Achieving The Successful Learning Cycle

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This document covers the steps for the Learning Cycle. Battery chemistry need to be determined before running learning cycle.

- Basics of how the Impedance Track algorithm works
- Information presented by the gauge on the current status of IT
- How a learning cycle works
- What can go wrong, how to diagnose problems, and how to solve problems

Impedance Track

For more information, check the application note: *Theory and implementation of Impedance Track battery fuel-gauging algorithm...* (SLUA450)

There are two primary pieces of information obtained from a gauge: 1) State of Charge, and 2) energy/coulombs remaining.

State of charge provides a percentage of the total battery capacity. Energy/coulombs remaining provides the time available to continue running.

The gauge uses a combination of open circuit voltage (OCV) measurements and coulomb counting to determine the absolute state of charge, and the IT algorithm determines how much energy can from a battery before it dies.

The main concern is with the absolute state of charge determination. While the battery is relaxed, the gauge measures the voltage and determines state of charge based on this value. When the battery starts charging/discharging, it then uses coulomb counting for relative calculations. When the charging/discharging stops, the gauge waits for the cell voltage to relax and then measures the OCV to determine absolute SOC again.

To determine remaining energy/coulombs, the gauge has an internal picture of the battery and runs a simulation of the battery voltage/impedance from its present state to end of discharge. To do this, the gauge needs to know the battery voltage versus state of charge (the chemistry ID), and the battery impedance versus state of charge. This information is learned by performing a learning cycle.

The Information That the Gauge Presents About IT

Data RAM Control/Flag Bits:

VOK: "Voltage OK for Qmax Update": This bit tracks when the gauge measures the battery's voltage. This bit is normally set when charging/discharging starts, and is cleared when discharging stops, the gauge has detected that the battery voltage has stabilized, and the gauge has taken the OCV measurement. It is a good way to track when OCV measurements occur.

QEN: Qmax Update Enable. This should be set to 1 during learning cycle.

RUP_DIS: Resistance update disable. This bit may be set for a number of reasons. When it is set, this means that the gauge is unsure of its current state and calculations, and is not confident enough to update the battery resistance tables with its presently measured data. It is cleared when a good OCV measurement is taken, as the gauge knows the absolute state of charge based on this value.

FC: Full Charge bit. This flag indicates whether or not the gauge detects the battery as "full"

Data Flash:

UPDATE_STATUS: This data flash value contains the current status of the learning cycle is: it can be 0, 1, 2.

Qmax Cell 0/1: This data flash value contains the max battery capacity in mAh unit.

How a Learning Cycle Works

The learning cycle starts with a discharged, relaxed battery (battery voltage is stable and at low (~3.0–3.3V) voltage). Upon running IT_ENABLE, the gauge measures this voltage and identifies what state of charge this is associated with using the correct chemistry ID.

At this point, RUP_DIS is cleared, VOK is set and QEN is set.

Now, charge the cell to full (**Note:** the GAUGE has to detect that the cell has a full charge and set the FC bit). Once the charge stops and the cell voltage relaxes again at high (4.1-4.2V usually) voltage, the gauge takes another voltage measurement and determines the state of charge it represents. With two known states of charge and the passed coulombs, the gauge calculates the maximum capacity (Qmax) of the battery.

At this point, UPDATE_STATUS goes to 1, indicating that it has successfully completed the first state of the learning cycle. Qmax Cell 0 is updated to the actual value. VOK is cleared.

Now, begin discharging at C/5. When this happens VOK should be set again. While discharging, the gauge should update the Resistance Tables in the Data Flash every 11.1% SOC (approximately), and then more rapidly below 20%. During this time, the gauge is measuring the battery impedance at each state of charge and storing it in these tables. When it reaches the end of discharge and the load is removed, the battery relaxes to a low (~3.0–3.3V) voltage. The gauge waits for this relaxation to occur (**Note:** this takes much longer at low state of charge than high state of charge), and then the gauge takes an OCV measurement.

At this point, VOK will be cleared, Qmax Cell 0 will be updated. The gauge will also check to see if the resistance table was properly updated. If the table is updated, then the gauge sets UPDATE_STATUS = 2.

