Drone Battery Modeling Equations (Recent IEEE-Indexed Studies)

Power and Energy Update Equations

- **Total Power:** The battery's instantaneous power draw is modeled by the product of discharge current and (nominal) voltage, e.g. $P = V_{\text{base}} \times I_{\text{discharge}}$ [1] In practice, UAV models often assume a fixed "base" voltage and compute power as $I(t) \cdot V$.
- **Discharge/Recharge Rates:** Energy change is given by current·voltage over time. In other words, discharge (or recharge) rates are expressed as $dE/dt = I(t)\, V\,(t)$ (in Wh/s, equivalent to watts). For SOC tracking, many works use coulomb-counting: for example, Jadhav *et al.* (2022) estimate SOC by integrating net current:

$$\text{SoC}(t) = \text{SoC}(0) + \frac{1}{Q_{\text{rated}}} \int_0^t (I_{\text{charge}} - I_{\text{discharge}})\, dt,$$

where Q_{rated} is rated capacity, $I_{\text{discharge}}$ is the discharge current, and any losses or charge currents are included [1] .
- **Power/Energy Update:** Battery state is updated each timestep by subtracting discharged energy and adding any recharge. Equivalently, one can write a discrete update such as

$$E_{k+1} = E_k - P_{\text{discharge}}\, \Delta t + P_{\text{charge}}\, \Delta t,$$

with $P_{\text{discharge}} = I_k V$ etc. This ensures the UAV's available energy (or remaining capacity) decreases as current is drawn and increases if the battery is recharged. For example, Vinay Jadhav *et al.* demonstrate a basic SOC update formula of this form in their drone-BMS study [1] .

Voltage–SOC and SoC Percentage Models

- **Nonlinear Voltage Model:** Li-ion UAV batteries are often modeled using nonlinear voltage-SOC relationships. In high-fidelity models, the open-circuit voltage (OCV) is treated as a nonlinear function of SOC (state-of-charge). Several classic models (Shepherd, Unnewehr, Nernst, etc.) use exponential and polynomial terms to fit the battery's OCV-SOC curve [2] . Such nonlinear functions capture the characteristic voltage sag of Li-ion cells as they discharge. For instance, Tudoroiu *et al.* (2020) note that OCV can be represented by combined mathematical models to match measured battery behavior [2] .
- **Linear/Polynomial Fits:** Simpler models assume a more direct (often linear or low-order polynomial) V-SOC mapping. In lightweight UAV applications, one may approximate terminal voltage as a linear function of SOC or remaining power. In practice, some controllers use linear or inverse-polynomial fits to approximate the voltage drop under load. The accuracy of these fits is typically validated against real flight data or HPPC tests [3] [2] .
- **SoC Percentage Formula:** A common engineering heuristic is to convert terminal voltage to a percentage by linearly scaling between known full/empty voltages:

$$\text{SoC\%} \approx 100\% \times \frac{V - V_{\min}}{V_{\max} - V_{\min}},$$

where $V_{\max}$ and $V_{\min}$ are the calibrated cutoff voltages for 100% and 0% charge. (Results are clipped to 0–100%.) This linear interpolation is widely used in UAV BMS implementations, even though the true voltage-SOC curve is nonlinear as above [2] .

Sources: Recent UAV battery modeling papers incorporate these equations. For example, Jadhav *et al.* (2022) detail a coulomb-counting SOC formula [1], and Tudoroiu *et al.* (2020) summarize nonlinear OCV-SOC models [2]. A comparative study (World Electr. Veh. J. 2025) further highlights how parameters like OCV and resistance vary with SOC in UAV batteries [3] , underscoring the use of nonlinear voltage-SoC relationships in practice.

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[1] (PDF) Battery Management System for Drones
https://www.researchgate.net/publication/366658959_Battery_Management_System_for_Drones

[2] SOC Estimation of a Rechargeable Li-Ion Battery Used in Fuel-Cell Hybrid Electric Vehicles—Comparative Study of Accuracy and Robustness Performance Based on Statistical Criteria. Part I: Equivalent Models
https://www.mdpi.com/2313-0105/6/3/42

[3] A Comparative Study on Battery Modelling via Specific Hybrid Pulse Power Characterization Testing for Unmanned Aerial Vehicles in Real Flight Conditions
https://www.mdpi.com/2032-6653/16/2/55