Application Report
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How to Complete a Successful Learning Cycle for the bq28z610/bq78z100

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ABSTRACT

The 1- to 2- series bq28z610 which uses I2C communication protocol and the bq78z100 which uses the HDQ communication protocol are based off the same hardware platform. The Impedance track algorithm on both devices is identical as well as most of the registers. This paper discusses the steps necessary to complete the initial optimization cycle (also known as learning cycle) in order to ensure the accuracy and excellent performance of the gauge.

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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 the total chemical capacity of the battery. In order to go into production using the bq28z610 / the bq78z100, a golden file has to be created which is programmed on multiple devices. The learning cycle is a part of the golden file creation process which requires the user to carry out a few cycles on the pack to make sure that possible variation in cell manufacturer processes is accounted for in the learned resistance as well as to account for the board contact and trace resistances which could impact the gauges state of charge reporting and accuracy.

2 Chem id Identification and Programming

The chem id is a look up table which the gauge uses for determination of state of charge during initialization. The gauge also uses this table as part of the IT algorithm to predict remaining capacity. This table consists of the open circuit voltage profile of the battery from full to empty as well as the resistance of the battery which is spit up into grid points that corresponds to different state of charges. Both the OCV and resistance tables have the temperature dependent components which aids gauge performance at different temperatures. It is important that the chem id programmed on the gauge was either generated by TI for that battery or a close match to an existing chem id in TI data base for batteries is identified using our online chem id identification tool - gpcchem. The chem id identification requires running a relax-discharge-relax (rel-dis-rel) test while logging data using the gauge's GUI (bqstudio) and then using gpc chem tool with the logged data to identify a close match. If there is no match, then the cells have to be sent to TI for characterization and chem id generation. Contact a local field applications engineer if cells have to be sent to TI. Once a chem id has been identified or created, it has to be programmed on the fuel gauge. The user can select the new found chem id and program it using the chemistry plug-in of bqstudio as shown in Figure 1.

NOTE: If an incorrect chem id is used, the learning cycle may never successfully complete and the state of charge prediction may never be accurate.

