Validation results of battery durability at vehicle + component levels

Prepared by Korea (LG Energy Solution with MOLIT, KATRI, KITECH)

69th EVE IWG

Overview

- Background
- Validation results of battery durability
- Summary

Background

As mentioned last time at 65th IWG meeting in Ottawa, we have planned 3 types of test for comparative analysis.

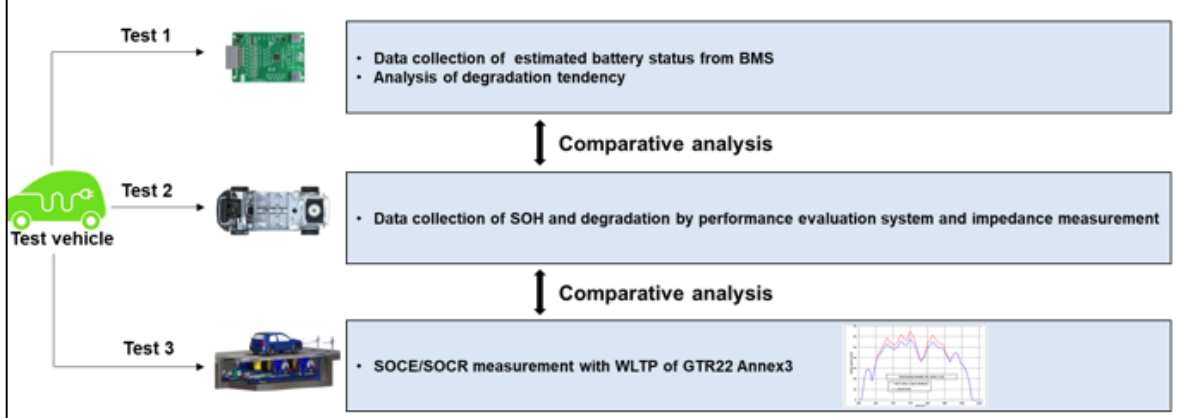
We've recently conducted preliminary tests with 2 PEVs prior to entering full-scale studies to verify several matters in advance.

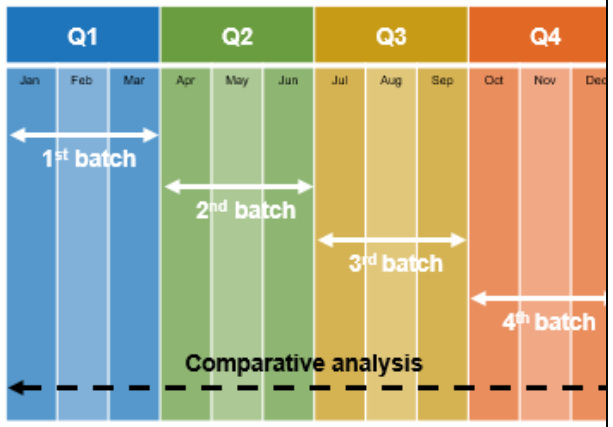
Those tests are intended to compare and analyze the durability values of battery measured in vehicle/Pack/BMS units.

Plan and strategy

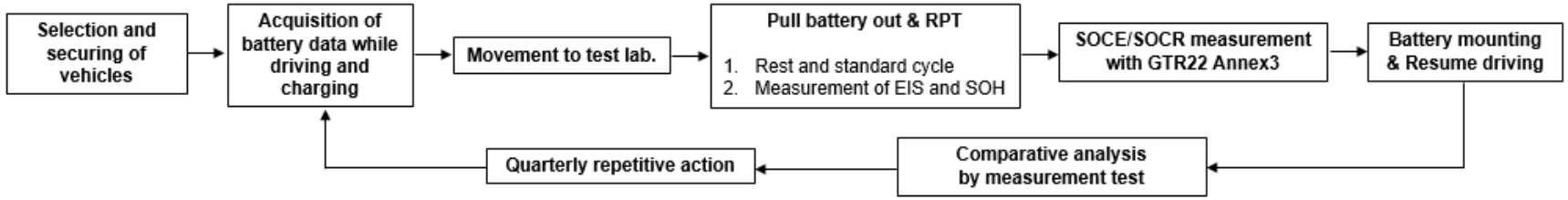
EVE-65-03e - UN GTR 22 Analysis of tendency and feasibility for MPRs

