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# Dynamically Adjusting State of Charge and Charging Method to Preserve Lithium-Ion Battery Cell Life

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# Dynamically Adjusting State of Charge and Charging Method to Preserve Lithium-Ion Battery Cell Life

**Abstract:**

Lithium-ion (li-ion) battery cells are used in the majority of portable computing devices. The components of a li-ion battery cell may age more quickly while the li-ion battery cell is maintained at a high state of charge (SOC) while having a high temperature. As described in this publication, the problem of accelerated aging of a li-ion battery cell due to a high SOC while having a high temperature is solved by a computing device implementing, through a Charging Manager, a smart charging algorithm that dynamically adjusts the SOC and charging method to preserve li-ion battery cell life. The Charging Manager, through implementing the smart charging algorithm, may determine the current SOC, determine the time available for charging (total charging time), estimate how long it will take to charge from the current SOC to a 100% SOC, and modify the charging process of the computing device based on these variables to maintain a lower SOC for as much of the total charging time as possible, thus inhibiting the aging process. In an aspect, the Charging Manager may direct completion of charging the li-ion battery cell to a 100% SOC shortly before the time available for charging ends.

**Keywords:**

Lithium-ion battery, li-ion battery, battery charger, state of charge, charging rate, battery aging, battery lifetime, battery health, constant-current charging, constant-voltage charging

**Background:**

Lithium ion (li-ion) battery cells are used in the majority of portable computing devices (e.g., smartphones, smartwatches, laptops, tablets). A li-ion battery cell is typically made of four major components: a cathode, an anode, an electrolyte, and a separator. The cathode hosts the lithium ions, in the form of an active material made of lithium-oxide (lithium is unstable in its elemental form), conductive additives, and a binder. The cathode determines the capacity and voltage of the battery cell. The anode is made of graphite and allows the passage of electrical current through an external circuit. The electrolyte has a high ionic conductivity and is made of salts, solvents, and additives, acting as a medium between the cathode and the anode through which lithium ions can travel. The separator is made of synthetic resin (e.g., polyethylene (PE), polypropylene (PP)), prevents electrical contact between the cathode and the anode, and prevents the flow of electrons within the electrolyte. These four components are made of different materials, are utilized for a li-ion battery cell to perform properly, and age in different conditions and at different rates. However, one or more of these components may age more quickly while the li-ion battery cell is in a high state of charge (SOC) while having high temperature.

A high SOC (e.g., 90%, 100%) while having high temperature decreases the lifetime of a li-ion battery cell by accelerating the loss of active material (lithium) in the cathode, the dissolution of the electrolyte and the binder, the growth of the solid electrolyte interphase (SEI) layer, and the decomposition of the electrolyte. In general, these phenomena decrease the usable capacity, known as “fade,” and diminish the power capability of the li-ion battery cell.

**Description:**

This publication describes techniques, implemented on a portable computing device, directed to determining the SOC of the li-on battery cell of the device, determining the total time available for charging, estimating how long it will take to charge the li-ion battery cell from the current SOC to a 100% SOC, and modifying the charging process based on these variables. By so doing, the techniques may maintain a lower SOC of the li-ion battery cell for as much of the total charging time as possible, thus inhibiting the aging process.

The computing device may include a li-ion battery cell, a processor, a transceiver for transmitting data to and receiving data from other devices, a sensor (e.g., a thermometer, an accelerometer, a barometer, a proximity sensor), and an input/output device (e.g., a display, a speaker, a microphone). The computing device may also include a computer-readable medium (CRM) that stores device data (e.g., user data, multimedia data, applications, operating system). The device data may include instructions of a Charging Manager that, responsive to execution by the processor, cause the processor to perform operations described in this publication to inhibit the aging process of the li-ion battery cell of the computing device.

As mentioned in the background, a high SOC (e.g., 90%, 100%) while having high temperature decreases the lifetime of a li-ion battery cell. In order to prolong the lifetime of a li-ion battery cell, the Charging Manager may implement a smart charging algorithm. The algorithm, implemented by the Charging Manager, may include the following techniques: determining if the computing device is attached to a charging device (e.g., power adapter, automotive multimedia head unit, external battery), estimating how long the computing device will be connected to the charging device, determining the current SOC of the li-ion battery cell of the computing device, and calculating how long it will take to charge the li-ion battery cell from the current SOC, if less than 100%, to a 100% SOC.

In this publication, an example scenario will be referenced in which a user takes a five-hour road trip after connecting a smartphone (computing device) to an automotive multimedia head unit (charging device) and selecting a destination in a mapping application installed on the smartphone. The Charging Manager may determine if the smartphone is connected to a charging device (e.g., automotive multimedia head unit) and may determine the current SOC of the li-ion battery cells of the smartphone. To estimate how long the smartphone will be connected to the automotive head unit (total charging time), the Charging Manager may query the mapping application; this assumes that the user input the road trip destination into the mapping application. To determine how long it will take to charge the li-ion battery cells from the current SOC to a 100% SOC, the Charging Manager may constantly recalculate the time that will be spent in a given charging method.

