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Driving Innovation to Success

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APPLICATION NOTE

Common Specifications and Test Instructions of Battery Cells

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Chroma ATE Inc.

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1. Objective

Due to the advantages of high performance, low carbon emission, and low noise, electric vehicles have become the development trend of automobiles, which will change people's mobile experience and car use habits. The evolution of lithium batteries has enabled electric vehicles to be realized and more superior. As the performance of electric vehicles is inextricably linked with lithium batteries, the battery quality has a great impact on acceleration, endurance, charging time, warranty, and even safety. What are the differences between the same lithium batteries in characteristics? What test methods can be used to compare the characteristics differences? This article gives you a comprehensive understanding of the basic performance of vehicle batteries through common vehicle battery test specifications.

2. Charge & Discharge OCV Table

2.1 Purpose

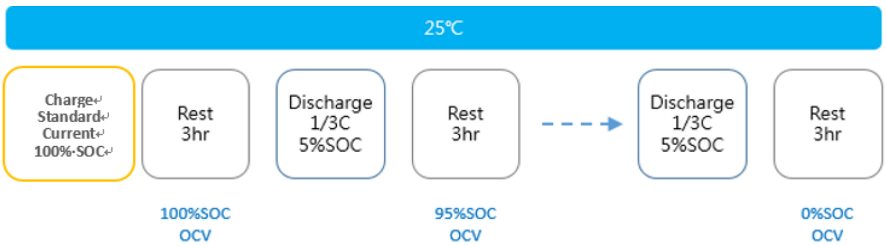
The capability to calculate the battery power is a must. Battery power capability is an important indicator related to xEV power performance. The power capability is evaluated by open circuit voltage (OCV), load voltage, and DC internal resistance, in which the OCV characteristic is often presented by a curve showing voltage versus battery capacity state (SOC%). For instance, the American FreedomCAR has standardized the test methods of the OCV table in their battery test manual.

2.2 Usage

In addition to the usage of power capability evaluation, open circuit voltage (OCV) is also commonly used as a simple reference to battery state of capacity (SOC). For example, when the open-circuit voltage is used to adjust the grouped battery cells to an approximate SOC; compared to measuring the capacity state by charging and discharging, the OCV measurement is much simpler and faster by looking up the table to estimate the current battery capacity. Moreover, the OCV/SOC curve gives users an understanding of the trend of battery working voltage, which would be quite helpful for battery selection during application.

2.3 Test Method

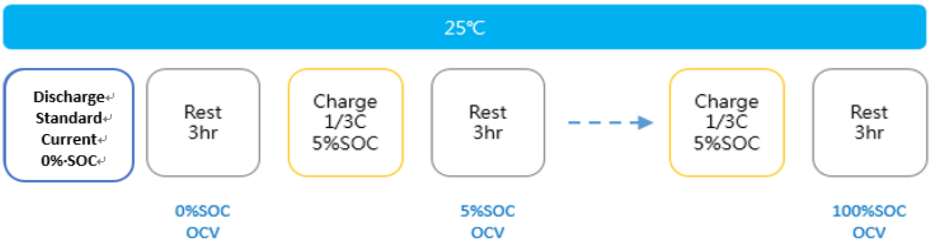
2.3.1 Discharge OCV table



① Charge standard current to reach 100% SOC in room temperature (RT).
② Rest for 3 hours.
③ Adjust SOC: Discharge 5% SOC at 1/3C current.
④ Rest for 3 hours.
⑤ Repeat step ③④ until SOC 0% or reach the lower limit voltage.
⑥ Record the voltage of each stage after rest for 3 hours, and draw the Discharge OCV

table.

2.3.2 Charge OCV table:



① Discharge standard current to reach 0% SOC in room temperature (RT).
② Rest for 3 hours.
③ Adjust SOC: Charge 5% SOC at 1/3C current.
④ Rest for 3 hours.
⑤ Repeat step 3,4 until SOC 100% or reach the maximum voltage.
⑥ Record the voltage of each stage after rest for 3 hours, and draw the Charge OCV table.

2.4 Test Guide

Tip. Use Chroma Battery Lab Expert to illustrate the editing of the OCV table test procedure.

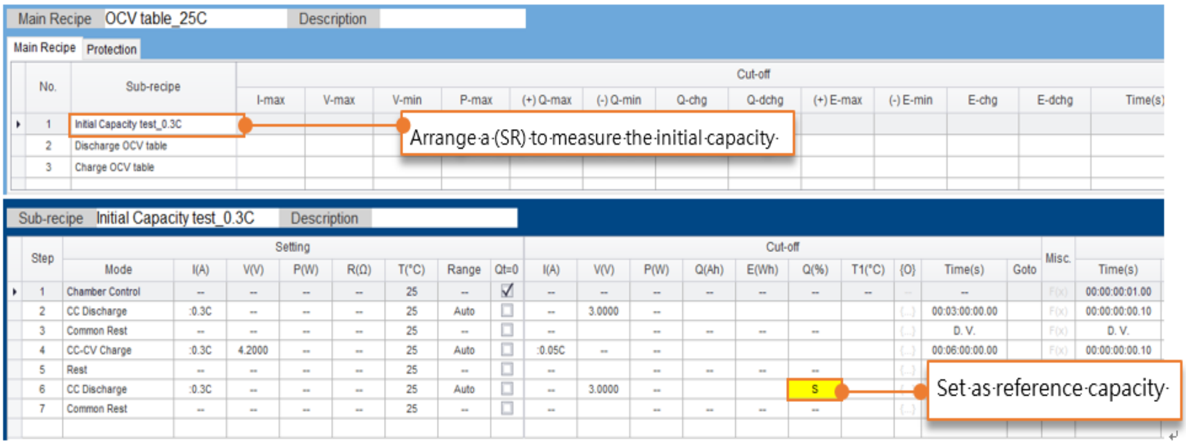


Figure (1) Sub-recipe (SR) to Measure the Initial Capacity

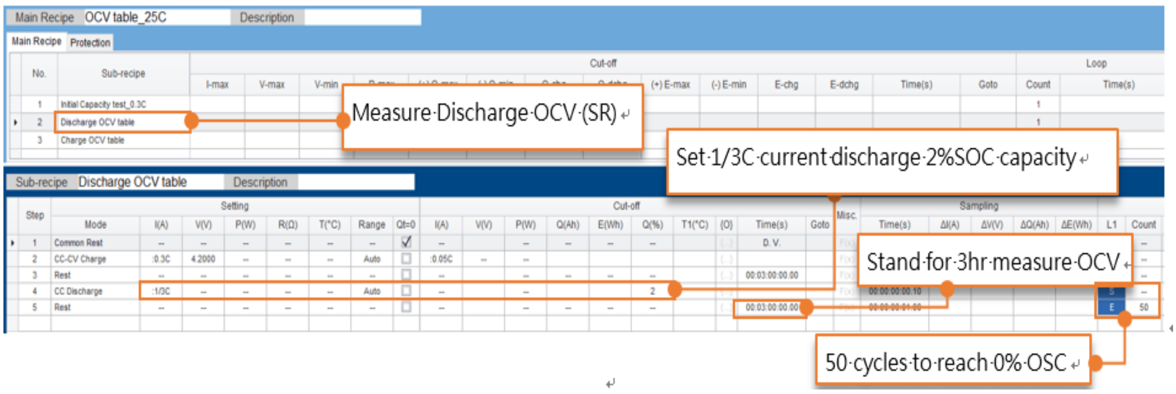


Figure (2) Discharge OCV Sub-recipe (SR)

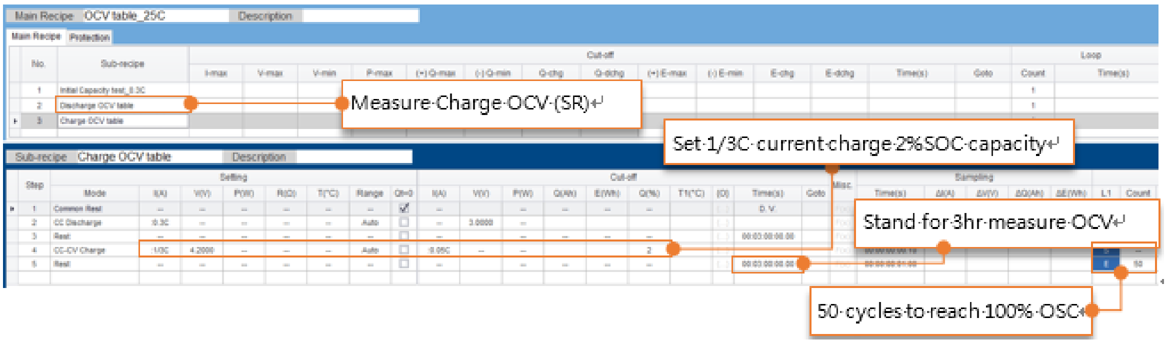


Figure (3) Measure Charge OCV Sub-recipe (SR)

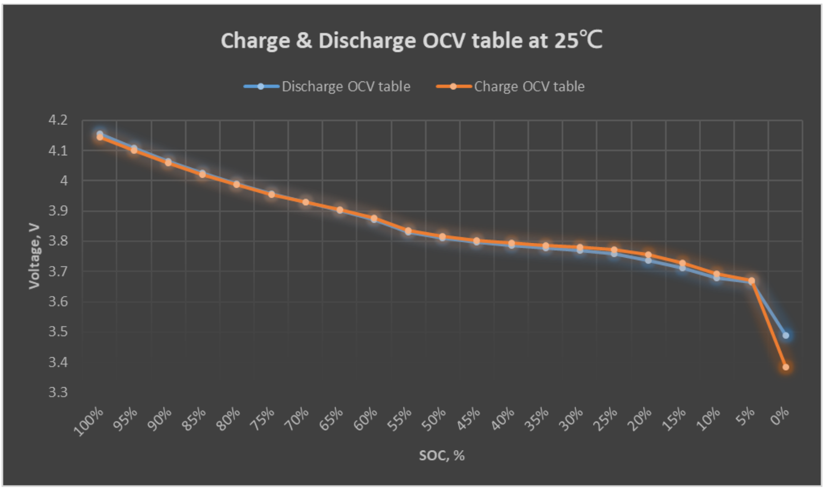
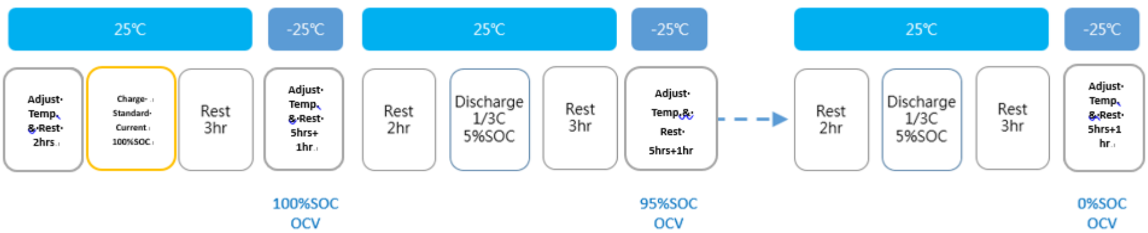


Figure (4) Example of Charge & Discharge OCV Table

2.5 Discharge OCV table _ at 25℃/ -25℃

Lithium-ion batteries are often affected by temperature due to material characteristics, and the battery's capacity and open circuit voltage are also varied with ambient temperature. Therefore, in addition to the OCV/SOC table at room temperature, the characteristic of temperature is also marked, and the commonly labeled temperature range is -25°C~45°C.