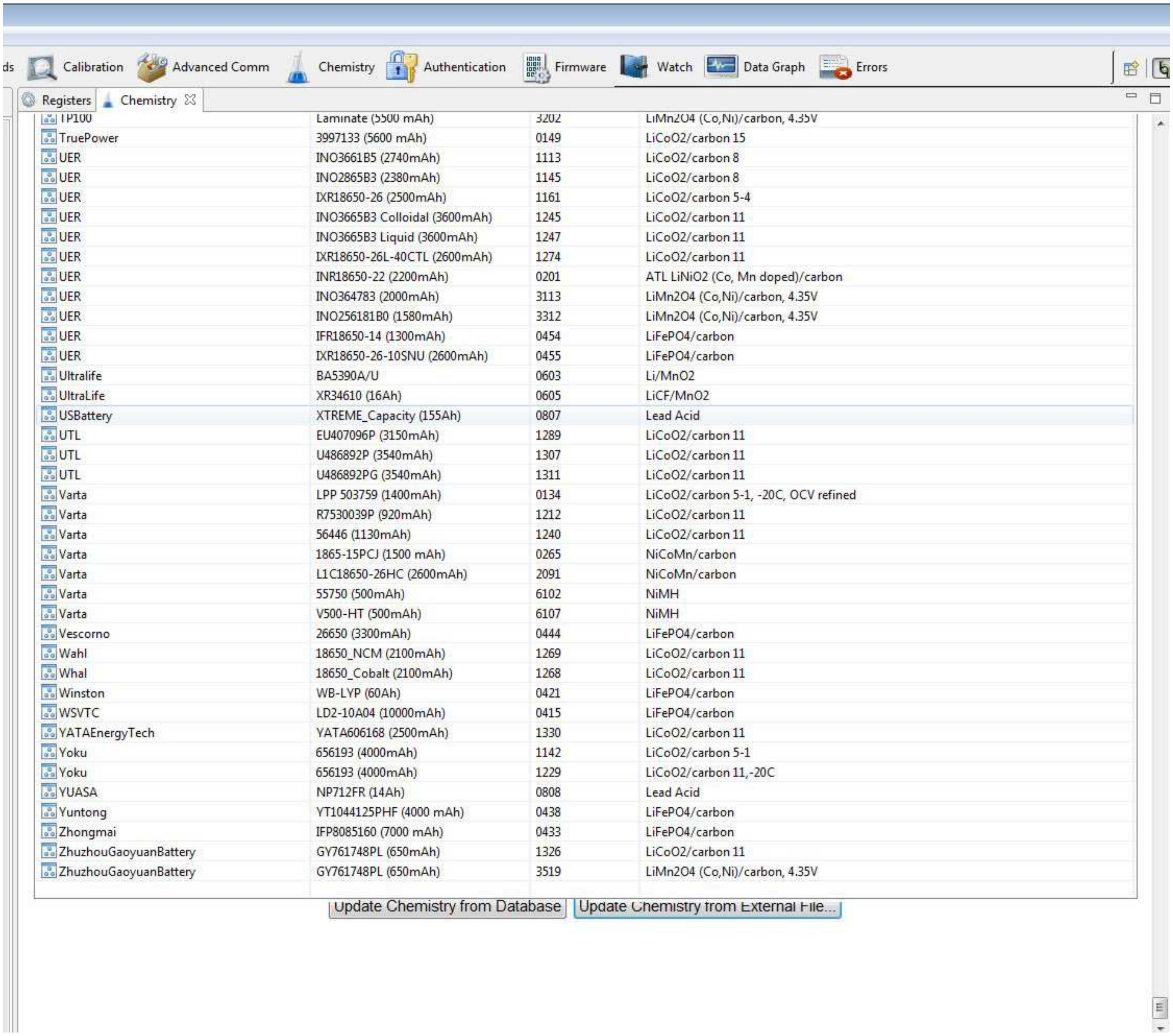

Figure 1. Chemistry Programming

3 Data Flash Configuration Settings Pertinent to Learning Cycle Completion

In order to have learning cycle successfully complete, certain parameters need to be configured specific to the application and the battery type in the gauge data flash. These parameters are design capacity, charge termination taper current, discharge current threshold, charge current threshold, quit current and term voltage.

3.1 Design Capacity

The design capacity should be set to the value specified in the cell manufacturer’s data sheet as the nominal capacity.

3.2 Charge Termination Taper Current

Most battery chargers have a ±10% error in taper current threshold at which point the charger cuts off charging. It is very important to set the taper current programmed in the data flash of the gauge slightly higher than the taper current threshold of the charger. This ensures that the gauge detects the battery is fully charged before the charger cuts off charge. For example, if the charger taper current is 50 mA, it is recommended to set the charge termination taper current in data flash greater than 50 mA. A good value to use is 70 mA. Also, it is recommended that the taper current should be less than C/10 to ensure that the battery gets properly fully charged.

3.3 Discharge Current Threshold

This is the current threshold above which the gauge detects that it is in discharge mode. It is an unsigned integer as the gauge has the ability to detect the direction of current flow. This value should be set lower than the charge termination taper current. In the previous example, if charge termination taper current is set to 70 mA, a good value for discharge current threshold is 45 mA.

3.4 Charge Current Threshold

This is the current above which the gauge detects that it is in charge mode. This value should be set lower than the charge termination taper current as well. As with the previous example, a good value for charge current threshold would be 40 mA.

3.5 Quit Current Threshold

This is the threshold that determines that the gauge is in relax mode. This mode is very important because this is where the gauge takes OCV readings which are used for Qmax calculations. It is recommended that the quit current be less than C/20 and must be less than the discharge and charge current threshold. In the previous example mentioned, a good value to use will be 10 mA.