- Comparative analysis in Test 1: estimated value of SOH(BMS), Test 2: measurement value of SOH(Battery pack) and Test 3: measurement value of SOCE/SOCR(Vehicle)
- Research plan : Quarterly follow up test starting from the first quarter of 2024
- Research bodies : KATRI(Korea Automobile Testing & Researching Institute), KITECH(Korea Institute of Industrial Technology), LG Energy Solution

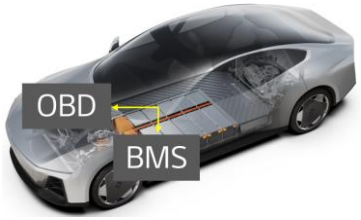




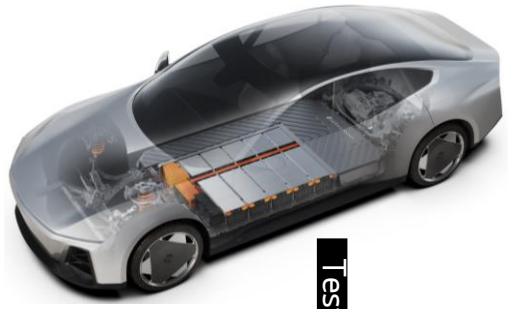
- Flow chart



Validation results of battery durability : Overview

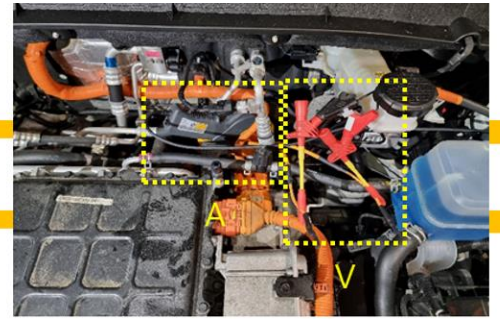


Test 1

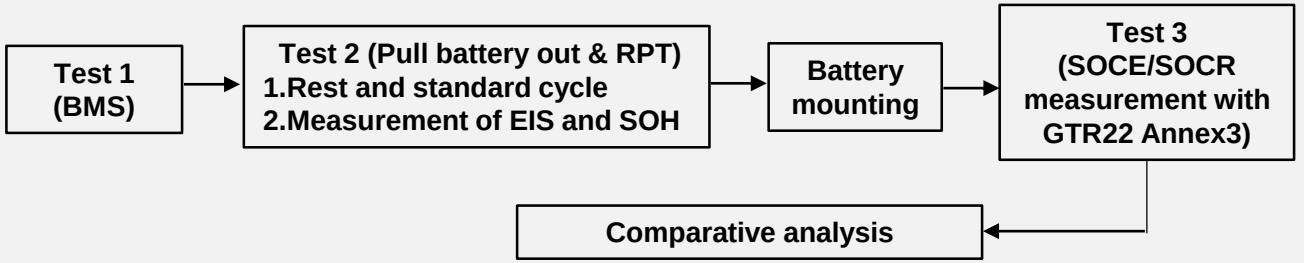


Test 2

Test 3



Flow chart

