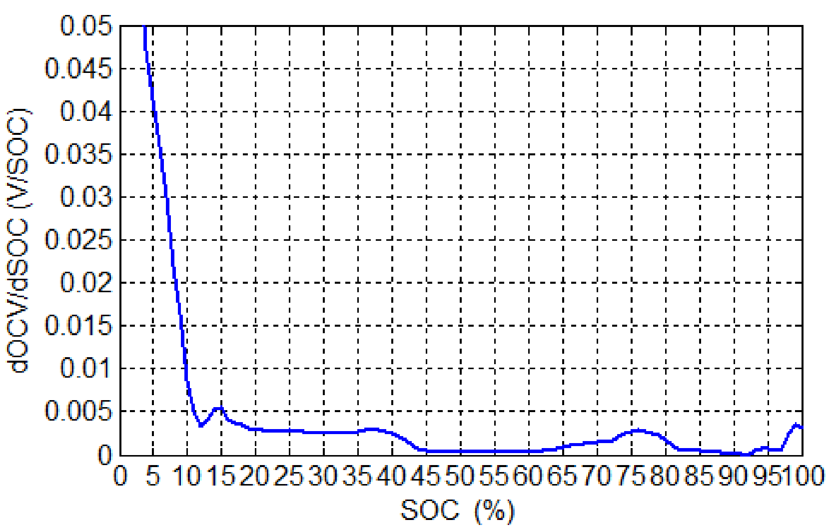


Compare of the OCV of different cells

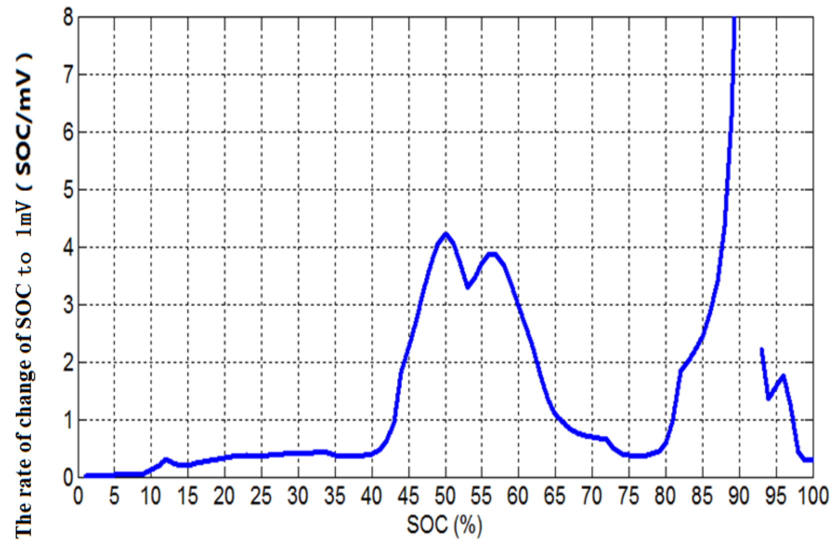
Test results and analyzing

- **The relationship between SOC and OCV**

LiFePO4 battery has two two-phase plat form (SOC40~70% and 80%~96%). At the platform, the rate of change of SOC is larger than 4% of 1mV. Because voltage acquisition accuracy of the current BMS is about 5mV, it is not possible to estimate the SOC by OCV at the platform. But when SOC<40% or 70% <SOC <80%, the rate of change of SOC is less than 0.5% of 1mV, so between these SOC range, the SOC estimation by OCV is possible.



The rate of change of OCV to 1%SOC

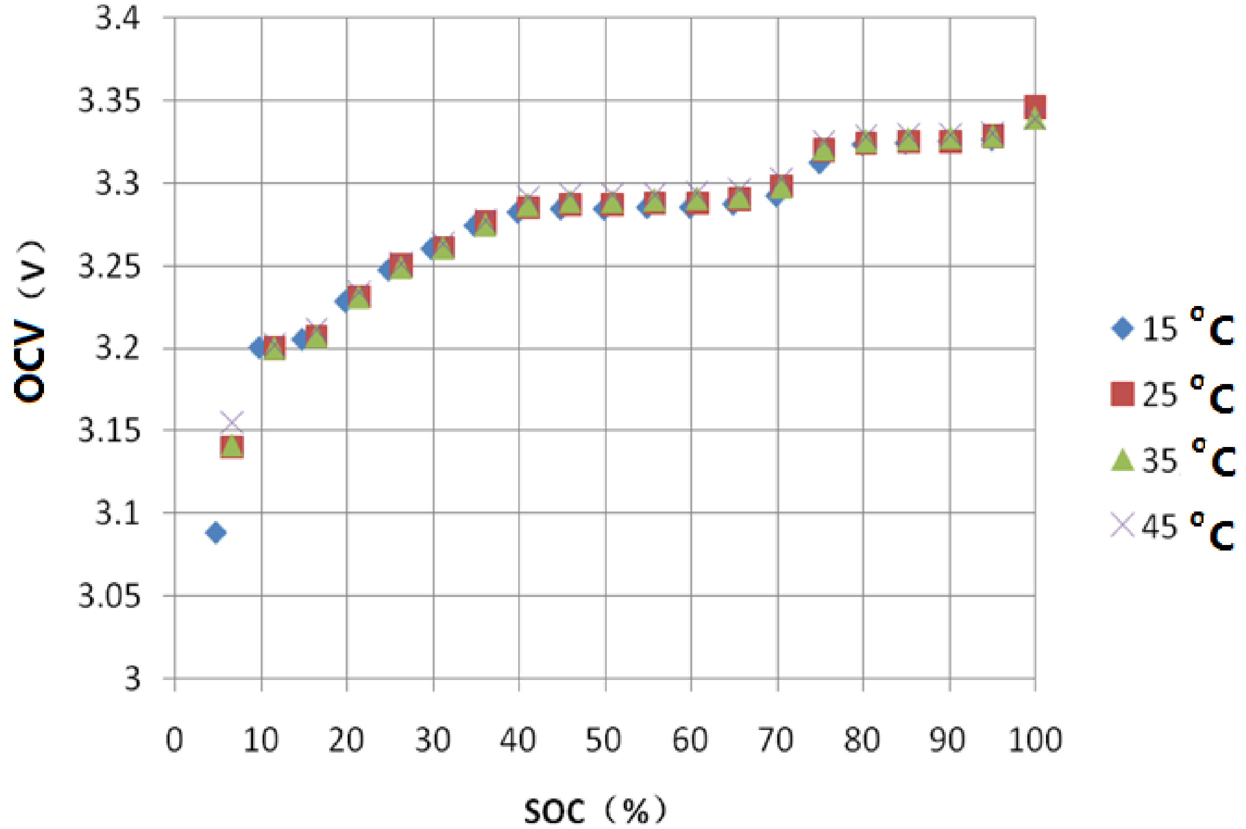


The rate of change of SOC to 1mV

Test results and analyzing

- **The relationship between OCV and temperature**

OCV is less depend on temperature.



