Chroma Turnkey Test & Automation Solution Provider

APPLICATION NOTE

17010 Application Note

How to Use Chroma 17010 for IEC 62660-1 Test Items

April, 2021

Chroma ATE Inc.

(1) Purpose

The IEC 62660-1 standard is an international test standard for lithium-ion secondary batteries in new energy vehicles, including battery electric vehicles (BEV) and hybrid electric vehicles (HEV). It serves to assess the performance of battery cells and its evaluation items include capacity (Ah), power density (W / l), energy density (Wh / l), storage life, and cycle life. Only battery cells that comply with the variety of indicators can be used in new energy battery pack design. This application note will focus on the relevant electrical tests introduced in the IEC 62660-1: 2010 standard, and explain how to implement the test plan using the Chroma 17010 charge and discharge test system.

(2) Equipment Requirements

IEC 62660-1 defines the accuracy of electrical equipment specifications as shown in *Table 1*. All equipment used in the testing process must meet these requirements. All models in the Chroma 17010 test solution can meet the voltage, current, and time specifications; the use of a compliant environmental chamber will ensure that the entire test meets all standard specifications.

Table 1 - Equipment Requirements

Equipment	Test Item	Specification
1. Programmable charge and discharge test equipment	Voltage accuracy	<±0.1% F.S. Voltmeter resistance >1 MΩ/V.
	Current accuracy	<±1% F.S.
	Time accuracy	<±0.1% F.S.
	Temperature accuracy	<±2°C
2. Programmable chamber	-20°C ~ 45°C temperature control	<±2°C
3. Vernier caliper	Measurement accuracy	<±0.1%
4. Electronic balance	Measurement accuracy	<±0.1%

(3) Electrical Test Items

1. General charge conditions (refer to section 7.1 of IEC 62660-1)

1.1 Function: Unless otherwise specified in the standard, the battery cells should be charged as follows before electrical testing.

1.2 Charging procedure: Temperature adjustment (continuous >12hr, or >1hr with battery temperature change <1°C) ➔ Full discharge with specified current (BEV uses 1/3C constant current, HEV uses 1C constant current) ➔ Full charge (following the charging method specified by the manufacturer).

Tip. Use Chroma's Battery Lab Expert (Battery LEx) to edit the charging procedure:

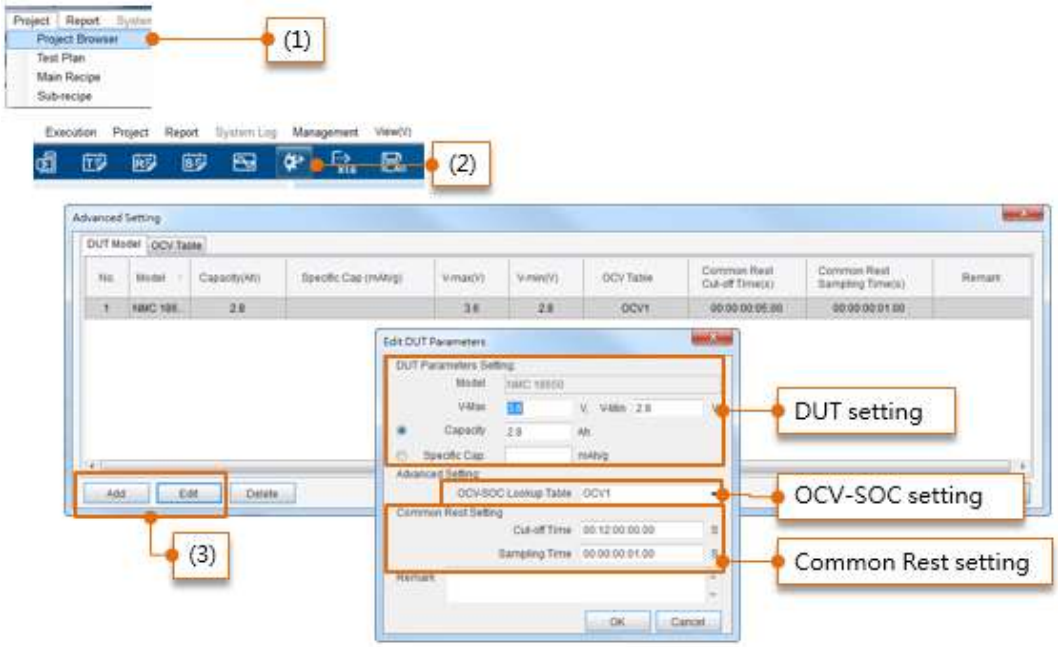

Figure 1 – Set DUT parameters in Battery LEx

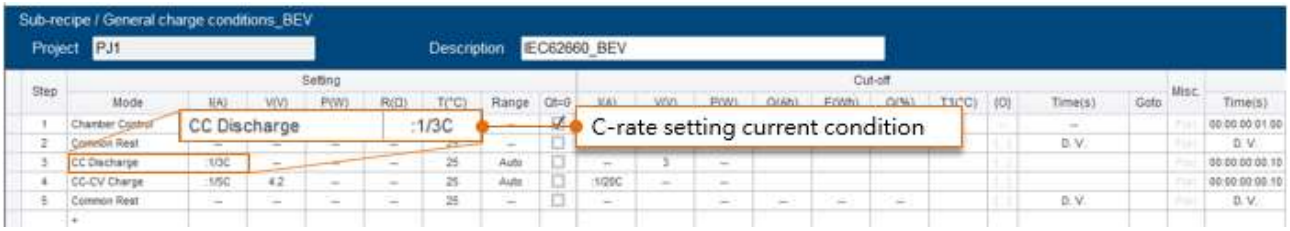

Figure 2 – General charging C-rate method to set current

2. Capacity test (refer to section 7.2 of IEC 62660-1)

2.1 Test procedure: General charge (refer to *Section 1.1*) ➔ Temperature adjustment (0°C/25°C/45°C) ➔ Capacity test (*Table 2* shows the current).

2.2 Verification items: Record the capacity changes at different temperatures.

The capacity test is often used in the initial test stage to define the reference capacity of the battery cell under test as a reference datum for the subsequent current size and cut-off conditions. In order to facilitate the cut-off condition setup, the Q% of the capacity test step can be set to [S] to denote the reference capacity[1].

Tip. Use Chroma's Battery LEx to edit the capacity testing procedure:

Figure 3 – Capacity test: field [S] represents reference capacity 1

Note 1. The [S] setting can cover SR, MR as the reference capacity; if you repetitively set [S], it will take the refresh step as the reference.

Table 2 - IEC62660 Discharge Conditions

	Discharge Current (A)	
Temperature	**BEV Application**	**HEV Application**
0°C	1/3 C	1 C
25°C		
45°C		

3. SOC adjustment (refer to section 7.3 of IEC 62660-1)

3.1 Test procedure: General charge (refer to *Section 1.1*) ➔ Rest ➔ SOC adjustment.

Tip. Use Chroma's Battery LEx to edit the SOC adjustment procedure:

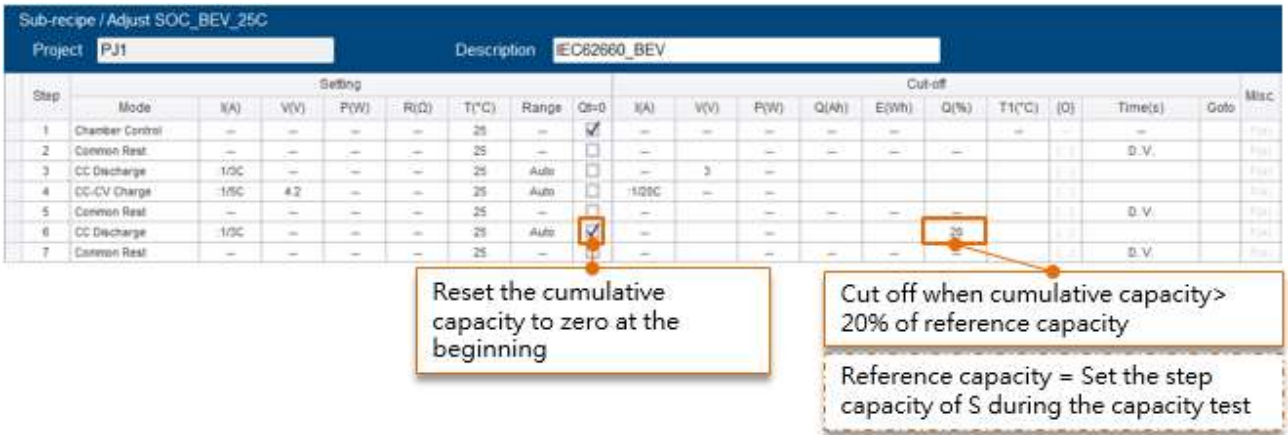

Figure 4 – SOC adjustment 80%: set discharge step Q% to [20%]

4. Power test (refer to section 7.4 of IEC 62660-1)

4.1 Test procedure:

[Step A] Mass measurement ➔ Dimension measurement.

[Step B] SOC adjustment (20%/50%/80%) (refer to *Section 3.1*) ➔ Temperature adjustment (45°C/25°C/0°C/-20°C) ➔ Current pulse discharge (*Table 3* shows the current).

4.2 Verification items: Record the power output capacity under different SOC& temperatures, and calculate the following parameters:

- Power $P_d = U_d \times I_{dmax}$
  - P_d: power (W)
  - U_d: measured voltage (V) at the end of the 10s pulse of I_{dmax} discharge
  - I_{dmax}: maximum discharge current (A) as specified by the manufacturer
- Power density per unit mass $\rho_{pd} = \frac{P_d}{m}$
  - ρ_{pd}: power density (W / kg)
  - P_d: power (W)
  - m: mass of cell (kg)
- Power density per unit volume $\rho_{pvlm} = \frac{P_d}{V}$
  - ρ_{pvlm}: volumetric power density (W / l)
  - P_d: power (W)
  - V: volume of cell (l)
- Regenerative power $P_c = U_c \times I_{cmax}$
  - P_c: regenerative power (W)
  - U_c: measured voltage (V) at the end of the 10s pulse of I_{cmax} charge
  - I_{cmax}: maximum charge current (A) as specified by the manufacturer
  - If P_c is an estimated value, it must be stated.
- Regenerative power density per unit mass $\rho_{pc} = \frac{P_c}{m}$

ρ_{pc}: regenerative power density (W / kg)
P_c: regenerative power (W)
m: mass of cell (kg)

- Regenerative power density per unit volume $\rho_{pvlmc} = \frac{P_c}{V}$

  ρ_{pvlmc}: regenerative volumetric power density (W / l)
  P_c: regenerative power (W)
  V: volume of cell (l)

Table 3 – Charge and Discharge Current

Application	Charge and Discharge Current (A)				
BEV	1/3I_t	1I_t	2I_t	5I_t	I_{max}
HEV	1/3I_t	1I_t	5I_t	10I_t	I_{max}

Tip. Use Chroma's Battery LEx to edit the power testing procedure:

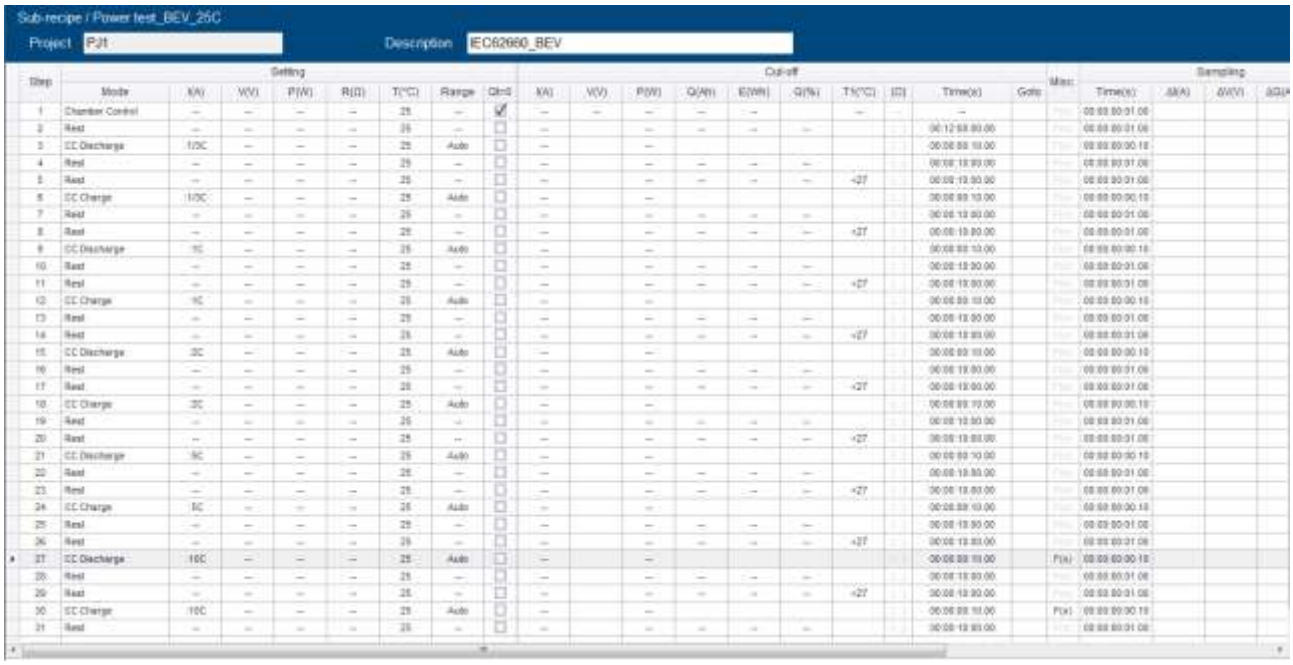

Figure 5 – Edit sub-recipe power test in Battery LEx

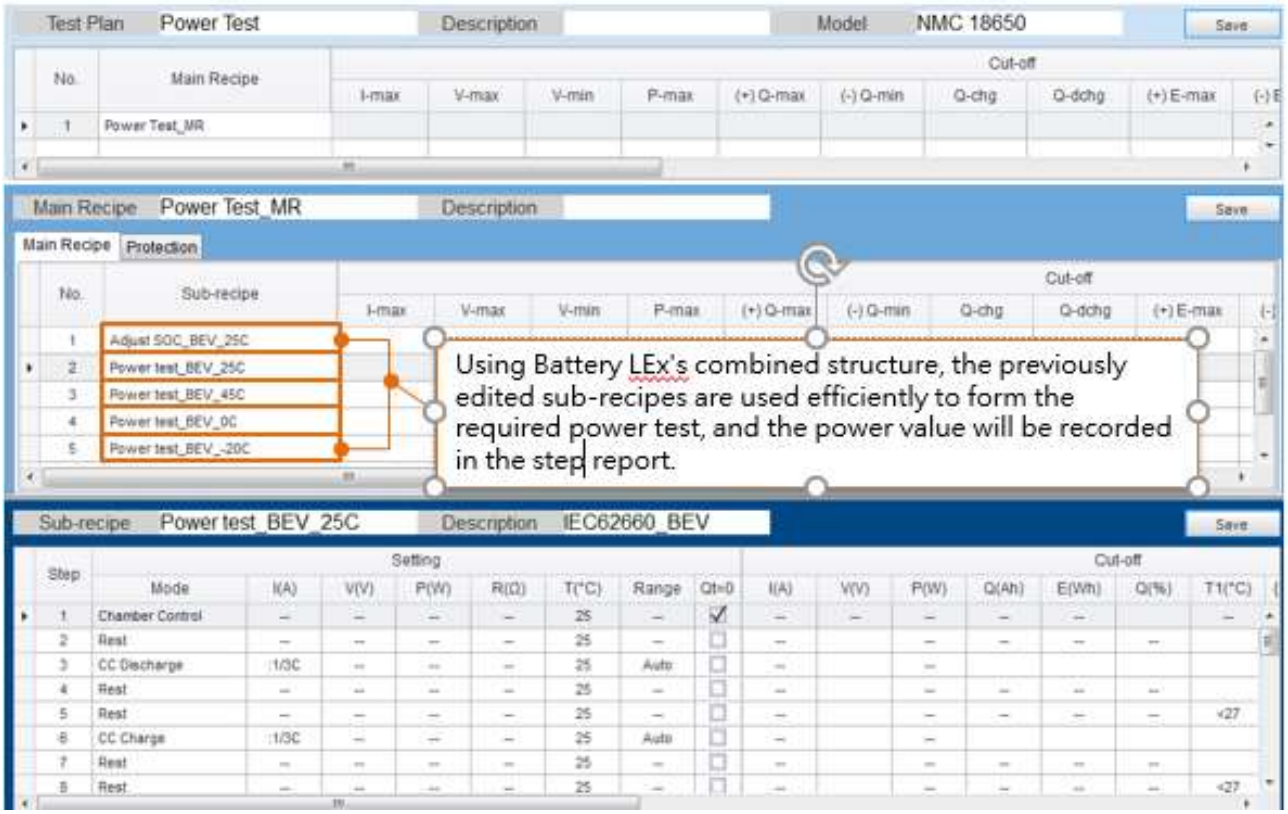

Figure 6 – Compose multi-level power test at 45°C/25°C/0°C/-20°C in Battery LEx

5. Energy test (refer to section 7.5 of IEC 62660-1)

5.1 Test procedure:
[Step A] Battery mass measurement ➔ Battery volume measurement.
[Step B] Capacity test (refer to *Section 2.1*).

5.2 Verification items: Record the average voltage, energy density per unit mass, and energy density per unit volume. Use the channel report to calculate the average voltage and battery energy. Next, calculate the energy density per unit mass and the energy density per unit volume.

- Average voltage $U_{avr} = \frac{U_1+U_2+\ldots+U_n}{n}$

  In the capacity test, obtain the average voltage value during discharge by integrating the discharge voltage over time and dividing by the discharge duration. Use the following method to easily calculate the average voltage: note the discharge voltages U_1, U_2, …, U_n every 5s from the start of the discharge, voltages that cut off the end of discharge voltage in less than 5s are discarded.

- Energy density per unit mass $W_{ed} = C_d \times U_{avr}$

  W_{ed}: electric energy of cell (Wh)
  C_d: discharge capacity (Ah) at 1/3 I_t (A) for BEV or 1I_t (A) for HEV
  U_{avr}: average voltage during discharging (V)
  $\rho_{ed} = \frac{W_{ed}}{m}$
  ρ_{ed}: mass energy density (Wh/kg)
  W_{ed}: electric energy of cell (Wh)
  m: mass of cell (kg)

- Energy density per unit volume $\rho_{pvlmd} = \frac{W_{ed}}{V}$

  ρ_{evlmd}: volumetric energy density (Wh / l)
  W_{ed}: electric energy of cell (Wh)
  V: volume of cell (l)

6. Storage test (refer to section 7.6 of IEC 62660-1)

6.1 Charge retention test (refer to paragraph 7.6.1 of IEC 62660-1)

6.1.1 Test procedure: SOC adjustment (50%) (refer to *Section 3.1*) ➔ Capacity test C_b ➔ SOC adjustment (50%) ➔ Temperature adjustment (45°C ±2°C) ➔ Rest 28 days ➔ Capacity test C_r.

6.1.2 Verification items: Calculate the charge retention rate.

- Charge retention ratio $R = \frac{Cr}{Cb} \times 100\%$

  R: charge retention ratio (%)
  C_r: capacity of cell after storage (Ah)
  C_b: capacity of cell before storage (Ah)

Tip. Use Chroma's Battery LEx to edit the storage testing procedure:

