Application Report
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Accuracy and Verification Methodologies for Advanced Fuel Gauges

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ABSTRACT

This document outlines the basic concepts of the fuel gauge. It also describes the verification and accuracy test methodologies.

For practical applications, an accurate gauge requires a combination of the battery characteristics and use conditions. It also needs to be optimized for the user experience. This document provides common gauge accuracy tests and associated verification methods, which not only can be used to verify TI fuel gauges, but also can be a reference solution to verify other battery measurements.

1 Background of the Gauge Test

1.1 Glossary

Charge or discharge rate (unit C): This is the terminology that describes the rate at which a battery charges or discharges. For example, if a 500-mA discharge current is applied to a 1000-mAh battery, the charge rate would be: 500 mA / 1000 mAh = 0.5C.

FCC: Full charge capacity, FCC is the available capacity from empty to full or from full to empty.

OCV: Open-circuit voltage, this is the terminal voltage of the cell after it has been at rest for an extended period of time.

RM: Remaining capacity, RM is the amount of capacity that can be discharged from the current state to empty.

SOC: State of charge, SOC is the remaining capacity of the battery in percentage, SOC = RM / FCC.

SOH State of health

Taper voltage and taper current: A lithium-ion battery charge cycle consists of pre-charge, constant current charge, and constant voltage charge.
Taper voltage is the voltage applied during the constant voltage charge period.
Taper current is the threshold that current must fall to before the charger stops and the battery is full.
These two parameters are used to detect charge termination.

Terminate voltage: Terminate voltage is based on the battery cell specification. It prevents damage to the cell and should be set to the absolute minimum system voltage. This is also the voltage at which the battery is considered to have 0% capacity remaining.

Voltage: In this document, voltage is usually referred to the voltage measured directly across the battery. The user can read the value from the gauge.

1.2 Factors That Affect Available Battery Capacity

The available capacity depends on battery characteristics and the use situation. The fuel gauge requires the relevant parameters of the battery as well as the usage record to obtain a better forecast. The available capacity is smaller at higher discharge rates and higher impedance because the cell I × R drop causes the Terminate Voltage threshold to be reached earlier. In other words, the usable capacity of a given battery can vary depending on the load.

Impedance Track is a trademark of Texas Instruments.

Impedance of the battery is related to the battery features (that is, chemistry and form factor), age, and temperature. The impedance of the battery increases as the number of charge or discharge cycles increases. TI gauges track this impedance change to ensure that accuracy is maintained throughout the life of the cell.

Typically, when the temperature is less than 15°C, the battery internal impedance begins to increase significantly. In low temperature applications, the gauge should consider the loss of available capacity because of the impedance increase. However, if the battery discharges at low temperature, it will heat up causing the impedance to reduce. This will result in some capacity recovery. TI gauges take this thermal behavior into account and can improve the gauge performance at low temperature.

Because the usable capacity will be different as the battery load changes, it is important for the gauge to choose which load it will use to predict the remaining capacity. Depending on the system load profile, the TI gauge can use the constant-current or constant-power model in the Impedance Track™ algorithm. The user also can select the type of power or current model to be used to compute the load-compensated capacity, such as average discharge current from previous cycle or present average discharge current. For some systems which have pulses, the TI gauge can record the pulse to avoid the sudden shutdown that can result when the battery is nearly empty.

TI has both pack-side and system-side gauges. When the battery is first inserted, there may be some initial error in the SOC due to taking an OCV reading while the battery is not fully at rest. A pack-side gauge is always connected to the cell, so it can avoid the accuracy error at the first insertion. A system-side gauge uses the current and impedance to compensate the voltage drop which can result a more accurate SOC when the battery is first inserted.

1.3 User Experience

A fuel gauge with good accuracy can allow the system to obtain more energy from the battery without the worry of unexpected shutdown. It can extend the run time and provide a better user experience.

Normally, some end customers think that the SOC should decrease when the battery discharges. However, in some situations, it is possible that the SOC can increase as the battery discharges. For example, when the temperature changes from low temperature to high temperature, the remaining capacity will increase because the impedance is smaller and the Terminate Voltage threshold will be reached later. This reasonable jump may be not easy to accept for some end customers, so TI has incorporated a configurable smoothing function to balance the user experience and measurement accuracy.

Most TI fuel gauges can also compute the battery SOH and the time to full or empty.

