Application Report
SLUA997–October 2019

Impedance Track Optimization for Applications Without Significant Rest Periods

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ABSTRACT

In some applications, users constantly charge and discharge the battery pack continuously without rest periods. Impedance tracks require adequate relaxation periods in order to learn the total chemical capacity (Qmax) of the cells; hence, in such applications with continuous usage and without relaxation, Qmax updates are not feasible. This forces the OEMs to have conditioning cycles where relaxation is forced to allow Qmax updates. This application note describes certain optimizations for impedance track gauges based on features that allow Qmax updates without significant relaxation.

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1 Introduction

Impedance track is a proprietary algorithm developed by Texas Instruments where the battery gauge dynamically learns the resistance and total chemical capacity of the battery (Qmax). As the battery ages, it is less able to hold charge, meaning Qmax deteriorates. In order to maintain high accuracy over the lifetime of the pack, Qmax has to be periodically tracked and updated, given that the state of charge is a derivative of Qmax. The depth of discharge of a battery (DOD) is the inverse of the state of charge (SOC) and simplistically can be represented as:

$$DOD = 100\% - SOC \quad (1)$$

The chem ID is a look-up table of the cell voltages (open circuit voltage (OCV)) and their corresponding DOD points. When a cell is under load, DOD is computed by the gauge from two sources of observable data:

$$DOD = DOD_0 - \frac{\Delta Q_{dod0}}{Q_{max}} \tag{2}$$

DOD_0 is the DOD looked up by first reading a well-rested cell voltage and then correlating that voltage to the corresponding DOD point on the chem id table. ΔQ_{dod0} is the cumulated passed charge since the last DOD_0 lookup. Qmax is the total chemical capacity. From Equation 1 and Equation 2, it is obvious that an incorrect Qmax value translates into errors in SOC.

2 Total Chemical Capacity (Q_{max})

Qmax is the maximum or total chemical capacity that the battery can hold. The gauge periodically measures Qmax by taking DOD measurements of a well-relaxed cell. In IT gauges, the time set, upon which it is assumed that the cell is fully relaxed, is two hours after charge and five hours after discharge. However, most cells achieve a relaxed state before these time frames. The gauge determines a cell is well-relaxed after the rate of change of voltage is less than 4 uV/s. Qmax is calculated using the following equation:

$$Q_{max} = \frac{\left|\Delta Q_{qmax}\right|}{\left|DOD_{0,2} - DOD_{0,1}\right|}$$

Where $DOD_{0,2}$ and $DOD_{0,1}$ are DOD values sampled at two separate relax phase (P1 and P2 in Figure 1). ΔQ_{qmax} is the cumulative charge passed between $DOD_{0,2}$ and $DOD_{0,1}$. (3)

The amount of passed charge between $DOD_{0,1}$ and $DOD_{0,2}$ must be at least 37% of design capacity while in the field. For optimized learning cycle during the golden file creation, that number is 90%.

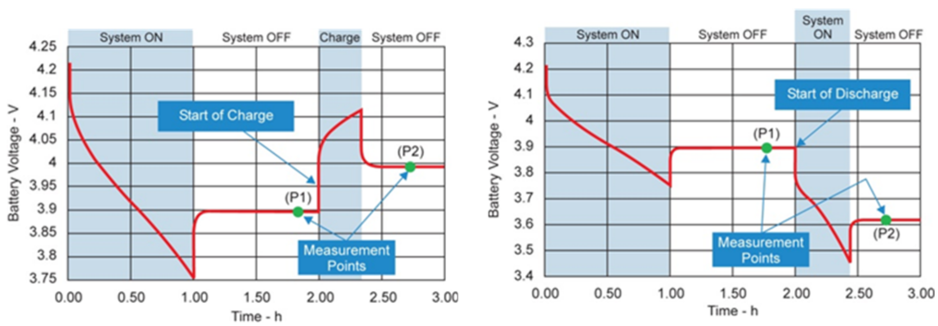

Figure 1. DOD0 Sampling Points for Qmax Update

3 Fast Qmax

This feature allows a Qmax update to occur using just one DOD0 (obtained from a relaxed OCV measurement) while the other DOD0 is calculated. Alternatively, a DOD taken at the end of charge (DOD@EOC) can be used as one DOD point while the other is calculated, thus effectively eliminating the need for relaxation. The second DOD is calculated by solving Equation 4.

$$V = +OCV(DOD) + I \times R(DOD)$$

Where "V" is the voltage measured, "I" is the load current, and "R" is the cell resistance. The DOD is correlated to the OCV value obtained from Equation 4. (4)

It is pertinent to point out that the Qmax calculated using this method is less accurate than a Qmax obtained with relaxation, but the error has been proven to negligible as long as the DOD0 estimates is done at DOD > 85%. Figure 2 shows how much error in Qmax can be introduced based on where DOD measurement is calculated.