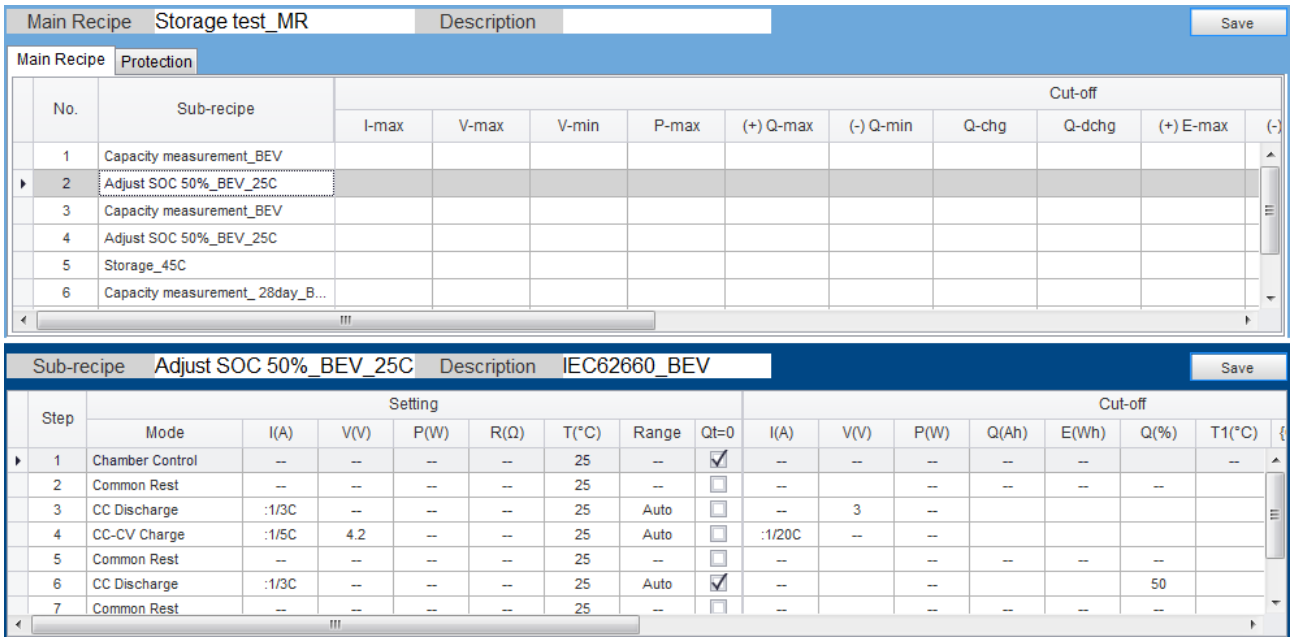

Figure 7 – Use sub-recipe to compose charge retention test in Battery LEx

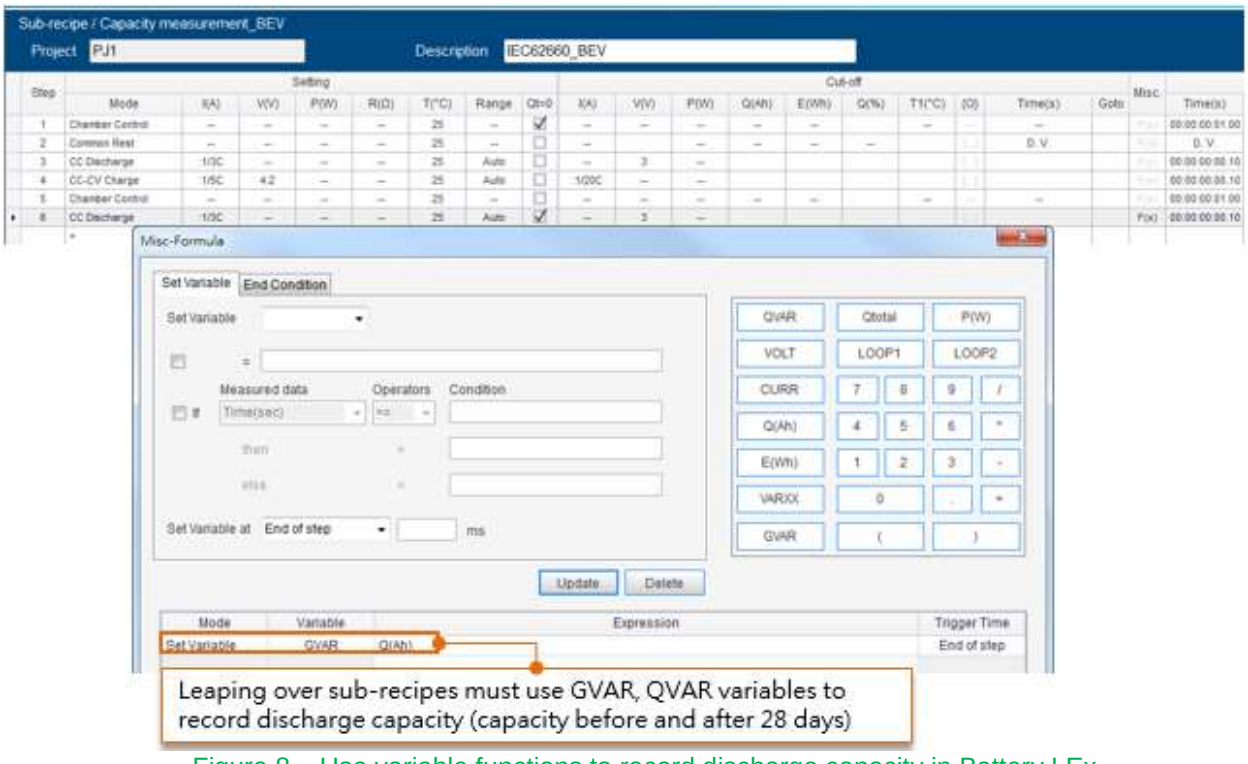

Figure 8 – Use variable functions to record discharge capacity in Battery LEx

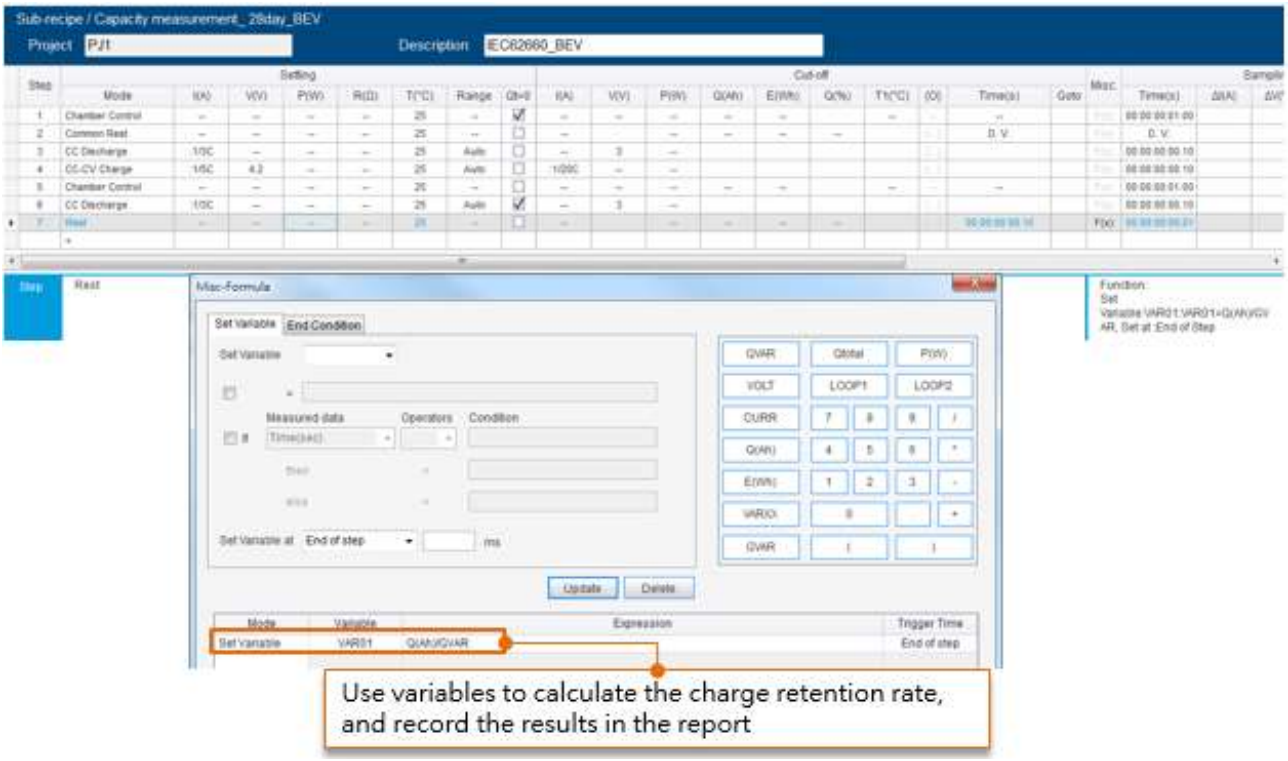

Figure 9 – Calculate the charge retention ratio (%)

6.2 Storage life test (refer to paragraph 7.6.2 of IEC 62660-1)

6.2.1 Test procedure:

[Step A] Battery mass measurement ➔ Battery volume measurement.

[Step B] Capacity test (refer to *Section 2.1*) ➔ Power test (refer to *Section 4.1*) ➔ SOC adjustment (BEV to 100%, HEV to 50%) (refer to *Section 3.1*) ➔ Temperature adjustment (45°C ±2°C) ➔ Rest 42 days ➔ Capacity test ➔➔ Repeat [Step B] three times.

6.2.2 Verification items: Report the capacity, power density, regenerative power density, and retained capacity.

Tip. Use Chroma's Battery LEx to edit the storage life testing procedure:

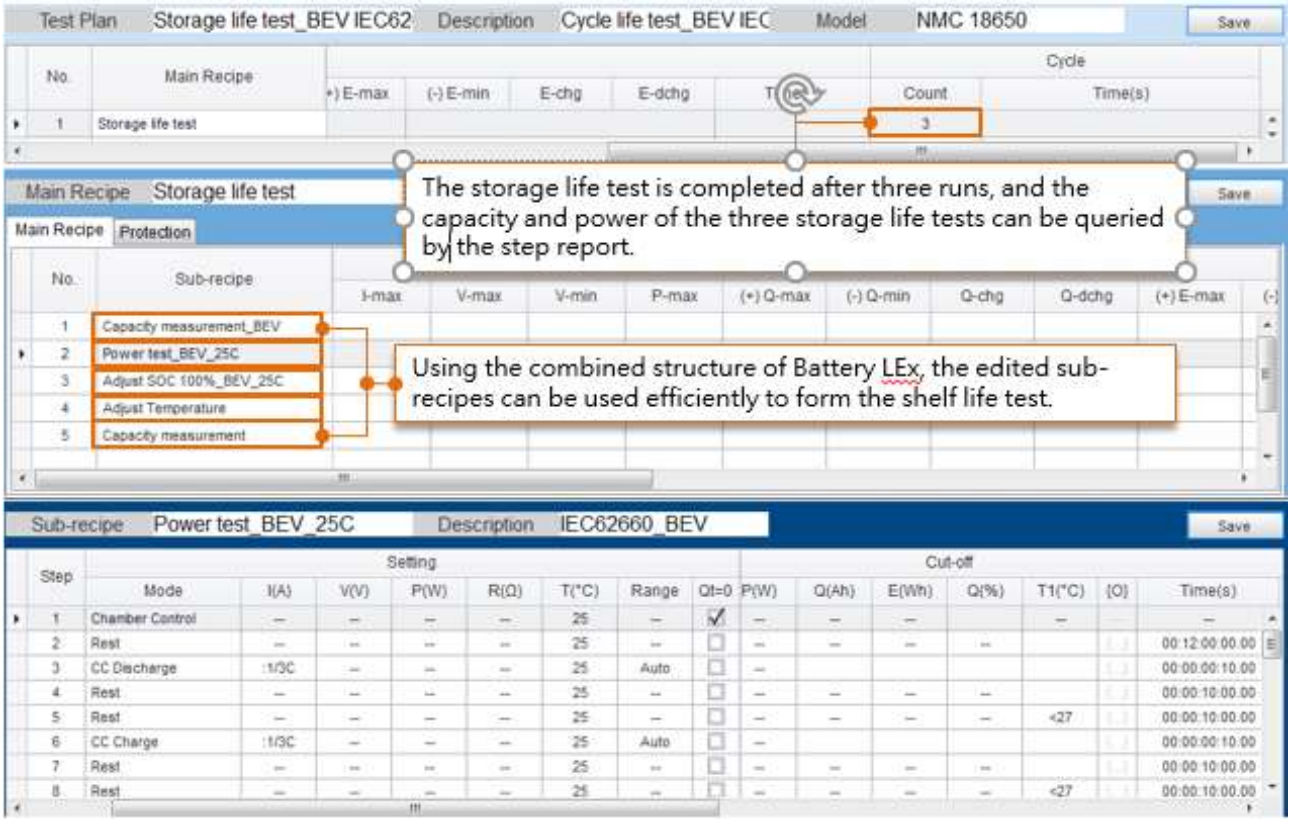

Figure 10 – Set the Battery LEx storage life test

7. Cycle life test (refer to section 7.7 of IEC 62660-1)

7.1 BEV cycle life test (refer to paragraph 7.7.1 of IEC 62660-1)

7.1.1 Test procedure:

[Step A] Capacity test (refer to *Section 2.1*) ➔ Dynamic discharge capacity test C_D (*Table 4* shows dynamic discharge profile A) ➔ Power test at (25°C/45°C), 50% SOC (refer to *Section 4.1*).

