CHE 324 SP17 – Process Control Blog

We've got this under control.

The Smartphone Battery and Its Charging System

Introduction

In our modern world of 2017, nearly everyone uses cell phones. We use them to communicate, we use them to play games, we use them to get the latest news, we depend on them for the most basic of our day-to-day activities. But have you ever wondered how these mini-machines just keep going for years and years with the battery life close to brand new? Have you ever wondered why unlike other electronics, these tiny machines don't burn down your house when you leave them plugged into a socket overnight? Well, you're about to find out. This article dives deep into the world of lithium-ion batteries and digs on charging processes employed by phone companies to ensure optimum life span of smartphone batteries. This project explores the control system employed by most modern day cell phones, which has been vital to improving battery life, preventing overcharging (and its consequences), and saving our batteries from sudden death.



What exactly is controlled and why?

As complex as it may seem, a lithium-ion battery simply converts chemical energy to electrical energy by the movement of lithium ions from a negative electrode to a positive electrode. The number of ions available at the negative electrode is an indication of the energy available in the battery for use, and it is the very variable sought to be controlled (increased) by chargers. It is quantified as the "state of charge" by phone manufacturers and displayed in percentage on the phone screen.

Theoretically, and in reality, the amount of ions at the negative electrode could go to absolute limits of 0% and 100%, however such repeated cycles damage the battery. By letting the amount of ions in the electrodes

go to absolute limits repeatedly, the structure of the electrodes degrades with time, and this reduces the amount of ions each electrodes can accept, and therefore reduces the battery capacity. To prevent the above, most phone systems display non-absolute limits within 10% of the absolute limits for the state of charge. In other words, a phone battery displaying 0% still has some ions at the negative electrode and could go less than 0% if it weren't designed otherwise, and a phone battery displaying 100% can still accept ions at the positive electrode and go above 100% if the voltage limit was higher.

Controlling the state of charge while charging a battery is critical to its operation because, it ensures that the battery stays within usable percentage and that long-term battery capacity is conserved. Also by controlling the state of charge, overcharging and total battery depletion are prevented. Overcharging occurs when the battery is fed more voltage than it can handle in its charging cycle, and as a result, heat is produced. While other types of batteries, like lead acid batteries, can handle this slightly better, in lithium ion batteries it causes undesirable side reactions, such as plating out of the lithium metal. When this metal plates out, there are less of the titular "lithium ions" left to hold the charge, and as such, the battery loses capacity over time.

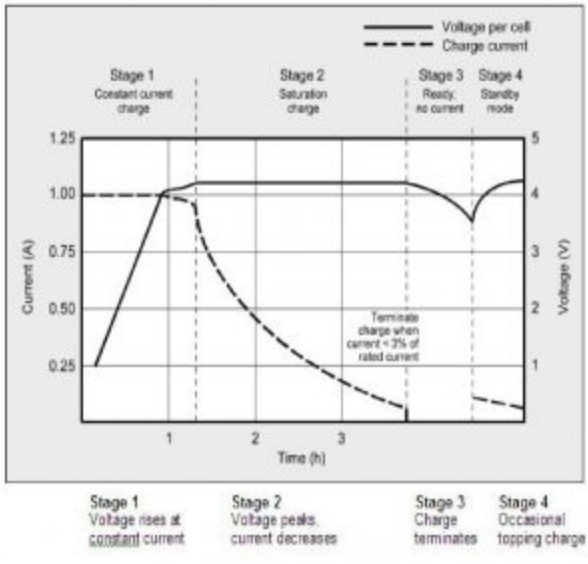
How does this system manipulate things to achieve control?

The controlled variable, the state of charge of a lithium-ion battery, is dependent on the number of ions at the negative electrode, and the number of ions at the negative electrode depends mainly the rate of discharge/charge of the battery (manipulated variable). As long as a phone is on, there will always be some discharge of the battery, and this rate of discharge would depend on the level of phone usage. Now, phone producers could have unsuccessfully tried manipulating the rate of discharge by advising users to use their phones intermittently, but instead phone manufacturers wisely chose to manipulate the rate of charge using wonderful innovations, called phone chargers.

As "complex" as phone chargers look, those portable things simply convert high voltage AC (alternating current) to low voltage DC (direct current), which is then suitable for and supplied to the battery. This step-down conversion is necessary because otherwise: BOOM!



