The performance of second-life EV batteries to be used in energy storage systems

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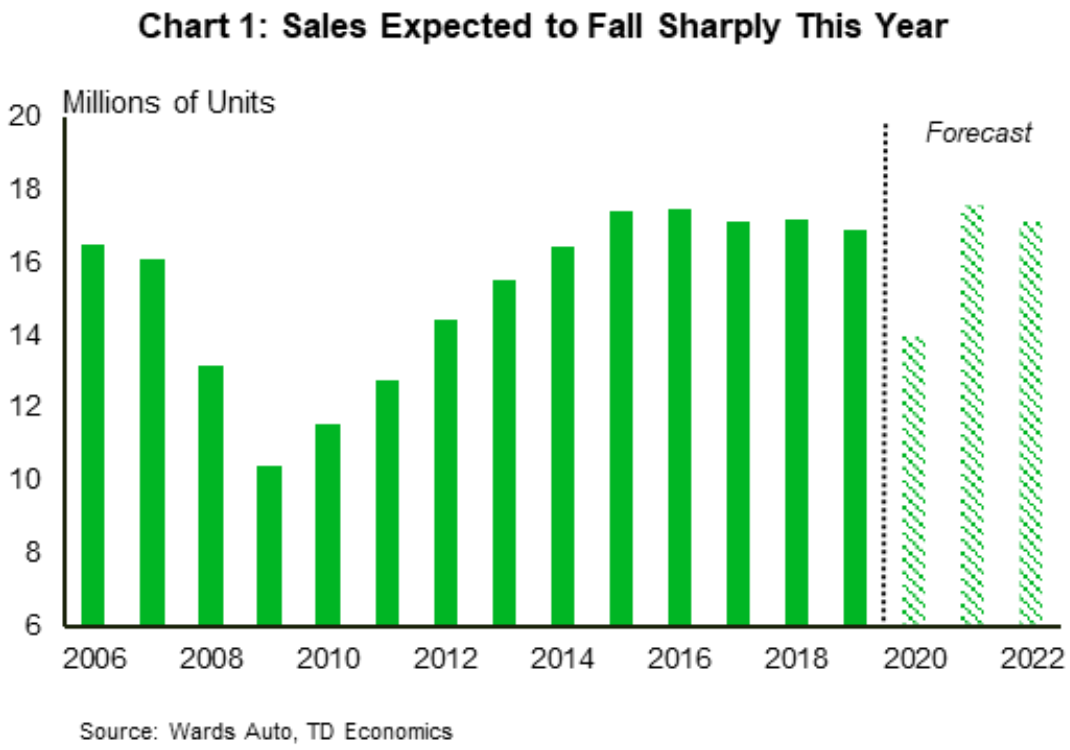
Outline

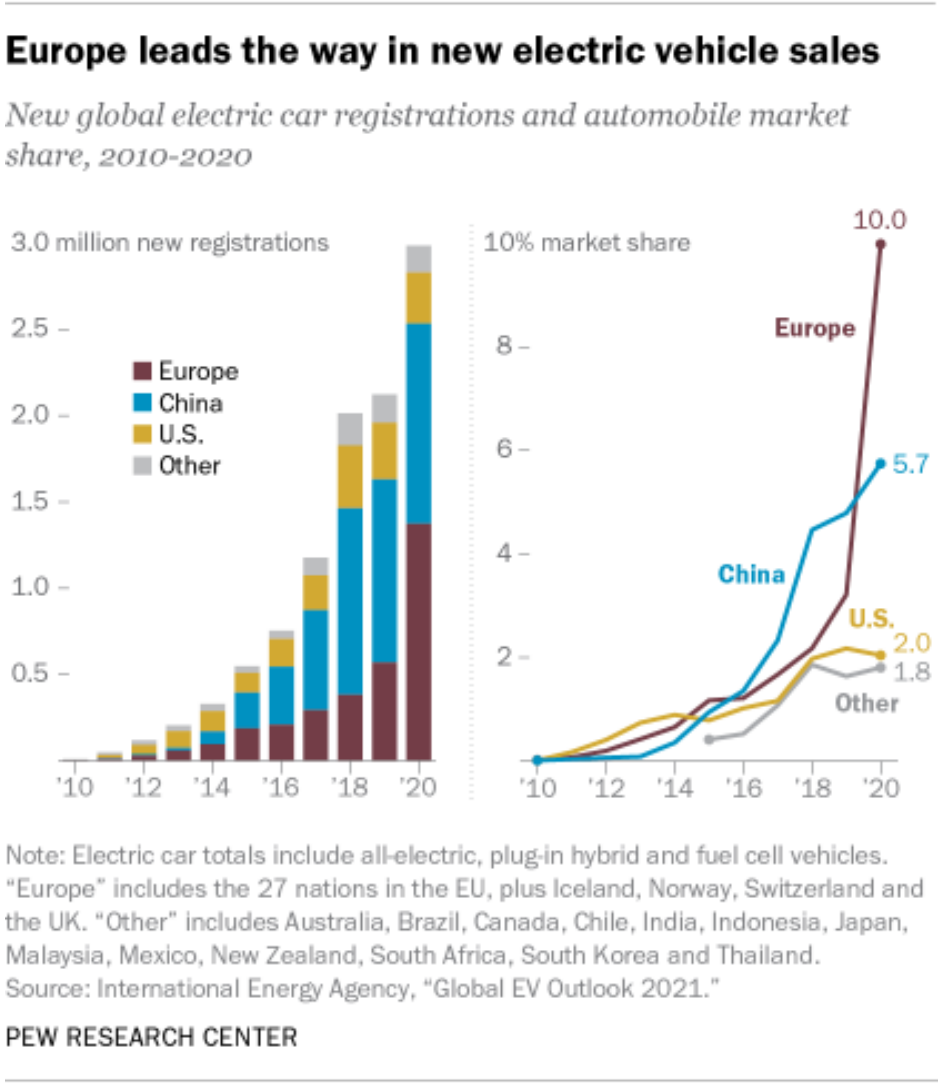
- The Second-life EV battery market in the future
- The health condition of the retired EV battery packs
- How many years / aging cycles can be used in Energy Storage Systems
- The challenge to design BMS for second-life batteries.
- A case study of the investment-return

This research is supported by California Energy Commission
Cost-Effective Integration of Second-life EV Batteries with Solar PV Systems for Commercial Buildings

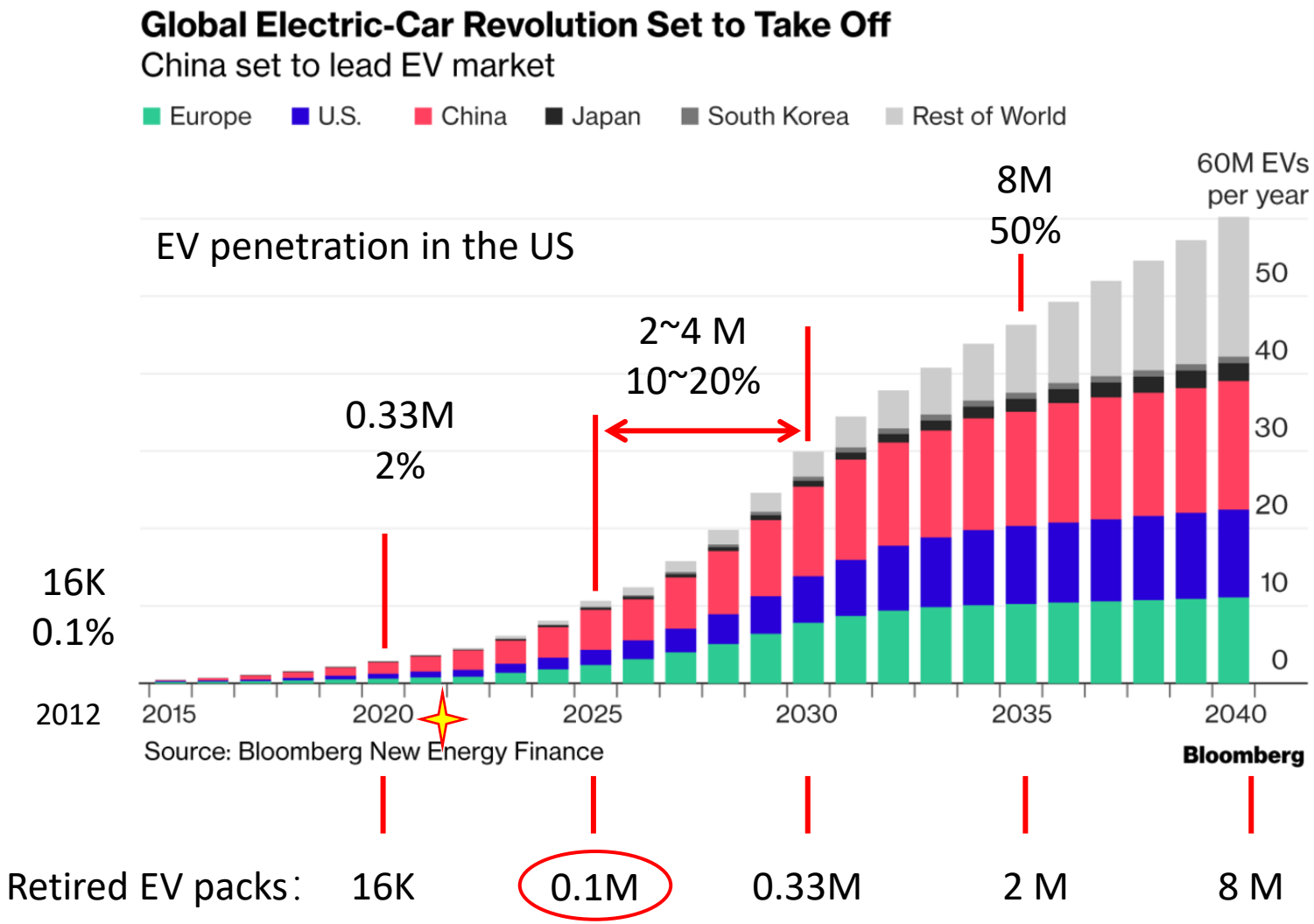
EV sales



In 2019 16 Millions Car Sales –USA
0.33 Million EV Sales (2%)