2.5.1 Test Method



① Charge standard current to reach 100% SOC in room temperature (RT) and rest for 3 hours.

② Adjust temperature: Change temperature (25°C→ test temperature), adjust and average temperature for 5 hours, rest for 1 hour.

③ Return to room temperature: Change temperature (test temperature→25°C), adjust and average temperature for 2 hours.

④ Adjust SOC: Discharge 5% SOC at 1/3C current, rest for 3 hours.

⑤ Repeat step ②~④ until SOC 0% or reach the lower limit voltage.

⑥ Repeat step ②~⑤ to perform different temperature tests (-25°C,-10°C,25℃,40°C)

2.5.2 Test Guide

Tip. Use Chroma Battery Lab Expert to edit the diagram of OCV table test program for the specific temperature.

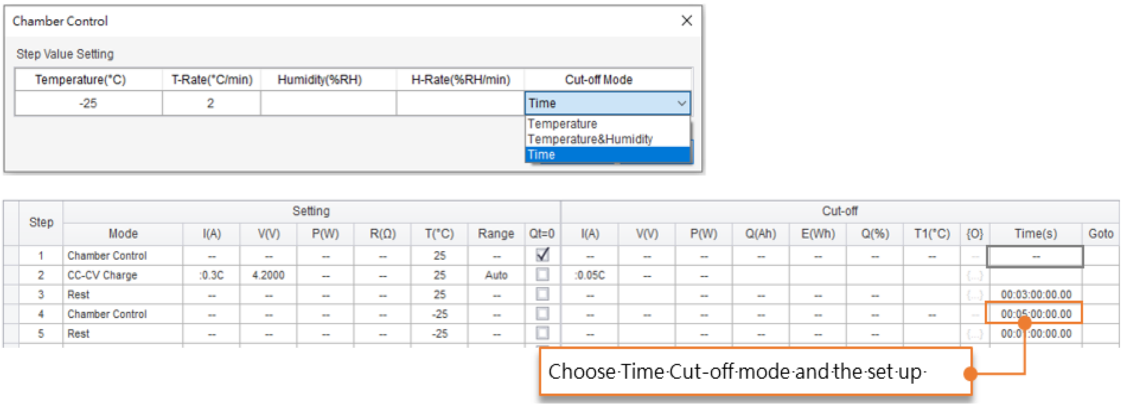


Figure (5) Time Cut-off Setting used by Chamber Control

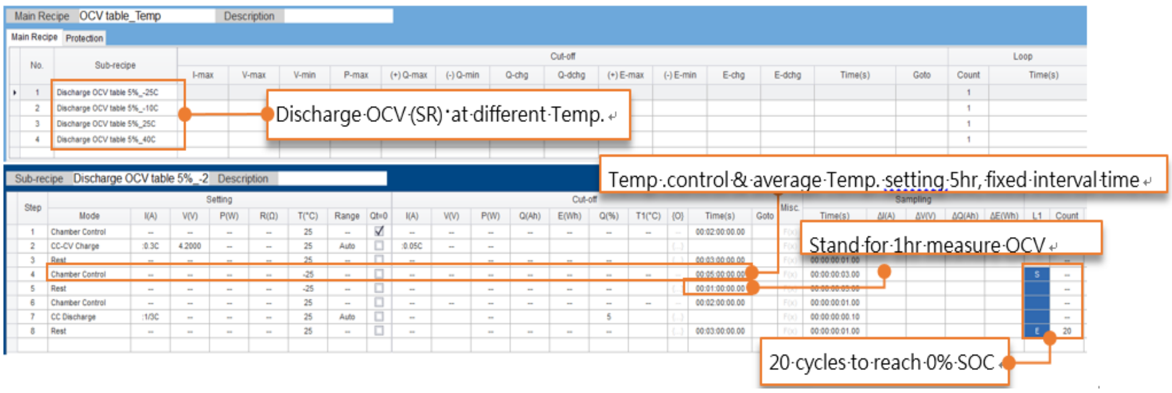


Figure (6) Discharge OCV Sub-recipes (SR) of Different Temperature form Master-recipe

3. Rated Capacity

3.1 Purpose

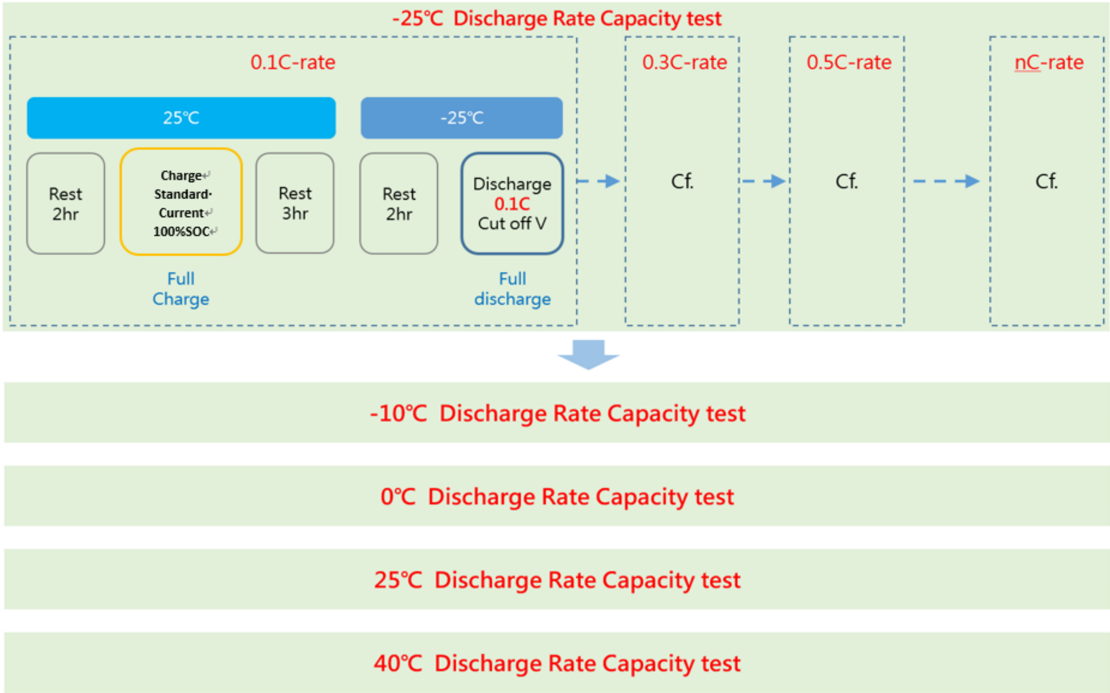
It improves the battery life of electric vehicles and displays the power status. For electric vehicles, the battery capacity is just as important as the gas volume of the fossil fuel vehicle, which affects the driving distance. The current situation of the unpopularity of the charging station often makes the electric vehicle driver feel anxious about the mileage. Selecting high-capacity batteries is the major means to improve the battery life of electric vehicles.

3.2 Usage

The rated capacity indicates the battery capacity under different current rates (C-rate) and temperature (T). Batteries have different DC internal resistance and temperature characteristics due to the variety of material traits, and the working current will show different voltage and capacity. These characteristics can be clearly displayed through the Rated Capacity curve, which can be used as a basis for BMS to adjust voltage and capacity, selecting battery type or finding the best operating parameters.

3.3 Test Method

- Rated Capacity



① Adjust temperature to room temperature, rest for 2 hours.

② Charge standard current to reach SOC 100%.

③ Rest for 3 hours.

④ Adjust temperature to test temperature (e.g.-25°C), rest for 2 hours.

⑤ Discharge test: Discharge at 0.1C until 0% SOC or until the cut-off voltage is met, record the data during process.

⑥ Repeat step ①~⑤, perform discharge tests with different current rates (e.g. 0.1C, 0.3C, 0.5C, 1C, 2C, 3C). It must include the maximum discharge current rate.

⑦ Repeat ⑥ under different ambient temperatures (40°C /25°C /0°C /-10°C /-25°C). Under negative temperature conditions, the test rate can be appropriately reduced according to the specifications of the DUT, but the test conditions need to be recorded.

3.4 Test Guide

Tip. Use Chroma Battery Lab Expert to illustrate the editing of the Rated Capacity test procedure.