Charging a phone is the exact opposite of discharging a battery's energy. By supplying current (the manipulated variable), a charger transfers lithium ions from the positive electrode to the negative electrode, thus restoring energy. Now, if charging simply occurred in a non-controlled manner by providing a constant current flow to a phone, we'd all have two choices: be negligent and accidentally leave the phone charging for long periods (this would only overcharge the battery and eventually blow up our lovely homes), or we could be very watchful and constantly watch until when our phone gets to a 100% state of charge (who has time for this?). Lucky enough for us, cell phones are designed to be charged smarter today; the process of charging smartphones occurs in three stages. The first stage occurs rapidly; a steady current flow is taken in to ensure the charge rate is far higher than the discharge rate. As the state of charge in the battery increases to about 80% the smart phone switches to the second stage in which the voltage is relatively constant, but resistance is applied to current flow to decrease it until a 100% state of charge of the battery is achieved. Once a 100% state of charge is achieved, the smartphone switches to the third "trickle charging" phase, in which the rate of current flow into the battery is just enough to balance the battery's discharge rate. This way, the battery is maintained at 100% state of charge. The above control system regulates the state of charge of the battery by manipulating the flow of current into the phone battery and this is why we can leave our phones charging all night and they will stay at 100% when you wake up, not 90%, not 105%; the control system minimizes overcharging and saves battery life.



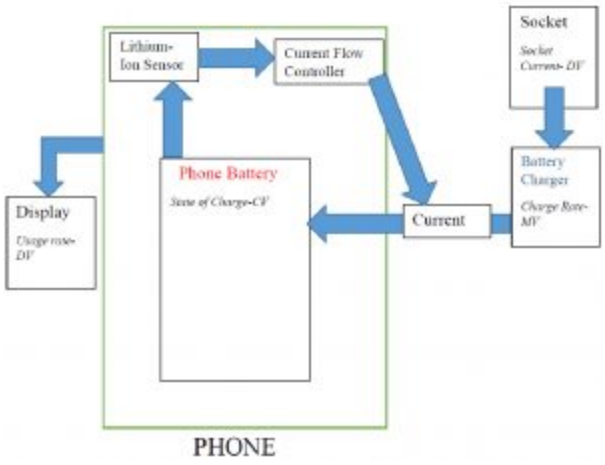
<http://batteryuniversity.com/learn/article/charging_lithium_ion_batteries>

What could possibly disturb the way my phone charges?

Disturbances to our control scheme come in several forms but the most common ones are an increased rate of battery energy depletion (when someone is charging their phone while using it) and changes to the amount of current coming into the charger from the socket. A simple charger can't be expected to compensate for something like a blackout, but is able to compensate for increased usage rate, and small surges/depressions in the charge coming from the socket. For example, the charger is able to compensate for the sudden depression that comes from turning on another energy intensive appliance plugged into the same grid, like an air conditioner. It is also able to compensate for small surges, in the reverse situation of when the air conditioner is turned off, and there is suddenly a surplus of current coming through the socket. The charger, of course, shouldn't be expected to compensate for something like a block-wide blackout, but small localized changes should be reasonable to manage. On the whole, though, changes to the current coming from the wall shouldn't be commonplace, but the charger should be able to compensate for some small perturbations, as controlling the current going into the phone is the entire purpose of the charger's control scheme.

In order to control the state of charge of the phone, the best way to do this is by implementing a straightforward feedback loop. In common vernacular, a feedback loop is a reactive model which involves measuring the controlled variable, and changing the manipulated variable upstream. A basic example would be of that of someone taking a shower: when you feel cold water, you increase the temperature, and when it is too hot, you decrease the temperature. Either way, you are making a change based on what the final outcome of the process is, which is what we are doing here.

This feedback loop measures the state of charge of the battery to determine the rate at which current should be taken by the battery. This will keep the phone charged but will not allow it to overcharge. Having a different rate of charge come in from the socket would simply be compensated for in what rate of charge the charger delivers to the battery. Since the charger already changes the current going into the batter, compensating for small perturbations in the original current should not be difficult. The diagram below represents a sample feedback loop implemented during the charging process of a cellphone.



This above described process of cell phone charging is extremely important. It prevents overcharging without much human effort and conserves battery life. So hey! Next time you see a mobile engineer at Samsung, thank him for saving you time, saving you cost, and most importantly saving you from burns.

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