Application Report
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End of Discharge SOC Jump Elimination

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ABSTRACT

In critical applications like very low temperatures with dynamic load, fuel gauges based on the Impedance Track™ algorithm may report a sudden state of charge (SOC) jump from several or tens of percent to zero towards the end of discharge, which causes system abruptly shut-down. This application report discusses the SOC jump issue, explains the possible root causes, and accordingly gives feasible solutions to eliminate it.

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Trademarks

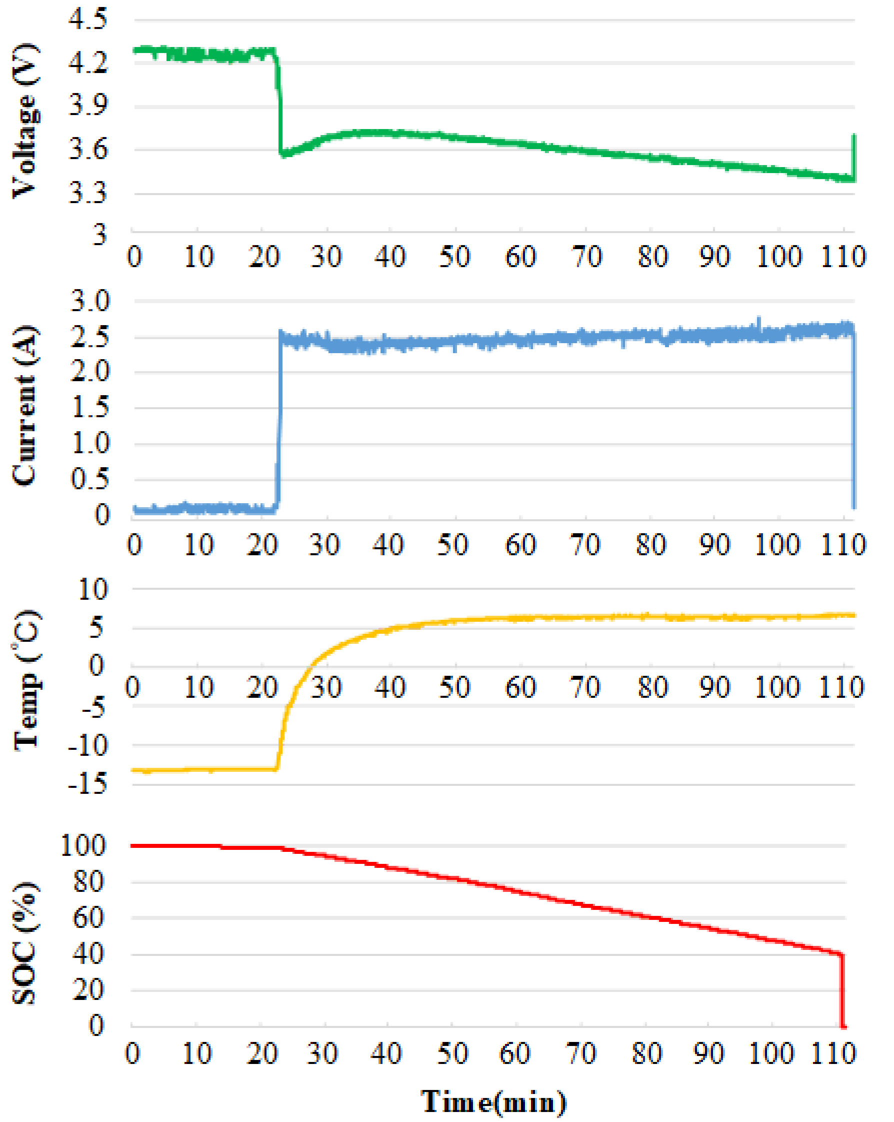
1 Introduction

Battery fuel gauge is used to calculate the remaining capacity and full-charged capacity under any given load. It can tell the host side when the battery is going to be empty or full, what state of the battery right now, how much life time has left. This information will help the host side to do smarter power management for the whole system and also ensure safe charge/discharge. An accurate gauge is critical for the longer battery runtime and life span.