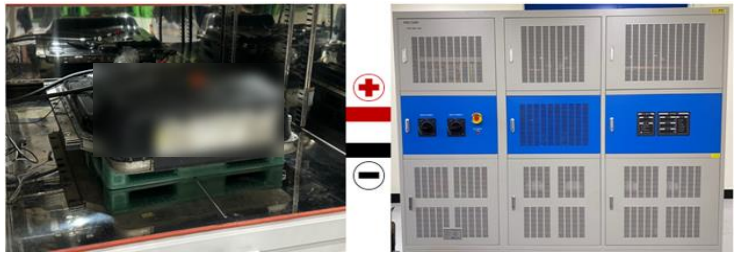


Test 1 : BMS

CAN

- To acquire estimated value of SOH from BMS communication via OBD port

Test 2 : Pack

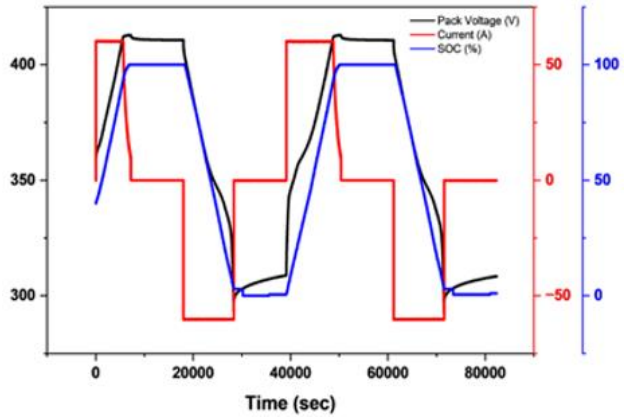


- To measure a value of SOH with RPT after taking apart battery pack

Test 3 : Vehicle

- SOCE/SOCR measurement with WLTP of GTR22 Annex3

Validation results of battery durability at component level



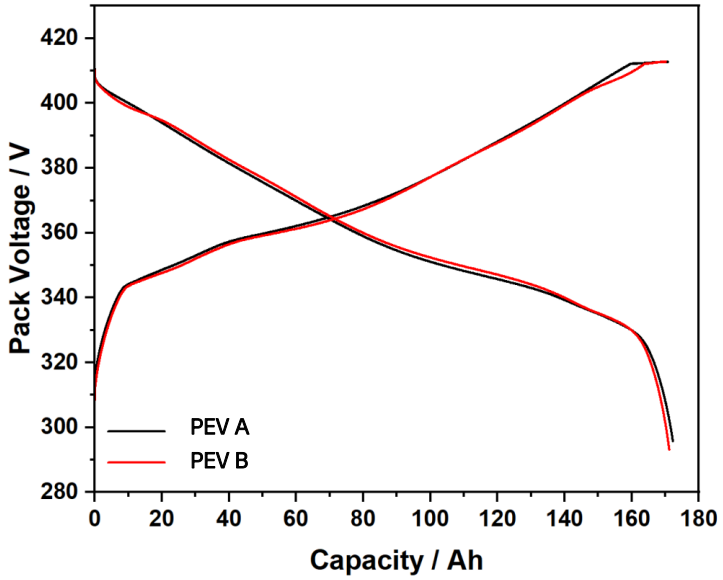
▪ Environmental condition of [1]RPT :

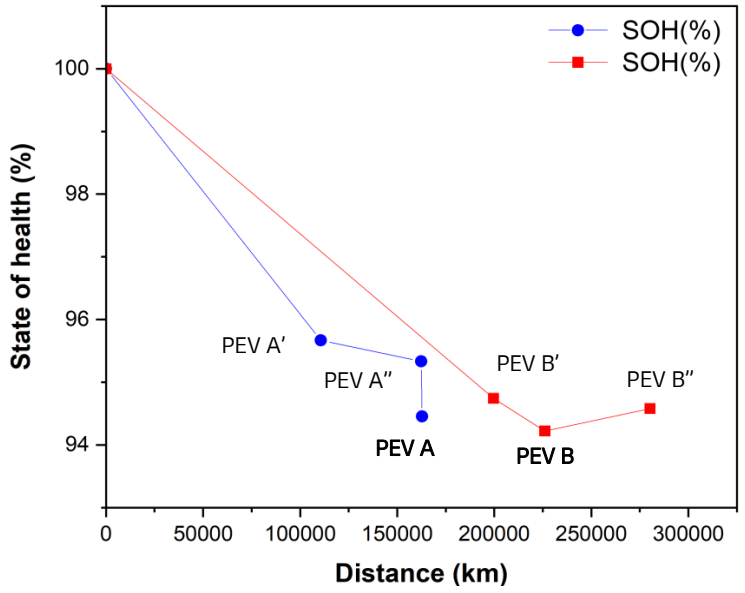
1) Chamber temp : 25℃

2) Coolant temp : 25℃

3) Charge/Discharge current : 60A (0.3C-rate)

Peak voltage has been founded around above 410V.