3.6 Term Voltage

This is the voltage where the gauge should detect that the battery is at 0% SOC. For learning cycle purposes, this should be set to the minimum voltage of the battery as specified in the manufacturer’s data sheet. After learning cycle is completed, this value can be adjusted upwards if there is a need for the gauge to report 0% at a higher voltage. If the cell is rated to operate from 3 V to 4.2 V and if the application is a 2s application, the term voltage should be set to 3 V x 2 cells = 6 V.

4 Learning Cycle

The learning cycle is needed for the gauge to update the total chemical capacity (Qmax) and the resistance (Ra) tables in data flash. It is also needed for the update status which the gauge controls to change indicative that a learning cycle has been completed.

4.1 Initial Qmax Update Criteria:

QMax update is enabled when gauging is enabled. The bq28z610 updates the no-load full capacity (QMax) when two open circuit voltage (OCV) readings are taken. These OCV readings are taken when the battery is in a RELAXED state before and after charge or discharge activity. A RELAXED state is achieved if the battery voltage has a dV/dt of < µV/s. Typically it takes 2 hours in a CHARGED state and 5 hours in a DISCHARGED state to ensure that the dV/dt condition is satisfied. If 5 hours are exceeded, a reading is taken even if the dV/dt condition was not satisfied. If a valid DOD0 (taken at a previous QMax update) is available, then QMax is also updated when a valid charge termination is detected. Qmax is not update if the following occurs:

- **Temperature** — If Temperature is outside of the range 10°C to 40°C.
- **Delta Capacity** — If the capacity change between suitable battery rest periods is less than 90 % during the initial cycle and 37% during field update (2nd and subsequent updates) of qmax.
- **Voltage** — If CellVoltage2..1 is inside a flat voltage region. (See the Support of Multiple Li-Ion Chemistries With Impedance Track Gas Gauges Application Report (SLUA372) for the voltage ranges of other chemistries.) This flat region is different with different chemistry. The GaugingStatus[OCVFR] flag indicates if the cell voltage is inside this flat region.
- **Offset Error** — If offset error accumulated during time passed from previous OCV reading exceeds 1% of Design Capacity, update is disqualified. Offset error current is calculated as CC Deadband/sense resistor value.

Several flags in GaugingStatus() are helpful to track for QMax update conditions. The [REST] flag indicates an OCV is taken in RELAX mode. The [VOK] flag indicates the last OCV reading is qualified for the QMax update. The [VOK] is set when charge or discharge starts. It is cleared when the QMax update occurs, when the offset error for a QMax disqualification is met, or when there is a full reset. The [QMax] flag is toggled when the QMax update occurs.

4.2 Learning Cycle Procedure

4.2.1 Discharge Battery to Empty

- Before beginning the discharge, turn on the charge and discharge fets by sending command 0x22, then send IT (Gauge) enable command (0x21) to set the GAUGE_EN in manufacturing status register and QEN flags in IT Status register. Then send the reset command (0x41) to set the RDIS flag and disable resistance updates during this initial discharge cycle. In this case, since IT has already been enabled, there is no need to disable it again during the entire learning cycle. Once IT has been enabled, update status in the gas gauging section of data flash will go from 00 to 04.
- An alternative method before starting this initial discharge would be to make sure impedance track is disabled. The GAUGE_EN flag of the manufacturing status register would be cleared if impedance track is disabled. If the GAUGE_EN flag is set, clear it by sending command 0x21 or clicking the GAUGE_EN button in the command window. This is different from earlier gauges in that IT enable command can be toggled on and off. In earlier gauges, once IT is enabled, it can never be disabled via command. Disabling impedance track prevents resistance updates from occurring during this initial discharge.

4.2.2 Relax for 5 Hours

- This relaxation time allows for a valid OCV reading to be taken and stored for the Qmax update. The valid OCV reading will occur when the dV/dt of the battery is < 1 µV/s for a 1s configuration or < 2 µV/s for a 2s configuration. The voltages does not need to be monitored, the gauge monitors for this condition and takes the OCV reading once met.
- The [VOK] and [RDIS] bits in the IT status() register clear once the gauge has taken an OCV reading and qualified it for a Qmax update.