EV sales in the future



Retired EV packs: 16K | 0.1M | 0.33M | 2 M | 8 M

Electric Buses: LFP batteries
5~6 years, at most 8 years

Electric Cars: LiNMC batteries
8~10 years

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The health condition of the retired EV battery packs

LiMO2/ LiNMC

- Nissan Leaf Gen1
  24 kWh LiMO2
  2012~2020 (8 years)

  100 Packs
  60%~67% SOH

- Nissan Leaf Gen2
  62 kWh LiNMC
  2018~2020 (2 years)

  20 Packs
  89~97% SOH

LFP

- Electric Forklift
  LFP 100Ah battery
  Retired after 4 years

  3 Battery Cells
  Cell: 89% SOH
  Pack: 50% SOH

- Electric Bus
  LFP 270Ah battery
  Retired after N years
  4 Battery Modules
  Cell: 75% SOH
  Pack: 52% SOH

The health condition of the retired EV battery packs

What is the battery state of health (SOH)?

For battery cell:

- Capacity
- Internal Resistance

For energy storage systems, the current is low, the capacity is more important.

For battery pack:

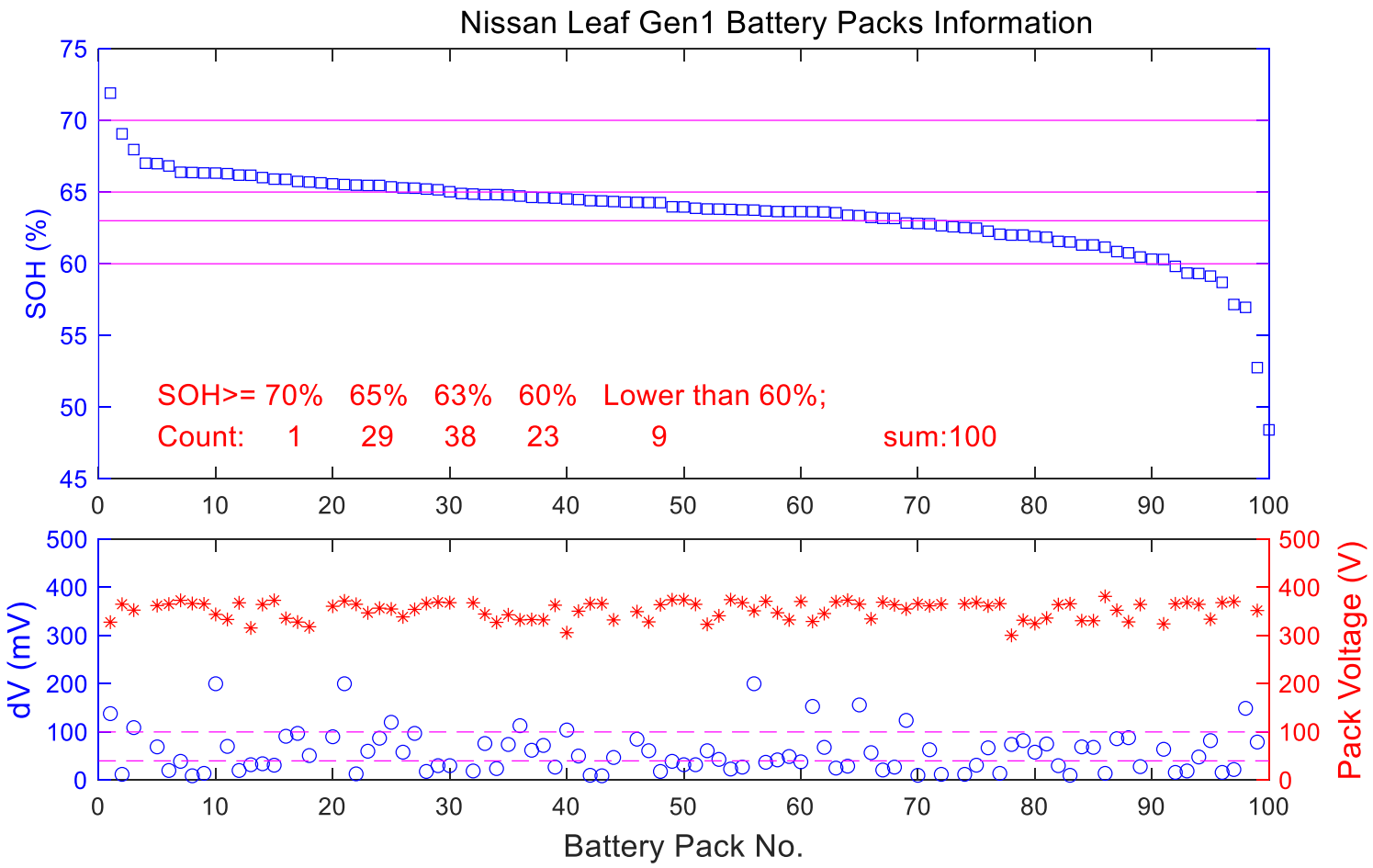
- Battery pack capacity
- Battery balance state
- Battery parameter consistency

What is the reason of Low Battery Pack Capacity?

- Battery cell capacity degradation — Non recoverable
- Serious balance issue — Recoverable

Case 1: Nissan Leaf Gen1

24 kWh LiMO2 | 100 Packs
2012~2020 | 60%~67% SOH
8 years 2400 cycles | 14.6% / 1000 cycles