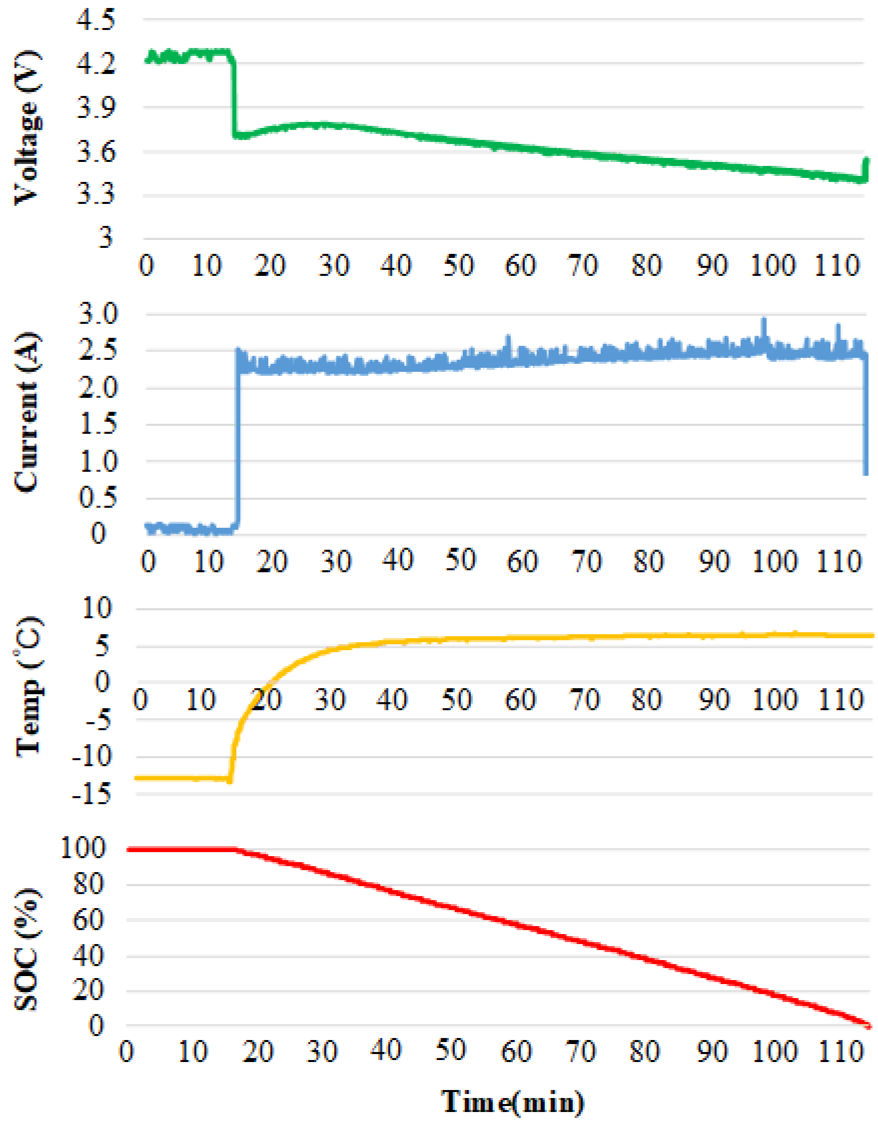
Impedance Track technology is a fuel-gauging algorithm developed by Texas Instruments. What makes it unique and more accurate than other solutions is the self-learning mechanism. IT algorithm continually measures and updates battery impedance and full chemical capacity. IT-based gauge can maintain its accuracy even as the battery ages. However, if the gauge was improperly configured, the gauge may perform badly in some applications. A possible issue encountering is the SOC jump issue.

Figure 1(a) describes a low temperature discharge test of the portable device using TI gauge BQ27Z561-R1. There is a significant SOC drop from 40% to 0% that causing the device abruptly shut down. Essentially, SOC jump issue is an overestimation issue. Due to overestimation, the gauge 'thinks' there is still 40% of capacity left before the voltage reaches **Termination Voltage** (EDV). But gauge is forced to report SOC=0% once the voltage hits the EDV, causing a 40% drop of reported SOC at the EDV.

The undesired drop can be eliminated using following methods of this document, the optimization result is shown in Figure 1(b), which will surely improve the experience and prevent data loss due to abnormal shutdown.



(a) 40% SOC Jump (before optimization)



(b) No SOC Jump (after optimization)

Figure 1. Low Temperature Discharge Test Using Gauge BQ27Z561-R1

2 Improve Battery Modeling

Figure 2 shows that the Impedance Track gauge uses a battery model to estimate how much capacity is still available until the cell voltage reaches EDV. It is a model-based algorithm. Battery model (including impedance model, temperature model, transient model…) needs to be determined before using the gauge. To solve reported SOC jump issue, firstly you should guarantee the model parameters are well extracted.