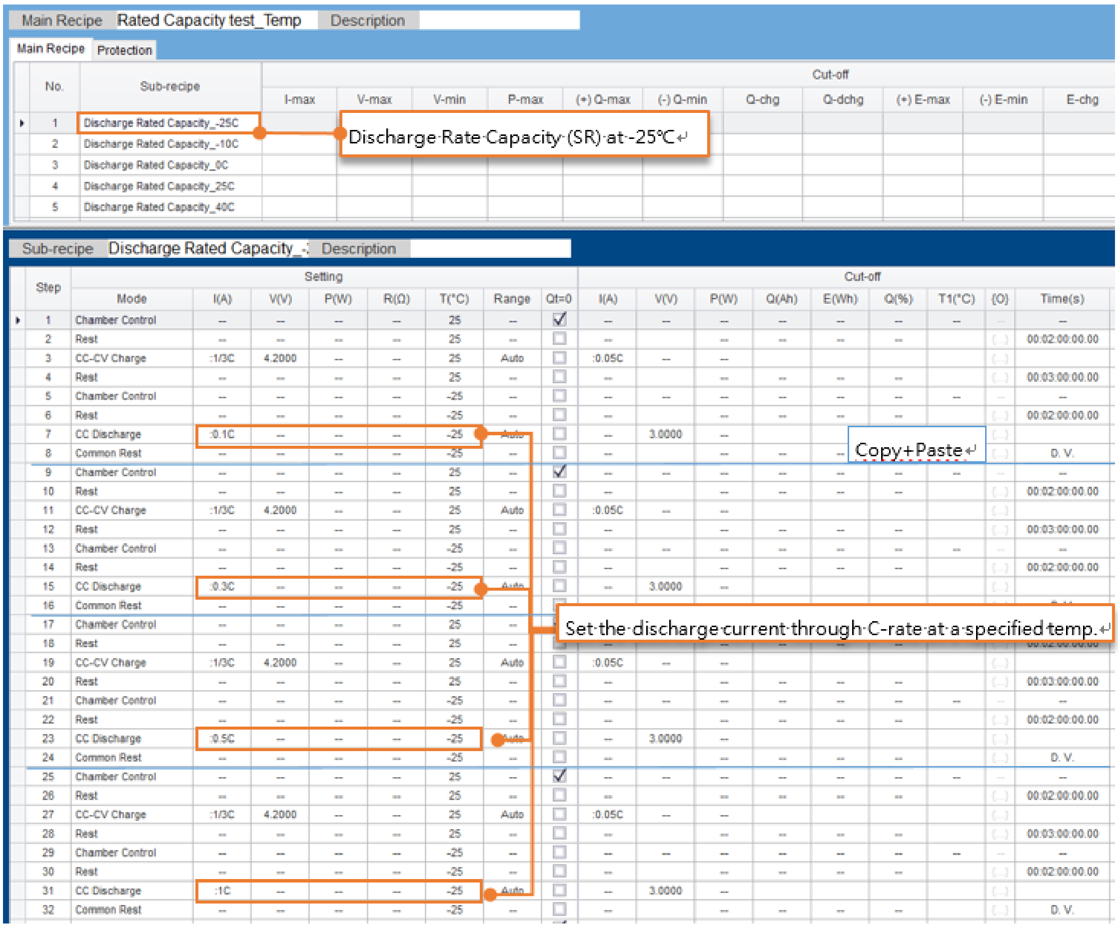


Figure (7) Use C-rate Method to quickly Set Current Parameters (SR)

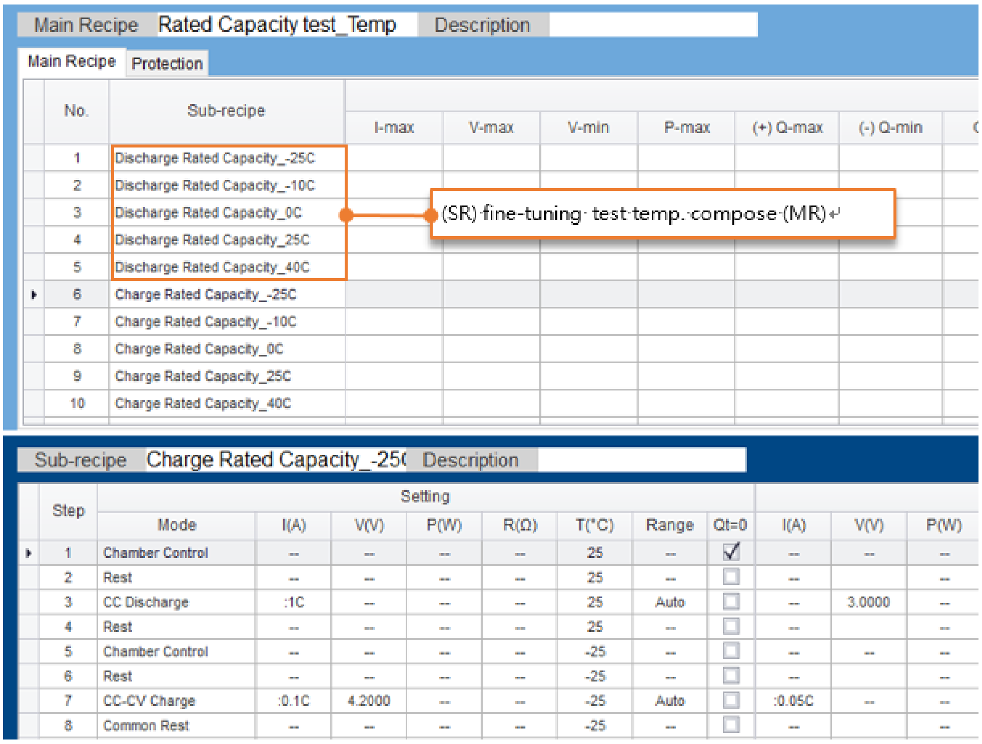


Figure (8) Fine Tune SR by Fast Editing Discharge Rate under Each Temperature for Testing (MR)

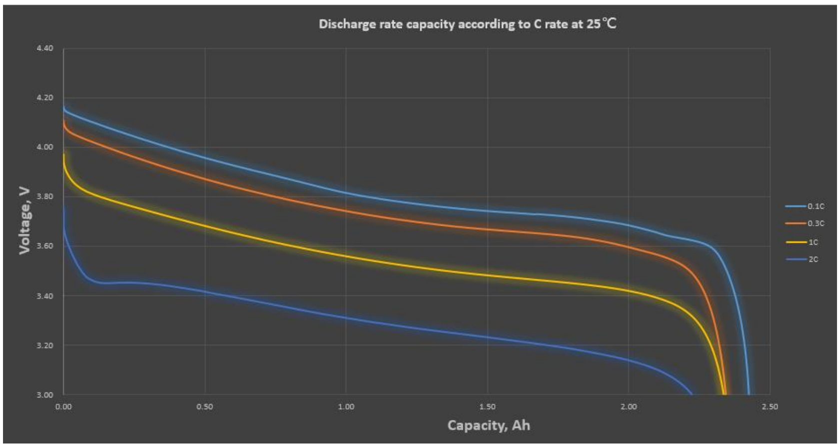


Figure (9) Discharge Rate Capacity Example

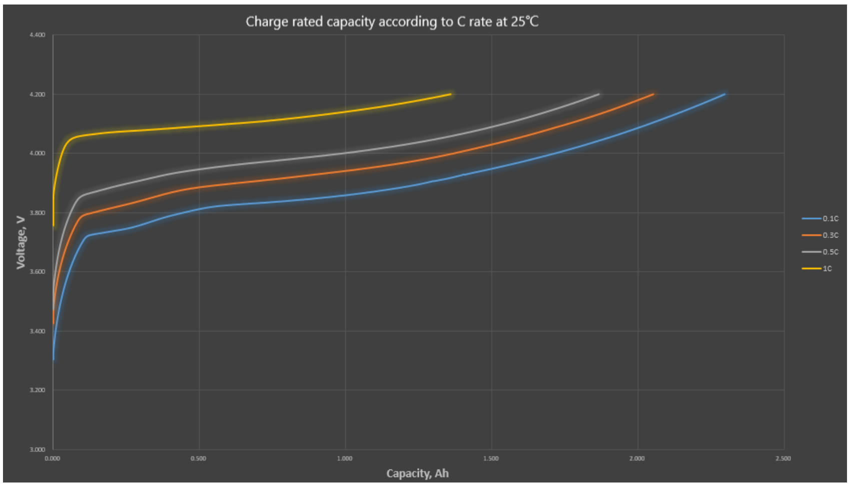


Figure (10) Charge Rate Capacity Example

4. Power and DCIR

4.1 Purpose

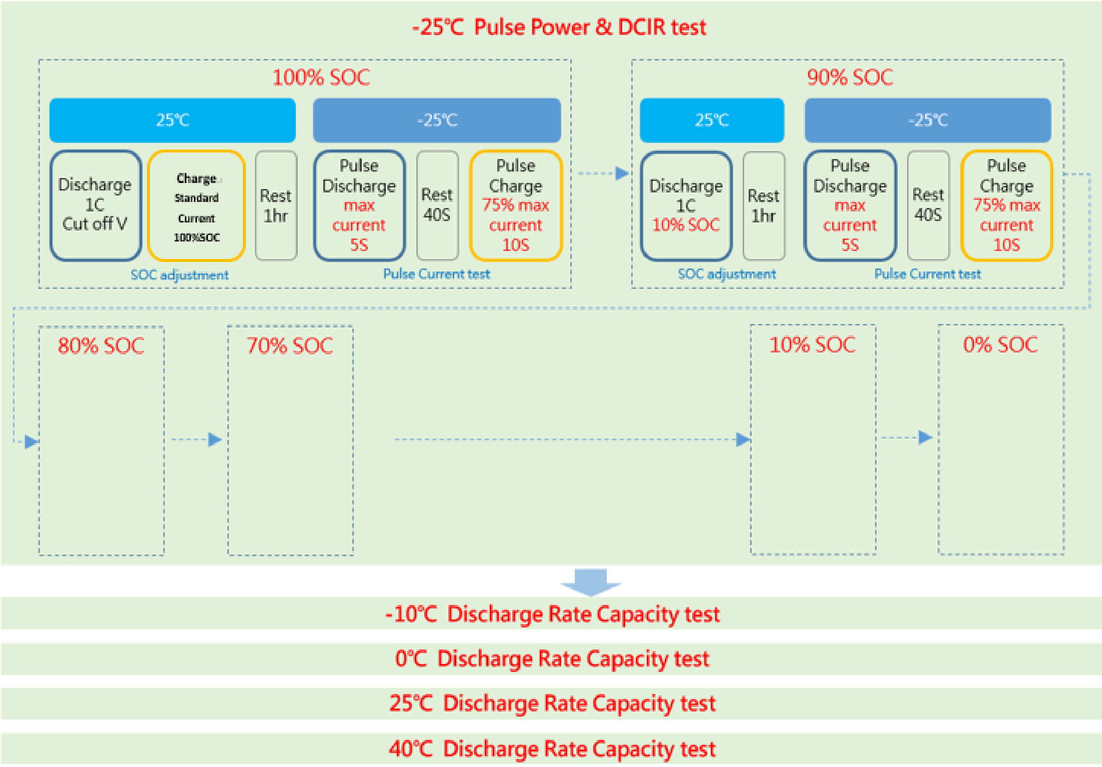
The acceleration and fast charging performance of electric vehicles depends on the power capability and internal resistance of the battery system. Different road conditions, temperatures, and power states may affect the driving of an electric vehicle. These variables should be taken into consideration when designing electric vehicles. The BMS system needs to refer to the power capability curve to effectively manage the output power of the battery pack, and the same goes for charging energy back during brake, or fast charging on the charging pile.