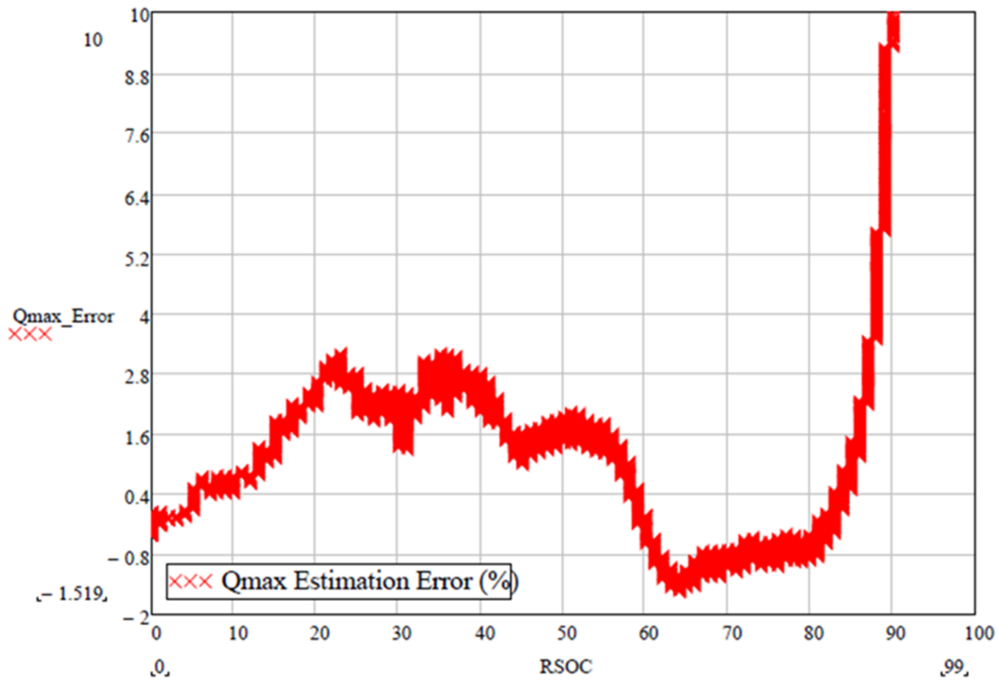

Figure 2. Estimated Qmax error Versus RSOC Where Second DOD was Taken

There are conditions that must be met in order for fast Qmax to work. These conditions are:

- The gauge must be in discharge mode.
- Current must be:
  - < MaxRatePercent x DesignCapacity (in multicell gauges).
  - < FastQmaxCurrentThreshold (in single cell gauges)
  - MaxratePercent defaults to 55% and FastQmaxCurrentThreshold defaults to 4. These are private parameters.
- D0D > FastQmaxStartDoDPercent. This defaults to 85% in multicell gauges and 92% in singe cell gauges.
- Temperature must be between Tempmin and TempMax, which default to 10 C and 40 C respectively. These are private parameters.
- Passed charge must be > Minpassedchargepercent. This defaults to 37%
- FastQmax_En and Reset_Qmax_VCT must be set. The latter is only available in newer gauges.

Figure 3 shows a battery pack using the BQ27Z561-R2 gauge that was cycled multiple times without relaxation. With each charge and discharge cycle, Qmax updated as shown in Figure 4. The initial Qmax (learned using the optimized process) was 5970 mAh. The first Qmax learned using Fast Qmax had an increase of about ~2.5% to 6120 mAh. However, with each cycle, the Qmax became more accurate and converged closer to the initial Qmax from the optimized cycle. Figure 5 shows the SOC accuracy with each cycle. It is visible that the SOC accuracy became better, and the overall error was less than 2.6%.