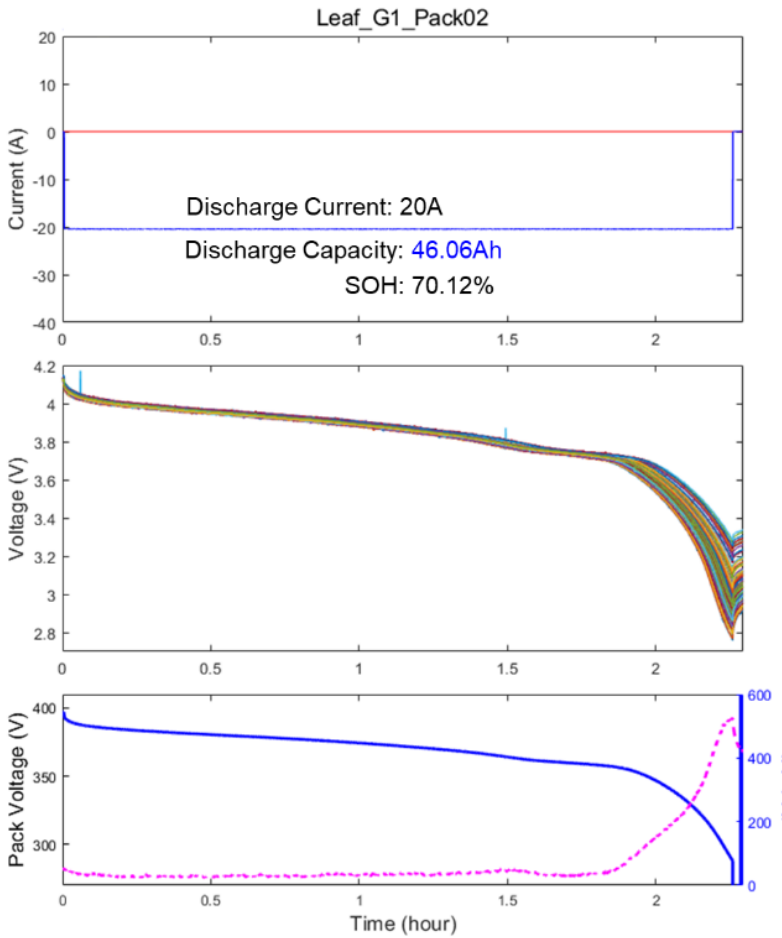


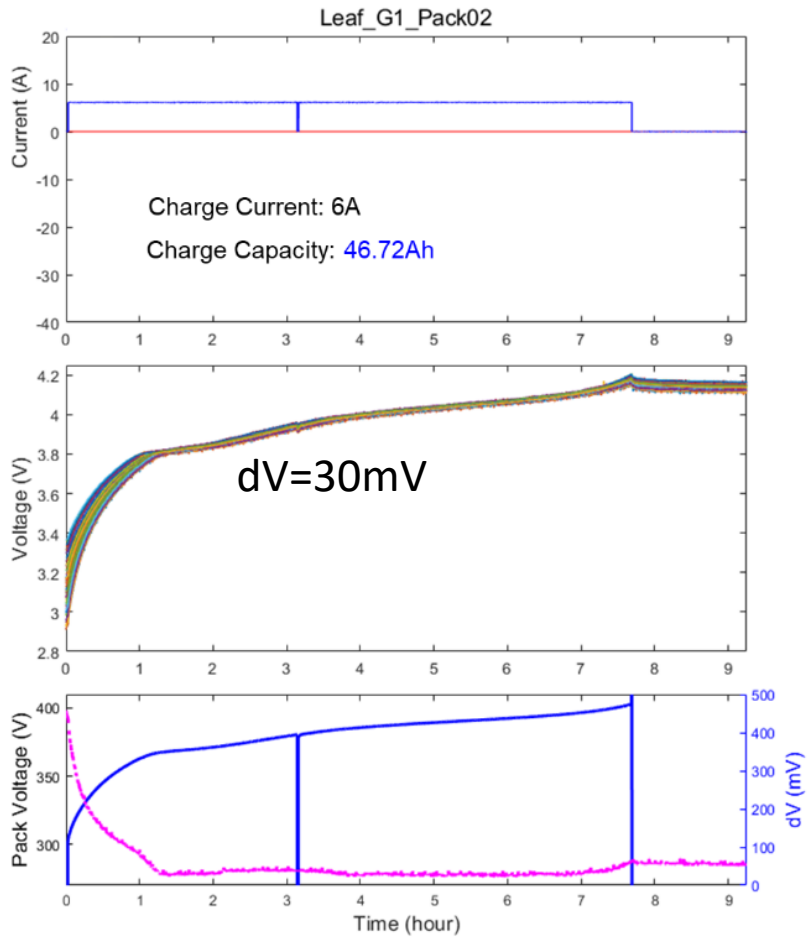
Case 1: Nissan Leaf Gen1

To further investigate the battery health condition, two battery packs are tested in the laboratory.

- No serious balance issue.
- Cell capacity consistency is good.

Capacity Test

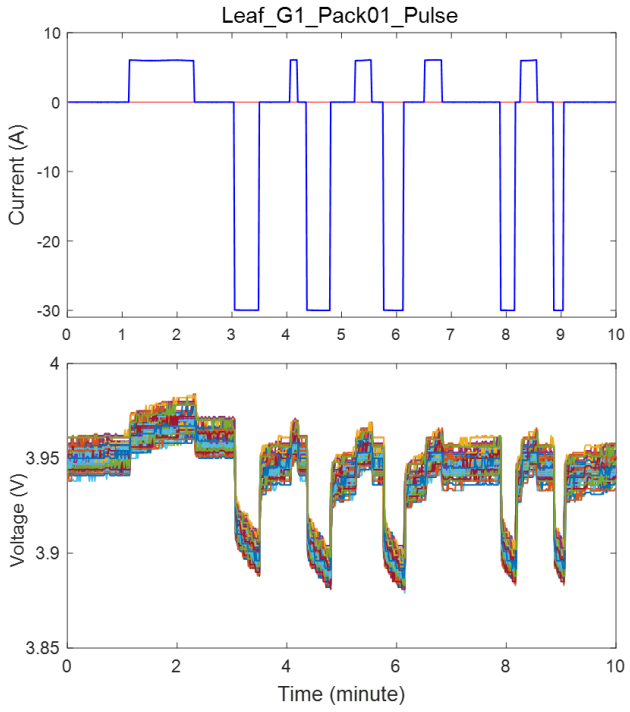




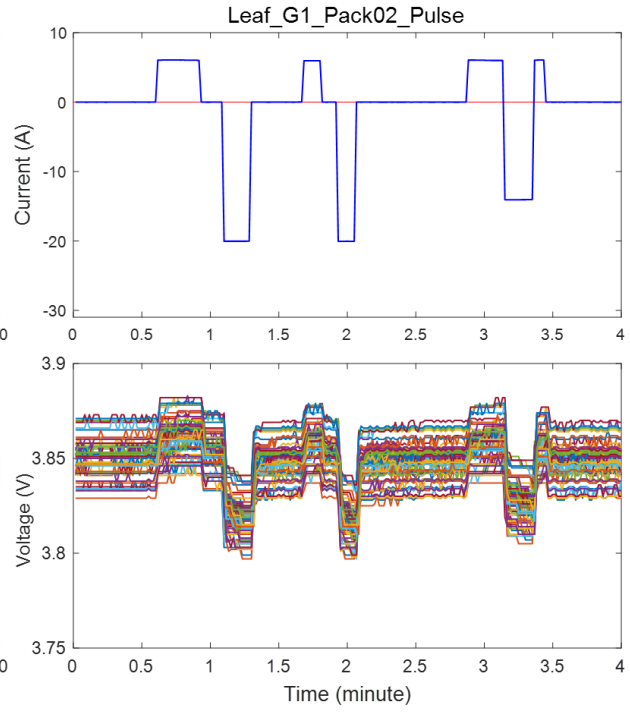
Case 1: Nissan Leaf Gen1

Internal Resistance Test

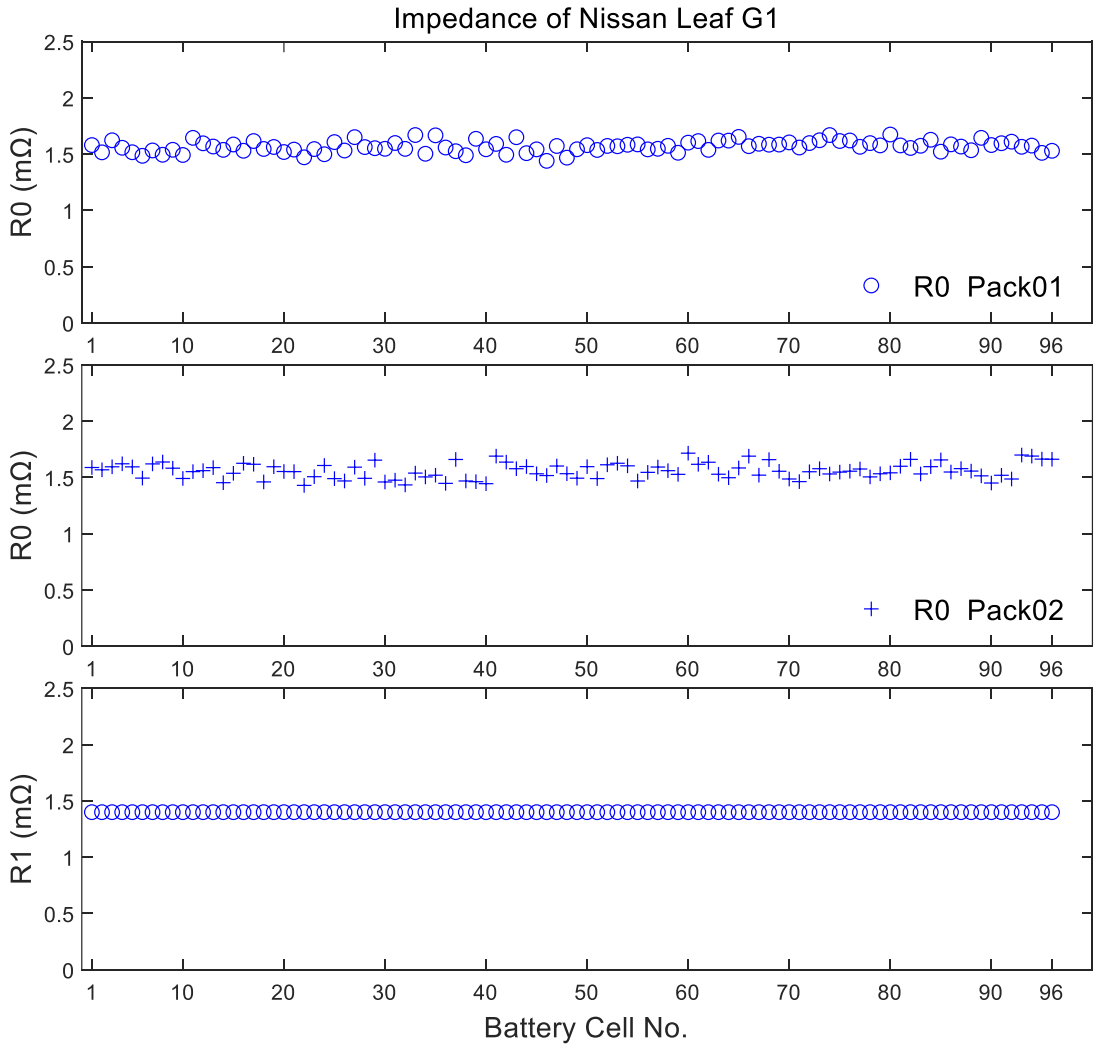
dV=39mV



dV=30mV



- Battery internal resistance consistency is also good.