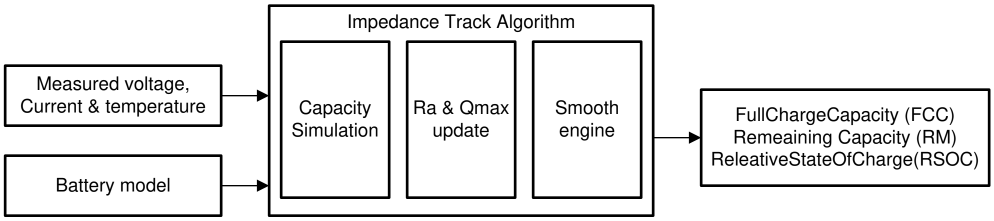
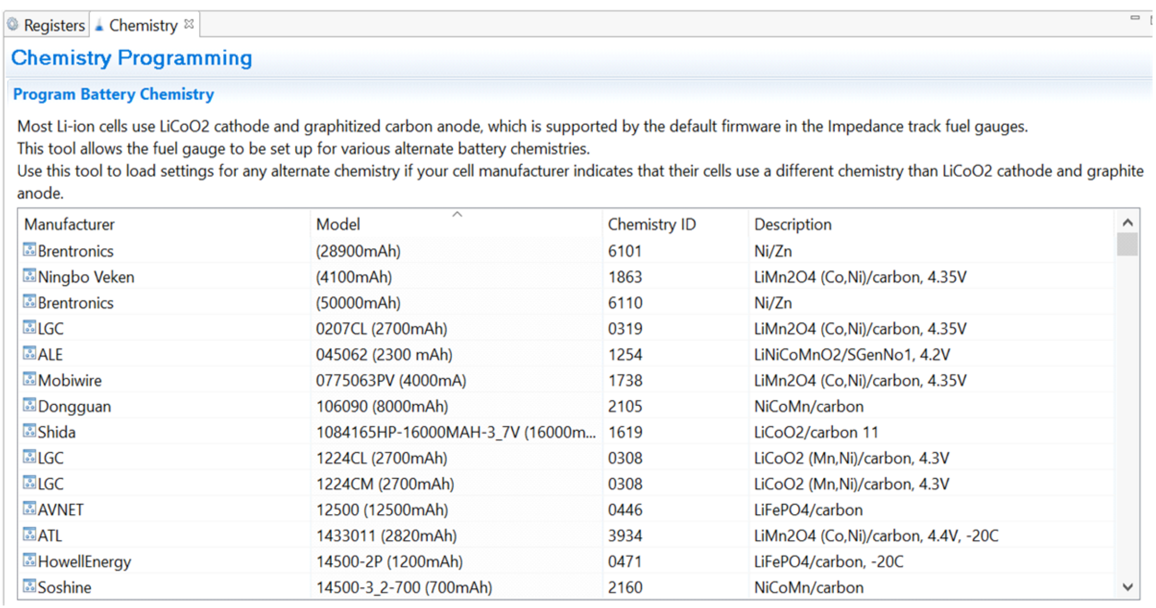


Figure 2. Basic Principles of Impedance Track Algorithm

2.1 Improve Battery Modeling -- Get Matched ChemID

Texas Instruments has a database of thousands of battery models, as shown in Figure 3. Each model has a unique number referred to as the chemistry identifier, or ‘ChemID’. It is important that the ChemID programmed into the gauge was either generated by TI for that battery or a close match to an existing ChemID in TI database using our online tool - GPCCHEM. The ChemID identification requires running a relax-discharge-relax test while logging data using the gauge’s GUI (bqStudio) and then using GPCCHEM tool with the logged data to identify a close match. If there is no match (model error > 3%), then the cells have to be sent to TI for characterization and ChemID generation. Contact a local field applications engineer if cells have to be sent to TI.



