## 1.2 State of Charge (SOC)

**1.2.1 Feature Objective:**

The objective of designing the State of Charge (SOC) system is to calculate the amount of charge remaining in the battery. It gives a value from 0% to 100%. It is important to let the user know the amount of charge left in the battery. It is like the indication from a fuel gauge in a gasoline powered car. This allows the user to make the maximum use of the battery. Also, over-charging or dis-charging a battery can result in reduced lifetime and hence estimation of SOC is necessary. It is also used by various other features to calculate amount of power that can be drawn or fed to the battery, calculate balancing commands for the cells. Along with the State of Charge it also measures the Capacity degradation of the battery.

**1.2.2 Functional Description:**

**1.2.2.1 State of Charge**

State of Charge is related to the chemical concentration present in a cell and there is no direct way to measure the concentrations. Hence, Open Circuit Voltage (OCV) vs State of Charge (SOC) calibration table and Coulomb counting is used to calculate the state of charge.

State of Charge feature uses the OCV vs SOC calibration table during first initialization of the battery when it is connected to the BMS first time. Following that it is used every time a key or charger is connected.

First Time Initialization : On first time initialization, the battery’s voltage is used to measure the state of charge using the OCV vs SOC calibration table, when the contactors are not connected. This value is then stored for using it next time.

Coulomb Counting : During normal functioning of battery, the state of charge is calculated using a method called Coulomb counting. In this method the current drawn or fed into the battery is integrated to find the amount of charge withdrawn or added to the battery. This requires the initial value of SOC. The initial value is decided is covered next paragraph.

A mathematical equation for Coulomb Counting is shown below:

, where Qcap is the cell capacity.

When the key is turned off or the charger is turned off, the SOC value is stored in the memory for using it next time.

Key – On or Charger – On : When is key or charger is turned on, the SOC is calculated from SOC vs OCV calibration before the contactors are engaged and is compared with the SOC value stored in memory by Coulomb Counting. If the value SOC vs OCV table is within a threshold of the value stored in memory, then the value from memory is used as the initial value for SOC, else the value from SOC vs OCV table is used as the initial value. The threshold is a calibratable value.

Note:

Coulomb Counting is done individually for each cell. So, in-case of N cells, there will be N integrations. This is important because each cell will not have the same current in-case of cell balancing and is taken into account. If cell balancing is switched ON for a cell, then the current through that cell will be:

**1.2.2.2 Capacity Degradation**

Capacity of a battery reduces after years of use due to aging. The reduction in capacity is very slow. It reduces by 2 to 3% over a couple of years use. Though the reduction is various the capacity is used in coulomb counting. Using the correct degraded value of the capacity will give more accurate results for SOC. The method used to calculate the capacity degradation is shown in the equations below. This calculation is done only after a socket charging cycle.

Now, assuming some small degradation in capacity has happened over time. Following are the equations after a charging cycle is complete.

, is the initial value of SOC when socket charger is connected

, is the value from Coulomb Counting when charging is switched OFF

, is the value from OCV vs SOC table when the car is turned ON after charging

Then,

When the battery is new, will be actual true capacity. After a charging cycle the will be calculated and be stored in the memory. This value is then used any coulomb counting application. This process will keep happening after every charging cycle and the will be the last stored degraded capacity value.

The degraded capacity of each cell is stored as a degradation factor which is the ratio of:

Though the degradation factors for cells are calculate in SOC feature, it is sent to State of Health (SOH) feature, which then passes it through. The essence being capacity degradation factors should be accessed by any feature from SOH feature as it tracks the health of the battery.

**1.2.2.3 Other Features**

1.2.2.3.1 SOC for customer:

Pack SOC is modified to show the customer.

*If* max(SOC of all cells) is *> 80% then* soc\_pack\_customer *=* 100%

*Else if* min(SOC of all cells) is *< 20% then* soc\_pack\_customer *=* 0%

*Else* soc\_pack\_customer *= interpolated value of* average(SOC of all cells) between 0% and 100%

The 20% and 100% are calibrations as max and min value of SOC for customer.

1.2.2.3.2 High rate of change of SOC:

If the change in SOC is greater than a particular percentage per second then a flag is raised. This value is a calibration.

**1.2.3 I/O description:**

The SOC feature requires the dynamic I/O shown in the following table

|  |  |  |  |
| --- | --- | --- | --- |
| **Signal(s)** | **I/O** | **Description** | **Units/comments** |
| vitm\_pack\_current | Input | Pack Current from VITM | A |
| vitm\_cell\_voltages | Input | Cell Voltages from VITM | V |
| cc\_main\_contactor | Input | Main Contactor command from CC | state |
| cc\_chg\_contactor | Input | Charger Contactor command from CC | state |
| cc\_pre\_chg\_contactor | Input | Pre-charge Contactor command from CC | State |
| soh\_C\_factors | Input | Degradation factors from SOH | Percentage/100 |
| bsc\_chg\_cc\_cmd | Input | Charger Contactor signal from BSC | state |
| cb\_cmds | Input | Cell Balancing commands from CB | State |
| soc\_cells\_pct | Output | SOC of all cells | Percentage |
| soc\_pack\_customer | Output | SOC value for the customer | Percentage |
| soc\_cells\_max | Output | Max value of the SOCs of all the cells | Percentage |
| soc\_cells\_min | Output | Min value of the SOCs of all the cells | Percentage |
| soc\_pack\_actual | Output | Average value of the SOCs of all the cells | Percentage |
| soc\_rate\_high | Output | SOC rate of change if high | State |
| soc\_C\_factors | Output | Capacity Degradation factors calculated after a charging cycle | Percentage/100 |