BU-808c

Coulombic and Energy Efficiency with the Battery

All batteries have losses. The energy retrieved after a charge is always less than what had been put in. Parasitic reaction that occurs within the electrochemistry of the cell prevents the efficiency from reaching 100 percent. Ultra-fast charging and heavy loading also reduces the energy efficiency. This also contributes to battery strain by reducing cycle life.

Battery efficiency is gaining interest. This is especially critical with large battery systems in electric vehicles, energy storage systems (ESS) and satellites. The efficiency factor is commonly measured by coulombic efficiency. A coulomb is a unit of electric charge. One coulomb equals one ampere-second (1As).

Coulombic Efficiency

Coulombic efficiency (CE), also called faradaic efficiency or current efficiency, describes the charge efficiency by which electrons are transferred in batteries. CE is the ratio of the total charge extracted from the battery to the total charge put into the battery over a full cycle.

Li-ion has one of the highest CE ratings in rechargeable batteries. It offers an efficiency that exceeds 99 percent. This, however, is only possible when charged at a moderate current and at cool temperatures. Ultra-fast charging lowers the CE because of losses due to charge acceptance and heat, so also does a very slow charge in which self-discharge comes into play(See BU-808b: What Causes Li-ion to Die)

The coulombic efficiency of Li-ion improves with cycling. To prove this, Panasonic, E-one Moli, Sony, LG and Samsung Li-ion batteries in 18650 cell format where cycled. Some cells began with a coulombic efficiency of 99.1 percent and improved to 99.5 percent with 15 cycles. Some started at 99.5 percent and reached 99.9 percent with 30 cycles. The consistency on repeat tests was high, reflecting in Li-ion being a very stable battery system.

Lead acid comes in lower at a CE of about 90 percent, and nickel-based batteries are generally lower yet. With fast charge, NiCd and NiMH may reach 90 percent but a slow charge reduces this to about 70 percent. Lower charge acceptance when above 70 percent state-of-charge and self-discharge that increases when the battery gets warm toward the end of charge are contributing factors for the low CE. Best efficiencies of all batteries are attained in mid-range state-of-charge of 30 to 70 percent. All battery systems provide unique CE values that vary with charge rates and temperature. Age also plays a role.

Voltaic efficiency

Voltaic efficiency is another way to measure battery efficiency, which represents the ratio of the average discharge voltage to the average charge voltage. Losses occur because the charging voltage is always higher than the rated voltage to activate the chemical reaction within the battery.

Energy Efficiency

While the coulombic efficiency of lithium-ion is normally better than 99 percent, the energy efficiency of the same battery has a lower number and relates to the charge and discharge C-rate. With a 20-hour charge rate of 0.05C, the energy efficiency is a high 99 percent. This drops to about 97 percent at 0.5C and decreases further at 1C. In the real world, the Tesla Roadster is said to have an energy efficiency of 86 percent. Ultra-fast charging on newer EVs will have a negative effect on energy efficiency, as well as the battery life.

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