Manufacturer	Model	Chemistry ID	Description
Brentronics	(28900mAh)	6101	Ni/Zn
Ningbo Veken	(4100mAh)	1863	LiMn2O4 (Co,Ni)/carbon, 4.35V
Brentronics	(50000mAh)	6110	Ni/Zn
LGC	0207CL (2700mAh)	0319	LiMn2O4 (Co,Ni)/carbon, 4.35V
ALE	045062 (2300 mAh)	1254	LiNiCoMnO2/SGenNo1, 4.2V
Mobiwire	0775063PV (4000mA)	1738	LiMn2O4 (Co,Ni)/carbon, 4.35V
Dongguan	106090 (8000mAh)	2105	NiCoMn/carbon
Shida	1084165HP-16000MAH-3_7V (16000m...	1619	LiCoO2/carbon 11
LGC	1224CL (2700mAh)	0308	LiCoO2 (Mn,Ni)/carbon, 4.3V
LGC	1224CM (2700mAh)	0308	LiCoO2 (Mn,Ni)/carbon, 4.3V
AVNET	12500 (12500mAh)	0446	LiFePO4/carbon
ATL	1433011 (2820mAh)	3934	LiMn2O4 (Co,Ni)/carbon, 4.4V, -20C
HowellEnergy	14500-2P (1200mAh)	0471	LiFePO4/carbon, -20C
Soshine	14500-3_2-700 (700mAh)	2160	NiCoMn/carbon

Figure 3. ChemID Database

2.2 Improve Battery Modeling -- Use GPCRB Tool to Optimize Low-Temperature Performance

SOC jump issue is more severe in very low temperature test, such as -15℃. Note that TI standardizes the modeling temperatures to 0℃, 25℃ and 50℃. ChemID was not operated at lower temperatures. it is recommended that the cells be characterized at 0℃ and that low temperature optimization tests can be performed using the online tool - GPCRB.

GPCRB is a dedicated tool to optimize low temperature performance of IT gauges. For IT gauges, resistance in data flash is normalized to 25°C as shown in Equation 1.

$$Ra\left[DOD\right] = \frac{R\left[DOD\right]}{\exp\left(Rb\left[DOD\right] \times T\right)} \tag{1}$$

Where, DOD is the depth of discharge, R[DOD] is the measured resistance at a given DOD, Rb[DOD] is the temperature coefficient of impedance change at a given DOD stored as a reserved data flash table, and T is temperature in °C. GPCRB tool can modify the Rb values to improve Ra calculation accuracy in low temperature test, as shown in Figure 4, so as to improve SOC accuracy and relieve SOC jump problem at low temperature. This tool also obtains thermal model parameters that do not update in gauges, which helps with high rate tests accuracy. This tool provides Ra0_charge value as well, that helps to reach 100% SOC during charge more accurately.

DOD_newRb_ratio - Notepad

File Edit Format View Help

0	0.833
0.111	0.843
0.222	0.834
0.333	0.792
0.444	0.984
0.556	0.856
0.667	0.93
0.778	0.806
0.81	0.763
0.841	0.753
0.873	0.811
0.905	0.811
0.937	0.811
0.968	0.811
1	0.811

Figure 4. GPCRB Report – New Rb

GPCRB tool requires two log files of a relax-discharge-relax test performed under load and temperature conditions similar to an actual device, and also requires the gg file exported from your gauge EVM or device PCB using bqStudio after chosen ChemID data has been programmed. This tool will generate a new chemistry file that provides both improved resistance temperature compensation and learned values.

3 Optimize Gauge Configurations

3.1 Optimize Gauge Configuration -- Load Prediction

Load prediction is an essential part of IT algorithm. Gauge cannot know future load would be, so has to make a prediction of future load.

IT gauge determines the remaining capacity (RM) using a voltage-simulation method based on predicted load current (I_{pred}). Simulation starts from the present DOD_{start}, and the future cell voltage is calculated by increasing DOD repeatedly in small steps as shown in Equation 2.

$$U_{pred} = OCV[DOD] - I_{pred} \times R[DOD] \tag{2}$$

In Equation 2, OCV is the battery open-circuit voltage derived from OCV[DOD] table, R is the battery resistance calculated by R = Ra × exp(Rb × T). When the simulated voltage U_{pred} reaches the battery termination voltage, the DOD corresponding to this voltage is captured as DOD_{final}. RM can be calculated as shown in Equation 3.

$$RM = DOD_{final} - DOD_{start} \tag{3}$$

From the above equations, it can be inferred that I_{pred} affects the remaining capacity accuracy. Sometimes SOC jump is due to load prediction that is not configured well, I_{pred} is far from the actual load, which leads to an overestimation of remaining capacity followed by the SOC jump at terminate voltage

The following sections provide a guidance of load prediction settings.