Case 1: Nissan Leaf Gen1

24 kWh LiMO2
2012~2020

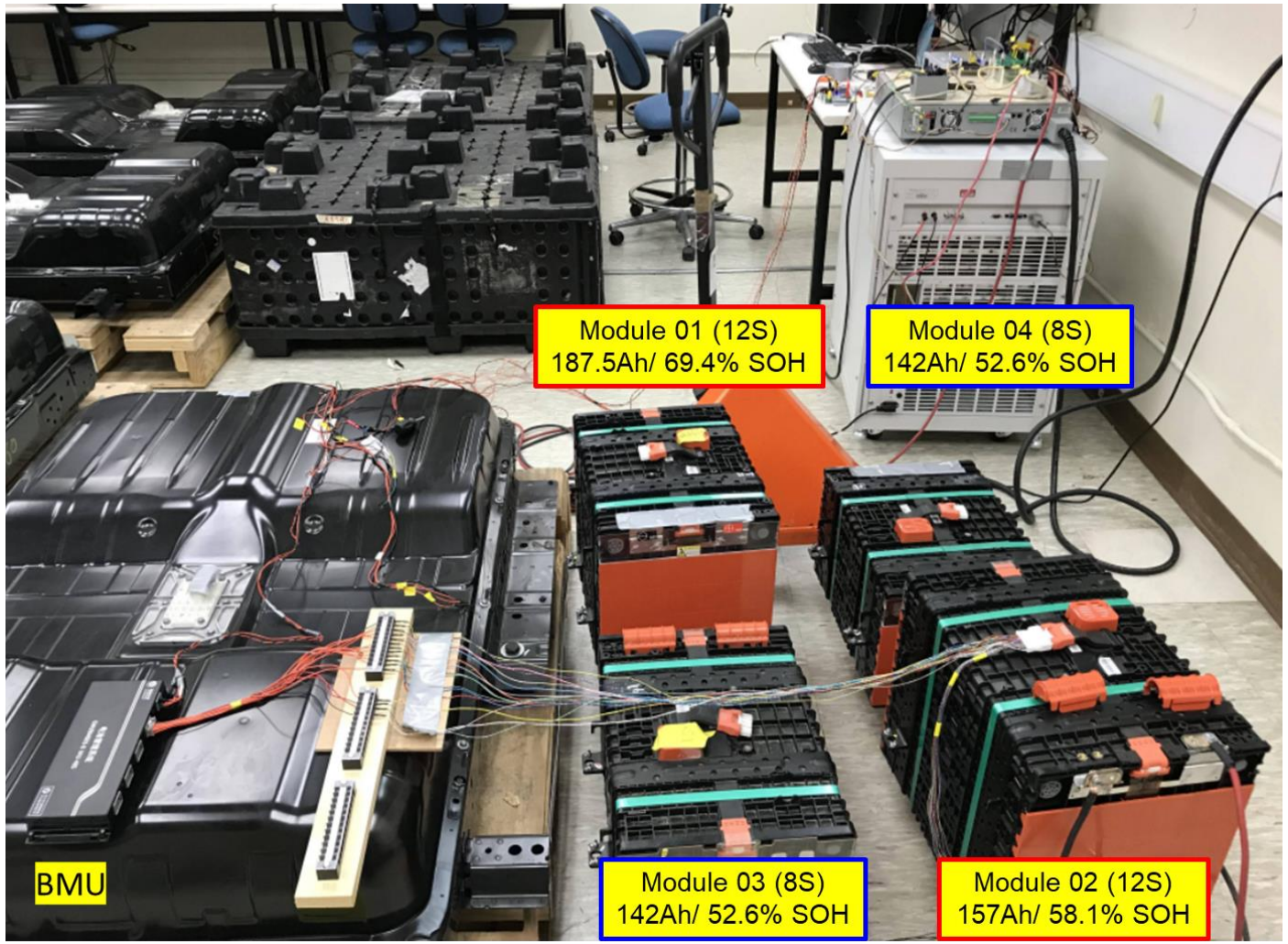
Summarization:

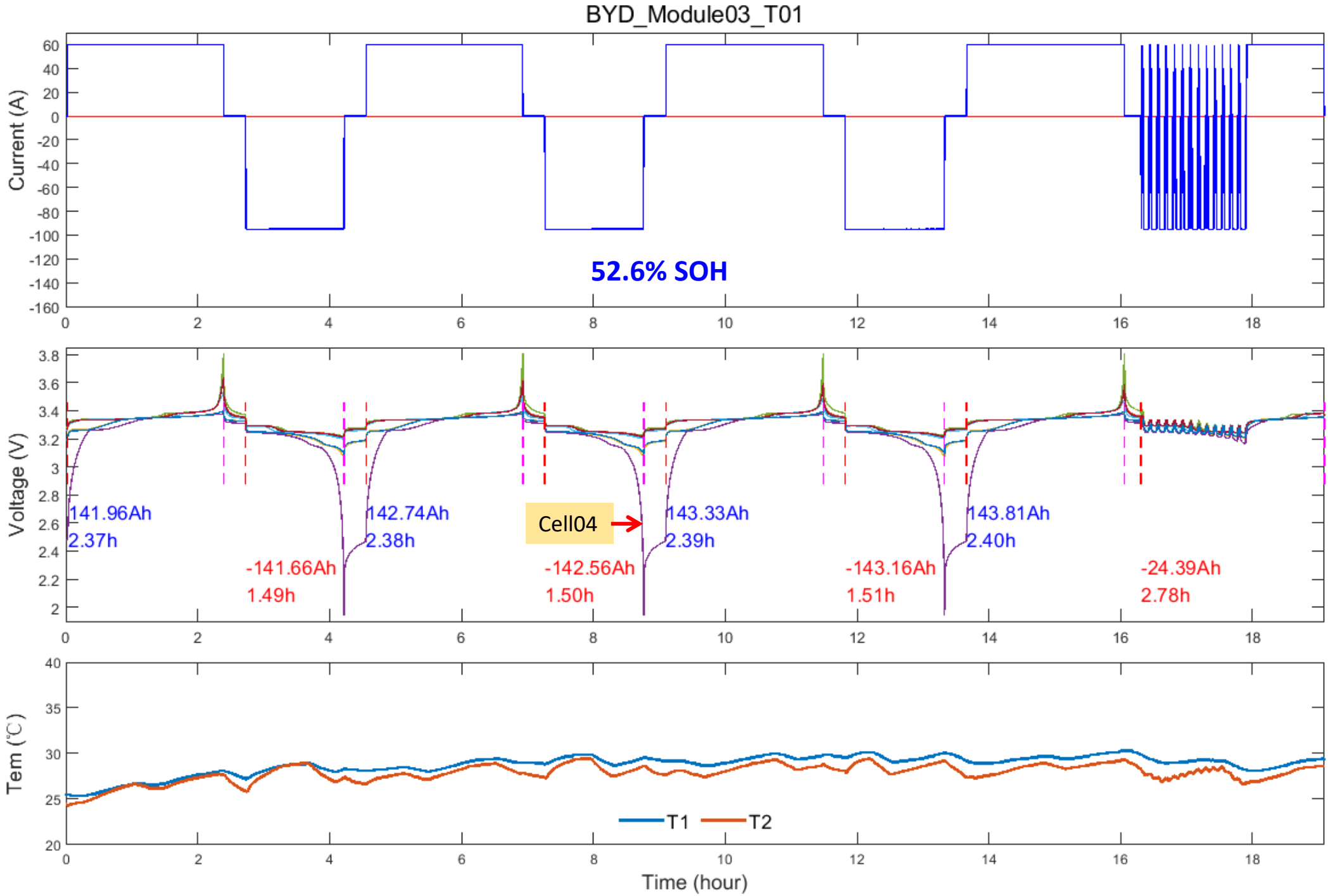
1. The battery packs tend to be retired when the capacity dropped to below 60%~66%.
2. The battery packs degradation mostly lies in the battery cell degradation, but not balance issue.
3. The battery cells' capacity and internal resistance consistency are good, which makes them ideal for second-life applications.