4.2 Usage

It indicates the dynamic power capability and internal resistance within the product applicable voltage range. Dynamic power capability can be used to design battery packs and develop energy systems of different sizes. Internal resistance can be used to assess battery aging and develop battery performance models for vehicle system analysis. It is common to use the power-to-SOC curve to represent the power capability under different SOC states; the resistance-to-SOC curve to show the characteristics of DC internal resistance under different SOC states, which is generally evaluated using a hybrid pulse power test (HPPC test).

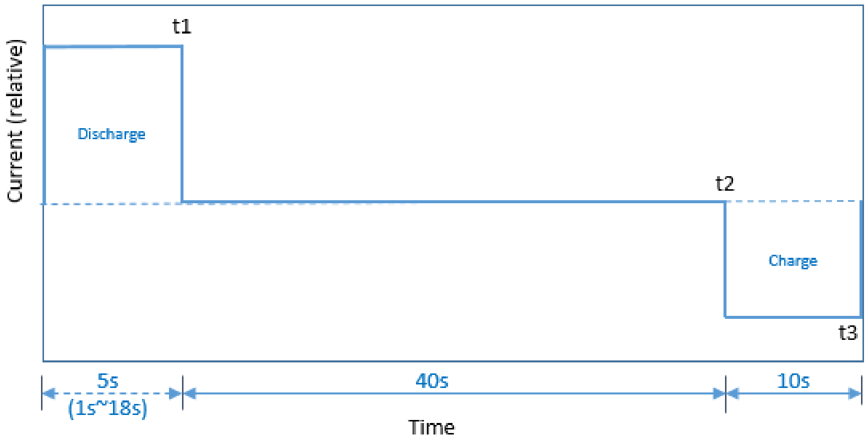
4.3 Test Method

4.3.1 Hybrid Pulse Power Test (HPPC)



① Adjust temperature to room temperature (RT), add the average temperature time to a total of 2 hours.
② Discharge standard current to reach 0% SOC.
③ Use standard charge to fully charge the battery (100%SOC).
④ Rest for 1 hour.
⑤ Adjust temperature to -25°C, add the average temperature time to a total of 2 hours.
⑥ Pulse discharge: Discharge 5S/30S at maximum current (refer to the time recommendations of various international norms).
⑦ Rest for 40 seconds.
⑧ Pulse charge: Charge 10S at maximum current.
⑨ Adjust temperature to room temperature (RT), add the average temperature time to a total of 2 hours.
⑩ Discharge in standard mode until the cumulative discharge capacity reaches 10% of the reference capacity (must include the pulse test capacity)
⑪ Rest for 1hour.
⑫ Pulse discharge: Discharge 5S/30S at maximum current (refer to the time recommendations of various international norms).
⑬ Rest for 40 seconds.
⑭ Pulse charge: Charge 10S at maximum current.
⑮ Repeat step 9~14 for 10 time (complete 90%~0%SOC pulse test).
⑯ Repeat step15 under different ambient temperatures (40°C /25°C /0°C /-10°C /-25°C). Under negative temperature conditions, the test rate can be appropriately reduced according to the specifications of the DUT, but the test conditions need to be recorded.

4.3.2 Resistance and Power Calculation for Hybrid Pulse Power Test



- Calculate the resistance of each discharge level

$$\text{Discharge Resistance} = \frac{\Delta V_{discharge}}{\Delta I_{discharge}} = \frac{V_{t1} - V_{t0}}{-(I_{t1} - I_{t0})} = \frac{V_{t1} - V_{t0}}{(I_{t0} - I_{t1})}$$

$$\text{Regen Resistance} = \frac{\Delta V_{regen}}{\Delta I_{regen}} = \frac{V_{t3} - V_{t2}}{-(I_{t3} - I_{t2})} = \frac{V_{t3} - V_{t2}}{(I_{t2} - I_{t3})}$$

- Calculate the pulse power capability

Pulse power capability is defined and plotted based on voltage and resistance characteristics, showing V_{MIN} discharge capability and V_{MAX} regeneration capability of each DOD state.

$$\text{Discharge Pulse Power Capability} = V_{MIN} \times (OCV_{dis} - V_{MIN}) \div R_{discharge}$$

$$\text{Regen Pulse Power Capability} = V_{Max} \times (V_{MAX} - OCV_{regen}) \div R_{regaen}$$

4.4 Test Guide

Tip. Use Chroma Battery Lab Expert to illustrate the editing of the Power & DC-IR test procedure

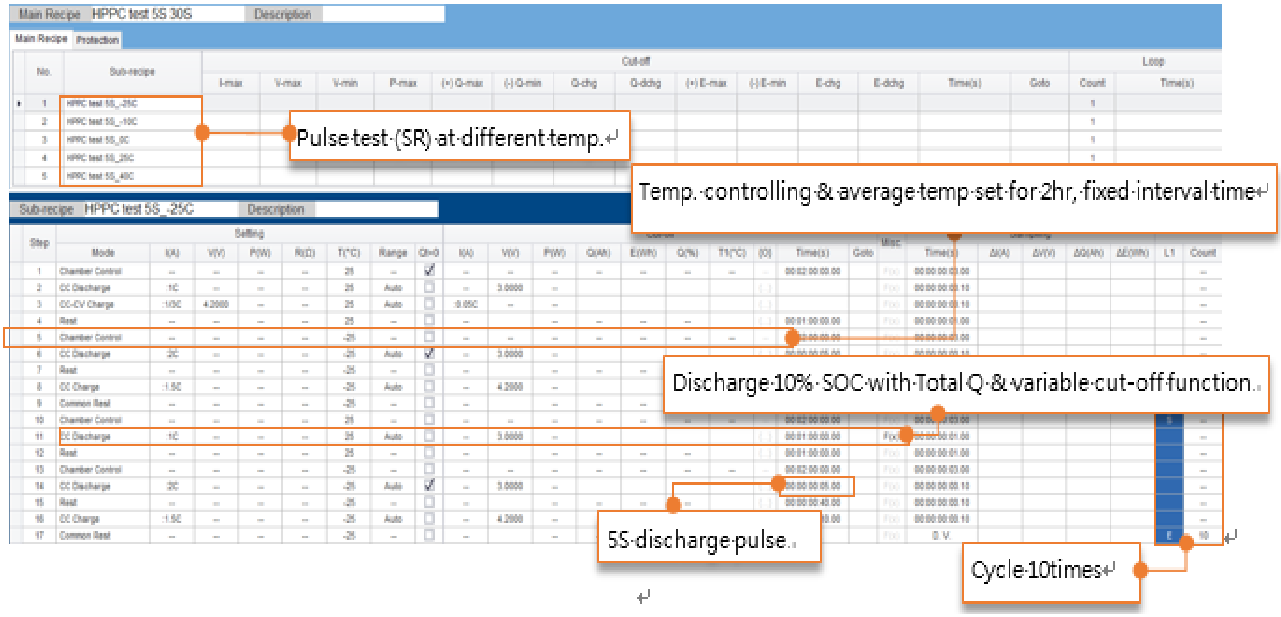


Figure (11) 100%SOC~0%SOC Pulse Test Sub-recipe (SR)

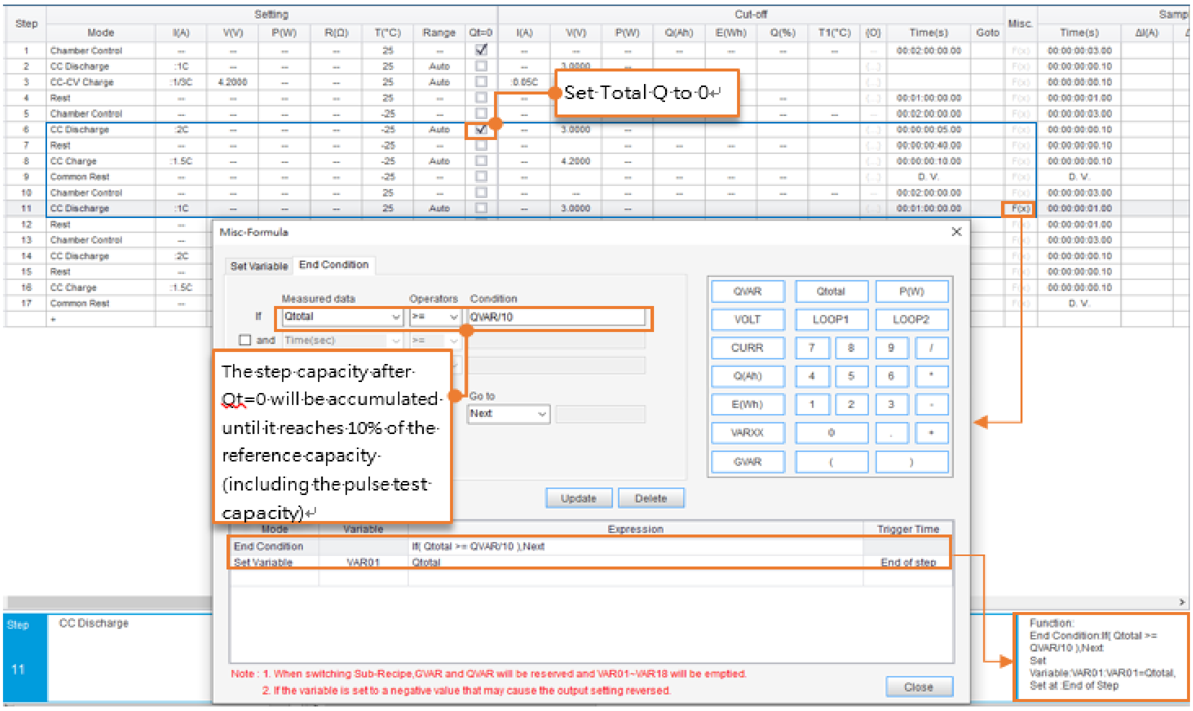


Figure (12) Setting for Discharging 10% SOC via Cumulative Capacity (Total Q) and Variable Cut-off Function