- The 5 hour wait time is a recommendation; the most accurate time is determine when the [VOK] and [RDIS] bits are clear. If the alternative method of disabling IT was used, IT enable command should be sent after the 5 hour wait time. This forces an OCV measurement to be taken, and because the cells are sufficiently rested, this OCV value is qualified for a Qmax update.
- The GaugingStatus[REST] flag is set when a valid OCV reading occurs

4.2.3 Charge Battery to Full

- A typical C/2 charge rate is recommended; however, the charge rate is of no consequence
- Make sure IT is already enabled at this point before the start of charge (the [Gauge_EN] bit in the manufacturing status() register should be set).
- At the start of charge, the [VOK] bit in the IT status () register should set.
- At the end of charge the [FC] bit in the Battery Status () register should be set.

4.2.4 Relax for 2 Hours

- This relaxation time allows for a valid OCV reading to be taken and stored for the Qmax update. The valid OCV reading occurs when the dV/dt of the battery pack is < 1 µV/s for a 1s system and < 1 µV/s for a 2s system. Again, the gauge monitors for this condition.
- The [VOK] bit in the IT status() register clears once the gauge has taken an OCV reading and qualified it for a Qmax update.
- The GaugingStatus[REST] flag is set when a valid OCV reading occurs
- The 2 hour wait time is a recommendation; the most accurate time will be looking to see when the [VOK] and [RDIS] bits are clear.
- At this point, the first Qmax update should have occurred. The [QMax] flag is toggled when the QMax update occurs. Update Status would now be 0x05.
- Note that it takes less time for a battery to relax once it is fully charged than it does when it is discharged

4.2.5 Discharge Battery to Empty

- A typical C/5 rate is recommend, but the rate can be as low as C/10. If using a C/10 load, make sure the gauge sees that the current is at least C/10, if the current is any lower, resistance updates does not occur.
- During the discharge, the resistance table is updated as each grid point is reached (the resistance table is stored in 15 grid points along the discharge curve).
- At this point Update Status should be at 0x06.

4.2.6 Relax for 5 Hours

- This relaxation time allows for a valid OCV reading to be taken and stored for the Qmax update. The valid OCV reading occurs when the dV/dt of the battery is < 1 µV/s
- The [VOK] bit in the Control() register clears once the gauge has taken an OCV reading and qualified it for a Qmax update.
- The GaugingStatus[REST] flag is set when a valid OCV reading occurs
- The 5 hour wait time is a recommendation; the most accurate time is determined by observing when the [VOK] bit are clears.
- There is another Qmax update at this point
- At this point Update Status should be at 0x0E. It is important to get an update status of 0x0E if a 2s gauge is used because it means that cell balancing has been enabled. If an update status of 0E is not obtained, the device can be charged to full, relaxed for 2 hours and then discharged to empty, at which point it should be 0E.

On legacy IT gauges, update status should be changed in the gg file from either 0E or 06 to 02 and once the golden file has been programmed, IT enable command should be sent to turn on the algorithm. When the IT enable command is sent, update status goes from 02 to 06. The reason for doing this is that enabling IT also enables lifetime data. On this gauge, there is a separate command for enabling lifetime data so Update status can be left as 06 for a 1s configuration or 0E for a 2s configuration.