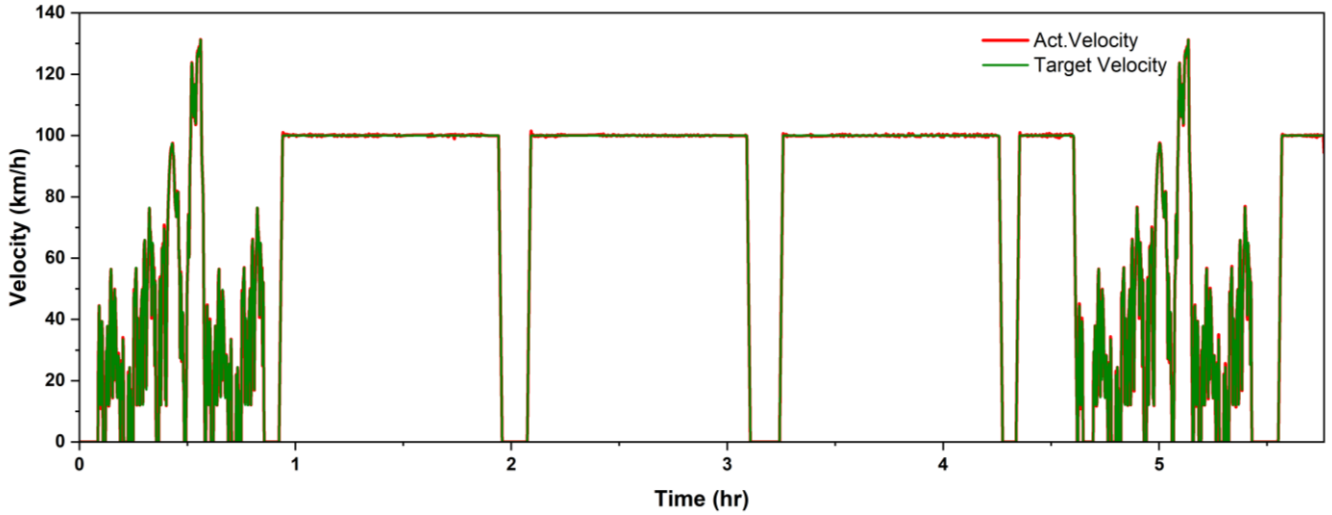
Item	Value
PEV A	61.3kWh (95.8%)
PEV B	60.0kWh (93.7%)

1) RPT(Reference performance test) : This is a test to measure the basic performance of a cell, such as capacity, resistance, or output. It is possible to define how the basic performance deteriorates by measuring RPT at regular intervals and periodically during storage or cycle testing.

Validation results of battery durability at vehicle level

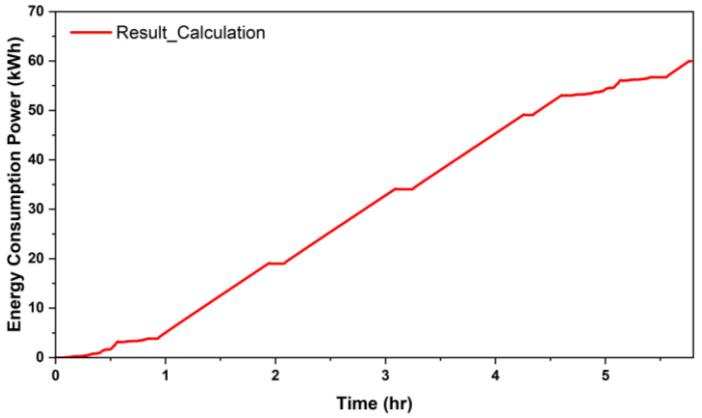
1. PEV A

WLTP (STP) profile of PEV A

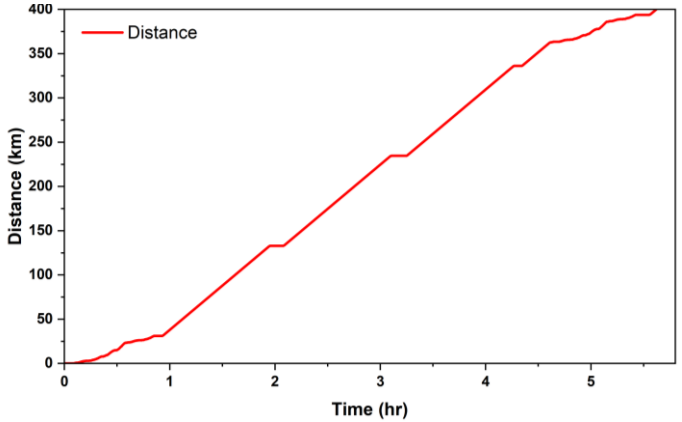


Item	Value
Test date	Feb 22nd
Total elapsed time including rest	5 hours and 46 mins
Mileage	160k km
Distance driven on chassis dynamometer	414.59 km
$UBE_{measured}$ by WLTP (STP)	59.95 kWh
WLTP range (Vehicle spec)	449 km
*Battery energy (Vehicle spec)	*64 kWh