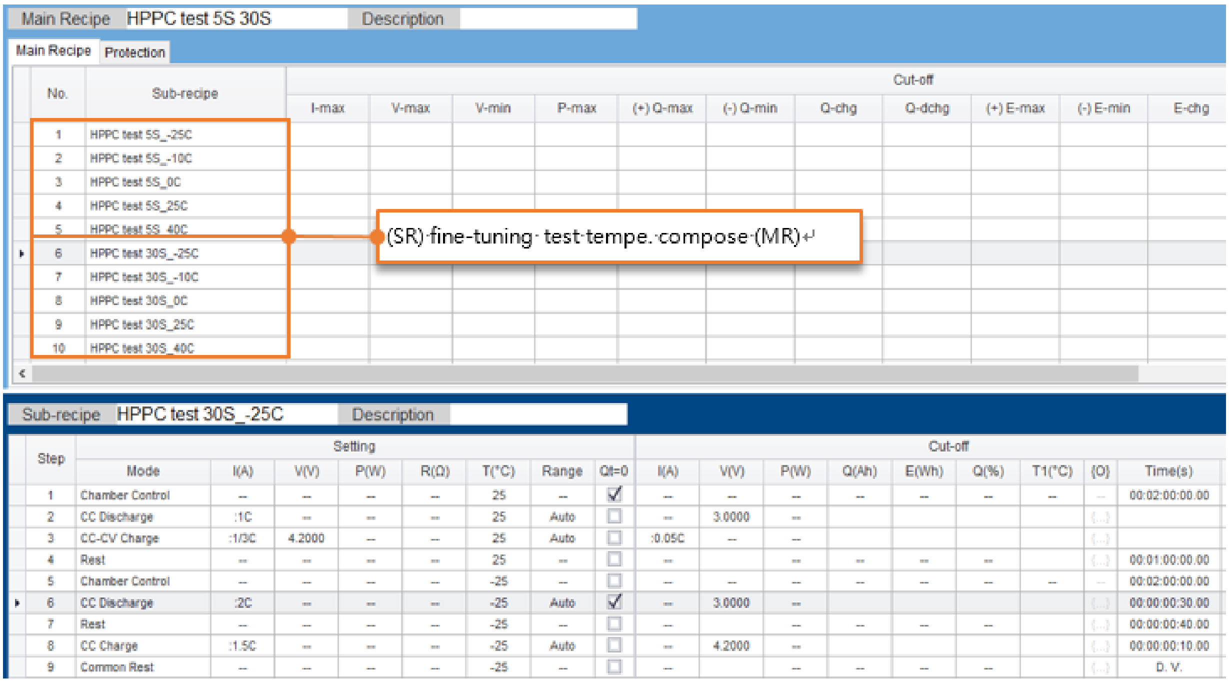


Figure (13) 5S and 30S Pulse Test Main Recipe (MR) for -25°C~100°C Ambient Temperature

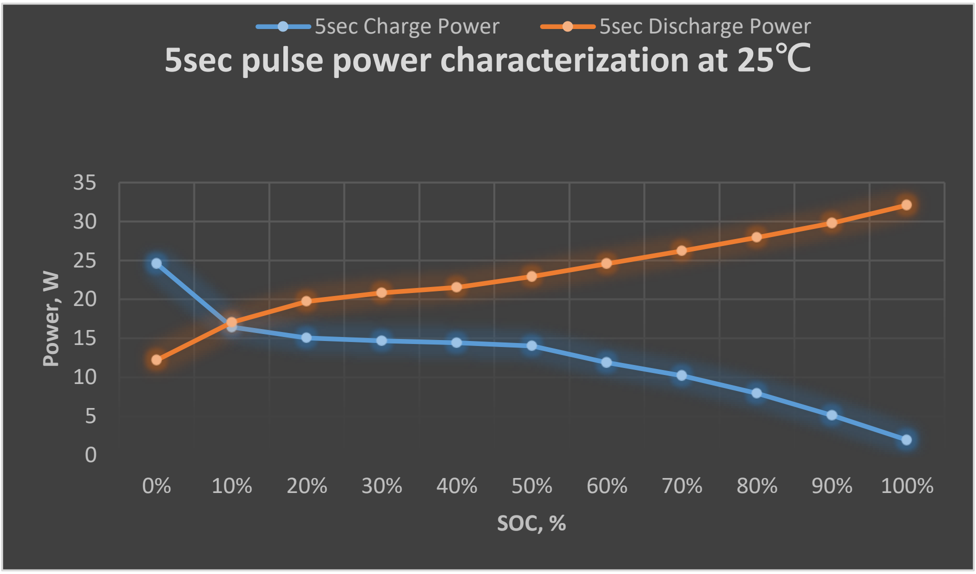


Figure (14) Example of 5 sec. Pulse Power at 25°C

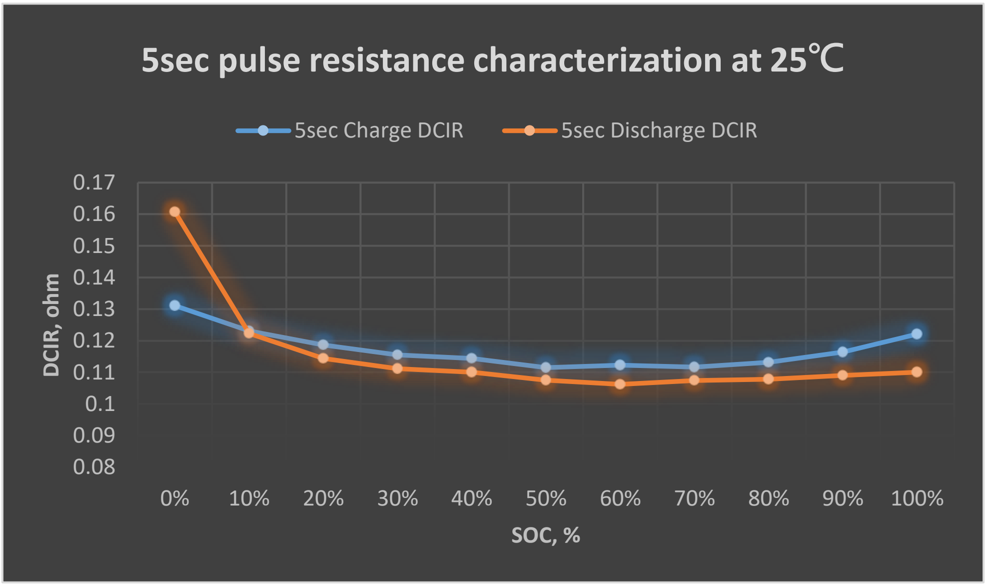


Figure (15) Example of 5 sec. Pulse Resistance at 25°C

5. Cycle Life

5.1 Purpose

It extends the guaranteed mileage of EV batteries. The battery cycle life determines the miles an EV can drive before the battery needs to be changed. For EV, there are system maintenance costs and warranty risks as replacing batteries is the largest maintenance cost. For consumers, prolonging the battery life can increase their purchase willingness. For the car manufacturer, it can reduce the cost of replacing the battery within the guaranteed mileage.

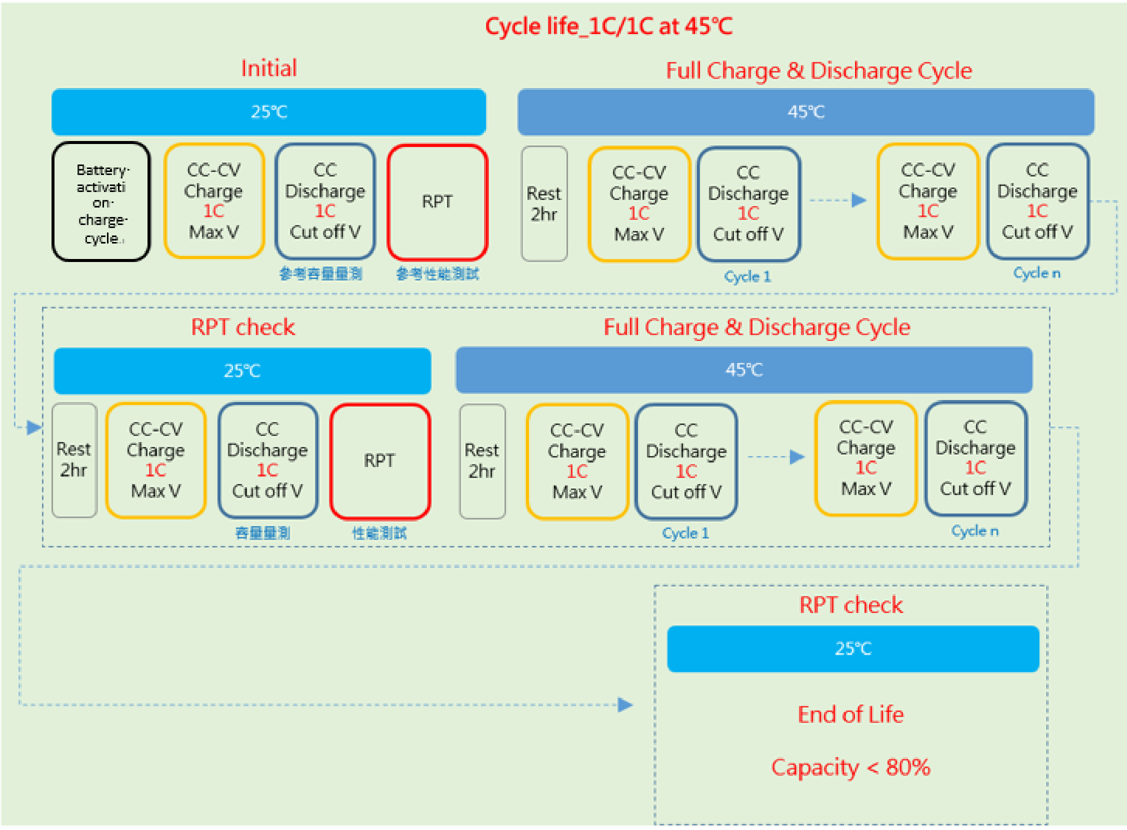
5.2 Usage

It indicates the battery life under charge and discharge. The life is presented by the number of cycles to estimate when the battery needs to be replaced. The battery life data is basically affected by the ambient temperature, SOC application range (state of charge & depth of discharge), and operating current. The life data report is usually accompanied by the test conditions used. For example, the car manufacturer usually defines the usage scenarios that match the model for charging and discharging to simulate and verify the battery life of the vehicle.

5.3 Test Method

Cycle life refers to the number of conventional cycles (full charge-discharge cycles) or operating cycles the battery has before the life ends. The test methods are varied with different standards. The example below is a common test method.