1.4 Gauge Accuracy Testing and Verification

This document describes tests that can be used to evaluate gauging accuracy in different situations. It does not include tests related to electrical specifications. Function testing checks the behavior of the gauge. Users may need to calibrate, configure, select the appropriate Chem_ID, and perform golden learning before attempting the tests in the upcoming sections. For more details, please see the product folder of the device being evaluated on http://www.ti.com/.

2 Measurement Accuracy Test

2.1 Voltage, Current, and Temperature Test

Voltage, current, and temperature are very important parameters used by the gauge, so the user needs to ensure the accuracy is good throughout the measurement range.

Most TI gauges need to be calibrated before this test.

2.2 SOC Accuracy Test

Charge and discharge the battery and check the error between the reported SOC and true SOC.

Users need to calibrate, configure, select the appropriate Chem_ID, and perform golden learning before they do this test for the TI gauge.

The test procedure for the TI gauge is as follows. This test procedure can also be used as a reference for other fuel gauges.

1. Charge the battery to full and connect a high accuracy current and voltage meter (or use the gauge data, if it is trusted).
2. Log the data (time, voltage, current, temperature, reported SOC, and reported RM) every 1 to 10 seconds.
3. Discharge the battery to empty using a constant load. Calculate:
   Q_integrated = rolling sum of (current × time interval).
   Integrating the current from full to empty will yield the true capacity, FCC_true. The true state of charge is:
   SOC_True = 100 – 100 × (Q_integrated / FCC_true).
   State of charge error is: SOC_error = SOC_true – SOC_report.
   Remaining capacity error is: RM_error = FCC_true – Q_integrated – RM_report
4. If the user just wants to check the SOC error and the load is stable, the user can use the ratio of the remaining run time and full run time to get the true SOC.
   For most applications, testing the gauge at room temperature with constant load is not enough. It is recommended to perform the following tests as well.

2.2.1 Dynamic Load Test

1. Load profile includes load spikes (that is, camera flash) or dynamically allows an electronic load to swing between a light, heavy, and medium loads.
2. Discharge the battery from full to empty and calculate the SOC error by the same method as described above.

2.2.2 Low Temperature Test

1. Using the system as load, discharge battery to empty and charge to full at room temperature, then discharge the battery from full to empty at low temperature.
2. Calculate the SOC error for the battery by the same method as described above.

2.2.3 Variable Starting Point

1. Insert battery charged to 80% SOC.
2. Use the system as load and discharge the battery to empty.
3. Calculate the SOC error for the battery by the same method as described above.
4. Repeat steps 2 and 3 for batteries charged to 60% and 40% SOC.

2.2.4 Aged Battery Testing

1. Add 100 to 200 mΩ in series with battery or use a real aged battery.
2. Use system as load and discharge the battery from full to empty.
3. Calculate the SOC error for the battery by the same method as described above.

2.3 SOC Accuracy Test Example

The SOC accuracy test charges and then discharges the battery to check the error of the reported SOC and true SOC.

Users need to calibrate, configure, select the appropriate Chem_ID, and perform golden learning or download the golden file before they do this test for a TI gauge.

The test procedure for the TI gauge is as follows. It can be used also as a reference test procedure for other fuel gauges.

1. Users can complete the configuration by using bqCONFIG.
2. Open GaugeStudio.
3. Perform a golden learning cycle.
4. Charge the battery to full and relax for 2 hours.
5. Set the log interval to 5 seconds and start the log.
6. Discharge the battery at about C/4 current until terminate voltage (3200 mV).
7. Export the .gg file.
8. Open the log file in the Excel.
9. Calculate a new column:
   Q_integrated (mAh) = rolling sum of (current × time interval) / 3600
   Q_integrated at the terminate voltage is FCC_true, where:
   FCC_true (mAh) = FCC_true / 3600
10. Calculate a new column:
    Qrem_true = FCC_true – Q_integrated,
    Qrem_true (mAh) = Qrem_true / 3600
11. Calculate a new column:
    RSOC_true (%) = (Qrem_true / FCC_true) × 100
12. Calculate a new column:
    Qrem_error (%) = 100 × (Qrem_true (mAh) – Qrem_gauge) / FCC_true (mAh)
13. Calculate a new column:
    RSOC_error = RSOC_true – RSOC_gauge

3 Summary

This document describes the verification and accuracy test methods of fuel gauge, TI also will release a tool called Gauge Development Kit to simplify the procedure of generating production file and accuracy test.

IMPORTANT NOTICE

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
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