*We put 64 kWh into $UBE_{certified}$ for this test since without certification data, the best estimation we have would be to use the vehicle spec. for the energy of battery pack, 64 kWh



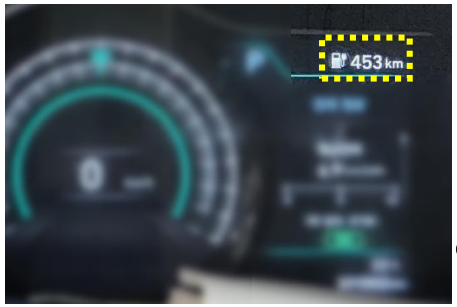
Energy consumption power of PEV A

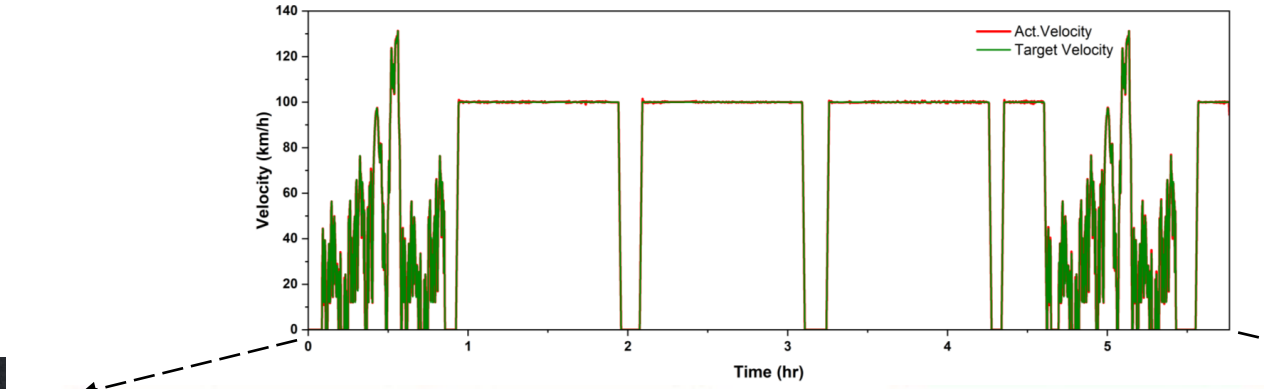


Distance driven of PEV A

Validation results of battery durability at vehicle level

1. PEV A





UBE_{STP}

$$UBE_{measured} = UBE_{STP} = \sum_{k=1}^{n} \Delta E_{REESS.k} = \Delta E_{REESS.DS1} + \Delta E_{REESS.DS2} + \Delta E_{REESS.CSS1} + \Delta E_{REESS.CSS2} \Rightarrow 59.95\ kWh$$

$Distance_{measured}$

$$Distance_{measured} = \sum_{k=1}^{n} D_k = D_{DS1} + D_{DS2} + D_{CSS1} + D_{CSS2} \Rightarrow 414.59\ km$$

DC energy each WLTC

$$EC_{DC.i} = \frac{\Delta E_{REESS.i}}{d_i} \Rightarrow \frac{3.101\ kWh}{23.265\ km} = 0.13329035\ kWh/km$$

$$EC_{DC.j} = \frac{\Delta E_{REESS.j}}{d_j} \Rightarrow \frac{3.013\ kWh}{23.266\ km} = 0.129502278\ kWh/km$$

Weighting factor

$$k_{WLTC1} = \frac{\Delta E_{REESS.WLTC1}}{UBE_{STP}} \Rightarrow \frac{3.101\ kWh}{59.95\ kWh} = 0.051726439$$

$$k_{WLTC2} = 1 - k_{WLTC1} \Rightarrow 1 - 0.051726439 = 0.948273561$$

Estimation of DC energy (WLTC)

$$EC_{DC.WLTC} = \sum_{i=1}^{2} EC_{DC.WLTCi} \times k_{WLTCi} = 0.129698221\ kWh/km$$