Test results and analyzing

- **The relationship between OCV and standing time**

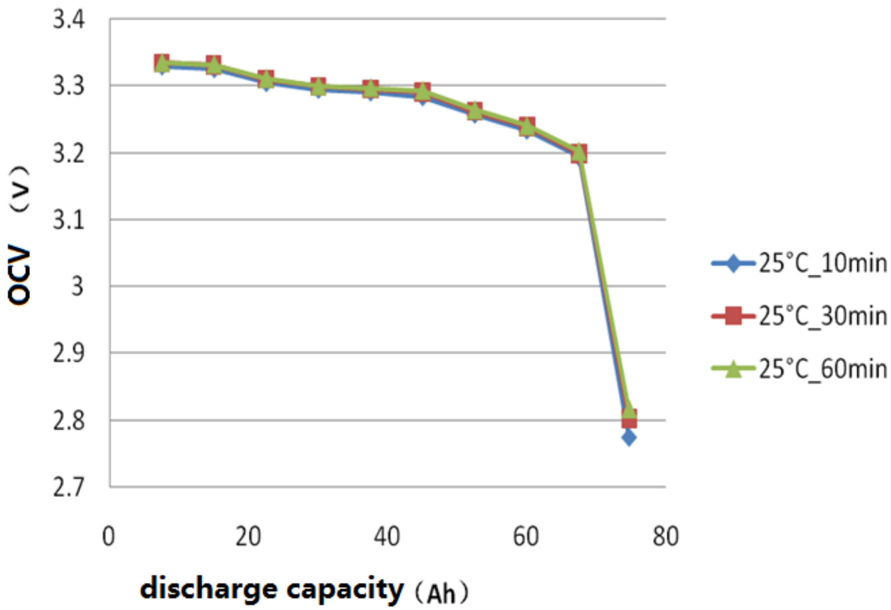
① At temperature great than 25℃, after 10min, the OCV change very slowly. SOC<40%, after 30min, the SOC error can less than 2%.

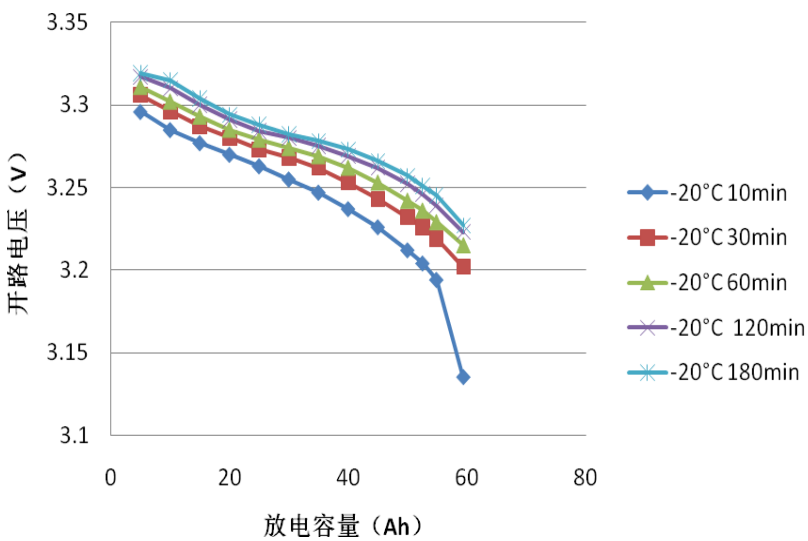
② At 15 ℃, stable time >30min

③ At 0 ℃, stable time >60min

④ At -10 ℃, stable time >120min

⑤ At 15 ℃, stable time >180min





Test results and analyzing

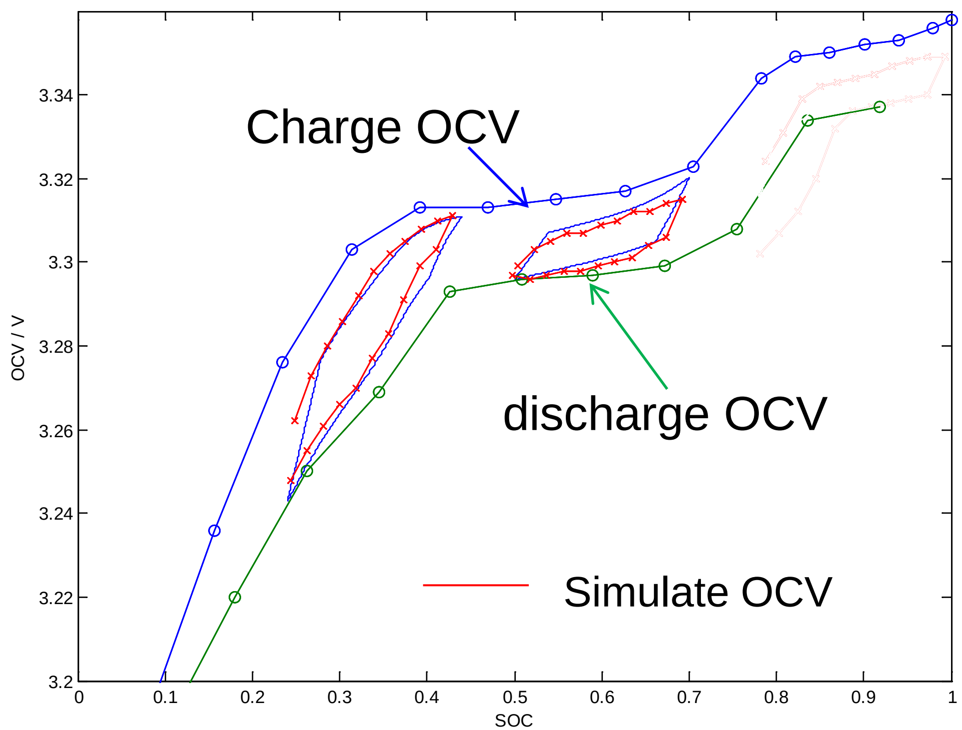
- **OCV hysteresis**

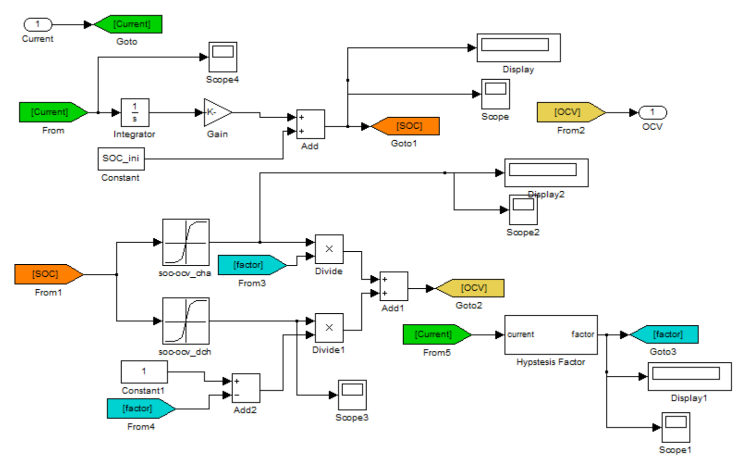
① **OCV is depend on the previous charge/discharge history.**

② **Charge OCV is higher than discharge OCV.**

③ **There are "eye hysteresis OCV" of cycle charge and discharge.**

④ **The SOC estimation of the HEV is more difficult than that of pure battery EV .**





Test results and analyzing

- **Battery resistance**

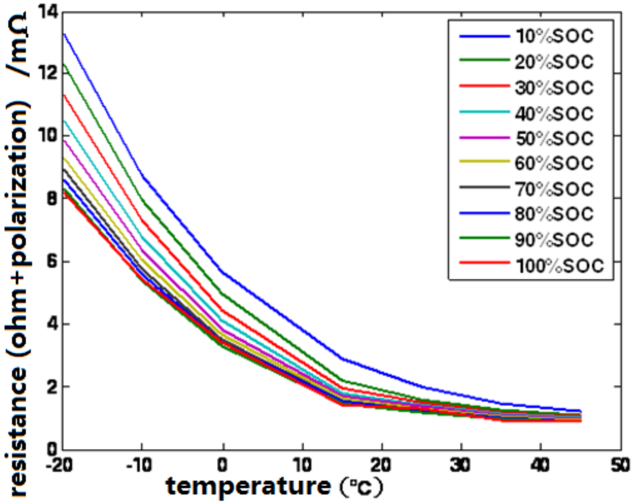
Resistance is strongly influence by temperature. The lower temperature ,the higher resistance. The resistance at -20℃ is 5 times greater than that at 25℃. Resistance and the temperature have cubical function relation (different with SOC).