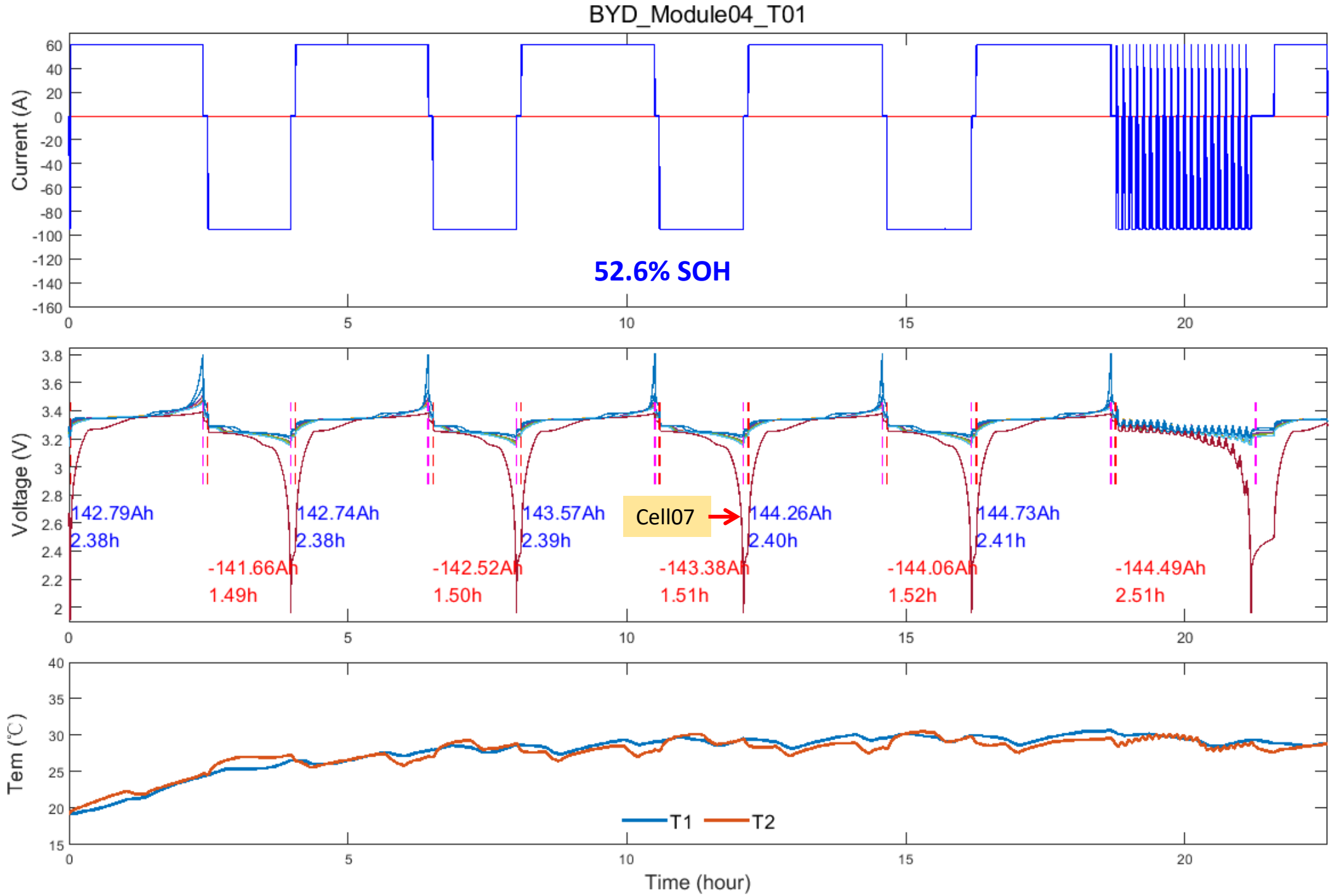
Case 2: Electric BUS batteries

- Electric Bus
  LFP 270Ah battery
  Retired after N years

  4 Battery Modules
  Cell: 75% SOH
Module: 52% SOH

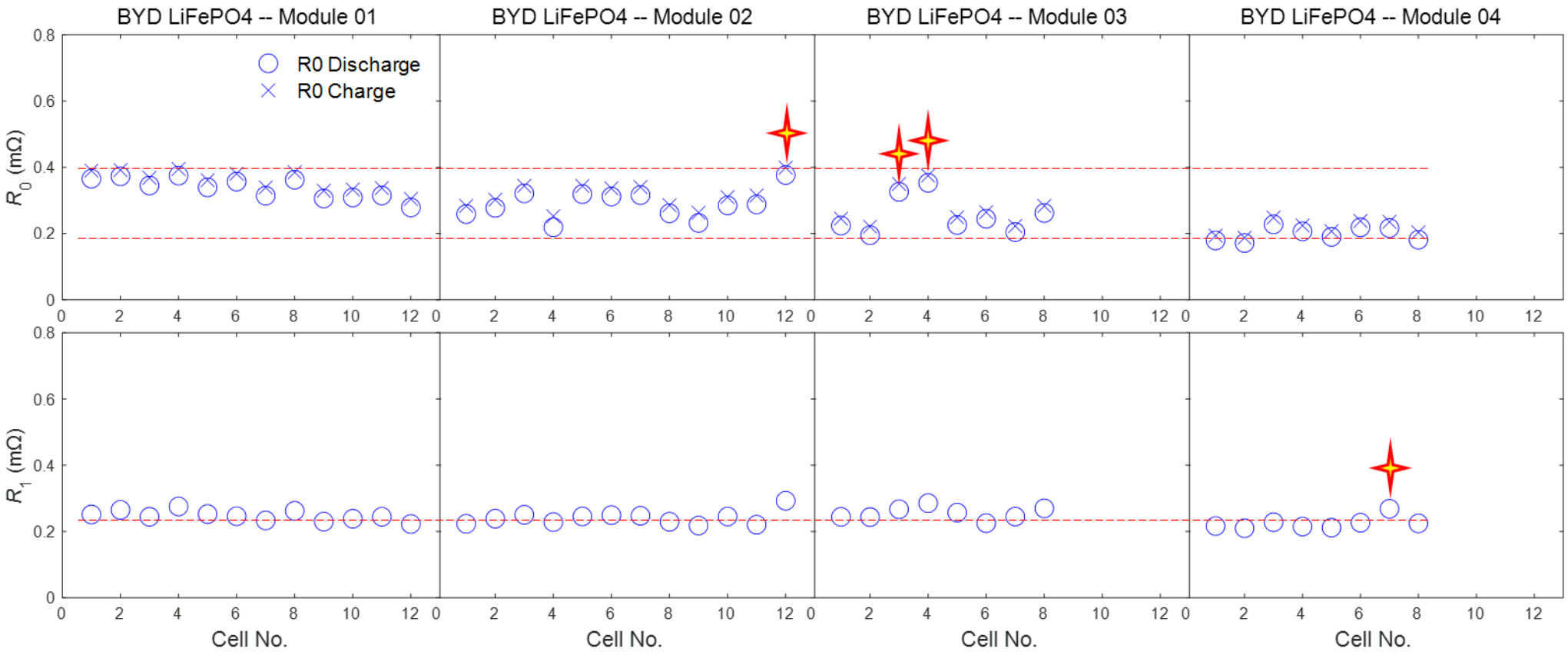



BYD_Module03_T01
Current (A)
52.6% SOH
Voltage (V)
141.96Ah
2.37h
-141.66Ah
1.49h
142.74Ah
2.38h
Cell04
-142.56Ah
1.50h
143.33Ah
2.39h
-143.16Ah
1.51h
143.81Ah
2.40h
-24.39Ah
2.78h
Tem (℃)
T1
T2
Time (hour)


BYD_Module04_T01
Current (A)
52.6% SOH
Voltage (V)
142.79Ah
2.38h
-141.66Ah
1.49h
142.74Ah
2.38h
-142.52Ah
1.50h
143.57Ah
2.39h
Cell07
-143.38Ah
1.51h
144.26Ah
2.40h
-144.06Ah
1.52h
144.73Ah
2.41h
-144.49Ah
2.51h
Tem (℃)
T1
T2
Time (hour)

Case 2: Electric BUS batteries

Internal Resistance



Case 2: Electric BUS batteries

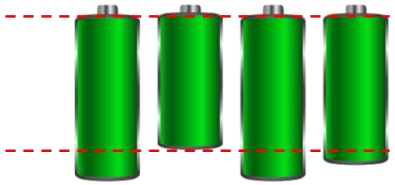
- Electric Bus
  LFP 270Ah battery
  Retired after N years

  4 Battery Modules
  Cell: 75% SOH
  Pack: 52% SOH

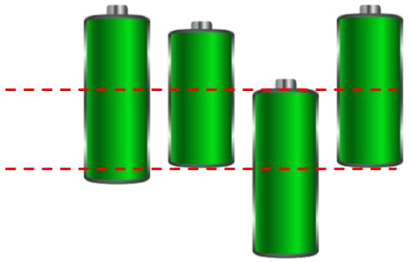
Summarization:

1. The battery packs tend to be retired when the capacity dropped to below 52%~60%.
2. The battery packs degradation:
   - Battery cell degradation; -- Not recoverable;
   - Balance issue; -- Recoverable;
3. The internal resistance variance among the battery cells tends to cause balance issues, which seriously reduces the pack capacity.
4. To make good use of the second-life LFP batteries, the battery balance issue has to be solved.