5.3.1 Conventional Cycle Life Test (full charge-discharge cycle)



① Adjust temperature to room temperature (RT), charge and discharge the battery several times to activate it (capacity difference <2%).

② Fully charge the battery with an experimental current in CC-CV mode.

③ Use an experimental current in CC mode to discharge the battery to cut-off voltage (Cut off V) as the reference capacity.

④ Conduct reference performance test (RPT), such as direct current internal resistance (DCIR) test, power test, etc., to determine the condition and rate of performance degradation on the battery under test.

⑤ Adjust temperature to test temperature (e.g. 45°C), add the average temperature time to a total of 2 hours.

⑥ Start the standard charge-discharge cycle, fully charge the battery with an experimental current in CC-CV mode, and then discharge the battery to cut-off voltage using an experimental current in CC mode.

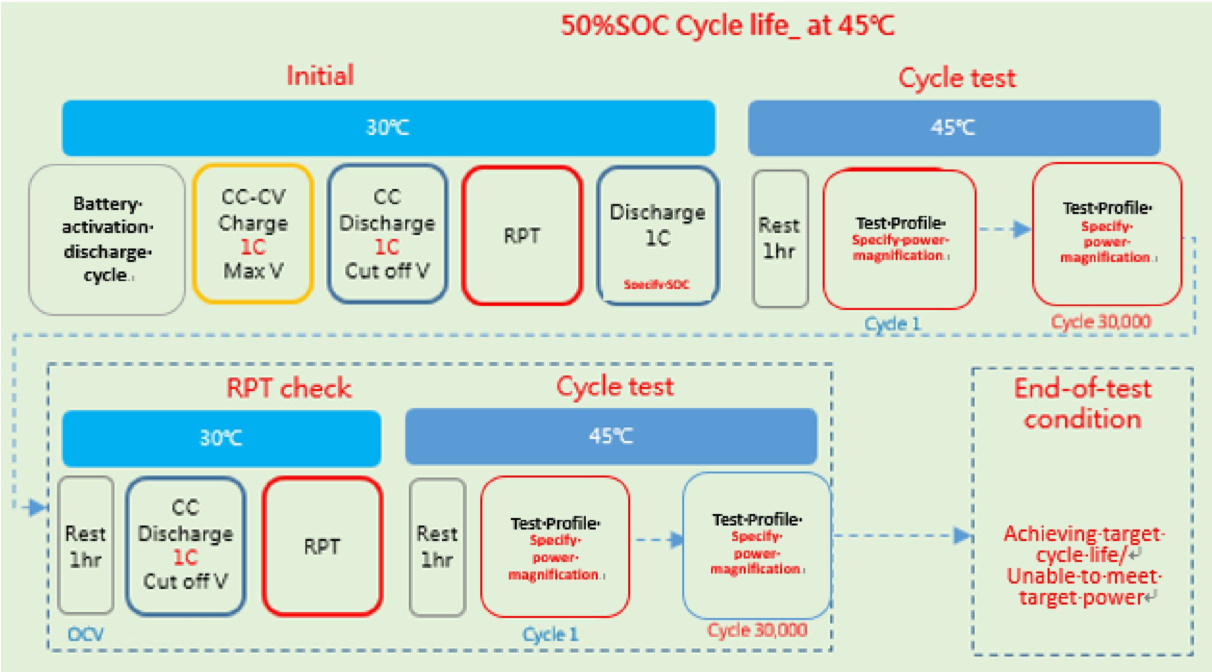
⑦ Cycle step ⑥ until the specified cycle number is met (e.g. 50 times).

⑧ Adjust temperature to room temperature (RT) and rest to average temperature, and then perform capacity and reference performance tests.

⑨ Repeat step ⑦⑧ for cycle test and performance check until the measured capacity is lower than 80% of the reference capacity.

⑩ Perform cycle life experiments under different temperatures and current rates.

5.3.2 Operating Cycle Life Test (e.g. FreedomCar specification)



① Adjust temperature to room temperature (30°C) and rest to average temperature for 1 hour. Cycle charge and discharge several times to activate the battery (capacity difference <2%).

② Fully charge the battery with an experiment current in CC-CV mode.

③ Use an experimental current in CC mode to discharge the battery to cut-off voltage (Cut off V) as the reference capacity.

④ Conduct reference performance test (RPT), e.g. HPPC test.

⑤ Adjust the battery to a specified SOC stat (e.g. 50% SOC).

⑥ Adjust temperature to test temperature (e.g. 45°C), rest for 1 hour.

⑦ Perform cycle test for 30,000 cycles according to the cycle life test profile defined by FreedomCar.

⑧ Adjust temperature to room temperature (30°C), rest to average temperature for 1 hour and then measure the open circuit voltage (OCV).

⑨ Measure the residual capacity with an experimental current to verify the depth of discharge cycle.

⑩ Conduct reference performance tests to determine the degradation degree of capacity or power capability.

⑪ Repeat step⑤~⑩for cycle test and performance check until test end conditions are met (the cycle life of the target is reached or unable to satisfy the target power).

⑫ Perform cycle life experiments under different SOC, different temperatures, and different power.

Minimum Power-Assist (25 Wh) Cycle Life Test profiles.							
Application	Test Profile	Pulse Characteristics					Profile Characteristics
			ENG-OFF	LAUNCH	CRUISE	REGEN	
25kW Power Assist	Baseline	Power(kW)	3.00	15.00	-1.15	-12.00	Discharge Energy(Wh) =25.00
		Duration(s)	20	2.00	66.00	2.00	Round-trip Efficiency=90.0%
		Energy(Wh)	16.67	8.33	-21.00	-6.67	Avg. Heating Rate (W)=111
		Stress Factors					Weighting Factor =80%
		Power(%)	100	60.00		60.00	Throughput (MWh) =6.00
		Energy(%)	5.6	12.00		12.00	Test Cycles =240,000
	95 Percentile		ENG-OFF	LAUNCH	CRUISE	REGEN	
		Power(kW)	3.00	20.00	-1.07	-16.00	Discharge Energy(Wh) =25.00
		Duration(s)	10	3.00	75.00	2.00	Round-trip Efficiency=80.0%
		Energy(Wh)	8.33	16.67	-22.29	-8.89	Avg. Heating Rate (W)=247
		Stress Factors					Weighting Factor =15%
		Power(%)	100	80.00		80.00	Throughput (MWh) =1.13
		Energy(%)	2.8	24.00		16.00	Test Cycles =45,000
	99 Percentile		ENG-OFF	LAUNCH	CRUISE	REGEN	
		Power(kW)	3.00	24.00	-1.11	-19.00	Discharge Energy(Wh) =25.00
		Duration(s)	6	3.00	79.00	2.00	Round-trip Efficiency=71.6%
		Energy(Wh)	5	20.00	-24.38	-10.56	Avg. Heating Rate (W)=397
		Stress Factors					Weighting Factor =5%
		Power(%)	100	96.00		95.00	Throughput (MWh) =0.38
		Energy(%)	1.7	29.00		19.00	Test Cycles =15,000

Figure (16) Cycle Life Test Profile (FreedomCAR) for Reference

5.4 Test Guide

Tip. Use Chroma Battery Lab Expert to illustrate the editing of the Conventional Cycle Life test procedure.

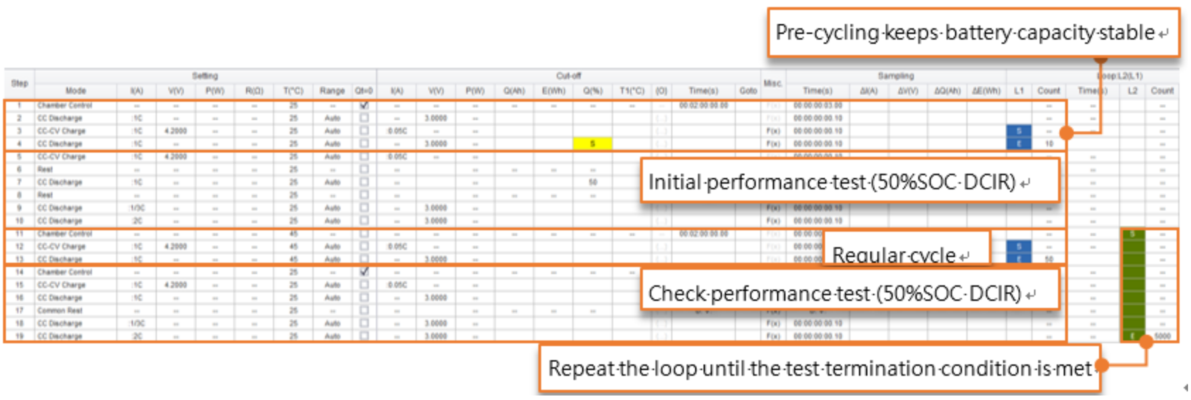


Figure (17) Conventional Cycle Life Test Structure (SR) for 1C Charge/1C Discharge