100%SOC：

$$R = -2.628\times10^{-5}T^3 + 3.595\times10^{-3}T^2 - 1.628\times10^{-1}T + 3.346$$

10%SOC：

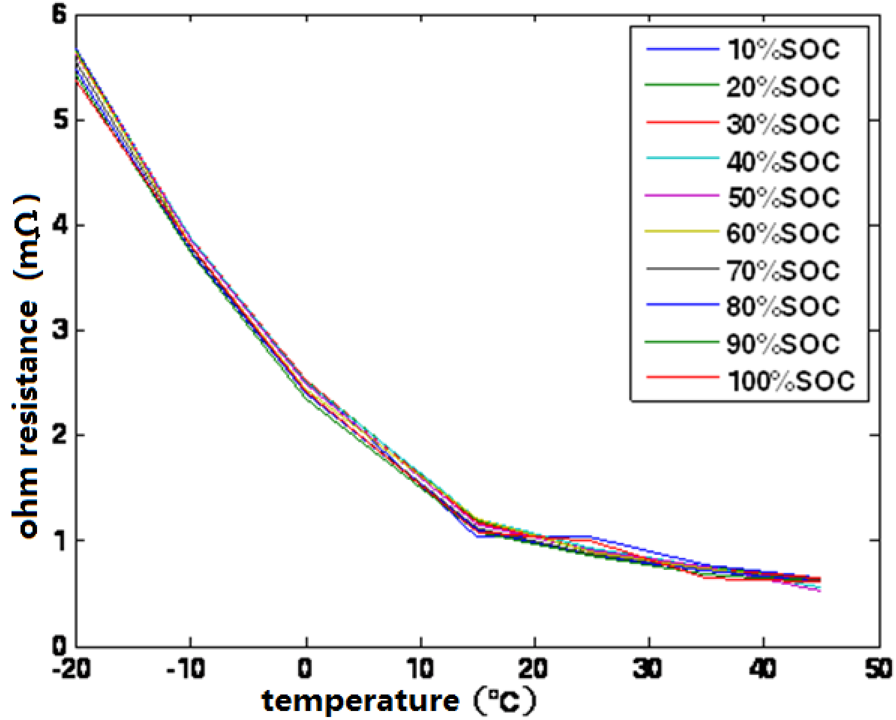
$$R = -4.3\times10^{-5}T^3 + 5.421\times10^{-3}T^2 - 2.559\times10^{-1}T + 5.633$$



Test results and analyzing

Ohm resistance is not concern with SOC, but influenced greatly by temperature. The lower temperature ,the higher ohm resistance because of the low ionic conduction under low temperature. The cubic equation is

$$R_{ohm} = -1.381^{-5} T^3 + 2.161 \times 10^{-3} T^2 - 1.102 \times 10^{-1} T + 2.487$$



Test results and analyzing

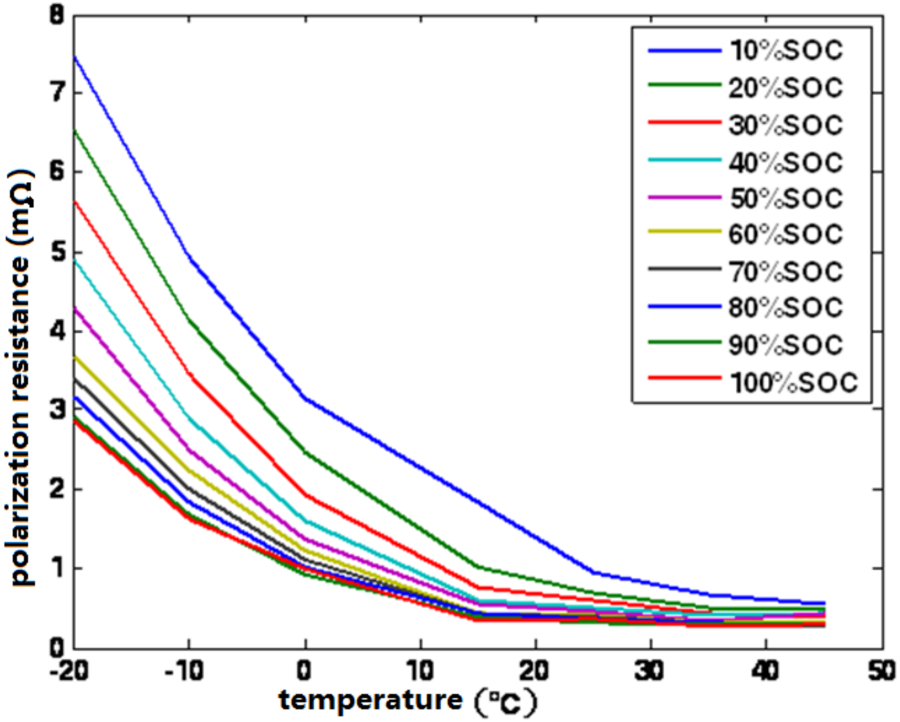
The polarization resistance is strongly concern with SOC, and influenced greatly by temperature. The lower temperature and the low SOC ,the higher the polarization resistance.

100%SOC

$$R_{act} = -1.648\times10^{-5}T^3 + 1.675\times10^{-3}T^2 - 5.619\times10^{-2}T + 0.9184$$

10%SOC

$$R_{act} = -2.216\times10^{-5}T^3 + 2.877\times10^{-3}T^2 - 1.446\times10^{-1}T + 3.218$$

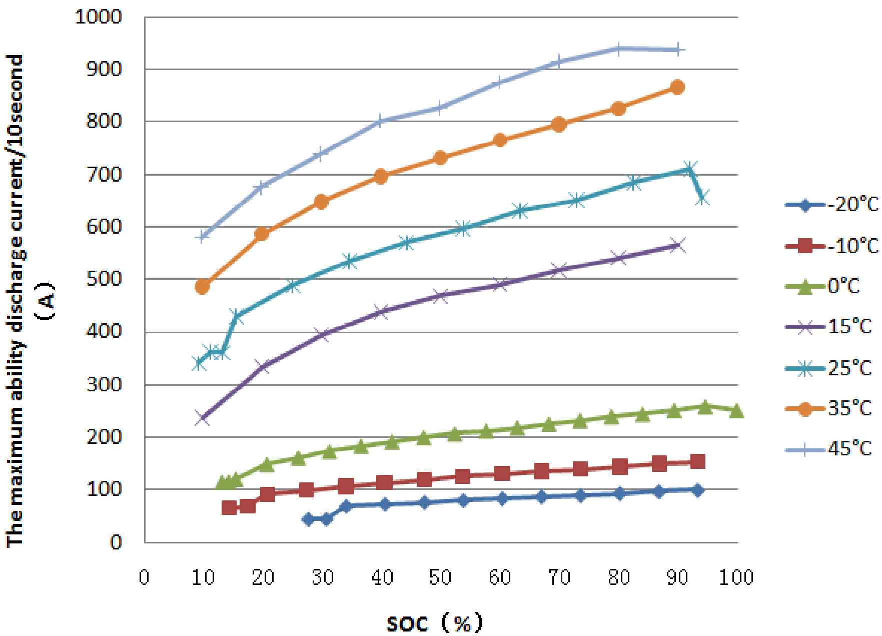


Test results and analyzing

- **The maximum ability discharge current (SOF)**

① **The ability discharge current (the lowest voltage is 2.5V) is strongly concern with temperature. The lower temperature, the lower ability discharge current because of high resistance under low temperature. The ability current at -20℃ is about 20% of that at room temperature.**

② **the SOF also concern with SOC, the lower SOC, the lower SOF because of the high resistance. The ability discharge current at 10%SOC is about 40% of that at 90%SOC.**