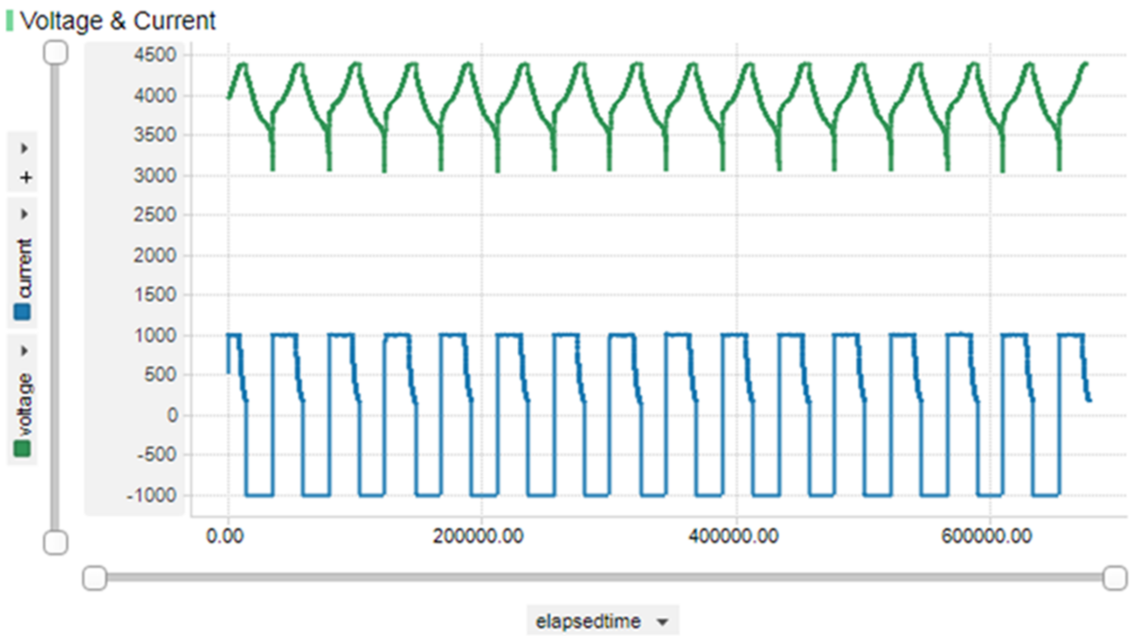

Figure 3. Voltage and Current Plots Showing Multiple Cycles Without Rest

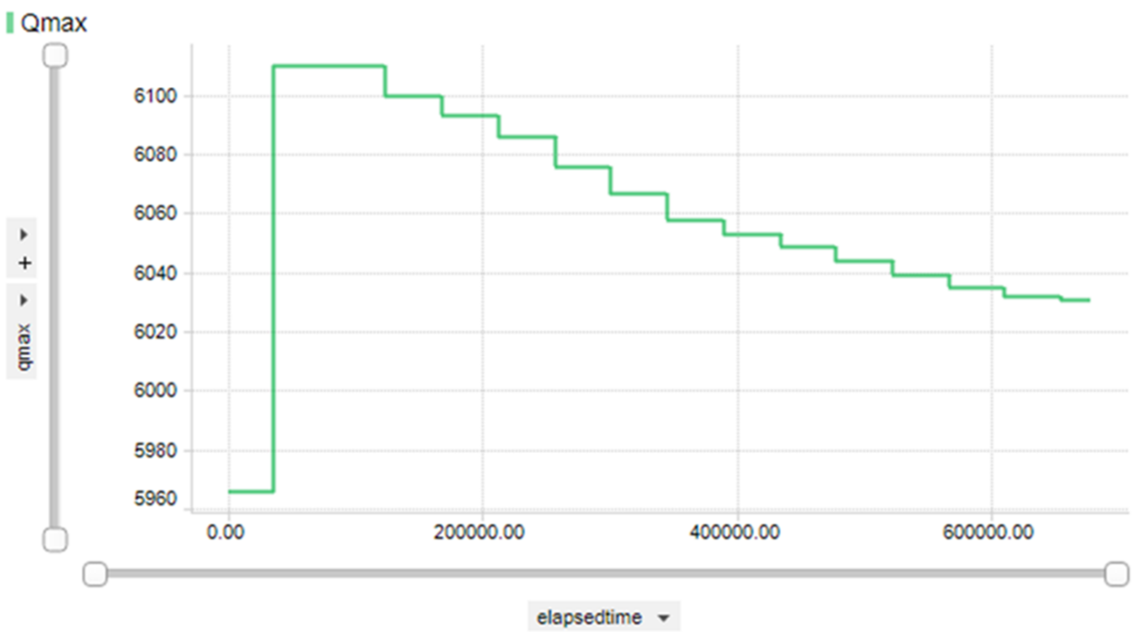

Figure 4. Qmax Updates with Each Cycle.

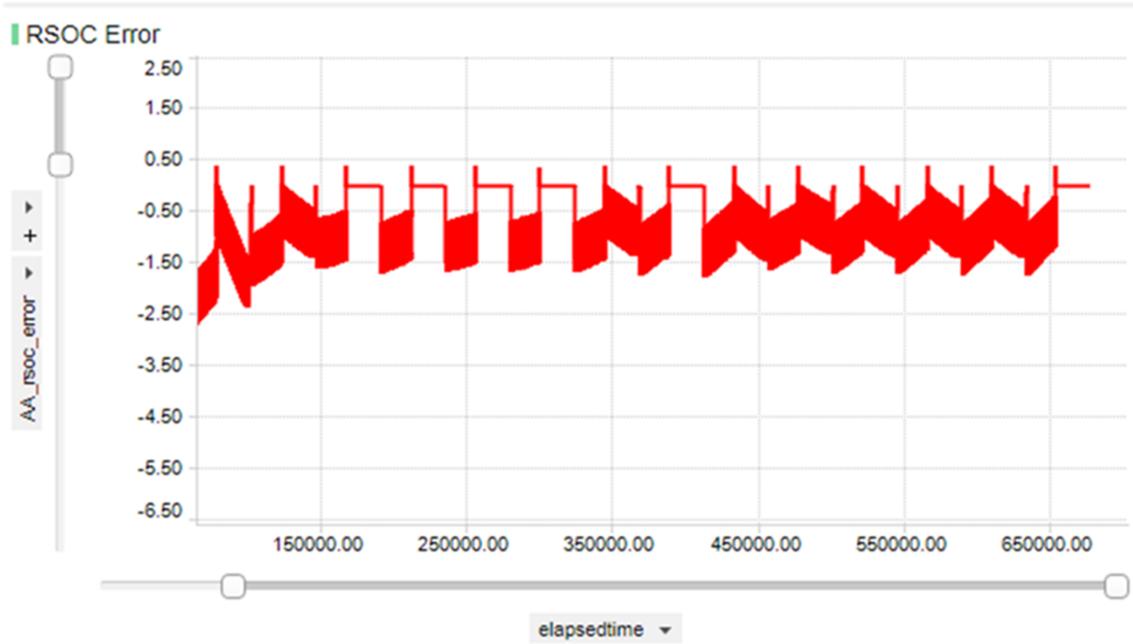

Figure 5. SOC Error with Each Cycle

4 Fast OCV

Some applications have very short relaxation times that are insufficient to achieve a Qmax update, and the cells may not be discharged deeply enough to achieve a Fast Qmax update (recall that for Fast Qmax to work, the cells have to be discharged to at least 85% DOD).

Such applications benefit from the Fast OCV feature where the gauge models the relaxation profile of the battery between 300 and 500 secs after discharge and then extrapolates the model to five hours time in order to get the effective OCV and correlate it with DOD_0.

After the DOD_0 is estimated, it is not used, but rather the firmware keeps checking for an actual relaxation to occur in order to take an OCV of a well-relaxed cell. If the dv/dt condition is achieved, then a new DOD_0 is obtained and the earlier estimated DOD_0 is discarded. If rest is exited without the dv/dt condition achieved, then the estimated DOD_0 is used to calculate Qmax. Note that the conditions governing a Qmax update are still applicable, meaning that two DOD_0 measurements need to be taken, and 37% of design capacity has to enter or exit the battery in-between these two DOD_0 measurements.