The Charging Manager may calculate how much time will be spent in constant-current (CC) charging. In CC charging, the Charging Manager may adjust the voltage, supplied by the automotive multimedia head unit, that is provided to the li-ion battery cells to maintain a relatively uniform supply of current. Based on system temperature, the Charging Manager may query a current/voltage/temperature (CVT) lookup table stored on the CRM to determine permissible CC charging rates. At a certain SOC, the Charging Manager may switch from CC charging to constant-voltage (CV) charging. In this example, assume the SOC at which charging methods are switched is X%. The calculation to determine how much time is spent CC charging is shown in Equation (Eq.) 1. The variables for Eq. 1 are described in Table 1.

$$time\_in\_CC = \frac{X*cell\_capacity - current\_SOC*cell\_capacity}{CC\_rate*cell\_capacity} * 60\frac{min}{h} \qquad (1)$$

| Variable | Unit | Description |
|---|---|---|
| X | % | SOC at which charging switches from CC to CV |
| cell_capacity | mAh | Total capacity of the li-ion battery cells |
| current_SOC | % | Current SOC of the li-ion battery cells |
| CC_rate | 1/h | CC charging rate |

**Table 1.  Variables for Eq. 1.**

The Charging Manager may calculate how much time is left after completing CC charging. To do so, the Charging Manager may subtract the time spent CC charging from the total charging time.  This calculation is shown in Eq. 2.  The variables for Eq. 2 are described in Table 2.

$$time\_left = time\_total * 60\frac{min}{h} - time\_in\_CC \qquad (2)$$

| Variable | Unit | Description |
|---|---|---|
| time_total | h | Time the smartphone is connected to the automotive multimedia head unit; total charging time |
| time_in_cc | min | Time spent CC charging |

**Table 2.  Variables for Eq. 2.**

The Charging Manager may calculate how much time will be spent CV charging, used to fully charge the li-ion battery cells from an X% SOC to a 100% SOC.  In CV charging, the Charging Manager may maintain a constant voltage, supplied by the automotive multimedia head unit, provided to the li-ion battery cells while allowing for changes in the provided current (impedance of a li-ion battery cell increases as the cell is charged).  The derivation of this calculation is shown below in Eq. 3 through Eq. 7. The variables for this derivation are described in Table 3.

$$i = \frac{dQ}{dt} \qquad (3)$$

$$i = i_0 e^{-kt} \qquad (4)$$

Setting Eq. 3 equal to Eq. 4 yields Eq. 5.

$$\frac{dQ}{dt} = i_0 e^{-kt} \qquad (5)$$

Multiplying both sides of Eq. 5 by dt yields Eq. 14.

$$dQ = i_0 e^{-kt} dt \qquad (6)$$

Integrating both sides of Eq. 6 and solving for the time spent CV charging yields Eq. 7.

$$t_{CV} = \frac{ln|e^{-kt_0} - k\frac{Q(t_{CV}) - Q(t_0)}{i_0}|}{-k} \qquad (7)$$

| Variable | Unit | Description |
|---|---|---|
| k | N/A | Fitting coefficient; determined experimentally from multiple charging cycles |
| $i_0$ | mA | Current when CV charging begins |
| $t_0$ | min | Time at which CV charging begins |
| $Q(t_0)$ | C | Amount of charge when CV charging begins |
| $Q(t_{CV})$ | C | Amount of charge when CV charging ends (a 100% SOC) |

**Table 3. Variables for Eq. 3 through Eq. 7.**

The Charging Manager may estimate when to start CV charging in order to achieve a 100% SOC before the user finishes the five-hour road trip. To do so, the Charging Manager may subtract the time spent CV charging from the estimated time of arrival (ETA) at the destination for the road trip.

The Charging Manager may correct for a potential change in charging time. For example, responsive to the smartphone heating up in direct sunlight during the last hour of the road trip, the Charging Manager may recalculate how much time will be spent in CV charging and re-estimate when to start CV charging in order to achieve a 100% SOC before the end of the road trip. To account for a potential change in charging time as described, the Charging Manager may include a buffer zone, beginning CV charging earlier by 10%, for example.

The Charging Manager may calculate how much time will be spent in an idle charging state. In an idle charging state, the Charging Manager may provide enough current, supplied by the automotive multimedia head unit, to the smartphone to continue normal operations while the SOC of the li-ion battery cells remain unchanged. To do so, the Charging Manager may subtract the time spent in CC charging and the time spent in CV charging, including the buffer zone, from the duration of the road trip. The Charging Manager may indicate via the graphical user interface (GUI) that the smartphone is in an idle charging state and thus maintaining a constant SOC.