What Can Go Wrong, How to Diagnose Problems, and How to Solve Problems

To diagnose a failed learning cycle, it is critical to set EVSW to log the Data Ram during the Cycle every ~5–10 seconds. It is also advisable to auto-export the Data Flash on a less frequent basis (every ~1–10 minutes). This way, all the information is collected to determine the point of failure.

Here are the most common points of failure:

1. Make sure that the battery is at low SOC and relaxed when running IT_ENABLE. This is usually not a problem, but it is important.
2. During the charge, make sure that the gauge detects the "full charge" condition. If after the learning cycle, UPDATE_STATUS has not been updated to 1 (i.e., it is still 0), then this may be the problem. The gauge detects the full charge condition with 3 criteria:
   (a) Battery voltage is within 0.1V of the "charging voltage" as defined in bqEASY.
   (b) Battery current is below "taper current" as defined in bqEASY.
   (c) Battery current stays below this "taper current" and above the "quit current" for over 40 seconds. This means that the battery must be charging with a significant current below the "taper current" for almost a minute. If the charger cuts off before or just after the current drops below the "taper current" as indicated in bqEASY, then the gauge does not detect the "full" condition.
3. When fully charged, make sure to wait long enough for the VOK bit to be cleared. This is generally 2 hours. Logging dataRAM shows if this has occurred. UPDATE_STATUS will stay 0 if this does not happen. If VOK is never set, then this means that it did not start with an empty battery, or did not fully charge the battery, or the charge cycle was disturbed in some way (see (#7) for charging advice.
4. When discharging starts, make sure that the VOK bit is set. The gauge has a data flash parameter "DSG Threshold" that determines the minimum current needed to enter the "discharge" state. If it discharges with less than this current, the VOK bit will not be cleared. The gauge will never go into the "discharge" state, and the Ra tables will never be updated. UPDATE_STATUS will be '1'. Either decrease "DSG Threshold" in the Data Flash, or increase the discharge rate.
5. During the discharge, the Resistance table is NEVER UPDATED. If during a learning cycle the Data Flash log shows that the Resistance Table never changed, this indicates that the discharge load was too light. The gauge needs to measure a significant voltage drop across the internal battery impedance before it can measure the impedance. If the load is too light, the measurement fails, and it will never get any Resistance Table updates.

6. During discharge, the Resistance Table may update for a while, and then stop. When this happens, RUP_DIS is set. This indicates that the Chemistry ID choice is incorrect. This means that the gauge has measured a resistance value that just doesn't make sense (i.e. is negative). A chemistry cycling is needed to identify the correct chemistry profile.
7. General Charge/Discharge Profile Advice: Most learning cycles fail because there is something generally wrong with the charge/discharge profile. Here are some suggestions:
   (a) Ensure charger cutoff upon charge completion : Most user's don't have a battery cycling automation setup, so a bench power supply is used to change a battery overnight. This DOES NOT work. The system does follow a CC/CV profile, but there is no cutoff. Therefore, when the gauge recognizes a full charge and tries to take an OCV measurement, it actually measures the supply voltage and disrupts the system.
   (b) CC/CV charge profile: In line with the above, make sure a CC/CV profile charger with a reasonable values is used. C/2 Fast charge rate, C/100 to C/10 taper current.
   (c) Continuous charge profile: While not strictly necessary, it is advisable to make sure the charging profile is continuous. If the charging cycle stops, then the cycle is may fail. If the battery discharges for any reason during this time, the cycle will absolutely fail.
   (d) After Charge, relax at least 2 hours with NO load/charger: Make sure to wait long enough to see VOK. 2 Hours is generally enough.
   (e) Discharge C/5 Constant Current: Make sure to use a C/5 current. This is preferred, and there can be some error. However, if the current drifts too high or too low, the cycle can fail. Too low is around C/10, too high is around C/3 to C/2. Smaller cells (<800mAH) are much less forgiving in this regard.
   (f) Continuous discharge: This is absolutely necessary. If the discharge ever stops before reaching the terminate voltage, the cycle will fail.
   (g) Termination voltage: Make sure that when terminate voltage is reached, the load is removed. Let the cell relax. If the load kept attached to the battery and allows the battery voltage to drop well below terminate, then not only does the learning cycle fail, but it also damages the battery.

The main point is: Log both Data Ram and Data Flash during learning cycle!

Look for the above recommendations in the log file, and correct the cycle/configuration accordingly.

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