[Step B] Temperature adjustment (45°C ±2°C) ➔ General charge (refer to *Section 1.1*) ➔ Discharge continuously according to the dynamic discharge profile A in *Table 4* (until dynamic discharge capacity reaches C_D DOD 50%) ➔ Single discharge according to the dynamic discharge profile B in *Table 5* ➔ Discharge continuously according to the dynamic discharge profile A in *Table 4* (until dynamic discharge capacity reaches C_D DOD 80%) ➔➔ Continuously repeat [Step B] for 28 days, then a single repeat of [Step A] (battery performance check) ➔➔➔ Continuous cycling until the test cut-off condition.

■ **Test cut-off conditions**

The cycle life test shall be terminated when either of the following conditions is satisfied. Otherwise, repeat the test procedure.
Condition A – The test procedure is repeated 6 times.
Condition B – When any performance decreased to less than 80% of the initial value.
Condition C – During the test, the battery reached the upper temperature limit defined by the manufacturer.

7.1.2 Verification items: Battery life evaluation based on the overall charge and discharge capacity (throughput).

Table 4 – Dynamic Discharge Profile A for BEV Cycle Test

Step	Duration (s)	Ratio to test power (%)	Charge/discharge
1	16	0	
2	28	12.5	Discharge
3	12	25	Discharge
4	8	-12.5	Charge
5	16	0	
6	24	12.5	Discharge
7	12	25	Discharge
8	8	-12.5	Charge
9	16	0	
10	24	12.5	Discharge
11	12	25	Discharge
12	8	-12.5	Charge
13	16	0	
14	36	12.5	Discharge
15	8	100	Discharge
16	24	62.5	Discharge
17	8	-25	Charge
18	32	25	Discharge
19	8	-50	Charge
20	44	0	

Table 5 – Dynamic Discharge Profile B for BEV Cycle Test

Step	Duration (s)	Ratio to test power (%)	Charge/discharge
1	16	0	
2	28	12.5	Discharge
3	12	25	Discharge
4	8	-12.5	Charge
5	16	0	
6	24	12.5	Discharge
7	12	25	Discharge
8	8	-12.5	Charge
9	16	0	
10	24	12.5	Discharge
11	12	25	Discharge
12	8	-12.5	Charge
13	16	0	
14	36	12.5	Discharge
15	8	100	Discharge
16	24	62.5	Discharge
17	8	-25	Charge
18	32	25	Discharge
19	8	-50	Charge
20	44	0	

Tip. Use Chroma's Battery LEx to edit the BEV cycle testing procedure:

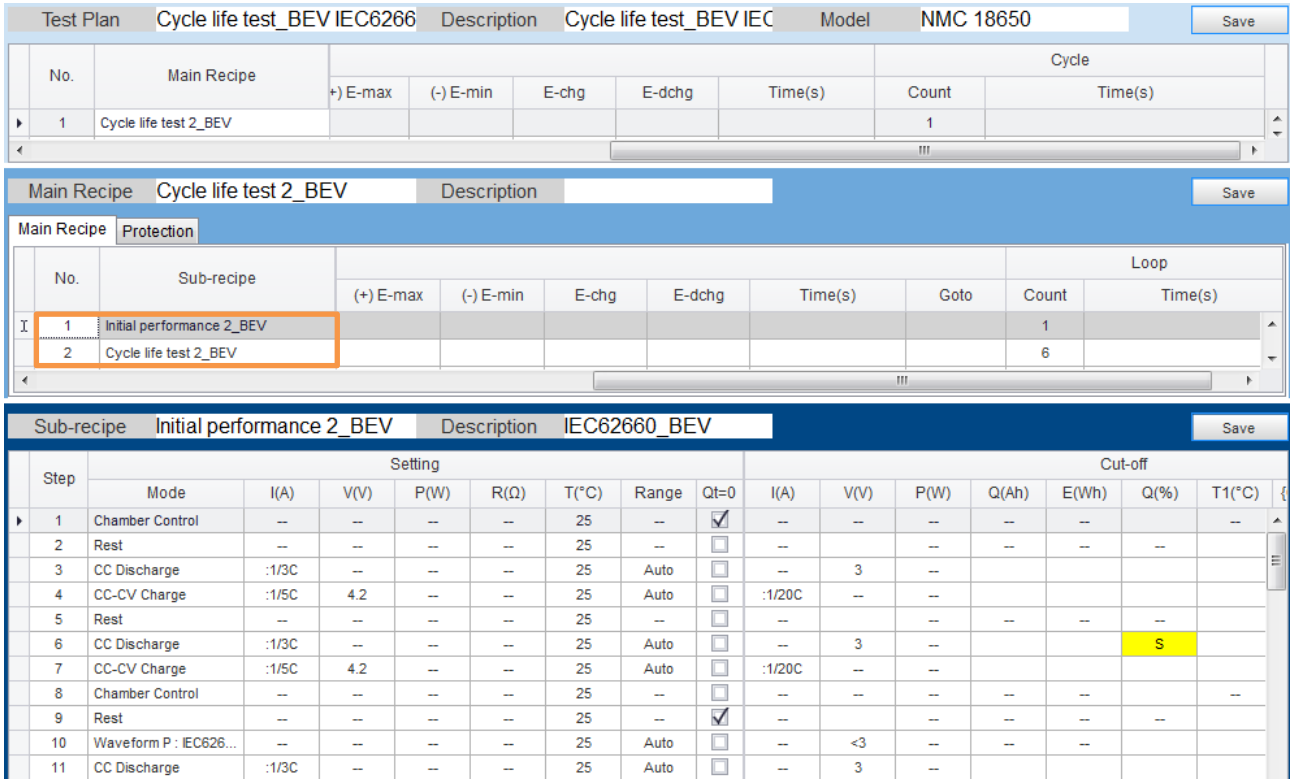

Figure 11 – Compose BEV cycle test sub-recipe 1 initial performance test & sub-recipe 2 cycle test

Edit the initial performance test for sub-recipe 1:

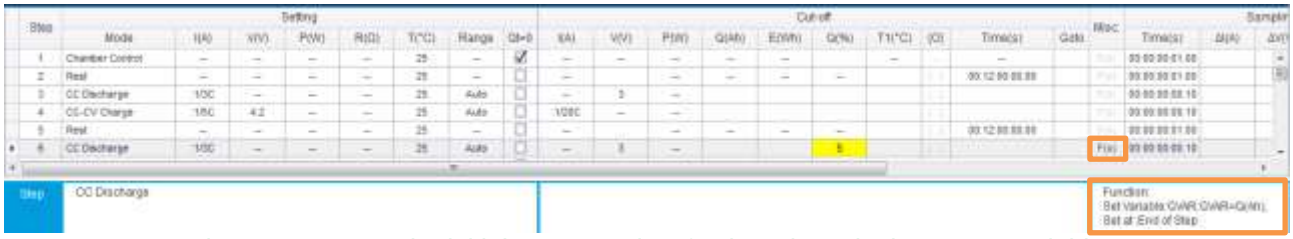

Figure 12 – Store the initial test capacity of sub-recipe 1 in the GVAR variable

Figure 13 – Store the initial test dynamic capacity of sub-recipe 1 in the QVAR variable

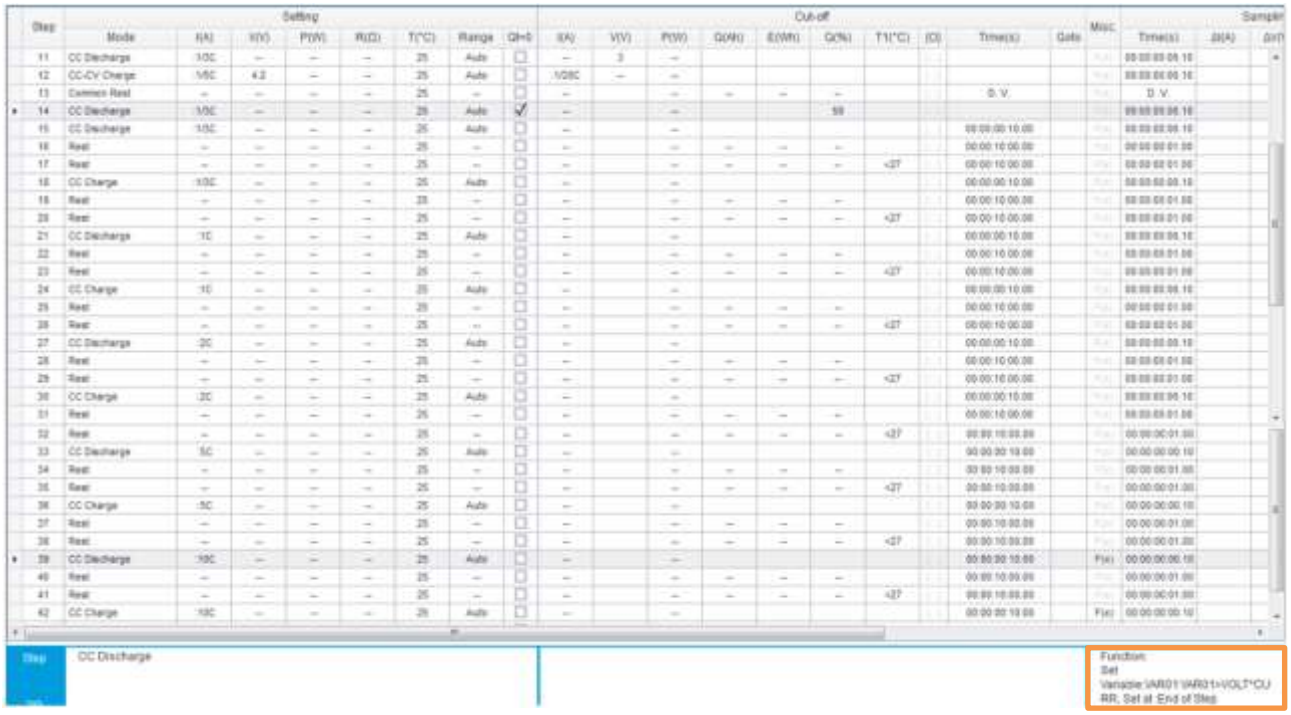

Figure 14 – Sub-recipe 1 initial power test (25°C 50% SOC)

Test in stages. The data obtained from the initial performance test of sub-recipe 1 will be used in the editing of the cycle test in sub-recipe 2. For example, **the power measurement value in sub-recipe 1 must be manually incorporated into the the output power calculation of the dynamic discharge profile A and the dynamic discharge profile B**, and is used as a cut-off parameter for the cycle.