Estimation of Pure Electric Range

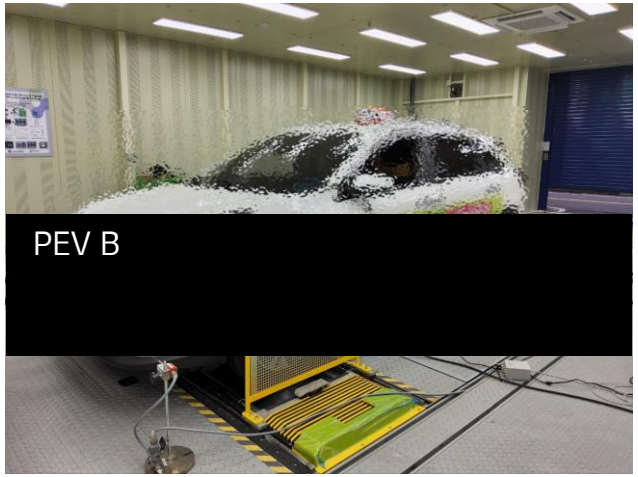
$$PER_{WLTC} = \frac{UBE_{STP}}{EC_{DC.WLTC}} \Rightarrow \frac{59.95\ kWh}{0.129698221\ kWh/km} = 462.2268471\ km$$

$$\mathbf{SOCE_{measured}} = \frac{\mathbf{UBE_{measured}}}{\mathbf{UBE_{certified}}} * \mathbf{100} \Rightarrow \frac{59.95\ kWh}{64\ kWh} \times 100 = 93.67\ \%$$

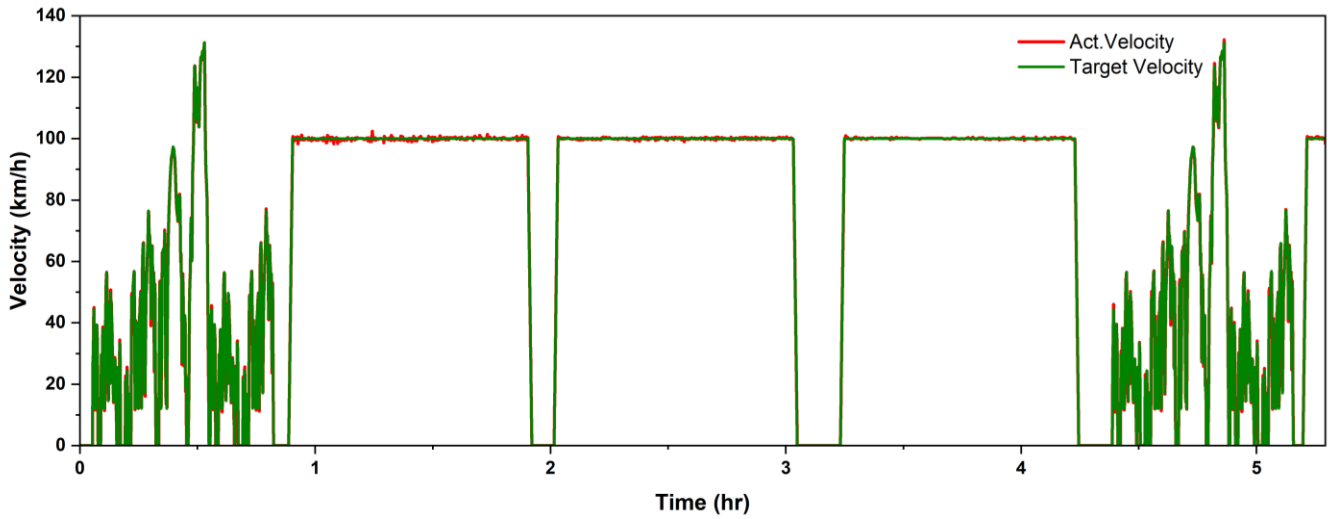
$$\mathbf{SOCR_{measured}} = \frac{\mathbf{Range_{measured}}}{\mathbf{Range_{certified}}} * \mathbf{100} \Rightarrow \frac{462.227\ km}{449\ km} \times 100 = 102.95\ \%$$