5 Learning Cycle Summary in Graphical Form

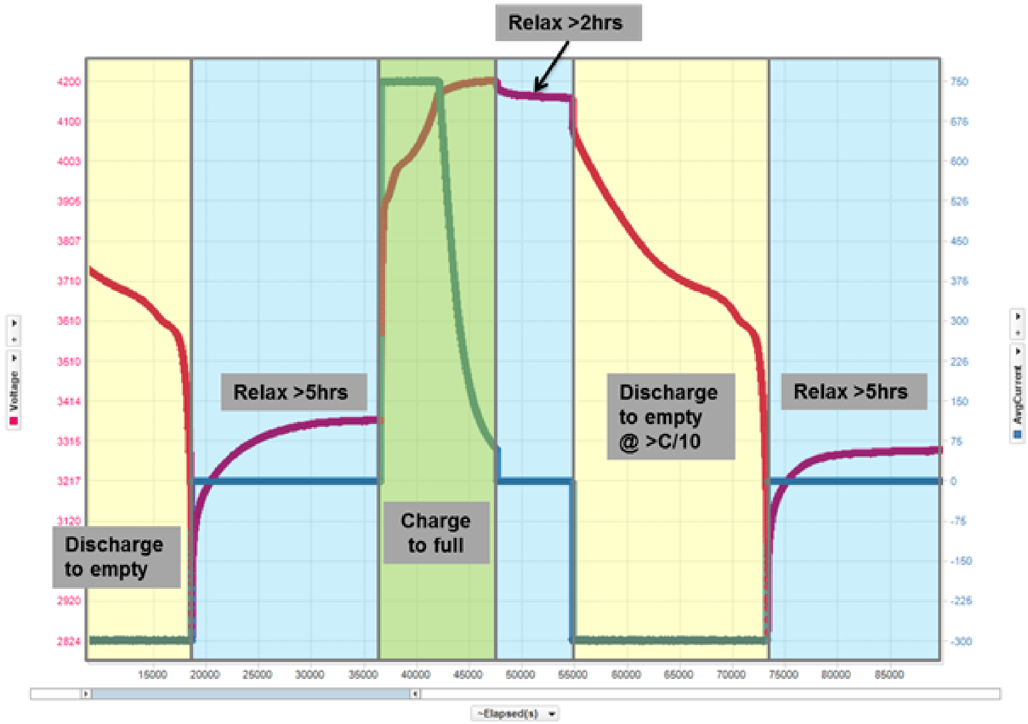

Figure 2. Overview of the Complete Step

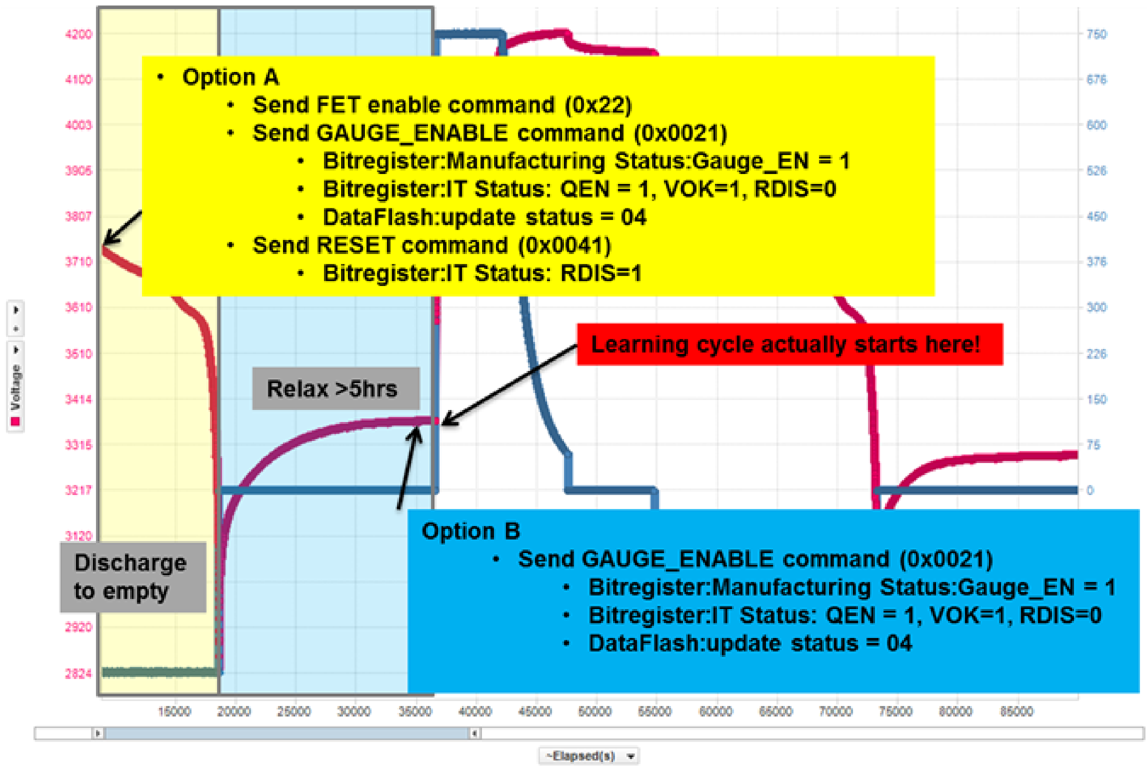

Figure 3. Breakdown of the Steps 1 and 2

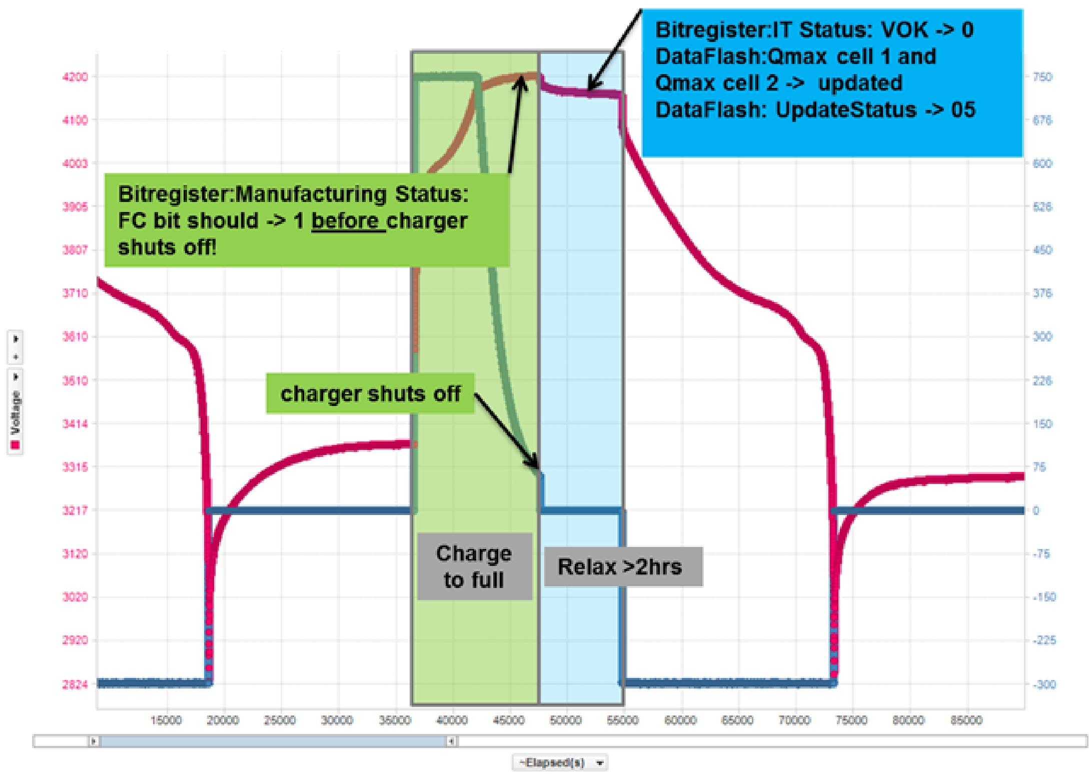

Figure 4. Breakdown of the Steps 3 and 4

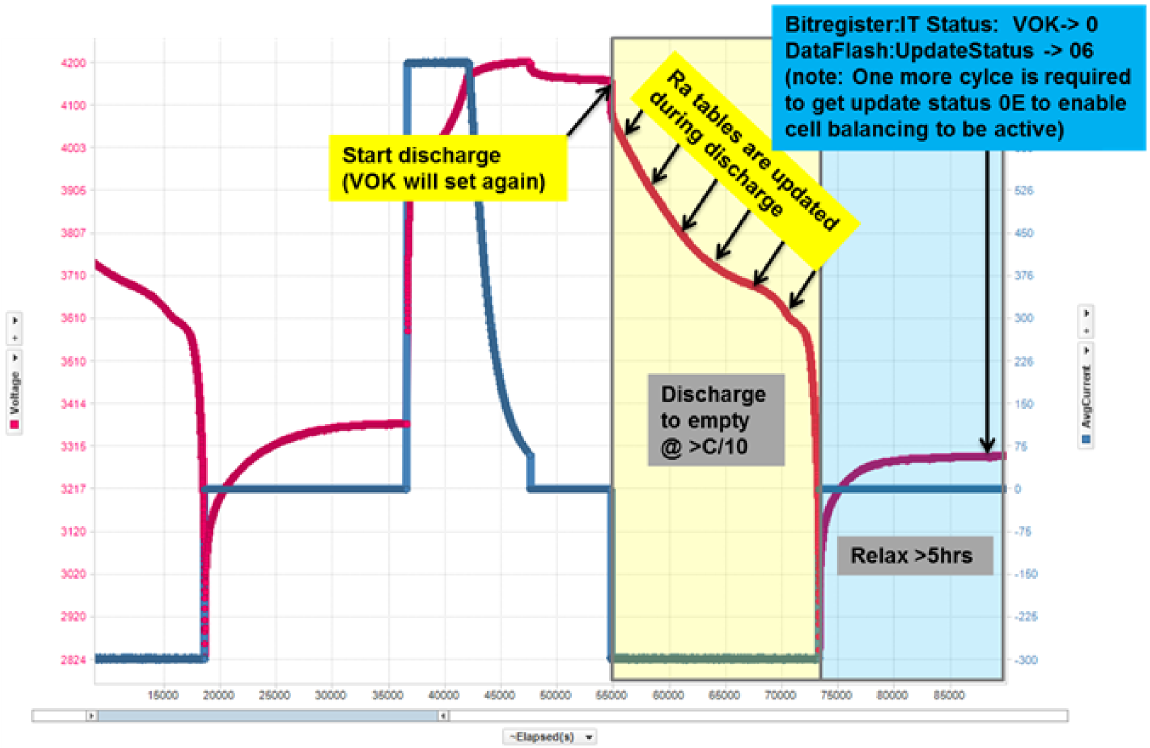

Figure 5. Breakdown of the Steps 5 and 6

6 Conclusion

The learning cycle is a critical and intergral part of ensuring the proper functionality of a battery pack using Impedance Track algorithm. The bq28z610 and bq78z100 which are I2C and HDQ devices respectively both use Impedance track and this step by step procedure for learning will ensure the gauge is properly and fully functional. The summary of the discussed steps are as follows:

- Program the chem id that matches the cell to be used in the application
- Configure the data flash parameters for the application. The pertinent df parameters that are required for successful learning cycle are design capacity, charge termination taper current, discharge current threshold, charge current threshold, quit current and term voltage. The following conditions must be met:
  - Charge termination taper current > charge and dishcharge current threshold > quit current
  - At least, 90% passed charge of design capacity is needed to occur during the charge and discharge cycles.
- The battery should be charged to the max voltage specified by the cell manufacturer and discharged to the min voltage specified as well to ensure the 90% passed charge condition is met. After a successful learning cycle, the term voltage and the voltage the cells are charged to can be adjusted to suit the application specifications.
- Enable impedance track (0x21), issue a reset command (0x41). Update status changes from 00 to 04
- Discharge the cells to empty and let them relax for 5 hours.
- Charge the cells to full ensuring that the fc bit gets set and let it relax for two hours. Qmax updates at this point and update status goes to 05.
- Discharge the cells to empty using the typical discharge rate of your application. It must be between C/5 to C/10 rate, otherwise, learning will fail. Resistance tables are updated during this discharge cycle.
- Let the cells relax for 5 hours during which the update status would change to 06.
- For a 2s application, another charge-relax-discharge- relax cycle should be run to ensure update status

changes to 0E to activate cell balancing.

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