The 37% passed charge, which is called min%passed charge for Qm in data flash, is a private parameter that can be further modified in applications that may not see up to this amount of passed charge. The trade-off is that a Qmax estimated with such an adjustment is susceptible to some errors that translate into errors in SOC. If the min%passed charge for Qm is changed, then the Qmax filter in data flash must be adjusted. Certain other filters need to be adjusted to limit the amount of error that can be introduced into the Qmax update, given that more frequent Qmax updates occur through this method.

Note that this feature is only available in newer IT gauges. A test ran on the BQ27Z561-R2 was able to achieve Qmax update after about 20% of discharge and less than 15 mins rest time. The first DOD_0 was taken from DOD@EOC, while the second DOD_0 was estimated. To enable the feature, the FOCV_EN flag in IT gauging register has to be set. The following changes can be made to the Qmax filters to reduce the errors that can be introduced due to frequent Qmax updates without a deeply discharged cell.

- Min%passed charge for Qm: 37% -> 10%
- Qmax filter: 96% -> 24%. The relationship between min%passed charge for Qm and Qmax fillter is: qmax filter <256*min%passed charge for Qm. One must not be modified without the other.
- Qmax delta: 5% -> 2%
- Qmax upper bound: 130% -> 105%

Figure 6 shows a cell that was discharged for less than 20% of the total capacity, and then relaxed for less than 15 minutes. It can be seen in Figure 7 that a DOD_0 update occurred due to fast OCV, and subsequently, a Qmax update occurred after about 500 s in relaxation. The SOC error after such a Qmax update was less than 3% over the course of the discharge, as shown in Figure 6 and Figure 8.