Edit the cycle test for sub-recipe 2:

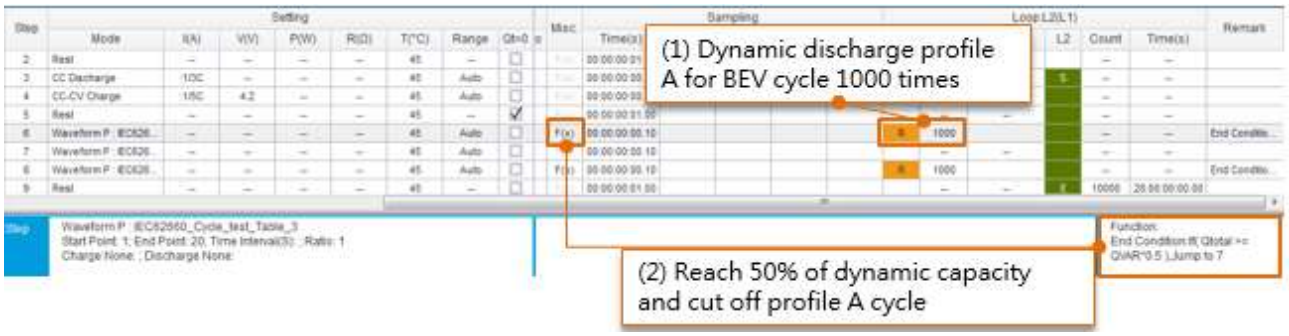

Figure 15 – Set sub-recipe 2 dynamic discharge profile A to cycle until it is equal to DOD 50% of the initial dynamic discharge capacity C_D

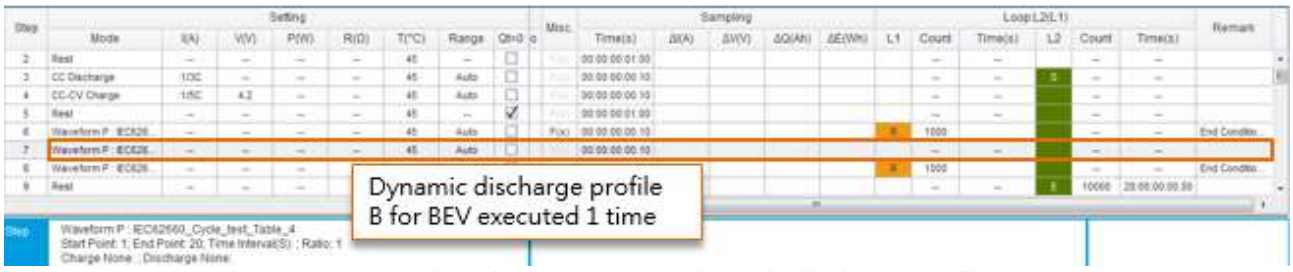

Figure 16 – Set sub-recipe 2 to perform dynamic discharge profile B once

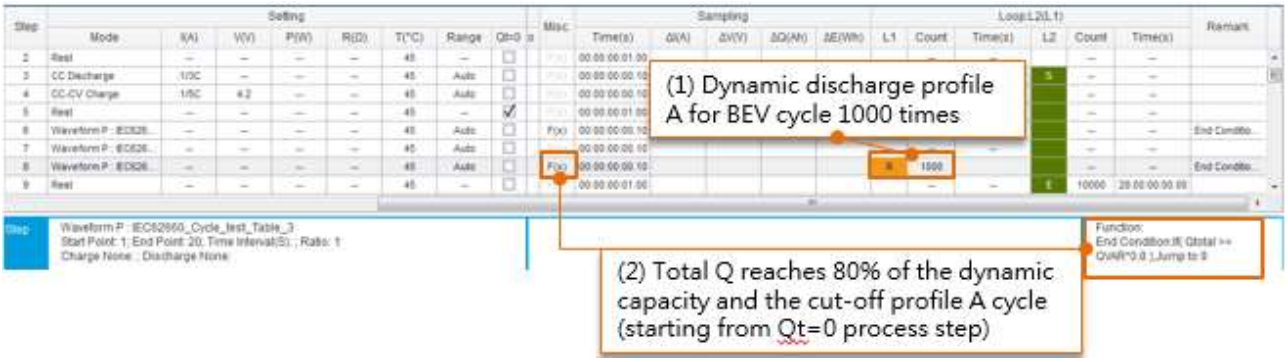

Figure 17 – Set sub-recipe 2 dynamic discharge profile A to cycle until it is equal to DOD 80% of the dynamic discharge capacity C_D

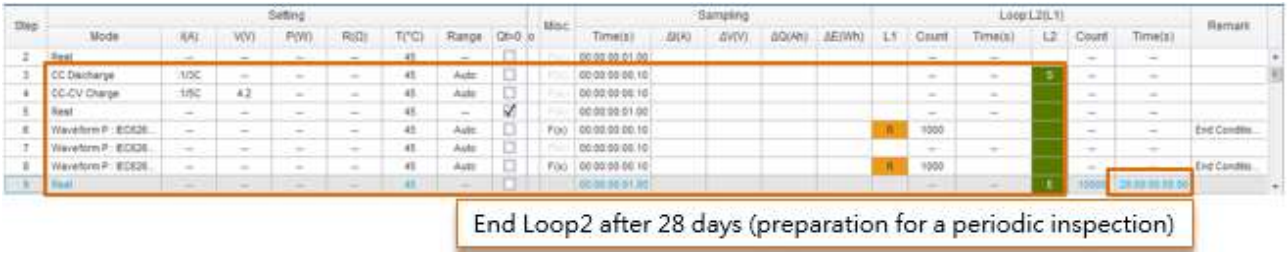

Figure 18 – Set sub-recipe to repeat 28 days

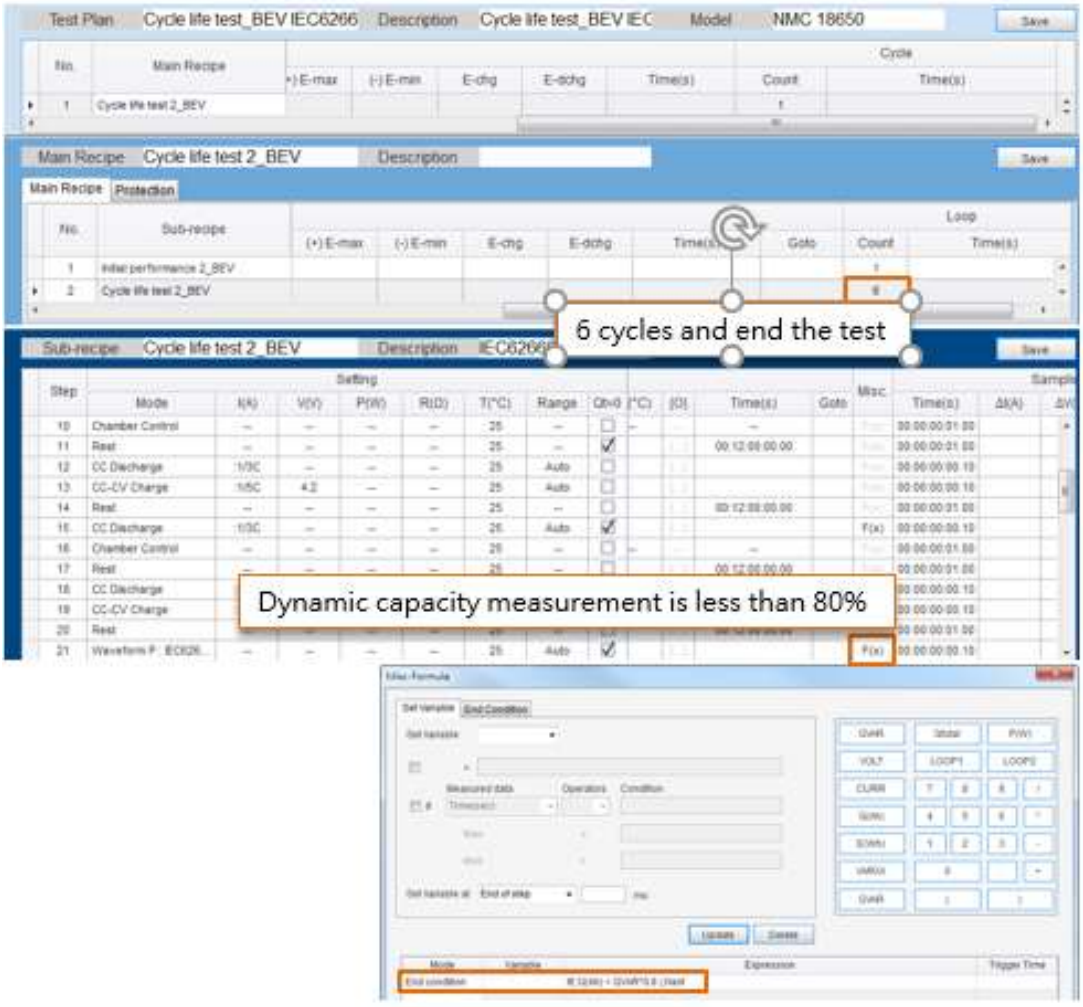

Figure 19 – Set cut-off conditions

7.2 HEV cycle test (refer to section 7.7.2 of IEC 62660-1)

7.2.1 Test procedure:

[Step A] Capacity test (refer to *Section 2.1*) ➔ Power test (refer to *Section 4.1*).

[Step B] General charge (refer to *Section 1.1*) ➔ SOC adjustment (30%) ➔ Temperature adjustment (45°C ±2°C) ➔ Single measurement of lower limit switching voltage at the discharge-rich profile (refer to *Table 6*) ➔ General charge (refer to *Section 1.1*) ➔ SOC adjustment (80%) ➔ Temperature adjustment (45°C ±2°C) ➔ Single measurement of upper limit switching voltage at charge-rich profile (refer to *Table 7*).

[Step C] Temperature adjustment (45°C ±2°C) ➔ General charge (refer to *Section 1.1*) ➔ SOC adjustment (80%) ➔ Repeated discharge through the discharge-rich profile (refer to *Table 6*) until it reaches the lower limit of the switching voltage ➔ Repeated discharge through the charge-rich profile (refer to *Table 7*) until it reaches the upper limit of the switching voltage ➔➔ Repeat for 22hr ➔ Rest for 2hr ➔➔➔ Repeat every 7 days to measure power; repeat every 14 days to measure capacity ➔➔➔ Continue repeating [Step C] until either of the cut-off conditions is met.

■ **Test cut-off conditions**

The cycle life test shall be terminated when either of the following conditions is satisfied. Otherwise, repeat the test procedure.

Condition A – The test procedure is repeated for 6 months.

Condition B – When any performance decreased to less than 80% of the initial value.