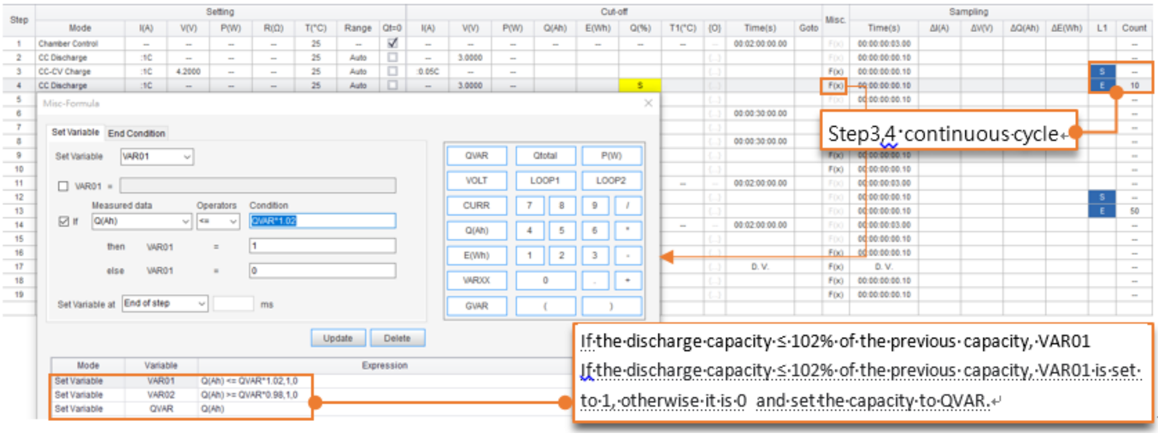


Figure (18) Use Variable to Determine if Capacity Change of Pre-cycle is ≤2%

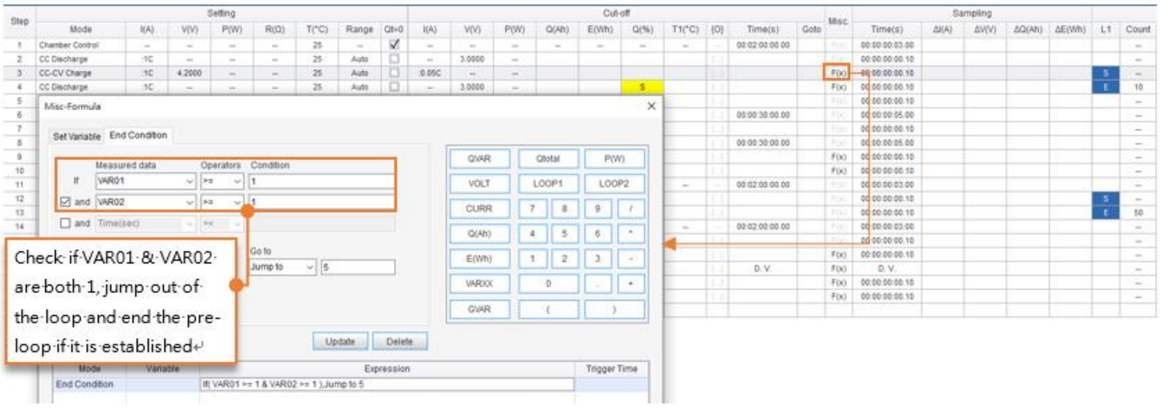


Figure (19) Use Variable to Determine if Capacity Change is ≤2% and End Pre-cycle

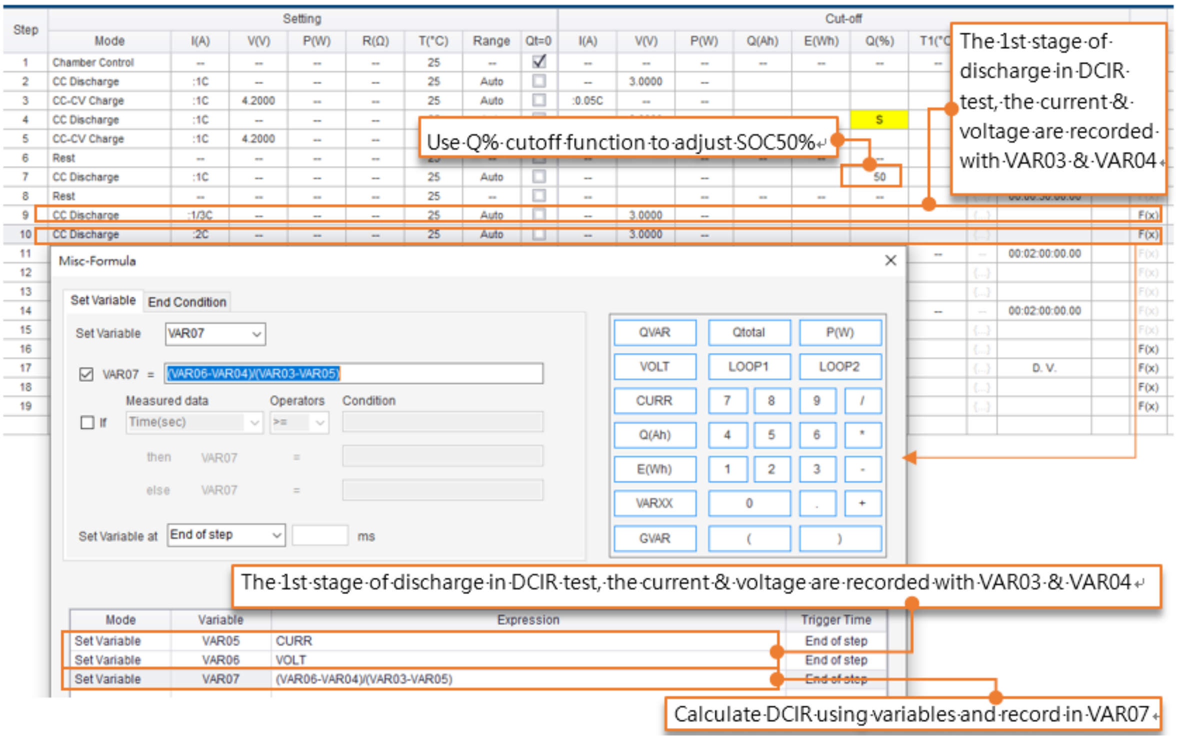


Figure (20) Edit Initial Performance for DCIR Test

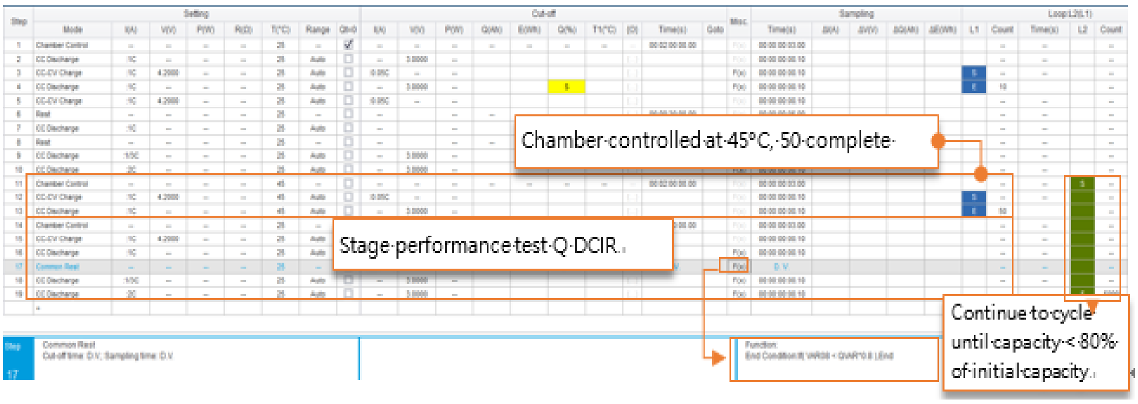


Figure (21) Edit Conventional Charge-Discharge Cycles, Stage Check Performance Tests, and Cycle Life Test Cut-off Conditions

Tip. Use Chroma Battery Lab Expert to illustrate the editing of the Operating Cycle Life test procedure.

The main difference from the conventional cycle life test is that it is cycled under operating conditions and the measurement items of the reference performance test (RPT) are different.

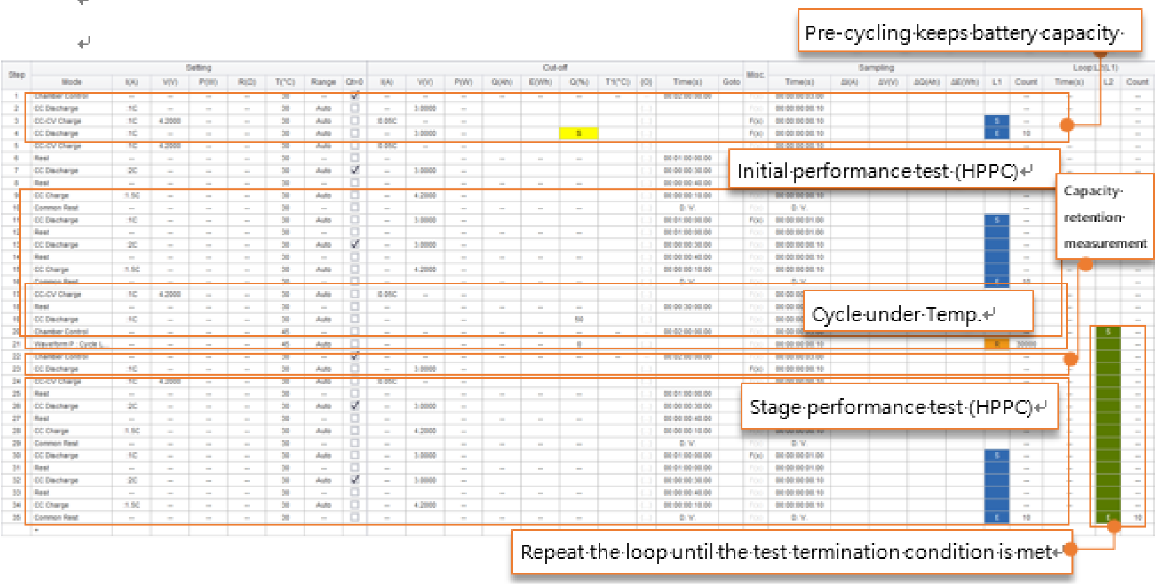


Figure (22) Operating Cycle Life Test Structure (SR)