3.1.1 Load Mode

The gauge provides various load options in data flash. It has two load prediction models (Load Mode) as shown in Equation 4 and Equation 5:

- **Constant Current:**

  $$I_{pred} = const. \tag{4}$$

  Capacity simulations use a constant current, regardless of simulated cell voltage. This is the default setting.
- **Constant Power:**

  $$P_{pred} = const. \quad I_{pred} = const. / U_{sim} \tag{5}$$

  Capacity simulations use a variable current as a function of simulated cell voltage. The current is adjusted automatically so that the simulated power drawn from the battery is constant.

Normally, **Constant Current** is chosen, but it is application dependent. If the application load file more closely matches a constant power model, then choose **Constant Power**.

3.1.2 Load Select

Besides choosing the Load Mode, you need to choose a prediction method (determine the 'const.' in Equation 4 and Equation 5) by setting the Load Select parameter, which has following options.

- **Average discharge load from the previous discharge cycle:**

  The gauge calculates the average load from the previous discharge cycle and saves this in data memory (Avg I/P Last Run). Capacity simulations use this data (regardless of present load) for load prediction. Use this if the load profile is not known but not expected to change much between discharge cycles.
- **Present average load from the beginning of the current discharge cycle:**

  The gauge calculates the average load from the current discharge cycle and uses this for capacity simulations. Use this if the load profile not known but expected to change significantly between discharge cycles. This is the default setting.
- **Present load:**

  The gauge uses present load value for capacity simulations. Use this if the load profile varies little.

- **Present Average load:**

  The gauge uses present average load value for capacity simulations. Use this if the load profile varies little.
- **Low-pass filtered average load:**

  The gauge calculates a low pass filtered version of the average load and uses this for capacity simulations. Use this if the load profile is dynamic. This may lead to underestimation of capacity if the low pass filtered load is larger than the average load over the discharge cycle, causing SOC report 0% before Terminate Voltage.
- **Design Capacity / 5:**

  The gauge uses a C/5 load value for capacity simulations. Use this if the load profile is not known.
- **User Rate:**

  The gauge uses a fixed load value for capacity simulations. Use this if the load profile is very dynamic (choose the max load) and if underestimation of capacity is preferred over SOC jump.

3.1.3 Discharge Current Threshold and Quit Current

The gauge is configured to enter discharge mode when the discharge current exceeds **Discharge Current Threshold**, exit discharge mode when the current goes below **Quit Current** for a period of time, as shown in Figure 5. The two parameters should be set low enough to be below any normal application load current but high enough to prevent noise, drift or disturbance affecting the accurate capacity simulation.