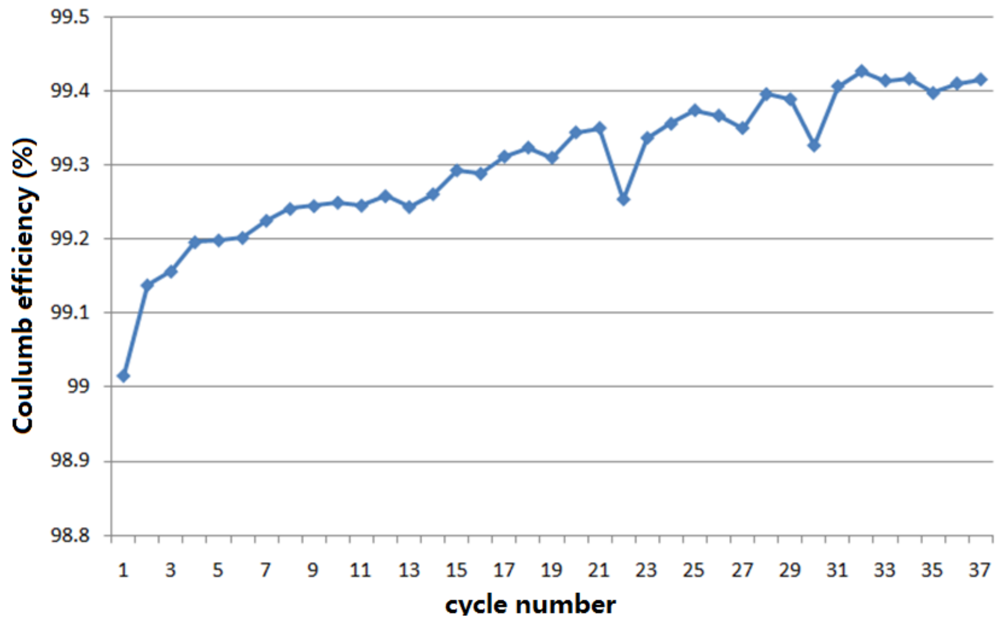
Test results and analyzing

- **Coulomb efficiency**

① Coulomb efficiency of $LiFePO_4$ battery increased with cycle number and stabilize

② Coulomb efficiency has little concern with aging.

③ Coulomb efficiency of $LiFePO_4$ battery is high (>99%) and has little concern with temperature.

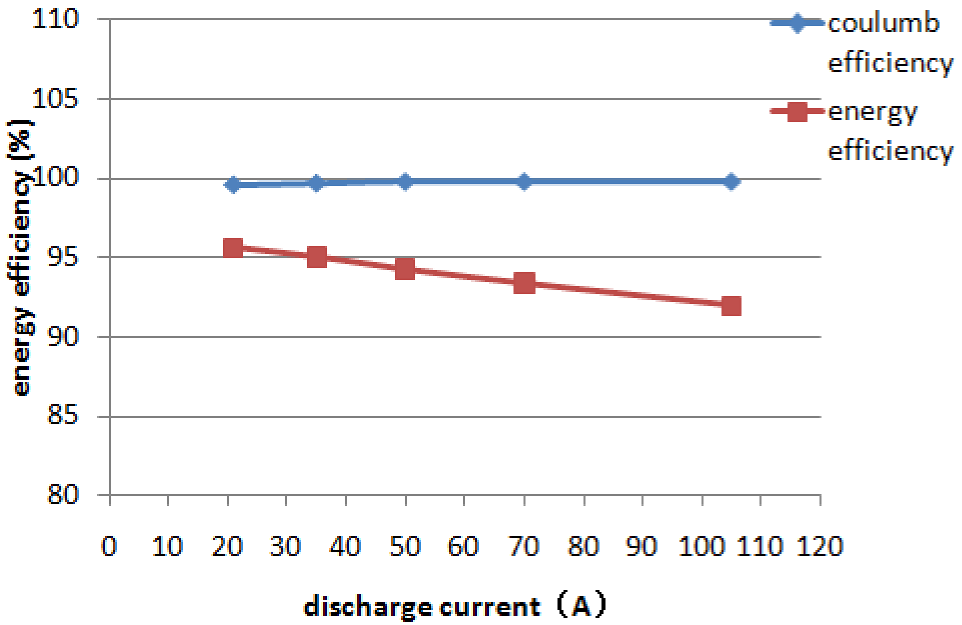


Test results and analyzing

- **Energy efficiency**

The energy efficiency of $LiFePO_4$ battery is high (charge current is 0.3C) and decreased as the current increased. Under 1.5C, the energy efficiency can still reach 92% at 25℃.

Discharge current/A	Coulumb efficiency/%	Energy efficiency/%
21	99.6	95.6
35	99.7	95
50	99.8	94.3
70	99.8	93.4
105	99.8	92



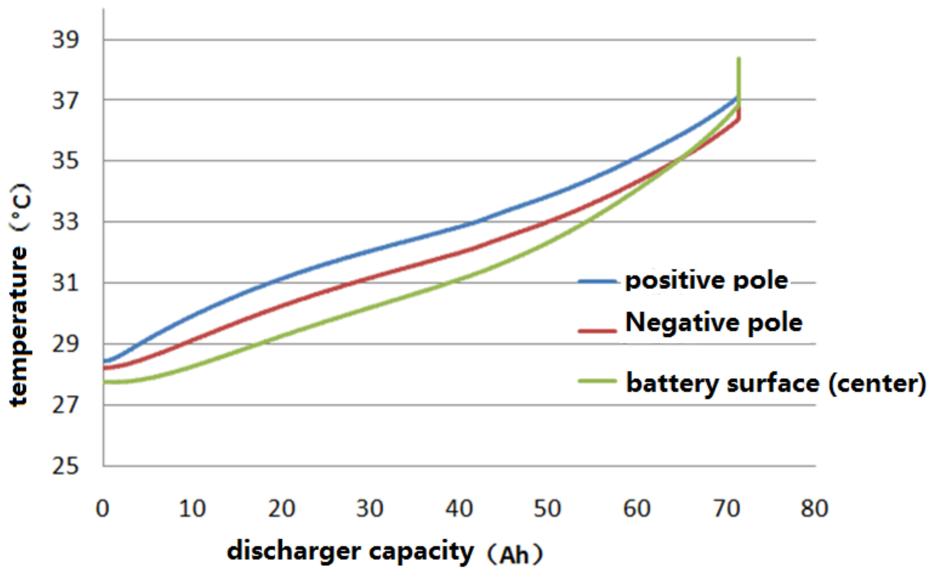
Test results and analyzing

- **heat capacity and adiabatic temperature rise**

① **Heat capacity C_{bat} of $LiFePO_4$ battery is about 955.4 $J \cdot kg^{-1} \cdot K^{-1}$ at 25℃, similar to other kind battery (heat capacity of Ni-MH battery 1028$J \cdot kg^{-1} \cdot K^{-1}$ and $LiCoO_2$ battery is 932.149 $J \cdot kg^{-1} \cdot K^{-1}$)**

② **Because of the high specific heat capacity, the adiabatic temperature rise is about 11℃ under 1C discharge current.**

③ **The temperature in the positive pole is high than other place (the temperature sensor should be located at positive polar)**