Validation results of battery durability at vehicle level

2. PEV B

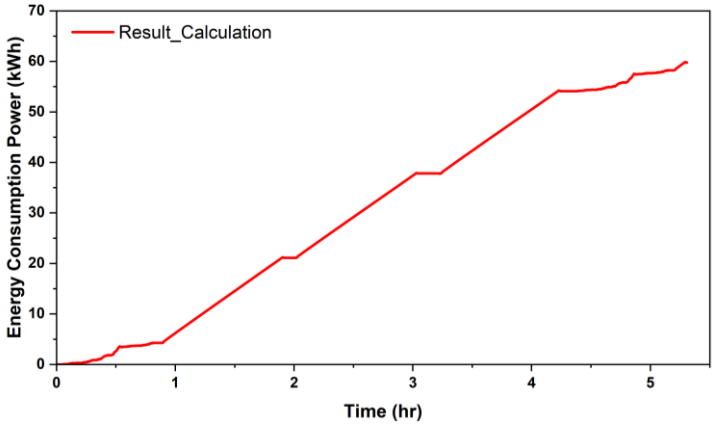


WLTP (STP) profile of PEV B

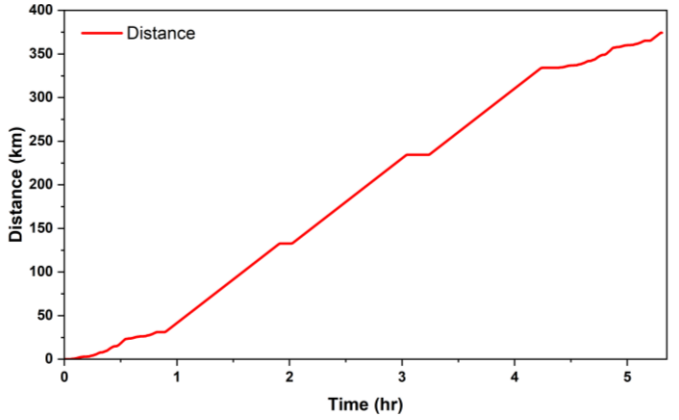


Item	Value
Test date	Feb 1st
Total elapsed time including rest	5 hours and 37 mins
Mileage	220k km
Distance driven on chassis dynamometer	374.29 km
$UBE_{measured}$ by WLTP (STP)	59.83 kWh
WLTP range (Vehicle spec)	455 km
*Battery energy (Vehicle spec)	*64 kWh

*We put 64 kWh into $UBE_{certified}$ for this test since without certification data, the best estimation we have would be to use the vehicle spec. for the energy of battery pack, 64 kWh