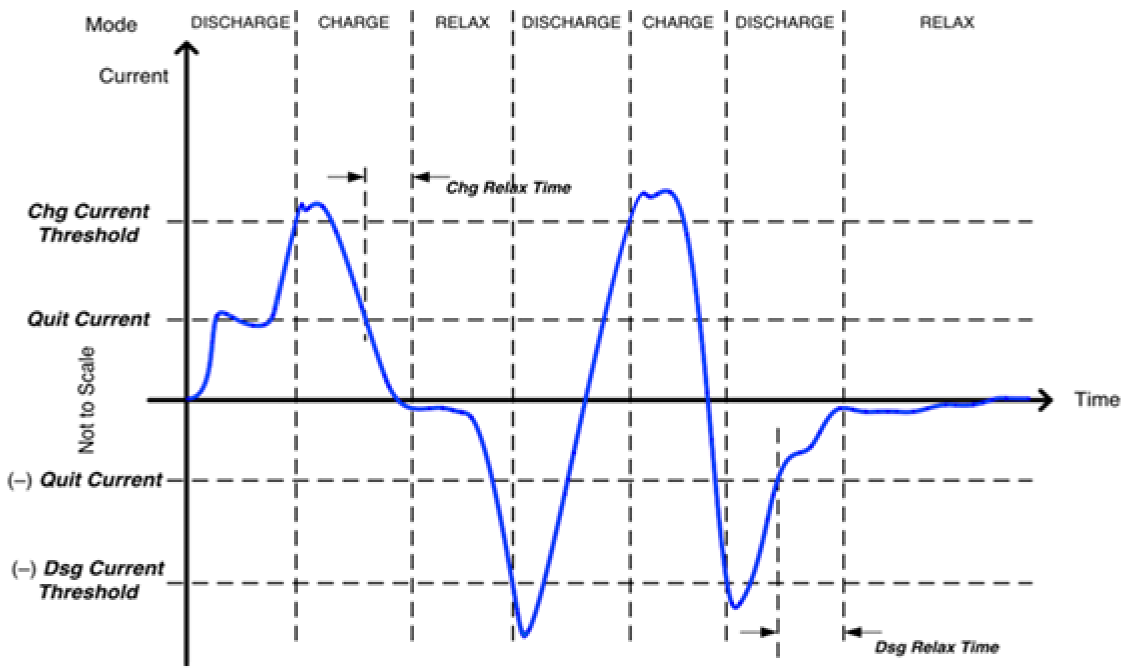


Figure 5. Gauge Operating Mode

Portable devices spend most of time in standby mode (for example, lock screen). There are cases where the gauge is in discharge mode for a long time with a very low standby current, then followed by a period of much higher load (e.g. leave the lock screen mode and fully turn on). The gauge cannot predict the higher load adequately if using the average load from start of discharge, leading to an undesired SOC jump.

It is recommended that you to set **Discharge Current Threshold** > **Quit Current** > device standby current. With these settings, the gauge will not enter or stay in discharge mode until there is a significant discharge. This excludes the standby load case from discharge mode. The gauge will still coulomb count and adjust remaining capacity during standby mode, but it will not perform capacity simulations or adjust the load prediction based on the small load, which fixes the jump.

3.2 Optimize Gauge Configuration -- Enable Smoothing to 0% in Discharge Mode

For preventing SOC jumps to 0%, some gauges such a BQ27Z561-R1 have a feature named **Smoothing to 0% in Discharge Mode**. This feature is designed to guarantee a smooth decrease in SOC at the end of discharge. This will allow voltage to go below EDV without forcing 0%.

3.3 Optimize Gauge Configuration -- Enable Fast Resistance Scaling

The gauge gets cell resistance from interpolating Ra table, which inevitably leads to some error in SOC. The error could be large at low temperature and heavy load, especially near the end of discharge when resistance changes quickly, which may cause SOC jump issue.

Fast Resistance Scaling is an algorithm that improves SOC convergence to 0% by scaling cell resistance as (R_{new} / R_{old}), where R_{new} is the most recent measured resistance and R_{old} is the interpolated resistance at present DOD. After a scale is calculated, an IT simulation is triggered to utilize the new resistance information.

3.4 Optimize Gauge Configuration -- EDV in Steep Zone

Termination Voltage (EDV) should be in the steep zone of the cell voltage profile. This will allow the simulation to terminate accurately and stable. If the EDV shifts into the flat zone, a small charge in simulated voltage can cause a big change in simulated capacity.

It is suggested to use lower EDV with some **Reserve Capacity**, instead of using high EDV. **Reserve Capacity** is to give the host system a buffer to make sure it shutdown properly without a sudden brownout.

4 Achieve Successful Ra Table, Qmax and DOD0 Learning

4.1 Complete a Learning Cycle to Update Ra Table and Qmax

The learning cycle is needed for the gauge to update the resistance (**Ra**) table and total chemical capacity (**Qmax**). You need to carry out a charge-relax-discharge-relax cycle. This is a part of the firmware creation process in order to get an accurate initial **Ra** and **Qmax**. The following procedure must be followed:

1. Discharge the cell to empty for at least 5 hours.
2. Charge the cell to full and let it relax for at least 2 hours.
3. Discharge the cell to empty using typical discharge rate of your application. It must between C/5 to C/10 rate.
4. Let the cell relax for 5 hours.

4.2 Add a Dedicated Relaxation to Update DOD0

A dedicated relaxation (zero discharge current) will result in a better **DOD0** and **Present DOD**, because the OCV lookup is more precise than the end-of-charge detection **DODatEOC**. The gauge will try to estimate a **DODatEOC** based on the charging voltage, the taper current and the impedance tables. This inherently is less accurate than a dedicated OCV measurement in relax, hence, SOC accuracy improves if relax is added. It can be implemented by the adaptor plugged in trick to power the device to maintain no current out of the battery.

5 References

- Texas Instruments: *Impedance Track Gauge Configuration For Dynamic Loads (EPOS)*
- Texas Instruments: *Achieving The Successful Learning Cycle*
- Texas Instruments: *Theory and Implementation of Impedance Track™ Battery Fuel-Gauging Algorithm in bq2750x Family*
- Texas Instruments: *BQ27Z561-R1 Technical Reference Manual*