7.2.2 Verification items: Report the number of profile implementations as in *Table 6* and *Table 7* and the number of times the switching voltage is reached. Finally, **evaluate the battery life based on the overall charge and discharge capacity (throughput).**

Table 6 Discharge-rich Profile for HEV Cycle Test

Step	Duration (s)	Current (A)	Charge/discharge
1	5	20	Discharge
2	10	10	Discharge
3	32	5	Discharge
4	20	0	
5	5	-15	Charge
6	10	-10	Charge
7	37	-5	Charge
8	20	0	
9	5	15	Discharge
10	10	10	Discharge
11	37	5	Discharge
12	20	0	
13	5	-12.5	Charge
14	7	-7.5	Charge
15	35	-5	Charge
16	42	0	

Table 7 Charge-rich profile for HEV cycle test

Step	Duration (s)	Current (A)	Charge/discharge
1	5	-15	Charge
2	10	-10	Charge
3	37	-5	Charge
4	20	0	
5	5	20	Discharge
6	10	10	Discharge
7	32	5	Discharge

8	20	0	
9	5	-12.5	Charge
10	7	-7.5	Charge
11	49	-5	Charge
12	20	0	
13	5	15	Discharge
14	10	10	Discharge
15	23	5	Discharge
16	42	0	

Tip. Use Chroma's Battery LEx to edit the HEV cycle testing procedure:

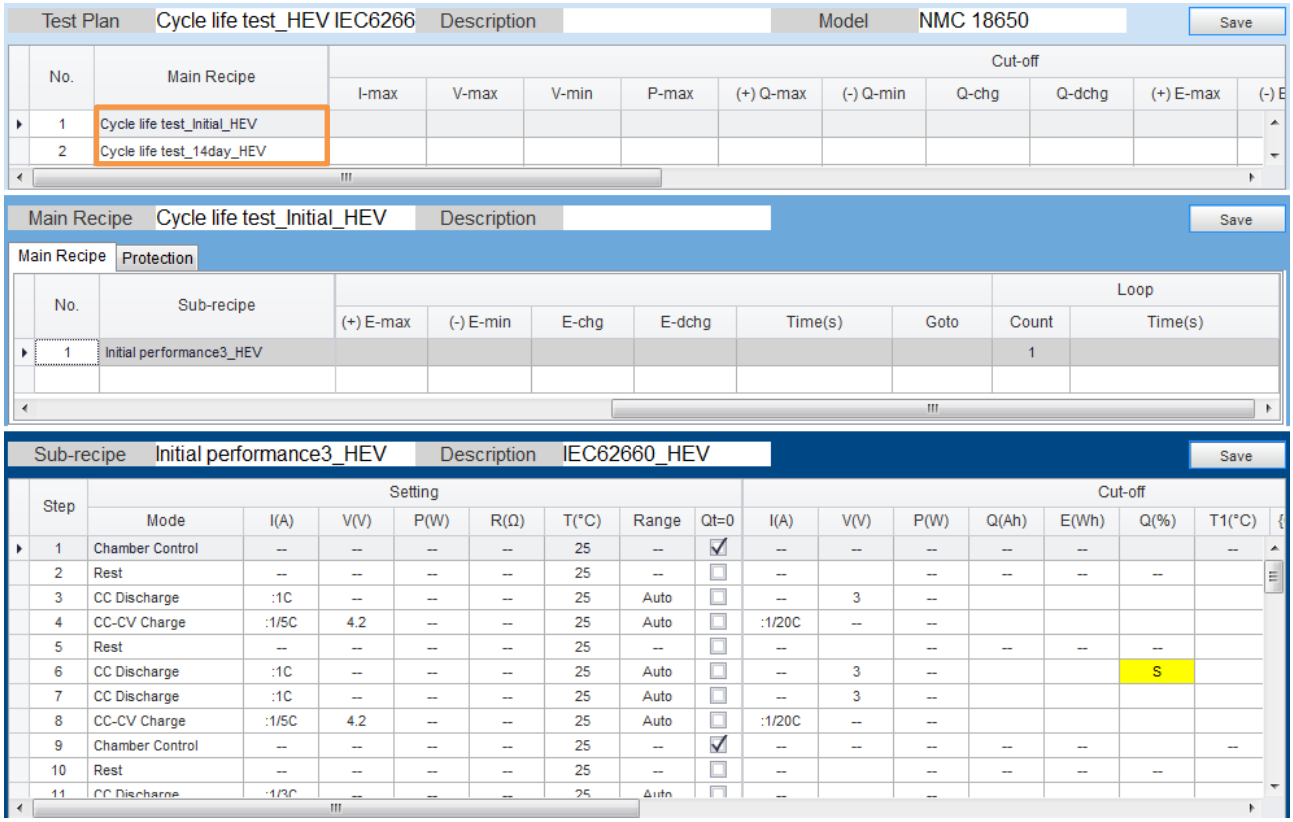

Figure 20 – Compose HEV cycle test main recipe 1 initial performance & main recipe 2 cycle test

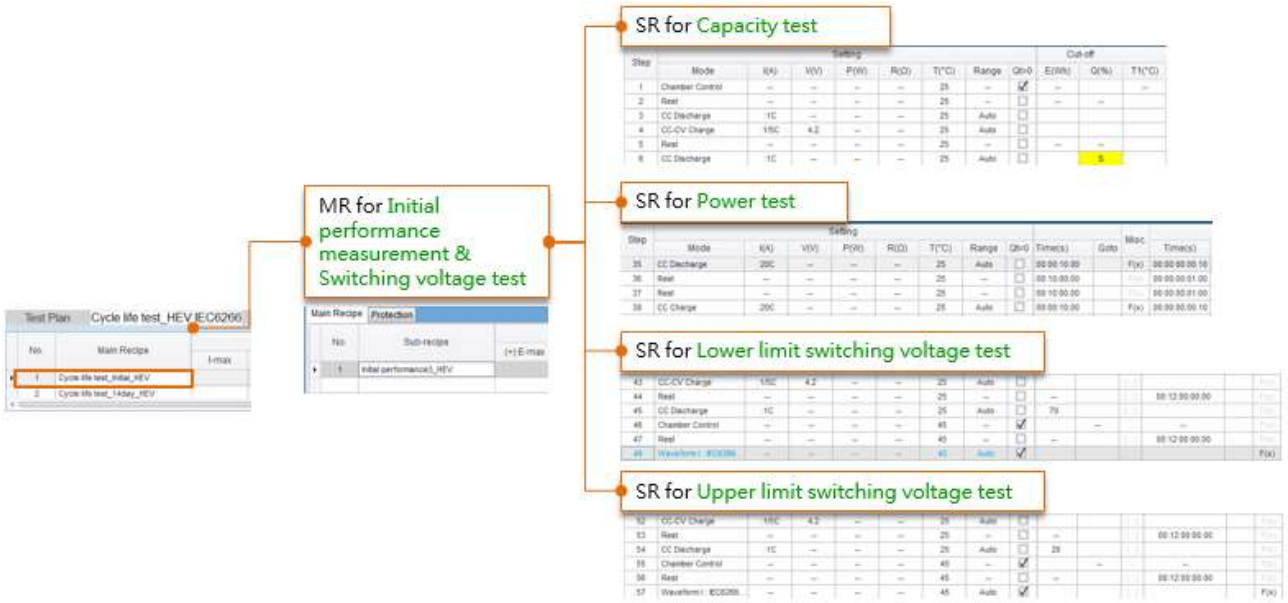

Figure 21 – Architecture diagram for main recipe 1 initial performance test

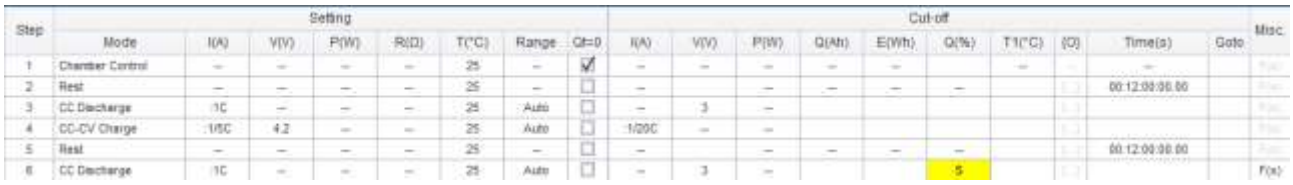

Figure 22 – Use the Q% function to set the reference volume

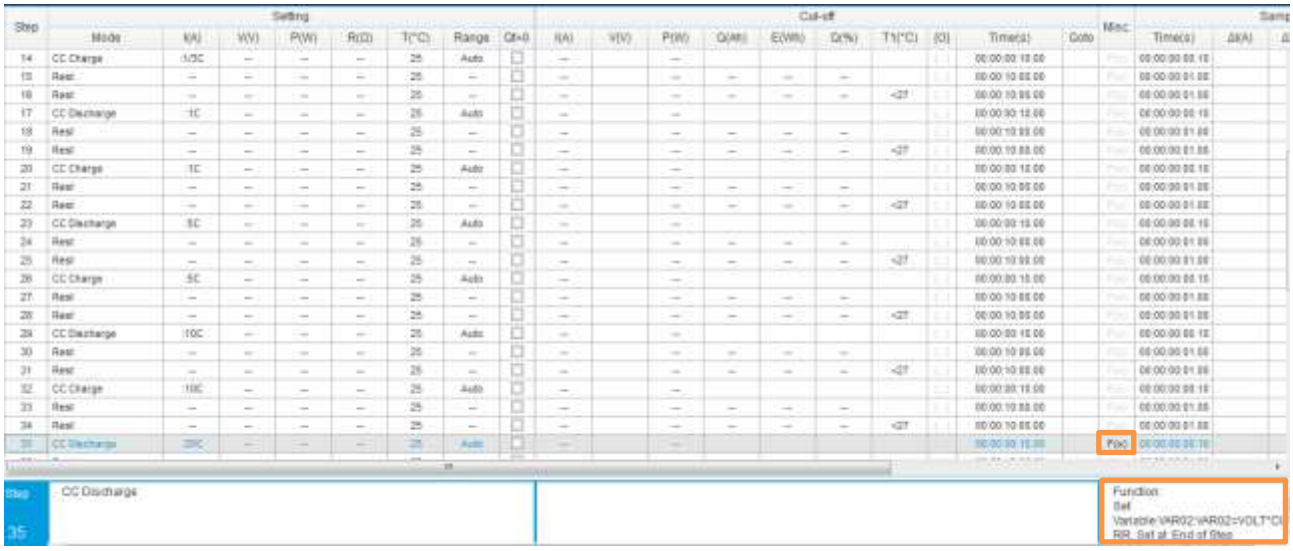

Figure 23 – Use the variable function to calculate the power test data automatically