Balanced battery pack



Unbalanced battery pack



Case 3: CALB 100Ah LFP batteries

- Electric Folklift
  LFP 100Ah battery
  Retired after 4 years

  3 Battery Cells
  Cell: 89% SOH
  Pack: 50% SOH

1. The battery packs tend to be retired when the capacity dropped to below 60%.
   However, most of the battery cells still have above 90% capacity, which suggests the battery packs have serious balance issues.
2. The battery packs degradation:
   - Battery cell degradation; -- Not recoverable;
   - Balance issue; -- Recoverable;
3. The internal resistance variance among the battery cells tends to cause balance issues, which seriously reduces the pack capacity.

- The Second-life EV battery market in the future
- The health condition of the retired EV battery packs
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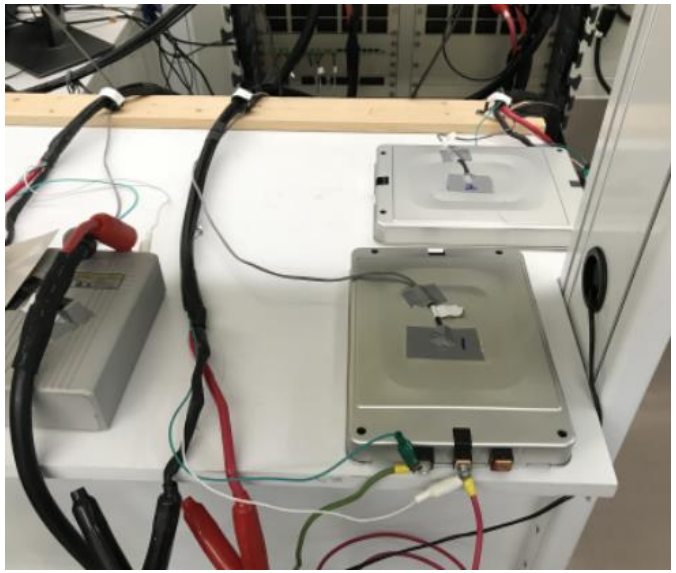
- A case study of the investment-return

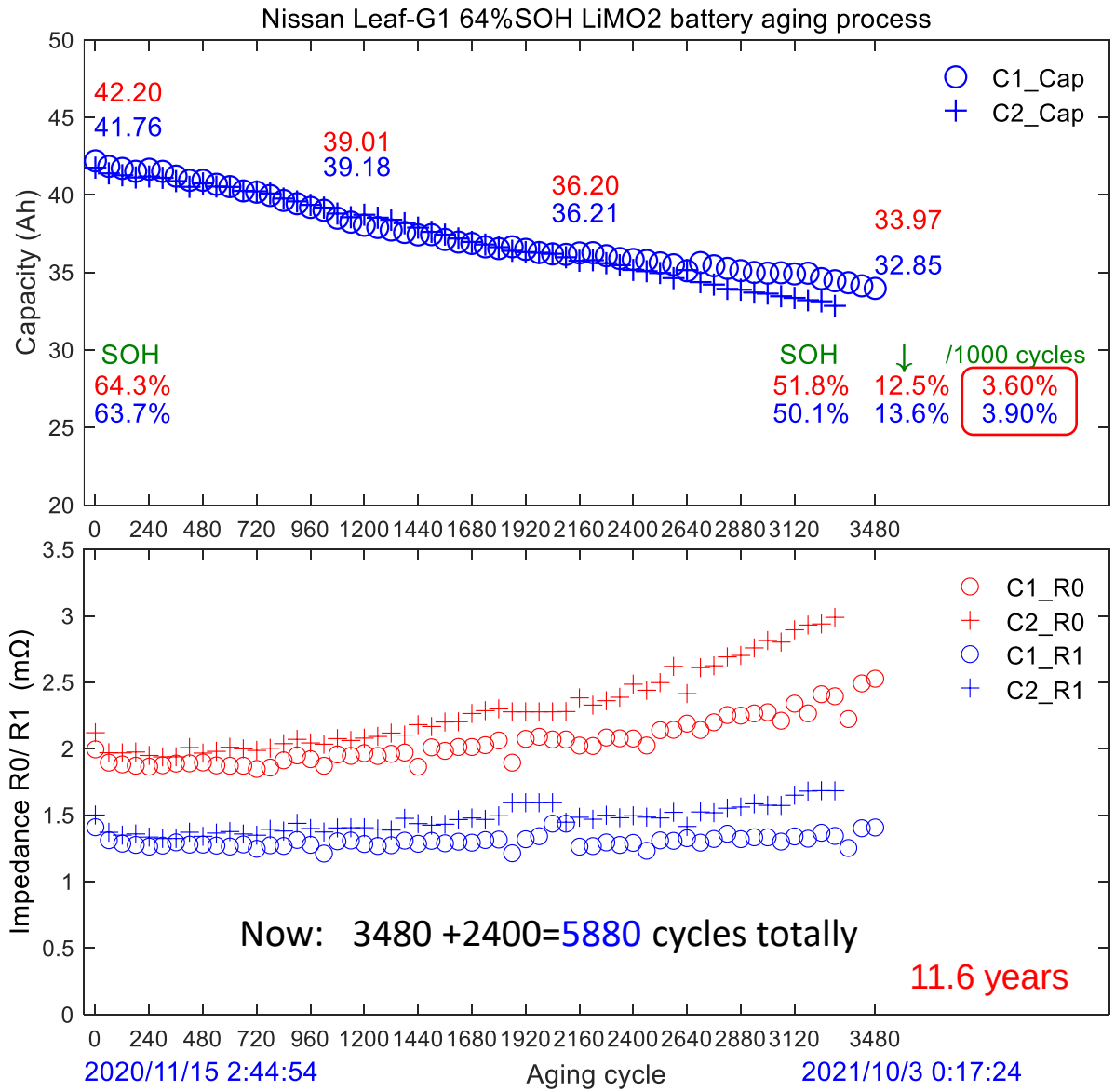
Case 1: Nissan Leaf Gen1 -- Battery Aging Test



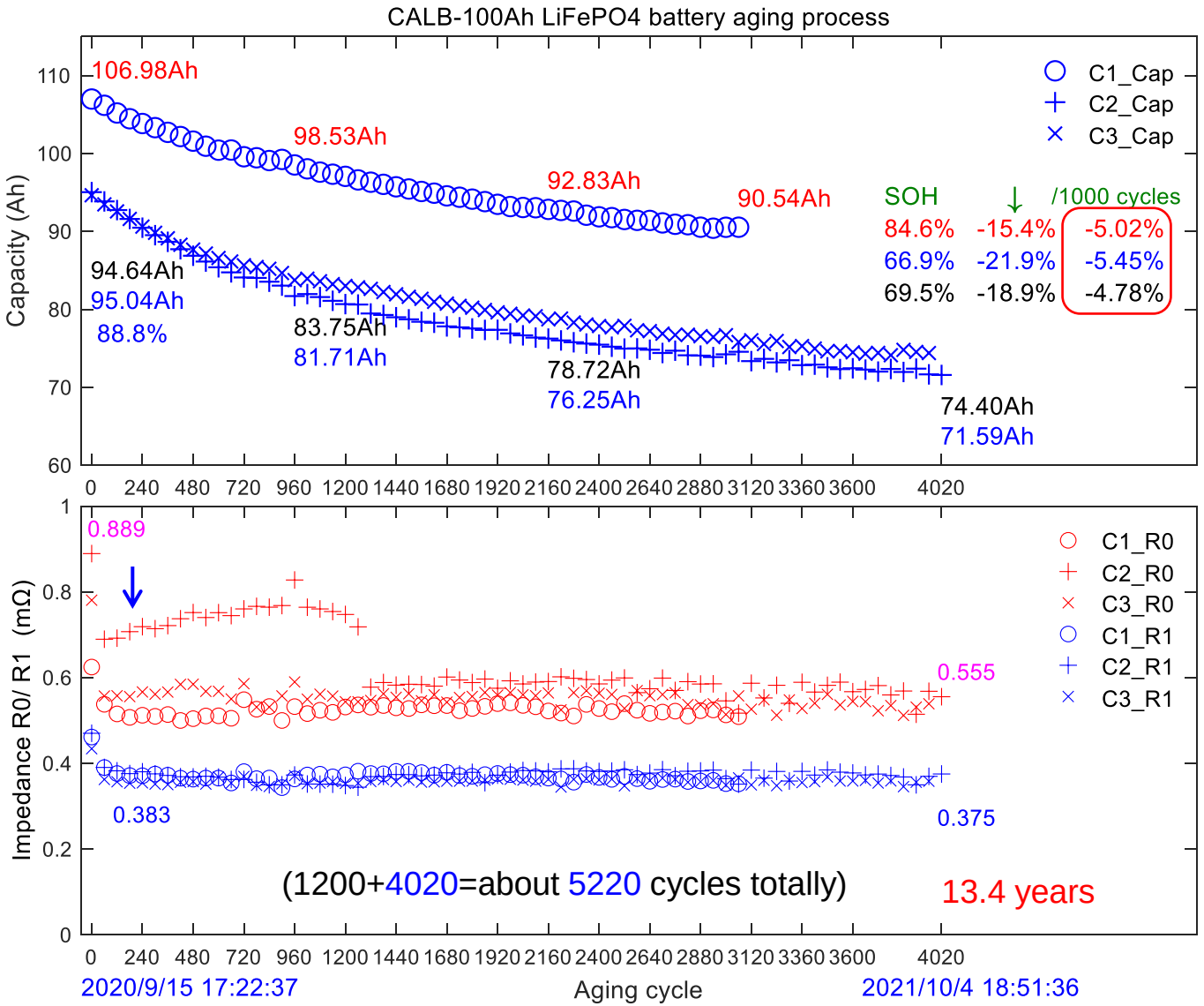
8 years 2400 cycles

14.6% / 1000 cycles

- If the working condition is well controlled, the second-life Nissan Leaf Gen1 batteries can be used for up to 15 years/ 4500 cycles, even though the initial capacity is only 64%.