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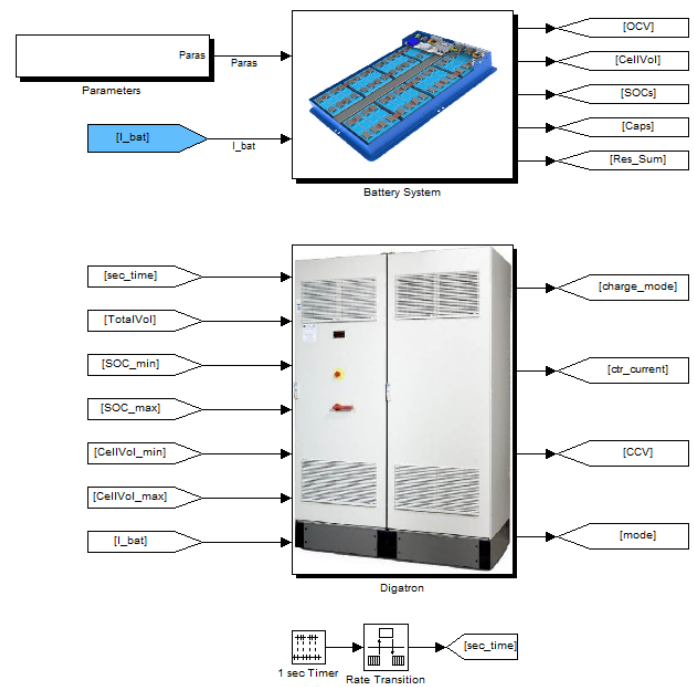
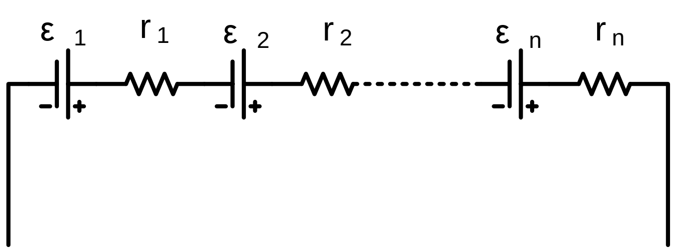
1. BMS requirements
2. Battery based performances testing and analyzing
3. Battery variance testing and analyzing
4. Applications

Simulation of the consistency

- **Using probabilistic methods**
- **The available capacity of the battery pack decreased about 9.31% after only 100 cycles, while the cell capacity decrease only 2%.**

	Minimum cell capacity/Ah	Maximum cell capacity /Ah	SOC difference /%	Available pack capacity /Ah
initial	75.59	76.44	0	75.59
After 100 cycle	73.46	74.62	7.41	68.55