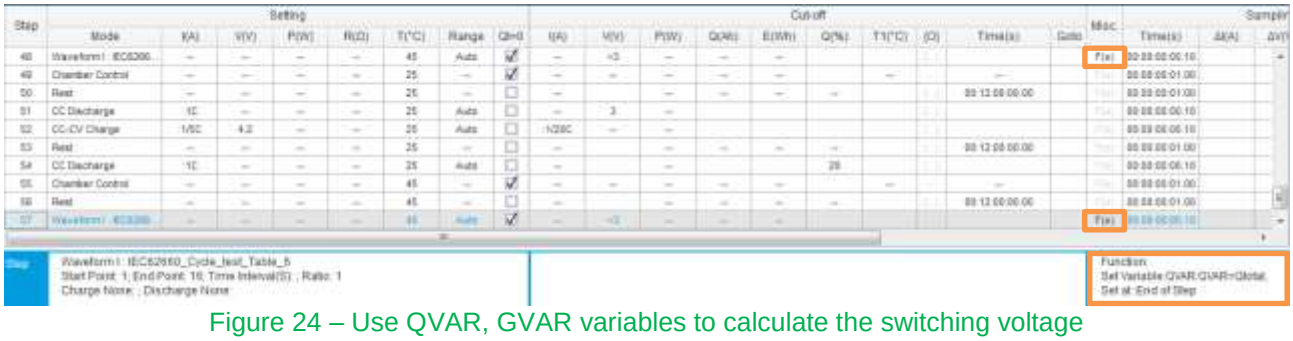

Figure 24 – Use QVAR, GVAR variables to calculate the switching voltage

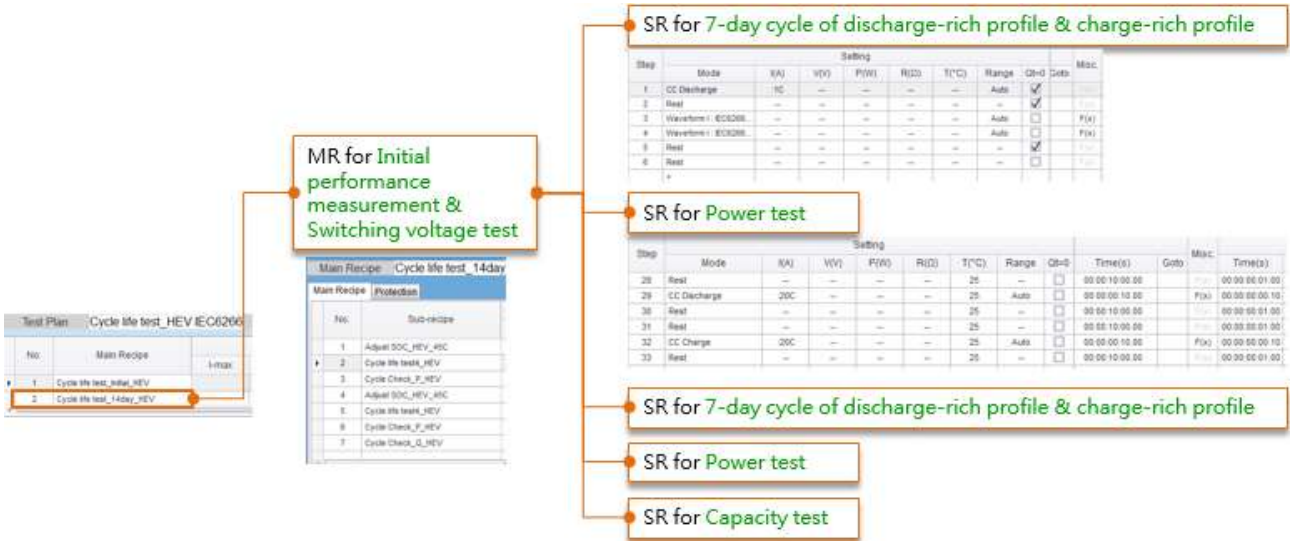

Figure 25 – Architecture diagram for main recipe 2 cycle test

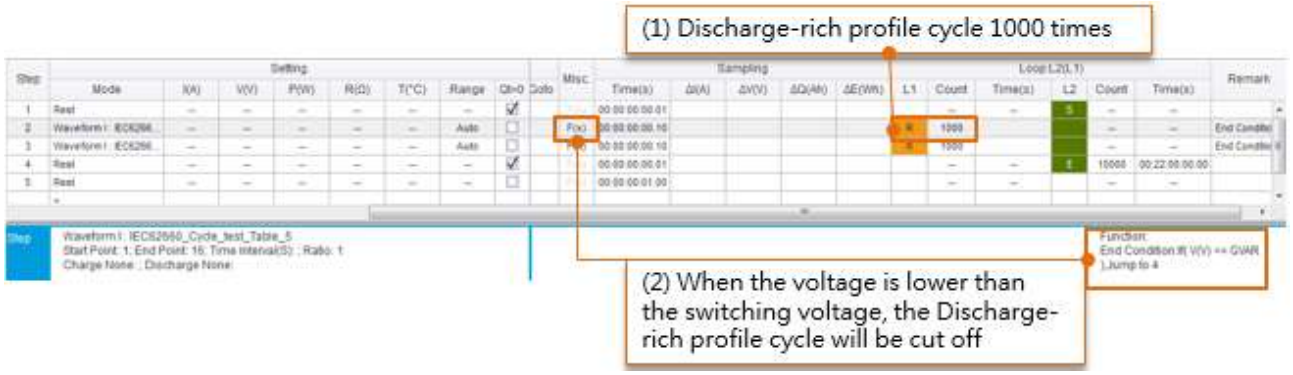

Figure 26 – Edit the discharge-rich profile until it reaches the lower limit of the switching voltage

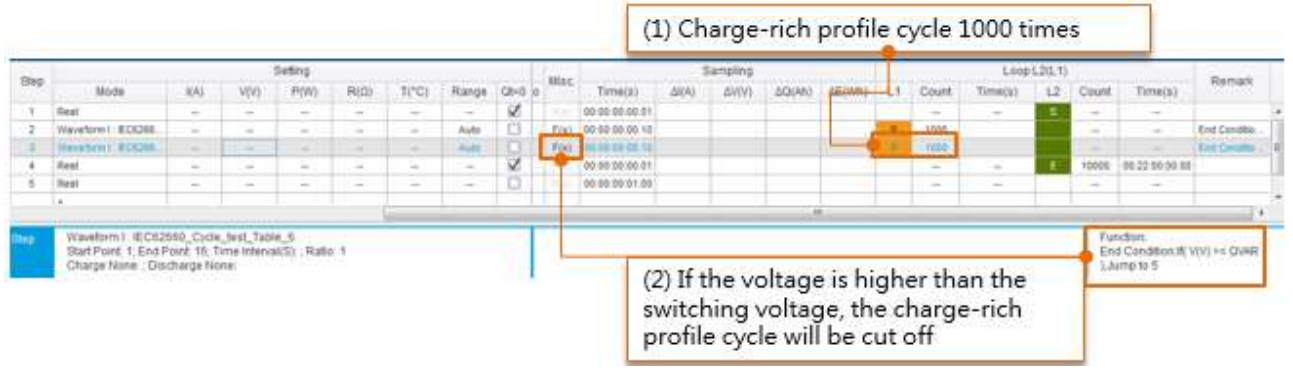

Figure 27 – Edit the charge-rich profile until it reaches the upper limit of the switching voltage

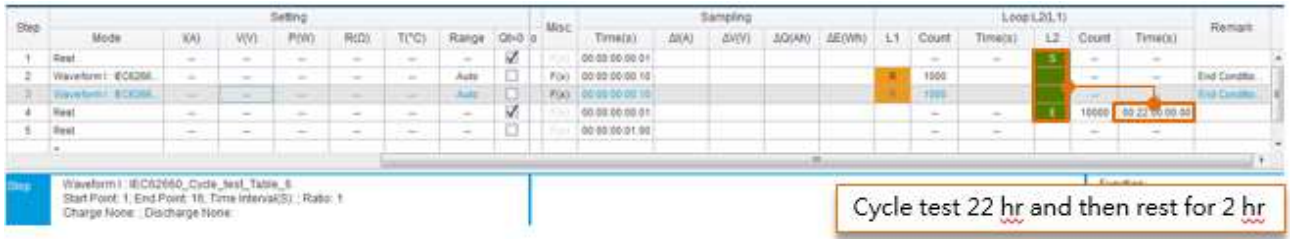

Figure 28 – Use L1, L2 to reach a 22hr operation cycle

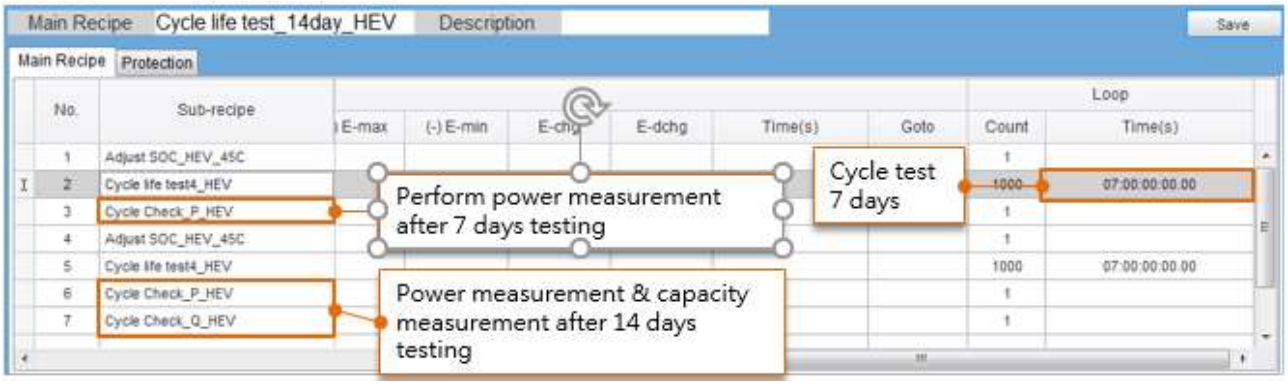

Figure 29 – Use the main recipe layer to edit a 14-day cycle test

The overall operation time is long. We recommend that operators periodically intervene with the operation. For example, when executing a performance check for seven days, the personnel should confirm whether the power & capacity is lower than 80% of the initial state, or the overall operation reached 6 months.

8. Energy efficiency test (refer to section 7.8 of IEC 62660-1). Determine the energy efficiency of the battery by choosing one of 8.1 or 8.2 test methods.

8.1 Test for normal conditions (refer to paragraph 7.8.1.1 of IEC 62660-1)

8.1.1 Test procedure: Capacity test ➔ Rest 4hr ➔ Charge to SOC 100% ➔ Rest 4hr ➔ Capacity test ➔ Charge to SOC 70% ➔ Rest 4hr ➔ Capacity test.