Case 3: CALB 100Ah LFP batteries -- Aging Test



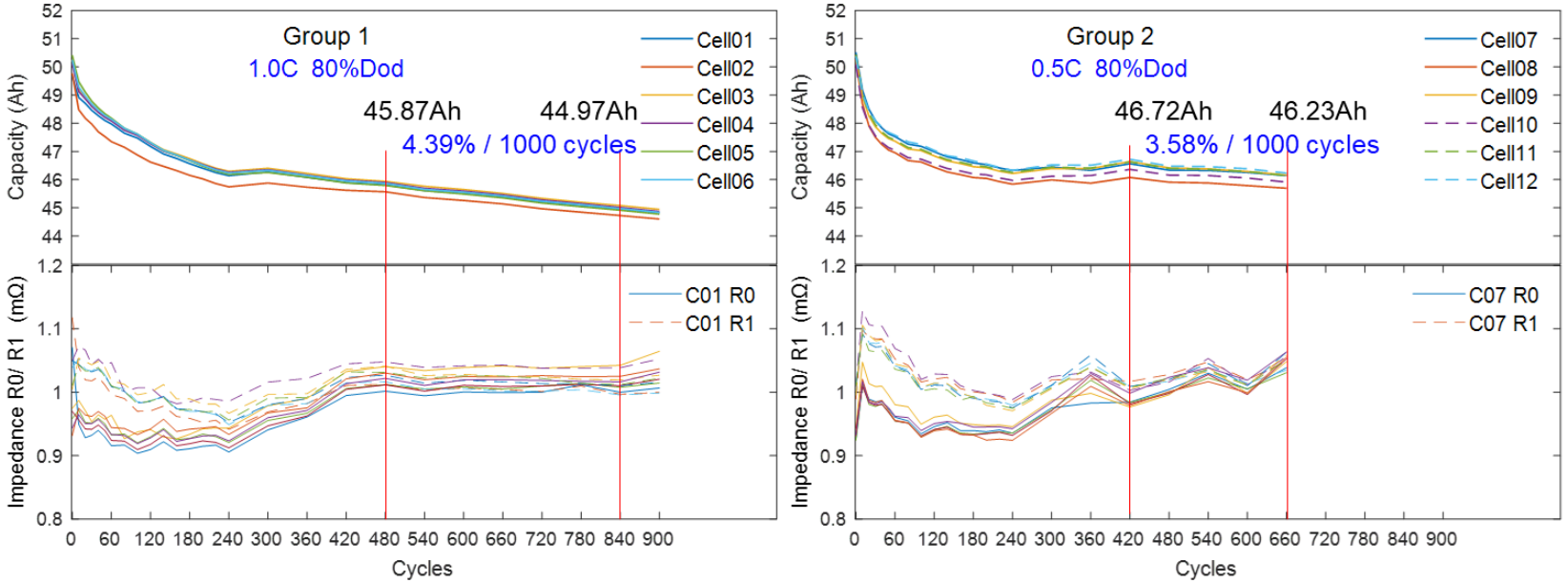
- Electric Forklift
  LFP 100Ah battery
  Retired after 4 years
  3 Battery Cells

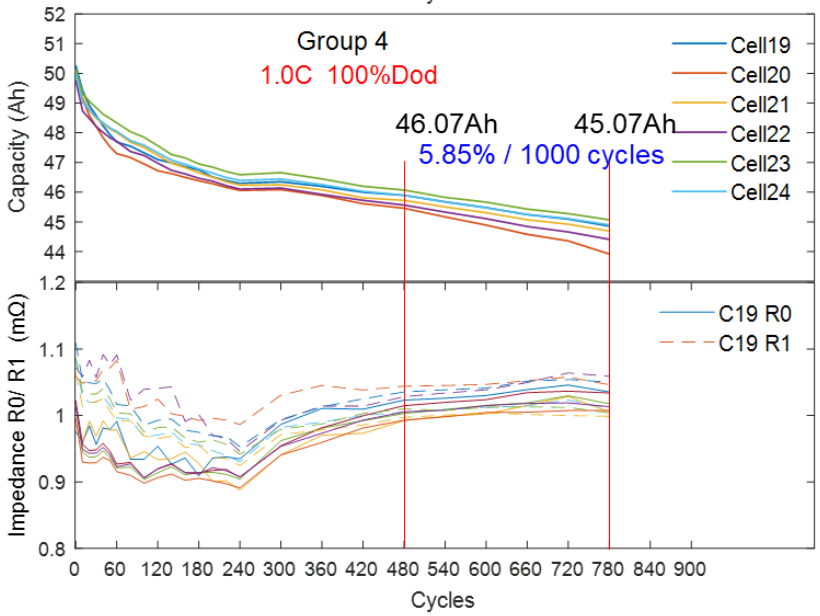
4 years 1200 cycles 11.2% ↓

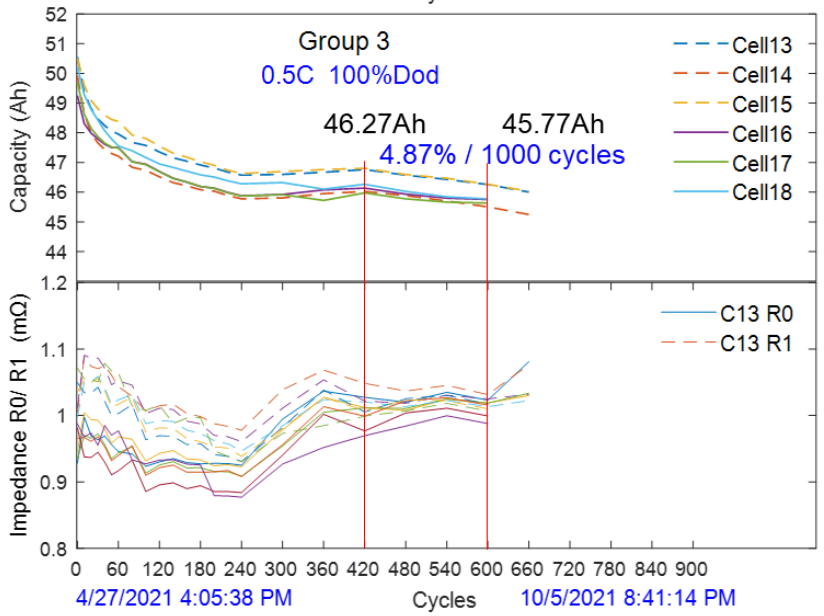
9.3% / 1000 cycles ↓

- The batteries are expected to work for 20 years/ 6000 aging cycles.

Case 4: Nissan Leaf Gen2 -- Battery Aging Test







How many years / aging cycles can be used

- Nissan Leaf Gen1
  24 kWh LiMO2

- Nissan Leaf Gen2
  62 kWh LiNMC

- Electric Forklift
  LFP 100Ah battery

- Electric Bus
  LFP 270Ah battery

Capacity degradation

	Nissan Leaf Gen1 24 kWh LiMO2	Nissan Leaf Gen2 62 kWh LiNMC	Electric Forklift LFP 100Ah battery	Electric Bus LFP 270Ah battery
First - Life	14.6% / 1000 cycles	10~15% / 1000 cycles	9.3% / 1000 cycles	
Second-Life	4% / 1000 cycles	3.6~5.9% / 1000 cycles	5.0% / 1000 cycles	
	64% SOH	89% SOH	89% SOH	75% SOH
	12~15 years 3600~4500 cycles	20~25 years 7000~8000 cycles	20 years 7000 cycles	

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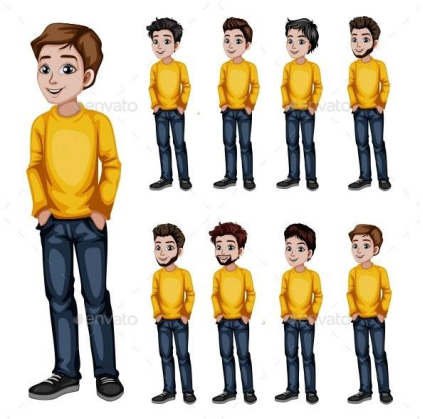
The challenge to design BMS for second-life batteries.

New Batteries:



Second-life batteries:

- Maintain a comfortable work environment.
  - Temperature: e.g., 15~30℃
  - Current <0.5C rate;
  - Only use 80% Dod;
- Update the battery health condition periodically.
  - Battery cell internal resistance;
  - Battery pack balance state;
  - Battery pack capacity;
- An efficient battery balance system, both hardware and strategy.