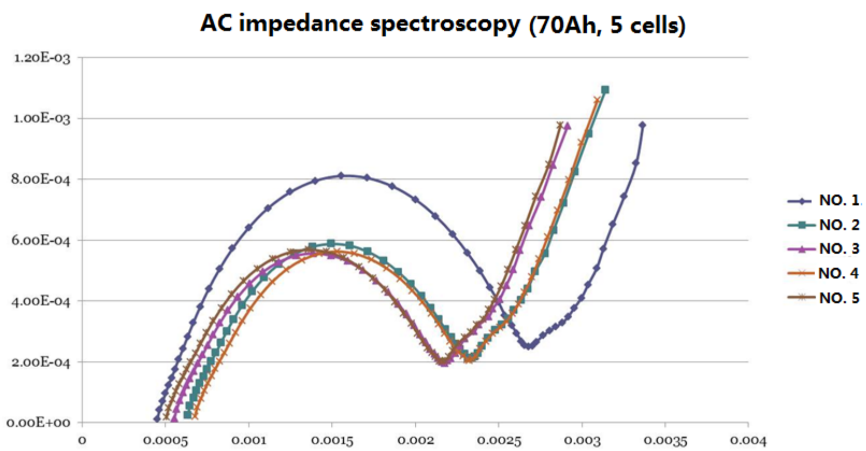


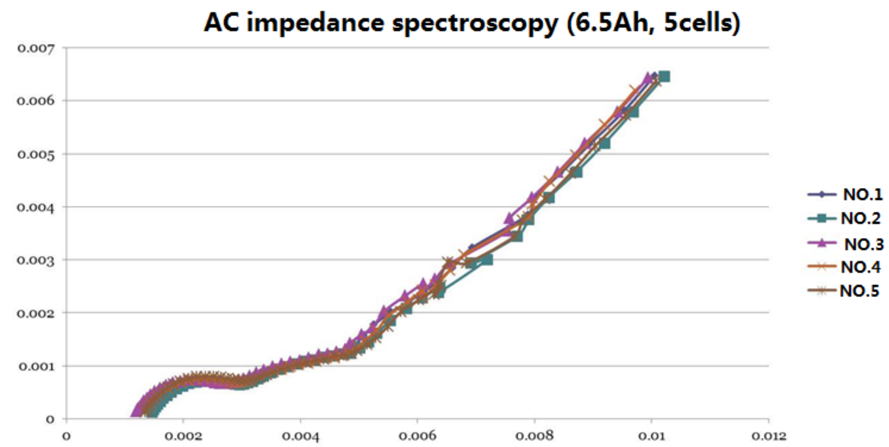


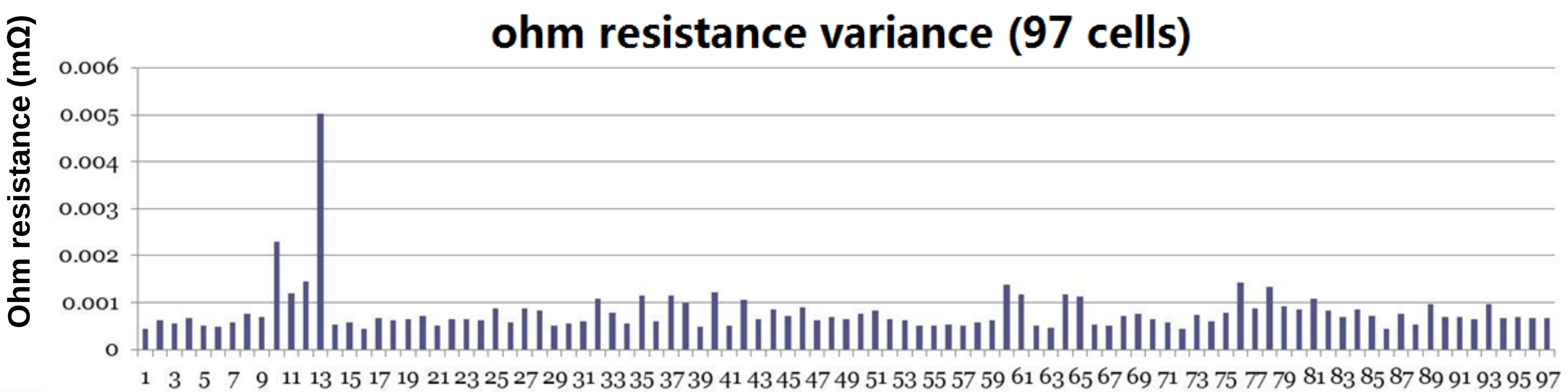
Resistance test

● Resistance variance

The resistance variance of the pack is large



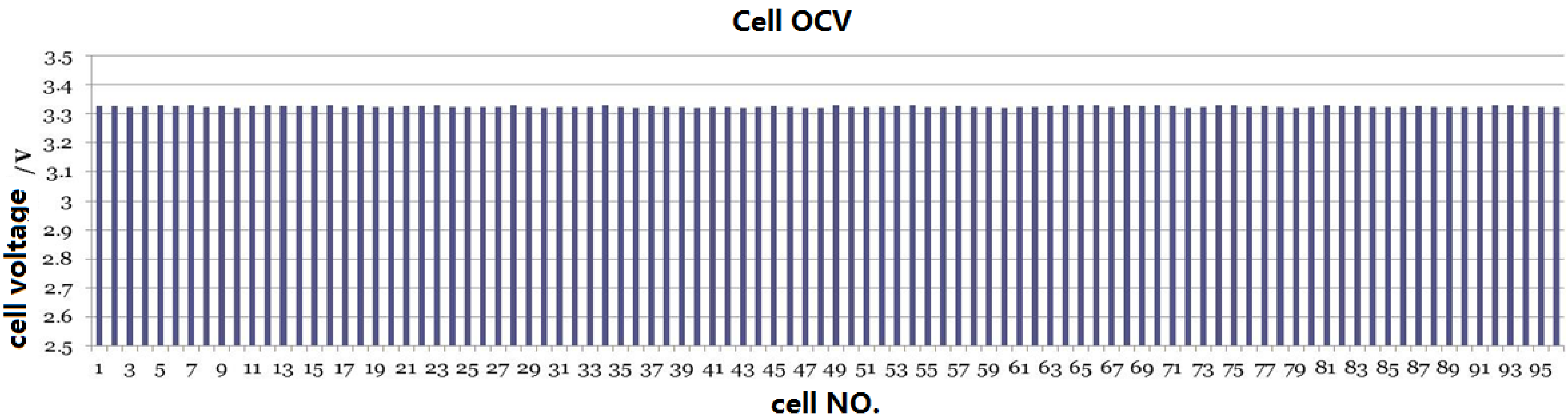


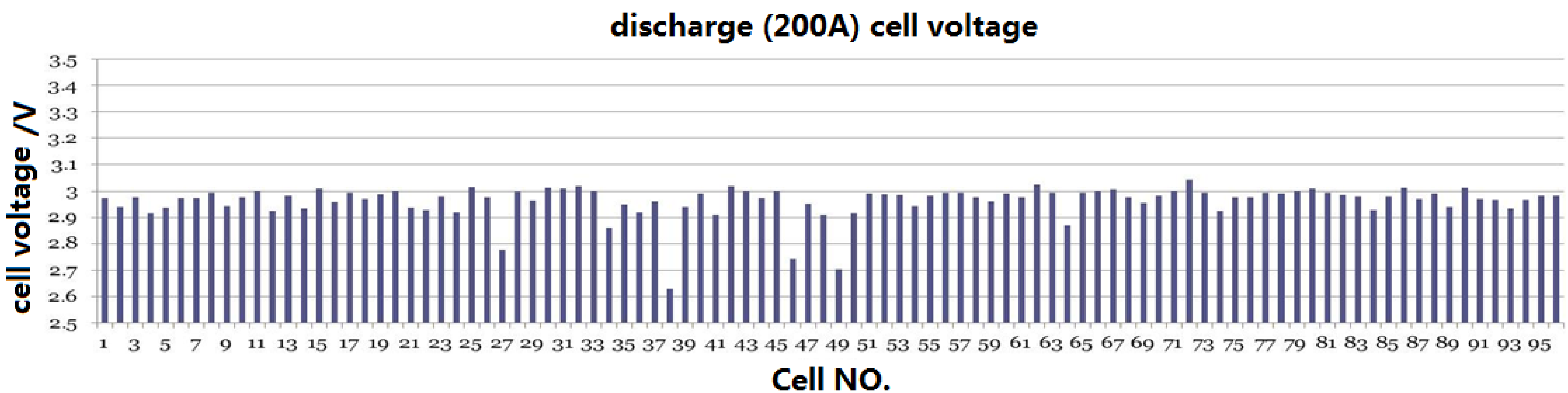


Battery variance

- **Discharging cell voltage variation**

Under large discharge current, the variance of cell voltage is huge

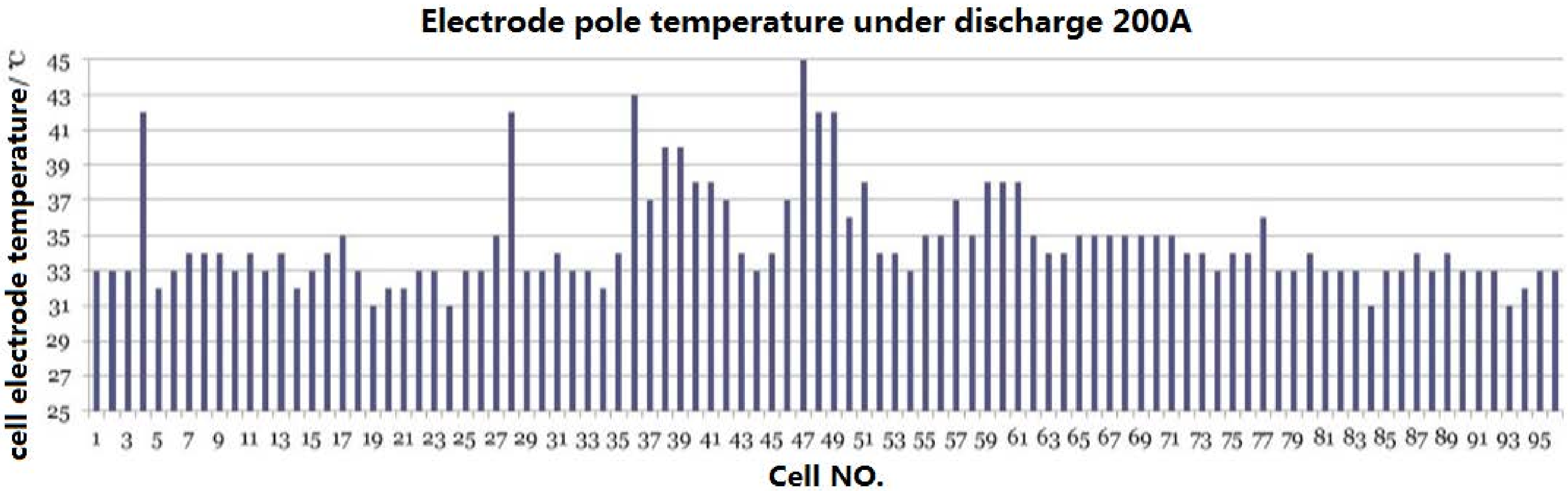




Battery variance

- **Electrode pole temperature variance under discharge current (200A)**

Under high discharge current the pole temperature variance is abnormal large, because the Loose connections.



Battery variance

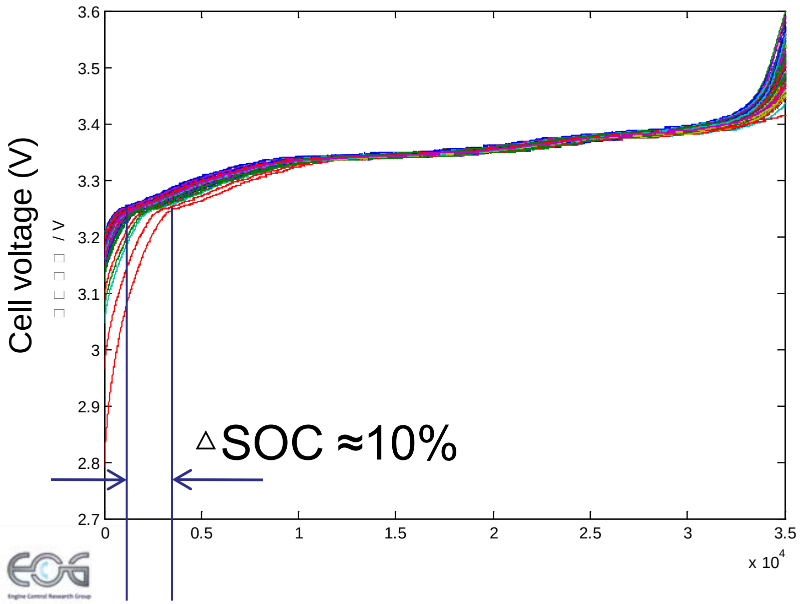
- **Cell voltage variance under charge**