8.1.2 Verification items: Calculate the coulombic efficiency and energy efficiency.

- Calculate the coulombic efficiency η_c (%) $\eta_c = \frac{Q_d}{Q_c} \times 100\%$
  Q_d: discharge electric quantity (Ah)
  Q_c: charge electric quantity (Ah)
- Calculate the energy efficiency η_e (%) $\eta_e = \frac{W_d}{W_c} \times 100\%$
  W_d: discharge electric energy (Wh)
  W_c: discharge electric energy (Wh)

Tip. Use Chroma's Battery LEx to edit the performance testing procedure:

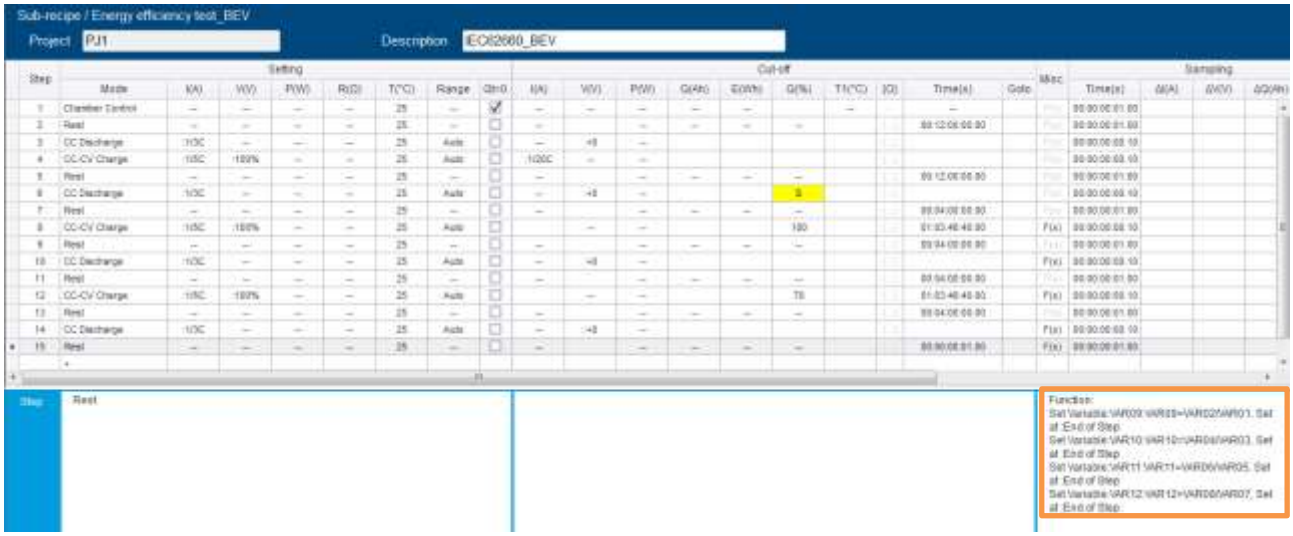

Figure 30 – Calculate the variables of coulombic efficiency and energy efficiency of the general test

8.2 Temperature test (refer to paragraph 7.8.1.2 of IEC 62660-1)

8.2.1 Test procedure: Temperature adjustment (25°C) ➔ General charge ➔ Rest 16 ~ 24hr ➔ [Temperature adjustment (-20°C/0°C/45°C)] ➔ Rest 4hr ➔ Capacity test ➔ Charge to SOC 100% ➔ Rest 4hr ➔ Capacity test.

8.2.2 Verification items: Calculate the coulombic efficiency and energy efficiency.

- Calculate the coulombic efficiency η_c (%) $\eta c = \frac{Q_d}{Q_c} \times 100\%$

  Q_d: discharge electric quantity (Ah)
  Q_c: charge electric quantity (Ah)
- Calculate the energy efficiency η_e (%) $\eta_e = \frac{W_d}{W_c} \times 100\%$

  W_d: discharge electric energy (Wh)
  W_c: charge electric energy (Wh)

Tip. Use Chroma's Battery LEx to edit the temperature testing procedure:

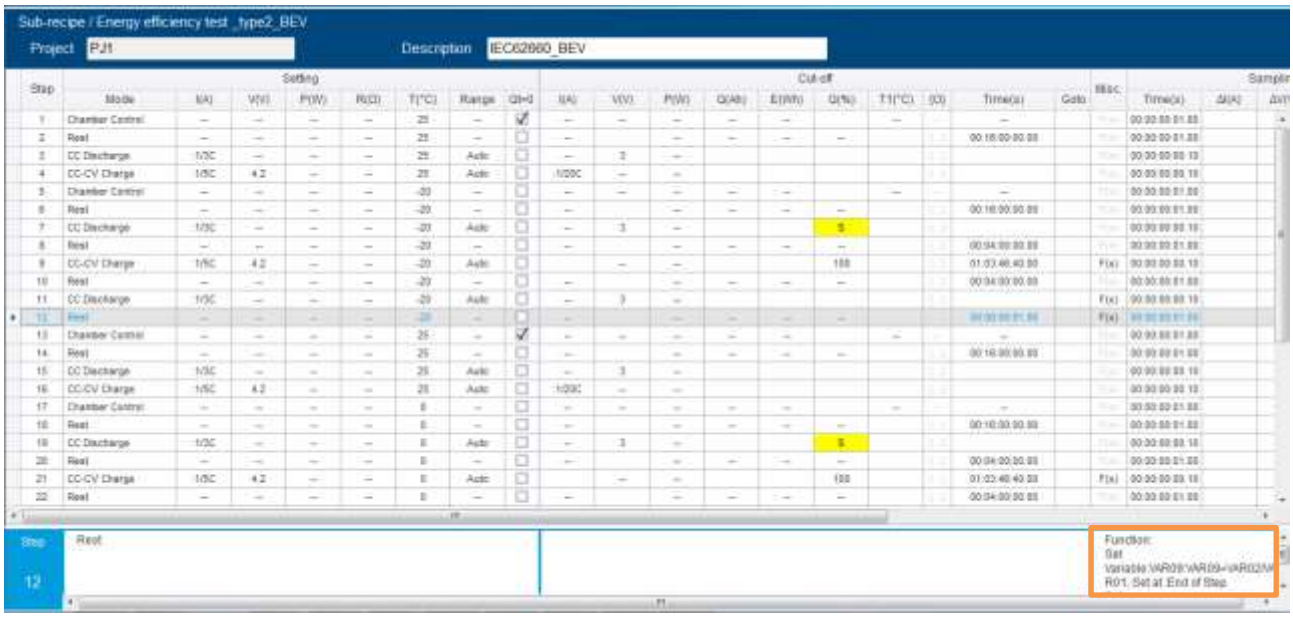

Figure 31 – Calculate the variables of coulombic efficiency and energy efficiency of the temperature test

8.3 Battery test for BEV application (refer to paragraph 7.8.2 of IEC 62660-1)

8.3.1 Test procedure: Capacity test (refer to *Section 2.1*) ➔ Rest 4hr ➔ 2C charge to SOC 80% ➔ Rest 4hr ➔ Capacity test.

8.3.2 Verification items: Calculate the coulombic efficiency and energy efficiency.

- Calculate the coulombic efficiency η_{c1} (%) $\eta_{c1} = \frac{Q_{d1}}{Q_{c1}} \times 100\%$

  Q_{d1}: discharge electric quantity (Ah)
  Q_{c1}: charge electric quantity (Ah)
- Calculate the energy efficiency η_{e1} (%) $\eta_{e1} = \frac{W_{d1}}{W_{c1}} \times 100\%$

  W_{d1}: discharge electric energy (Wh)
  W_{c1}: discharge electric energy (Wh)

Tip. Use Chroma's Battery LEx to edit the testing procedure:

Figure 32 – Use variables to calculate the coulombic efficiency and energy efficiency of the battery test for BEV applications

8.4 Battery test for HEV application (refer to paragraph 7.8.3 of IEC 62660-1)

8.4.1 Test procedure: Same as energy test (refer to *Section 5.1*).

8.4.2 Verification items: Calculate the charge electric energy, discharge electric energy, and energy efficiency.

- Calculate charging energy and discharging energy

  W_{C2}: charge electric energy (Wh)

  $$W_{C2} = \frac{I_{c1}U_{c1}+I_{c2}U_{c2}+\ldots+I_{cn}U_{cn}}{3600}$$

  I_{cn}: charge current value at n point of measured intervals (A)

  U_{cn}: charge voltage value at n point of measured intervals (V)

  $$W_{d2} = \frac{I_{d1}U_{d1}+I_{d2}U_{d2}+\ldots+I_{dn}U_{dn}}{3600}$$

  W_{d2}: discharge electric energy (Wh)

  I_{dn}: discharge current value at n point of measured intervals (A)

  U_{dn}: discharge voltage value at n point of measured intervals (V)

- Calculate the energy efficiency η_{e2} (%) $\eta_{e2} = \frac{W_{d2}}{W_{c2}} \times 100\%$

  W_{d2}: discharge electric energy (Wh)

  W_{c2}: charge electric energy (Wh)

Tip. Use Chroma's Battery LEx to edit the testing procedure:

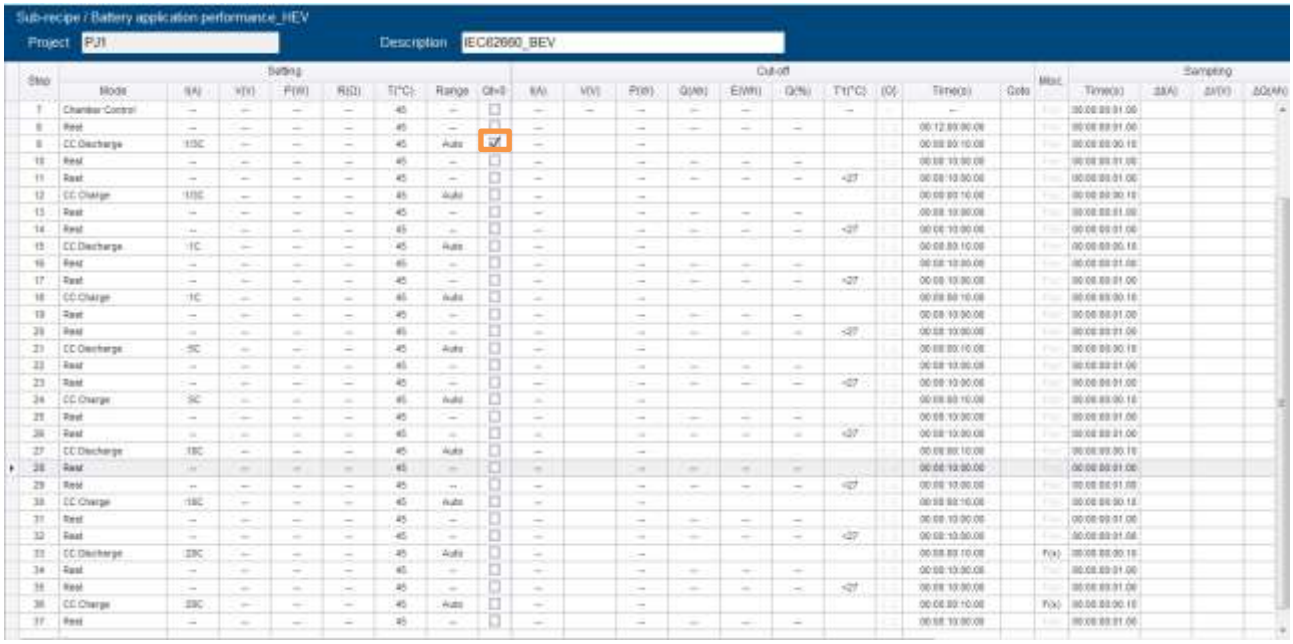

Figure 33 – Select Qt=0 before the power test to cut off the report and accumulate charge/discharge energy from step 9.

The Battery LEx step report automatically records the accumulated energy values of charge energy (W_{C2}), discharge energy (W_{d2}) across steps. These can be used to calculate the energy efficiency η_{e2} (= discharge energy / charge energy).

(4) References

[1] IEC 62660-1: 2010

[2] Chroma 17010 Battery Cell Charge & Discharge Test System Software Instruction Manual