The challenge to design BMS for second-life batteries.

- Don’t rest the battery for a long time, e.g., more than half a year
  - Especially for LFP batteries.

Cathode material inactive.

↓

Internal resistance increase

↓

Battery characteristics variance

↓

Serious balance issue.

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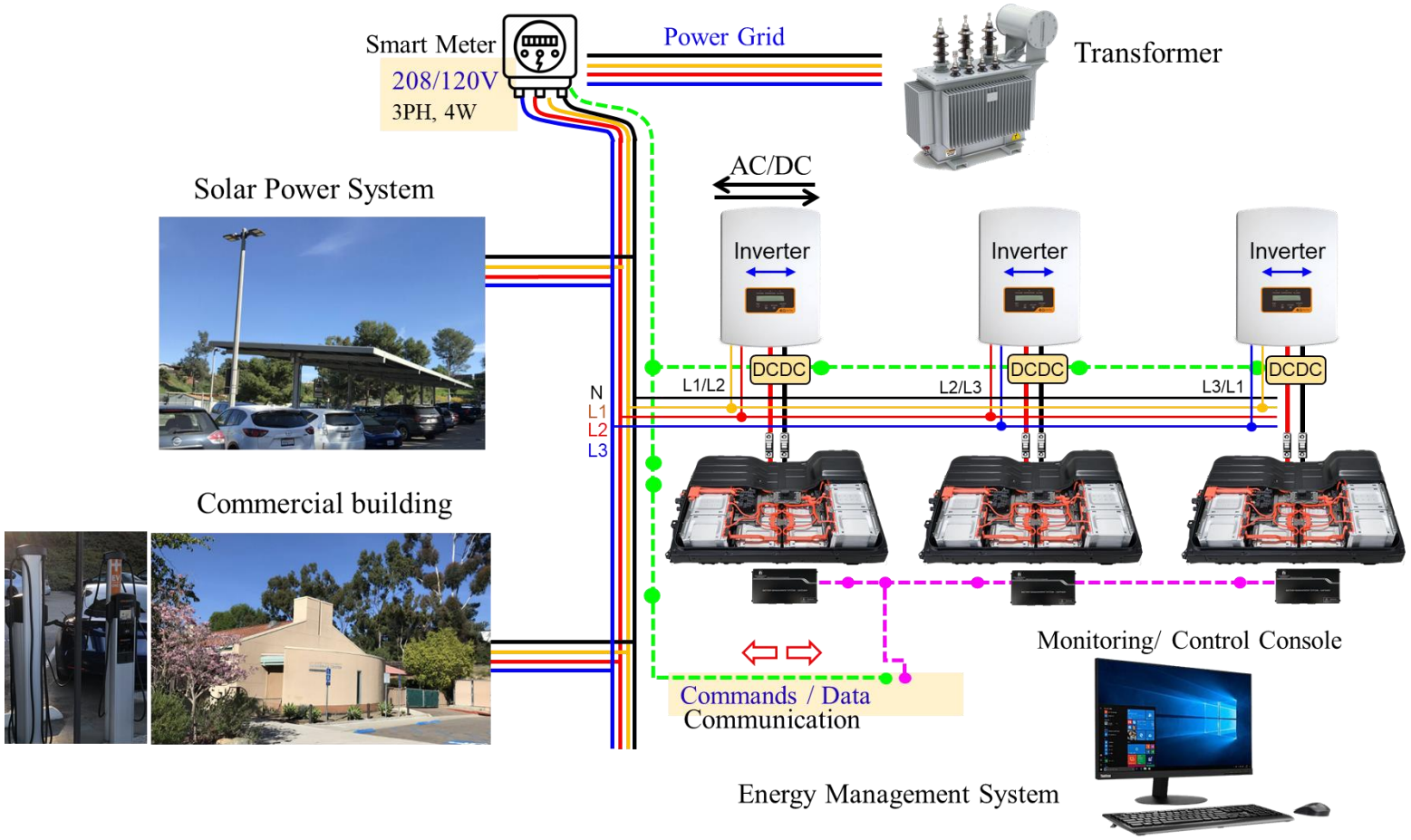
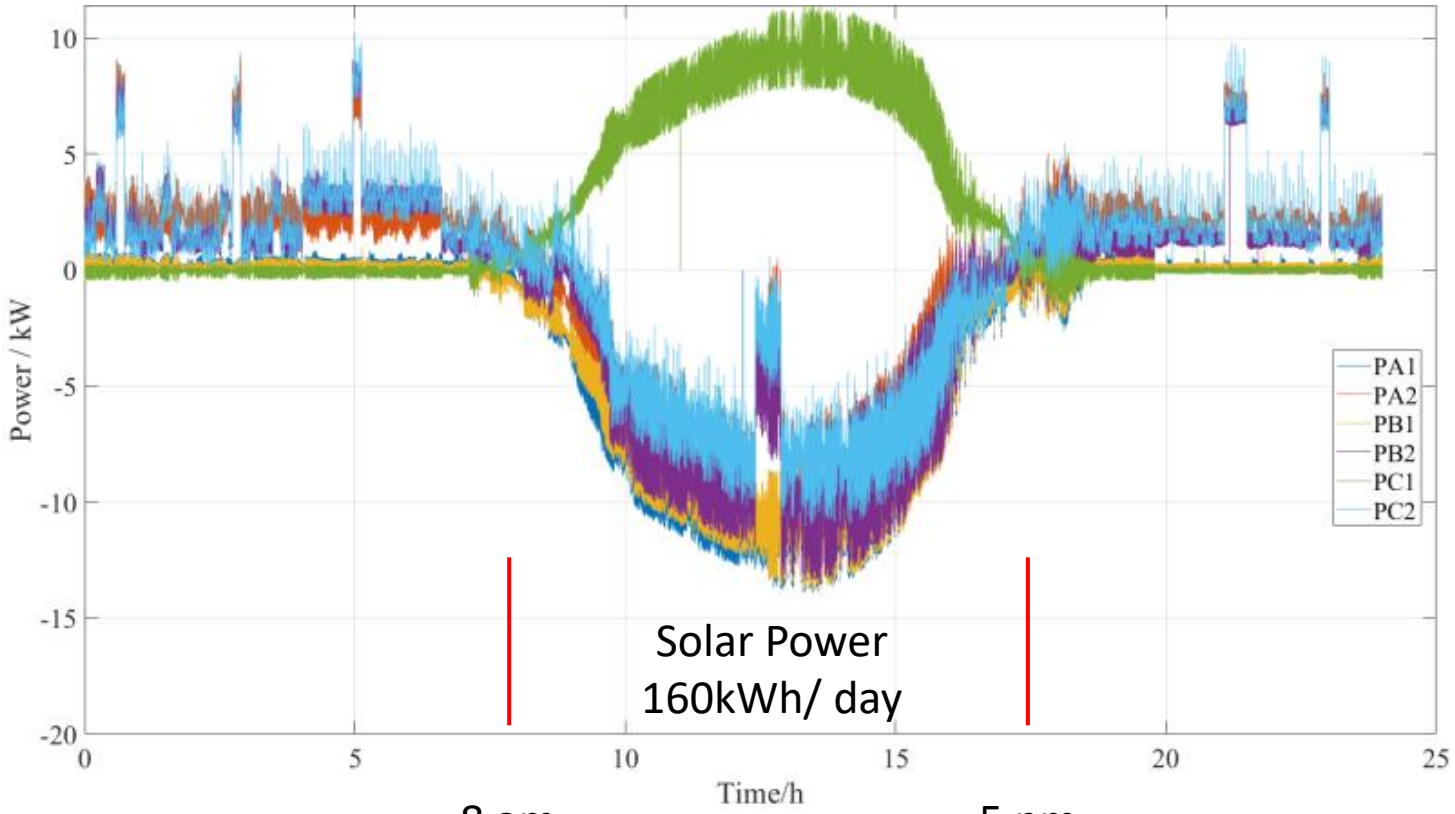
A case study of the Solar Power + Energy Storage System



A case study of the Solar Power + Energy Storage System

Battery Discharge Battery Charge Battery Discharge



Electric Bill of a month:

Basic Charge:
$0.11 / kWh * 7272 kWh = $800

Demand Charge:
$20/kW * 80kW = $1600

Mean Power of a day:
7272 kWh/ 20 days/ 24hour= 15.15kW

Basic Charge:
$0.11 / kWh * 5454 kWh = $600

Demand Charge:
$20/kW * 30kW = $600

The bill could be reduced by half:
$2400 to $1200

A case study of the Solar Power + Energy Storage System

Every year save electric bill $12,000~$14,000

300kWh battery system	$100/ kWh	(For example, a Nissan Leaf Gen1 pack with 16kWh, sell $1600)
Inverter and other things	$100/ kWh	
	$200/ kWh	

Total Cost: 300kWh * $200/ kWh = $ 60,000

It will cost 4~5 years to make back the invested money.
20%~25% rates of return.

Summary

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Thank you!