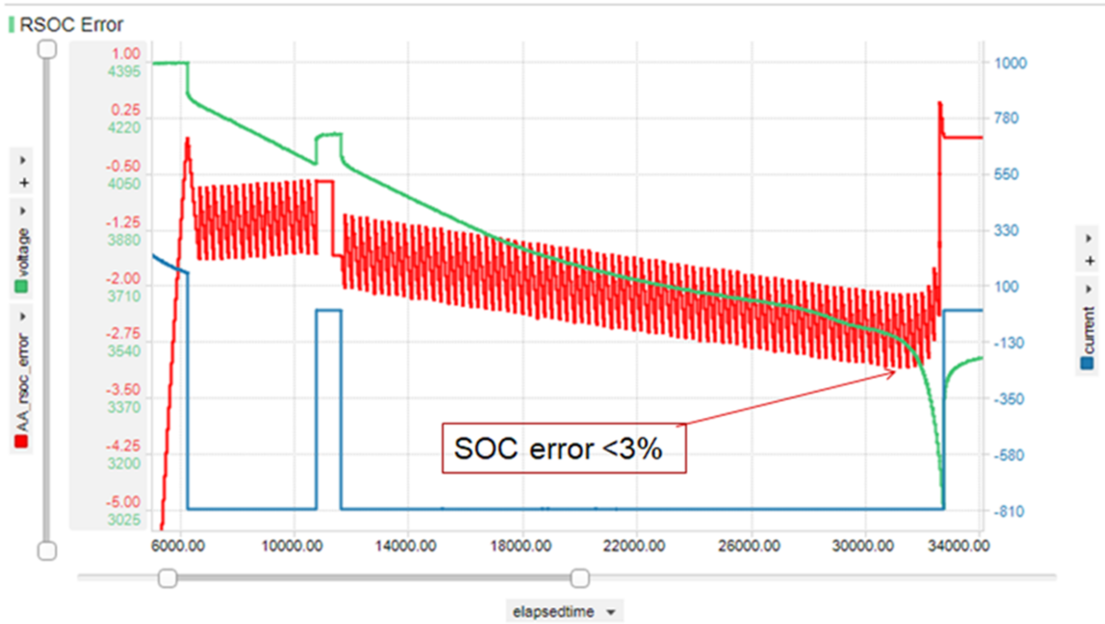

Figure 6. SOC Error After a Qmax Update due to Fast OCV

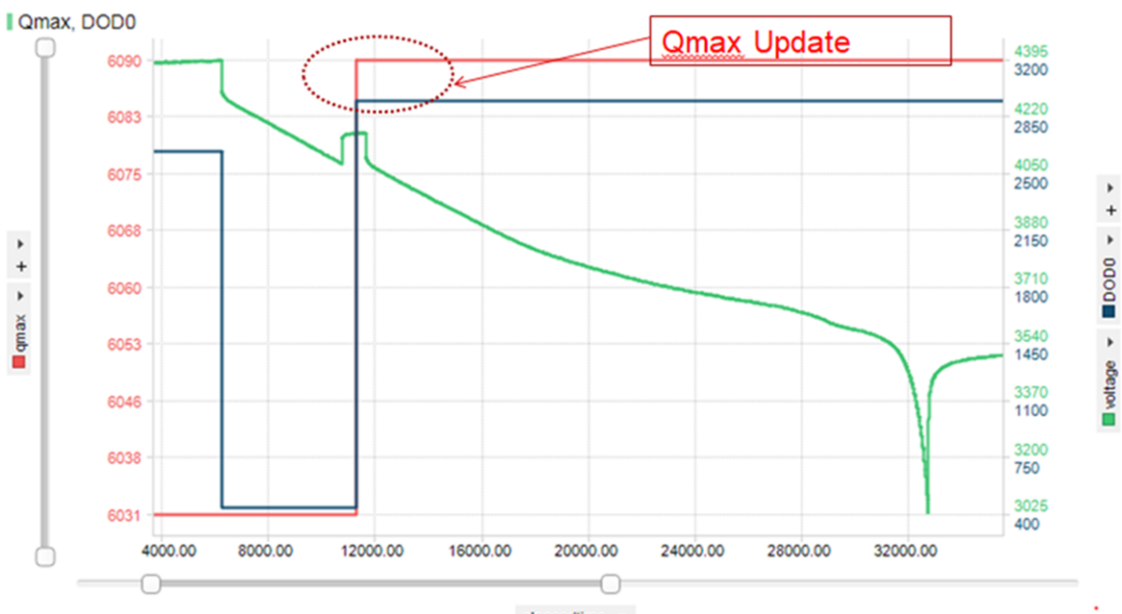

Figure 7. DOD_0 and Qmax Updates After A Partial Discharge

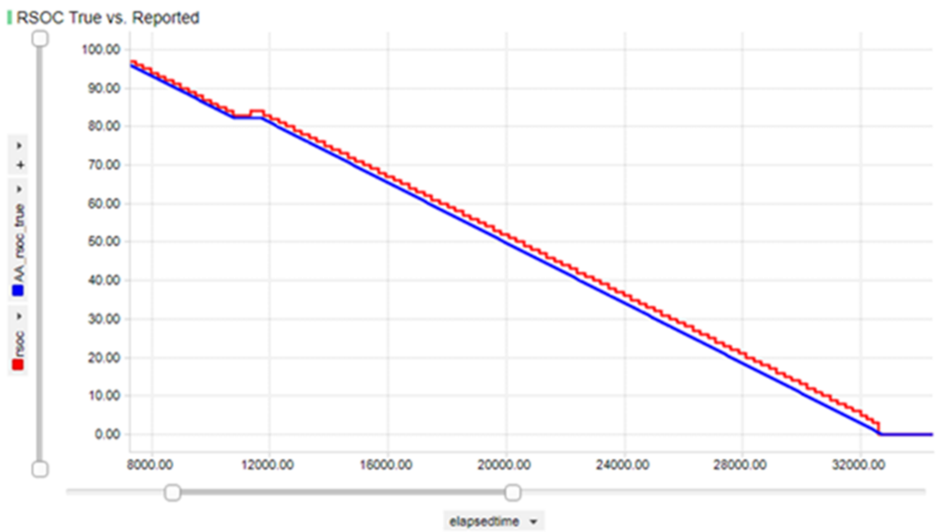

Figure 8. True SOC (Blue) Versus Gauge Reported SOC (Red)

5 Conclusion

Fast Qmax and Fast OCV are features that allow Qmax to learn in applications that may not have the sufficient rest periods required for conventional Qmax learning. Fast Qmax can be used in applications where there is continuous charge-to-full-discharge-to-empty cycles without rest, while fast OCV allows learning to occur in applications where deep discharges do not occur and rest periods are minimal. A combination of both features ensures the accuracy of SOC over the lifetime of the application.