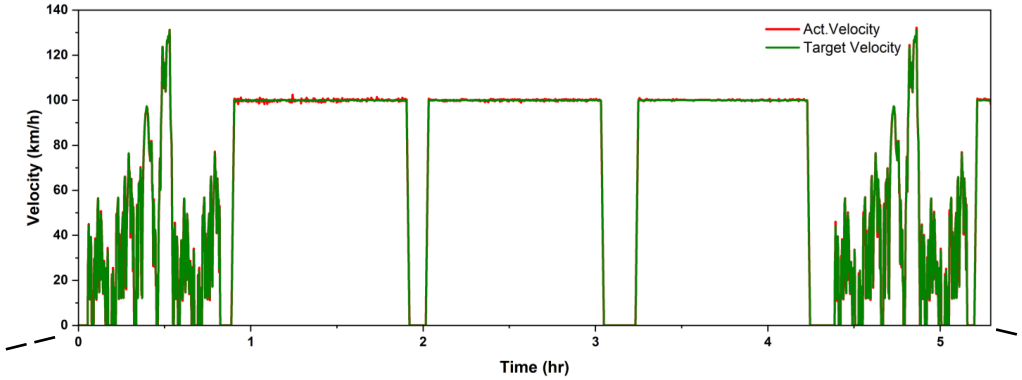
Energy consumption power of PEV B

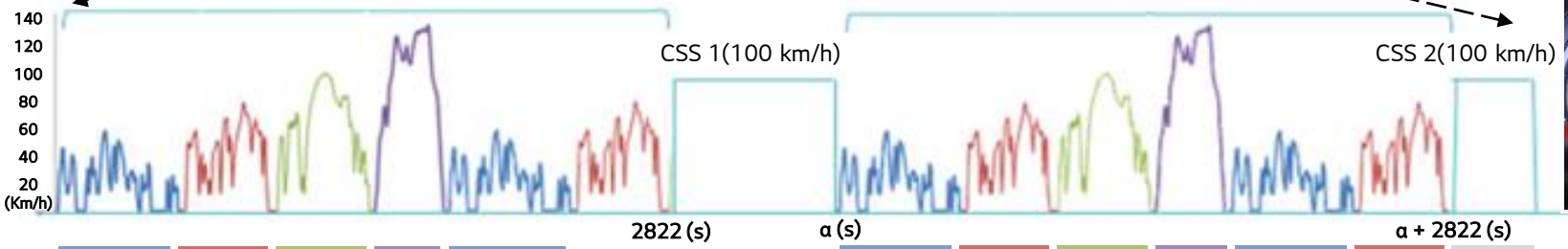


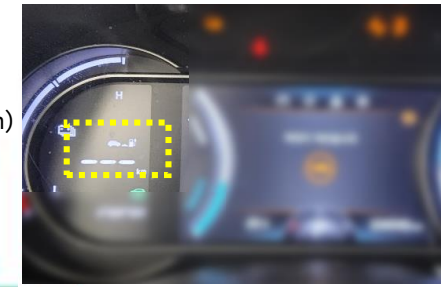
Distance driven of PEV B

Validation results of battery durability at vehicle level

2. PEV B







UBE_{STP}

$$\text{UBE}_{measured} = \text{UBE}_{STP} = \sum_{k=1}^{n} \Delta E_{REESS.k} = \Delta E_{REESS.DS1} + \Delta E_{REESS.DS2} + \Delta E_{REESS.CSS1} + \Delta E_{REESS.CSS2} \Rightarrow 59.83\ kWh$$

$\text{Distance}_{measured}$

$$\text{Distance}_{measured} = \sum_{k=1}^{n} D_k = D_{DS1} + D_{DS2} + D_{CSS1} + D_{CSS2} \Rightarrow 374.29\ km$$

DC energy each WLTC

$$\text{EC}_{DC.i} = \frac{\Delta E_{REESS.i}}{\text{d}_i} \Rightarrow \frac{3.4416\ kWh}{23.239\ \text{km}} = 0.14809\ kWh/km$$

$$\text{EC}_{DC.j} = \frac{\Delta E_{REESS.j}}{\text{d}_j} \Rightarrow \frac{3.30533\ kWh}{23.2\ \text{km}} = 0.14247\ kWh/km$$

Weighting factor

$$\text{k}_{WLTC1} = \frac{\Delta E_{REESS.WLTC1}}{\text{UBE}_{STP}} \Rightarrow \frac{3.4416\ kWh}{59.83\ kWh} = 0.057522982$$

$$\text{k}_{WLTC2} = 1 - \text{k}_{WLTC1} \Rightarrow 1 - 0.057522982 = 0.942477018$$

Estimation of DC energy (WLTC)

$$\text{EC}_{DC.WLTC} = \sum_{i=1}^{2} \text{EC}_{DC.WLTCi} \times \text{k}_{WLTCi} \Rightarrow 0.142795\ kWh/\text{km}$$

Estimation of Pure Electric Range

$$\text{PER}_{WLTC} = \frac{\text{UBE}_{STP}}{\text{EC}_{DC.WLTC}} \Rightarrow \frac{59.83\ kWh}{0.142795\ kWh/\text{km}} = 418.99\ \text{km}$$

$$\mathbf{SOCE_{measured}} = \frac{\mathbf{UBE_{measured}}}{\mathbf{UBE_{certified}}} * \mathbf{100} \Rightarrow \frac{59.83\ kWh}{64\ kWh} \times 100 = 93.48\ \%$$

$$\mathbf{SOCR_{measured}} = \frac{\mathbf{Range_{measured}}}{\mathbf{Range_{certified}}} * \mathbf{100} \Rightarrow \frac{418.99\ km}{455\ km} \times 100 = 92.09\ \%$$

Summary

- Taking into account the mileage, the durability values turned out to be higher than expected.
- The test results are vary slightly, however, in PEV B tests SOCE and SOH are quite similar compared to PEV A's tests.
- We plan to run tests with large quantity to see correlation and tendency of each tests.
- The reason why SOCR is 100% in PEV A test is, we assume, that DC energy each WLTC is somewhat high. And there was no error with data/calculation logic. It could have happened because of human error who drove according to the profile. But it was still within tolerance of GTR15.

DUT	Mileage	Energy	Test 1	Test 2	Test 3	
			Estimated value of SOH (BMS)	Measurement value of energy (Battery pack)	SOCE	SOCR
PEV A	160k km	64kWh	96.52%	61.3kWh/95.8%	93.67%	100%
PEV B	220k km	64kWh	95.89%	60.0kWh/93.7%	93.48%	92.09%