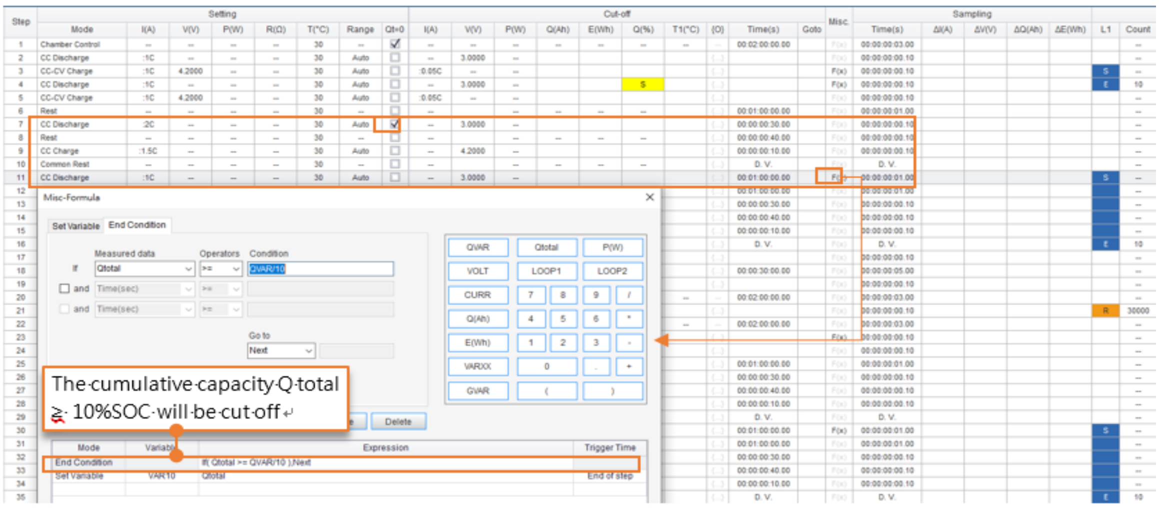


Figure (23) Use Qtotal to Perform Accurate 10% SOC Adjustment

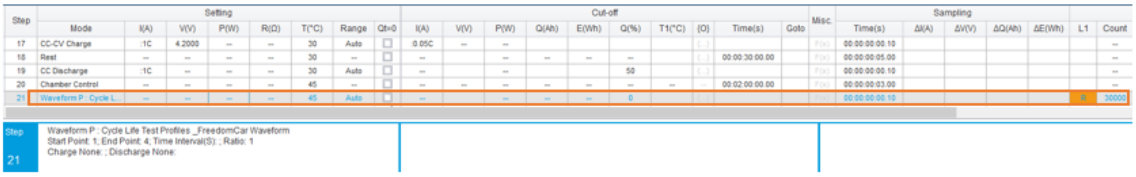


Figure (24) Use Waveform Power to Perform Operating Test and Cut Off after Cycled 30,000 Times

6. Calendar Life

6.1 Purpose

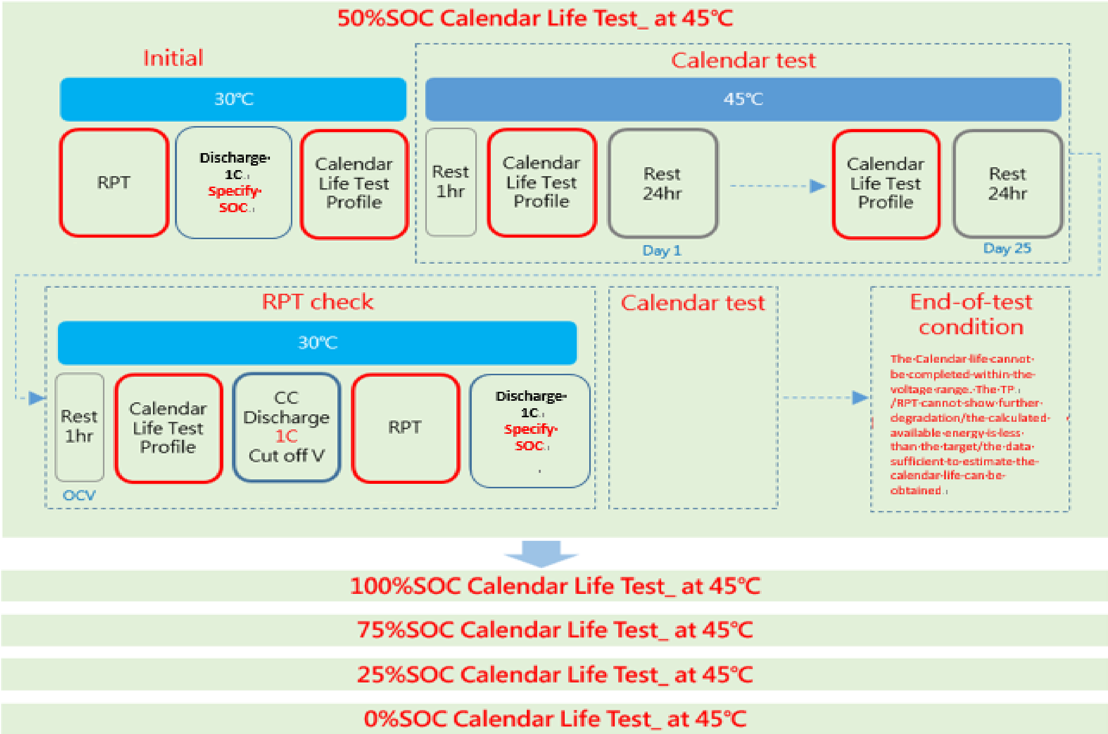
It extends the warranty period of electric vehicle batteries. The battery calendar life is the time elapsed until replacing a new battery after purchase. For consumers, the prolongation of battery life will positively increase their purchase intention.

6.2 Usage

It indicates the battery life in the state of standby or use by calendar days. The tests of cycle life and calendar life are used to evaluate the battery life, but the latter focuses more on aging over time after installation, and the usage behavior of these two tests is different. The data of battery calendar life is basically affected by the ambient temperature and the daily SOC state. The life data report is usually accompanied by the test conditions used.

6.3 Test Method

It uses time to evaluate the battery degradation with multiple batteries performed at the same time. A high temperature environment can facilitate aging to shorten the test time, thus, it can select several high temperatures for testing. The life test can be stopped if the test process does not meet the target performance, or terminated early when the performed test is enough to estimate the linear trend.



① Conduct reference performance test (RPT) such as static capacity measurement, HPPC test.

② Adjust the battery to a specified SOC (e.g. 50% SOC).

③ Perform a calendar life test curve defined by FreedomCar with an experimental current (Calendar Life Test Profile).

④ Adjust temperature to the test temperature (e.g. 45°C), rest for 1 hour.

⑤ Perform a calendar life test curve with an experimental current (Calendar Life Test Profile).

⑥ Rest for 24 hours.

⑦ Repeat step 6, 7 for 25 days (about 600 hours).

⑧ Adjust temperature to room temperature (30°C), rest to average temperature for 1 hour and measure the open circuit voltage (OCV).

⑨ Perform a calendar life test curve with an experimental current (Calendar Life Test Profile).

⑩ Discharge 1C current to measure the residual capacity and verify the capacity retention rate.

⑪ Conduct Reference Performance Testing (RPT) to determine the degradation degree of capacity or power capability.

⑫ Adjust to the experimental SOC.

⑬ Repeat step ⑤~13 for calendar test and performance check until any of the test end conditions is met (the Calendar Life TP cannot be completed within the voltage range / RPT cannot show further degradation / the calculated available energy is less than target / sufficient data has been obtained to estimate the calendar life).

⑭ Perform calendar life experiments under different SOCs, different temperatures, and different powers.

Calendar Life Test profile			
Step Time (s)	Cumulative Time (s)	Relative Current (s)	Relative Net Charge (s)
9	9	1	9
60	69	0	9
2	71	-1	7
2	73	0	7
47	120	-0.149	0

Figure (25) FreedomCar Calendar Life Test profile

6.4 Test Guide

Tip. Use Chroma Battery Lab Expert to illustrate the editing of the Calendar Life test procedure.

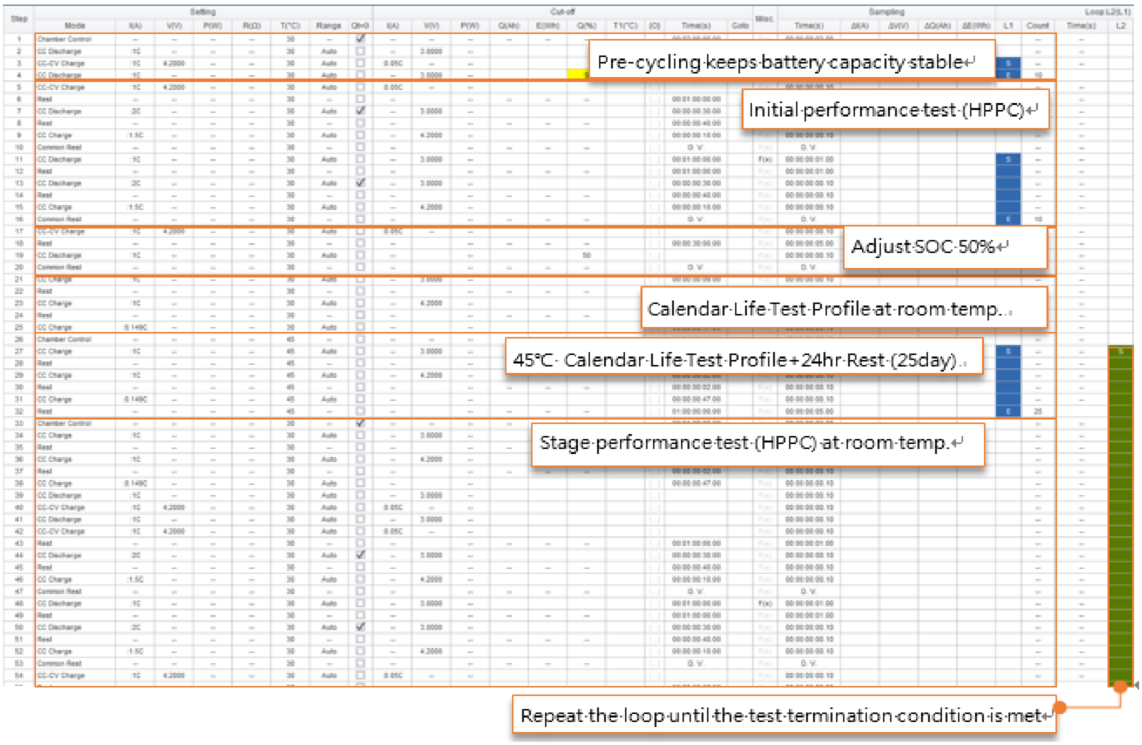


Figure (26) Calendar Life Test Structure (SR)

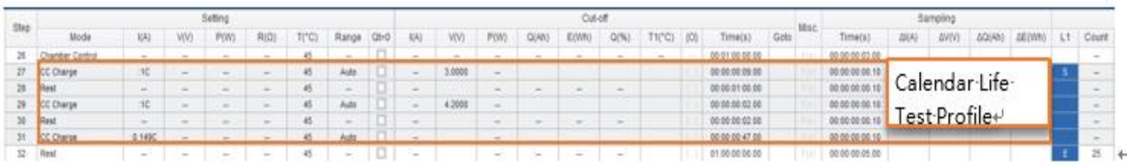


Figure (27) Simple Steps and Cycles Editing for Calendar Life Test Profile

7. Reference Documents

[1] DOEID-11069 FreedomCAR_Power_Assist_Battery_Test_Manual, October 2003

[2] IEC 62660-2011

[3] Battery Reliability Test System 17010 Software User’s Manual of Chroma