As illustrated in Fig. 1 below, the Charging Manager may use the techniques and the acquired information, described above, to make a series of decisions in order to prolong the lifetime of the li-ion battery cells of the smartphone. The Charging Manager may determine if the smartphone is connected to a charging device (e.g., automotive multimedia head unit). If the smartphone is not connected to a charging device, the Charging Manager may take no action. If the smartphone is connected to a charging device, the Charging Manager may determine the current SOC of the li-ion battery cells. If the current SOC is 100%, the Charging Manager may maintain the SOC at 100%. If the current SOC is less than 100% and greater than X%, the Charging Manager may allow the smartphone to discharge until the SOC is equal to X%, at which point, the Charging Manager may maintain the SOC at X%. If the SOC is less than X%, the

Charging Manager may CC charge the li-ion battery cells until a SOC equal to X% is achieved. Once a SOC equal to X% is achieved, the Charging Manager may maintain the SOC at X%. Once it is time to achieve a 100% SOC, the Charging Manager may begin CV charging to top off the SOC of the li-ion battery cells before the user completes the road trip.

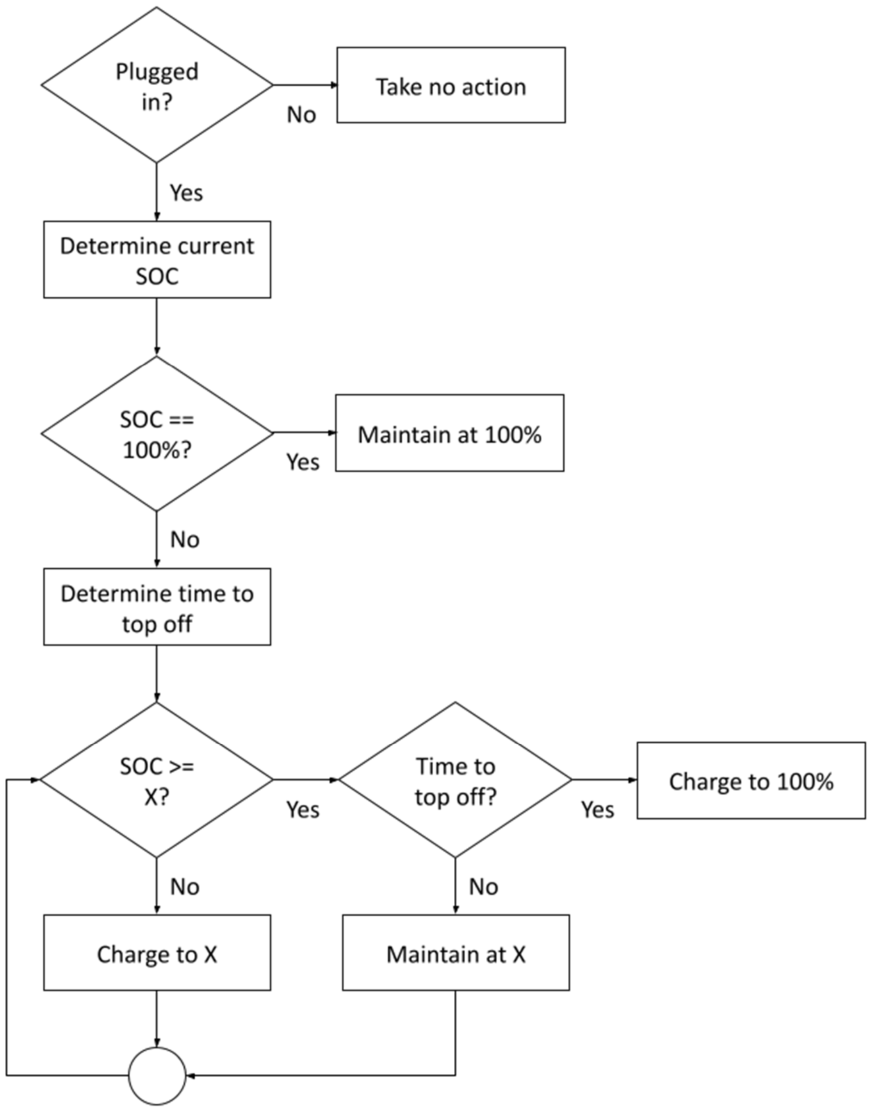


**Fig. 1. Flowchart illustrating a charging method to preserve li-ion battery cell life.**

This publication described two major factors that accelerate aging of a li-ion battery cell: a high SOC while having high temperature. A Charging Manager, implemented on a computing device, may determine the current SOC of the li-ion battery cells, query how much total charging time is available, estimate a time to charge to 100%, and modify a charging process based on this information to inhibit the accelerated aging of a li-ion battery cell due to a high SOC while having high temperature.

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