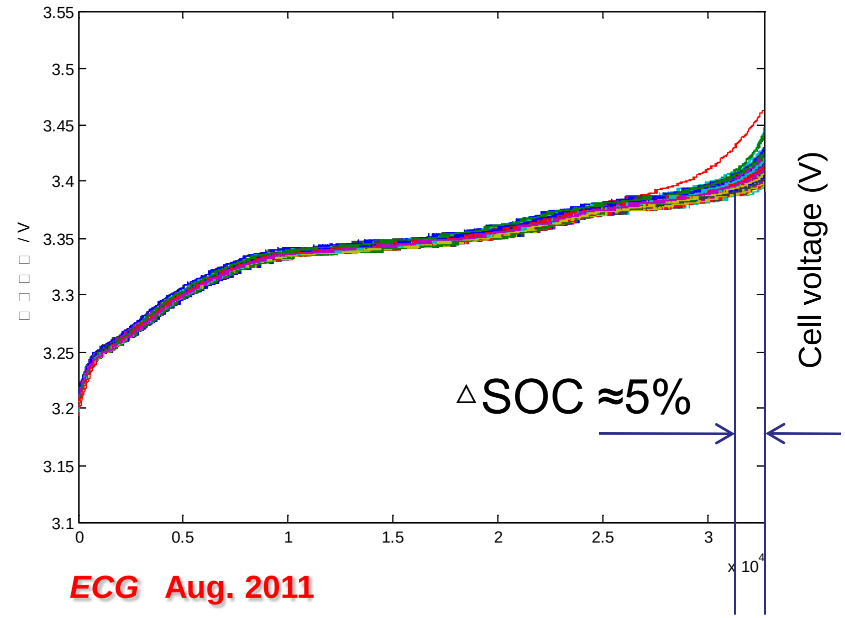
At the beginning and the end of charging, the cell voltage variance is large:

① **The cell initial SOC variance is about 10%, which can be diminished by cell balance**

② **The cell capacity variance is about 5%**

So the available capacity of the battery pack is about 85% of the cell's if there are no cell balance .





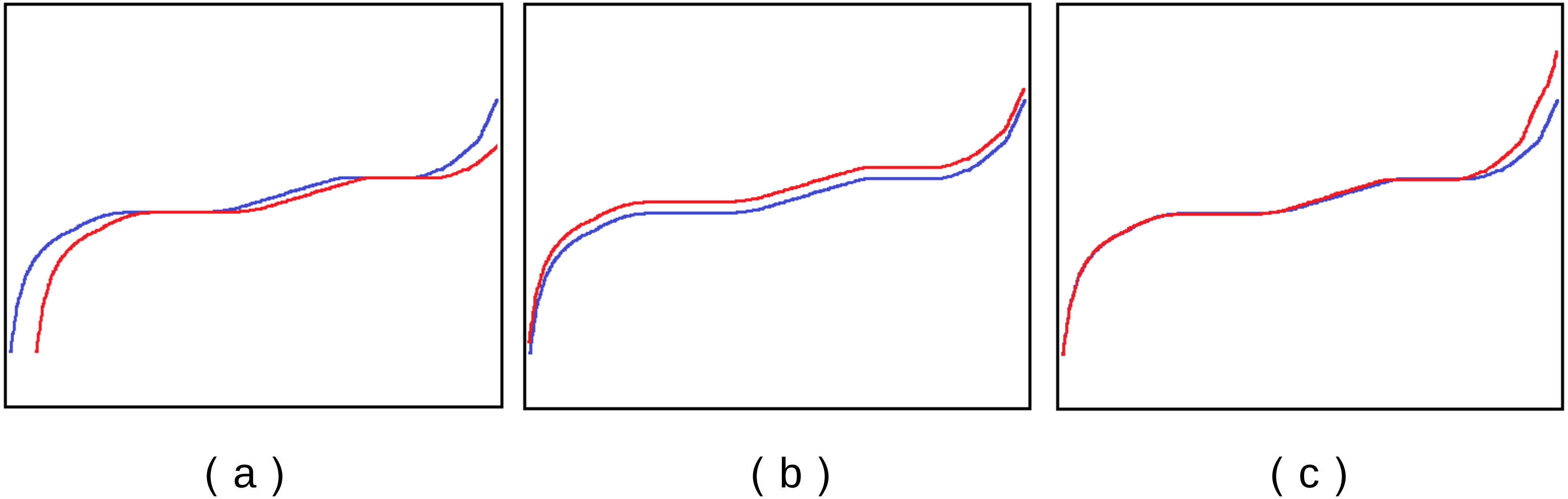
Battery variance

- **The reasons for the cell voltage variance**

（a）different initial cell SOC

（b）different cell resistance

（c）different cell capacity



Contents

Applications

BMS Main Control Unit

BMS cells monitor Unit
(24 cell voltages, 24 temperatures)

EV with quick-change battery pack

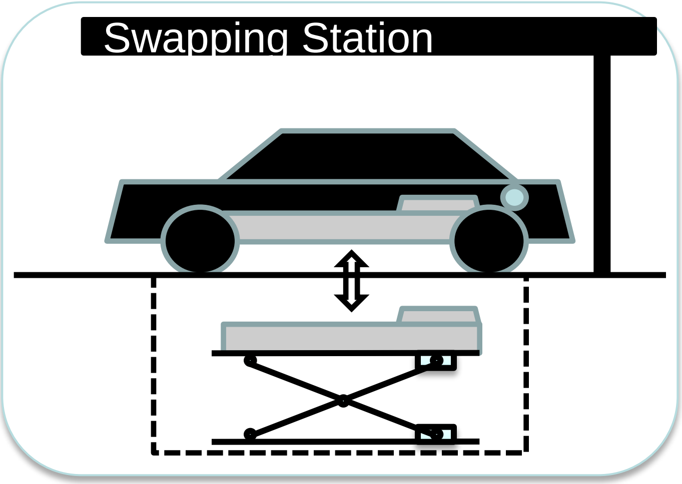
Battery pack for EV

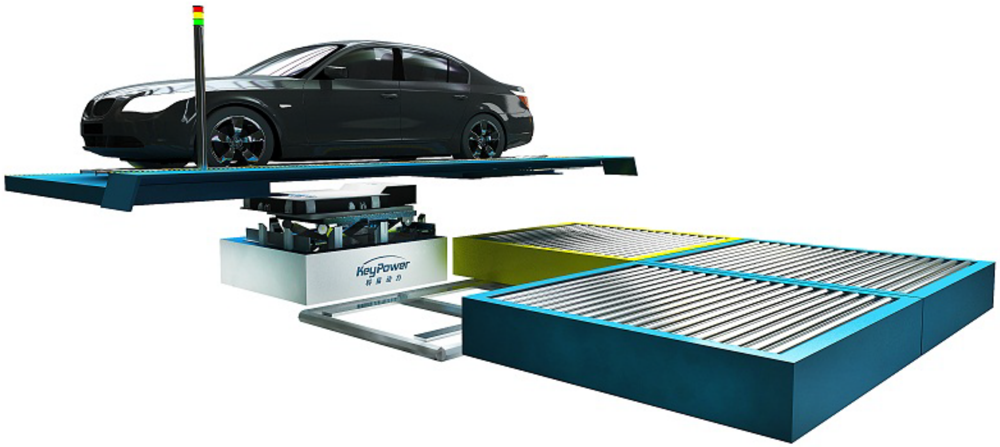
Battery pack for EV

Battery monitor with iPad

EV with quick-change battery pack

Swapping System: The Key Equipment for EV Infrastructure

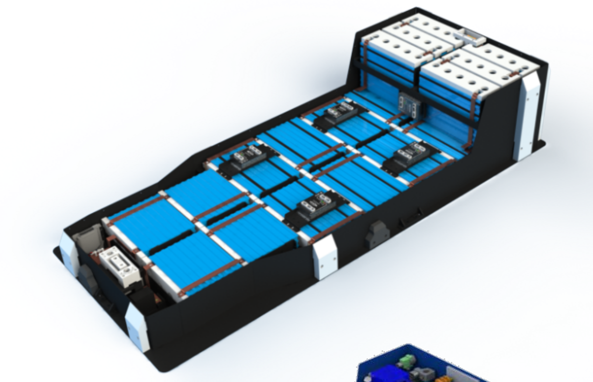


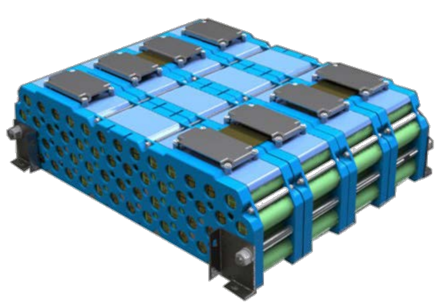
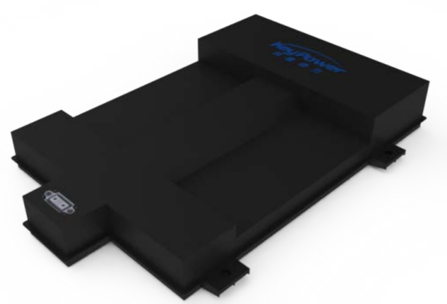
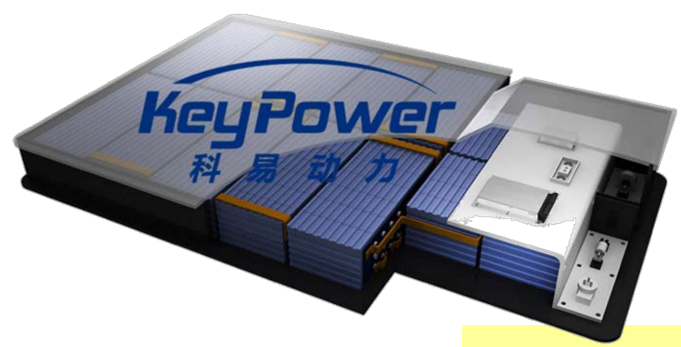


- Swapping finished in 2 min., the only practical way of rapid refilling
  - ◆ Rapid charging needs at least 15min., will damage battery
- Battery is located underneath car floor, the only practical location
  - ◆ Battery installed in trunk will cause lots of safety issues
- Swapping equipment can adapt all types of cars
  - ◆ Battery are standardized in four category, to adapt for various car sizes

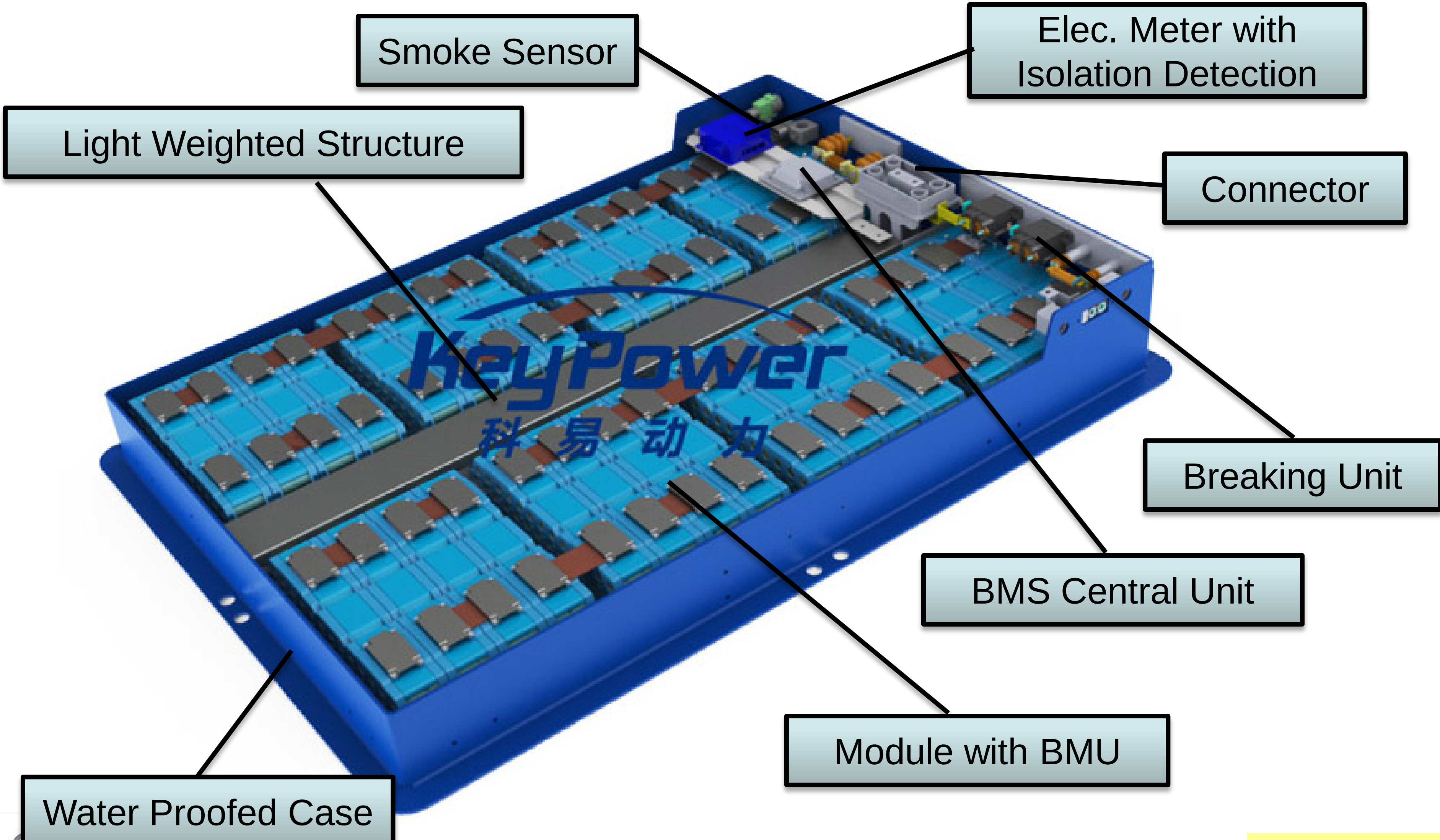
Value of Packaging: Keep Safe, Prolong Life

- **Meet requirement of auto industry**
  - **Reliability: 10 years, 100,000 km**
  - **Temperature: -40~60℃ with thermal shock**
  - **EMC: ISO 11452/7637, GB 18765, CISPR 25**
  - **Vibration: ISO 12405/16750-3**
  - **Water Proof**
- **Key Power's ability：**
  - **Cell evaluation and grading**
  - **Electrical thermal management**
  - **SOC/SOH/SOF State estimation**
  - **Redundant safety mechanism**
  - **Holistic testing to ensure durability**



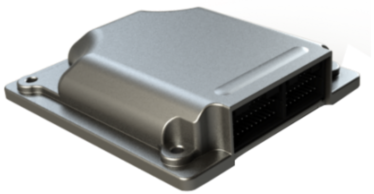





Packaging: An Integration of ME/EE/FD Technology



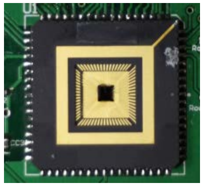
BMS: the Key to Prolong Battery Life

- **Key feature of Key Power BMS**
  - **Safer:**
    - **Volt/temperature sensor on every single cell**
    - **Active circuit breaking unit**
    - **Real-time isolation detection**
  - **Longer life:**
    - **Sophisticated modeling and SOC/SOH/SOF estimation based on comprehensive testing result**
    - **Active cell balancing with failure protection**
    - **Active charging control algorithm**
    - **Predictive warning**
- **Next generation BMS: smart cells**
  - **Integrate cell level sensor/balancing into single chip**
  - **Embed the chip into cells, reduce cost**
  - **Only communication bus is necessary, reduce harness**
  - **Everlasting cell history data storage**



BMS Central Unit

BMU



Smart Cell Chip

Thank you for your attention !