

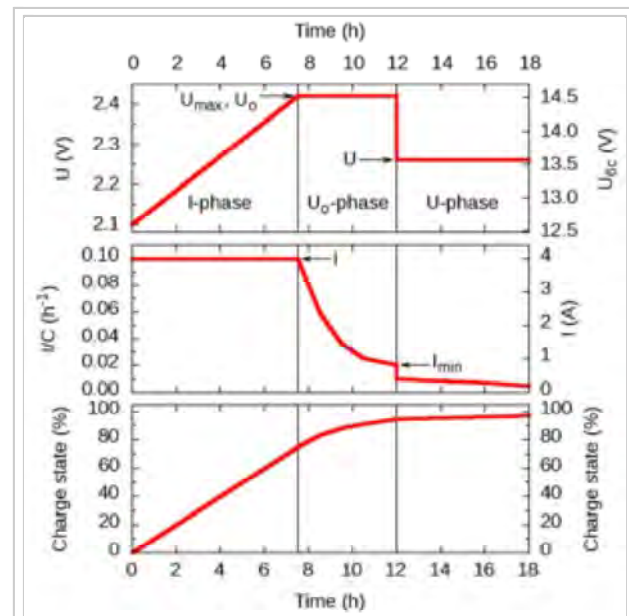
IUoU battery charging

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IUoU is a DIN-designation^[1] (DIN 41773) for a lead-acid battery charging procedure that is also known as *3-stage charging*, *3-phase charging*, or *3-step charging*. It consists of three phases (or stages), to be executed by a battery charger. The three phases are: *I-phase* (constant electric current), *U_o-phase* (constant over-voltage), and *U-phase* (constant voltage). The purpose is to fully charge the battery in a relatively short time without reducing its life span and to indefinitely keep the battery charged as long as the charger is connected.

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Example charging graph. On the left: per-cell quantities. On the right: example values for a 40 Ah, 6-cell (12 V) battery. Note: schematic illustration; not based on actual measurements.

Stages

Stage 1 is called the *I-phase*, *constant-current stage*, or *bulk charge stage*. This phase occurs when an IUoU charger is connected to a deeply discharged battery. The charger provides a constant current, typically the maximum current that the charger is capable of producing. As a result of the current, the battery absorbs the charge and its voltage rises. The charger limits the maximum voltage to U_{max} , a constant or temperature-dependent maximum, typically around 2.4 V per cell. Once the U_{max} voltage is reached, typically when the battery is charged to 70–80% of its capacity,^[1] the charger enters the U_o -phase. In case of a battery that is more than 80% full, this may happen immediately once the charger is switched on. Some chargers^[1] may keep the voltage at U_{max} for some time and allow the current to drop to 80% of the constant-current value, before proceeding to the next stage.

Stage 2 is called the *U_o-phase*, *constant-voltage boost stage*, *absorption stage*, or *topping charge*. In this stage, the battery is continued being charged at a constant (over)voltage U_o , but the charge current is decreasing. The decrease is imposed by the battery. The voltage in the U_o -phase is too high to be applied indefinitely (hence, overvoltage), but it allows charging the battery fully in a relatively short time. The U_o -phase is concluded when the charge current goes below a threshold I_{min} , after which the U -phase is entered. This happens when the battery is charged to around 95% of its capacity.^[1] Some manufacturers

^[2] follow this stage by a second constant-current stage (with a gradually increasing voltage) before continuing with the U-phase. The voltage U_o may be the same as U_{\max} in the previous stage, or it may be taken slightly higher.

Stage 3 is called the *U-phase* or *float charge state*, the voltage is reduced to a value that is safe to be applied for long periods (weeks) without significantly reduce the lifetime of the battery. During this phase, the charge current decreases gradually to a small residual value that compensates for any self-discharge of the battery.

Voltages and currents

The current in the I-phase (stage 1) should be chosen depending on the capacity of the battery. In practice, it depends on the capability of the charger. The battery capacity C is expressed in Ah units, typically the C_{20} value based on a 20-hour discharge time.^[3] The charging current (in A units) can be written as C/t where t is a time. For example, for a battery with $C = 40$ Ah, a current $C/(10\text{ h})$ (usually written as $C/10$, omitting the 'hours' as time unit) is equal to 4 A. The charging current is a compromise between charging time (favoring high currents), the prevention of damage due to overheating or gassing (favoring low currents), and cost of the charger (favoring low currents). Recommendations for the maximum charging current vary between $C/10$ ^[2] and $C/2$.^[3] At high charging currents, active cooling measures may be necessary to prevent overheating.^[3]

The voltages in the U and U_o phases (stages 2 and 3) depend on the type of battery and the temperature. Batteries have varying numbers of cells (typically six for an automotive battery) and may be flooded-cell, absorbed-glass-matt (AGM), or gel-electrolyte types. The numbers in the table below are for a temperature around 20 °C (68 °F).^{[1][3]} For temperatures that deviate more than about 5 °C (10 °F), a negative correction should be applied of $-5\text{ mV}/^\circ\text{C}$ ($-2.8\text{ mV}/^\circ\text{F}$) per cell^[1] or $-0.03\text{ V}/^\circ\text{C}$ ($-17\text{ mV}/^\circ\text{F}$) for a 12 V (6-cell) battery.

3-stage battery charging voltages and currents at 20 °C (72 °F)

Battery type	Ref.	Stage 1		Stage 2		Stage 3
		U_{\max} (V)	I	U_o (V)	I_{\min}	U (V)
Wet/flooded, single cell	[1]	2.32	< C/5	2.42	I/10	2.27
	[3]	2.47	< C/2	2.47–2.50	C/100	2.25–2.30
	[2]	2.37–2.47	C/10	2.37–2.47	C/33	2.19
Wet/flooded, 6-cell (12 V)	[1]	13.9	< C/5	14.5	I/10	13.6
	[3]	14.8	< C/2	14.8--15.0	C/100. [3] also recommends to limit the time period for this stage to a maximum of 12 to 24 hours, perhaps to save the battery from overheating, gassing etc. effects.	13.5--13.8
AGM, 6-cell (12 V)	[1]	13.9	< C/5	14.5	I/10	13.6
	[3]	14.1	< C/2	14.1--14.4	C/100	13.6--13.8
Gel electrolyte, 6-cell (12 V)	[1]	13.9	< C/5	14.1	I/10	13.6
	[3]	14.1	< C/2	14.1--14.4	C/100	13.5--13.8
Deep-cycle antimony, 6-cell (12 V)	[3]	14.7	< C/2	14.7--14.9	C/100	13.2--13.4

Special cases

A bad battery will have short I-phase and U_o -phase, but there is a risk of gassing, further damaging the battery.

If a battery is connected to a significant load during charging, the end of the U_o -phase may never be reached and the battery will gas and be damaged, depending on the charge current relative to the battery capacity.

References

1. Samlex Switch Mode, Automatic, Lead Acid Battery Charger 3 Stage (IUoU): Owner's manual (<http://www.chargingchargers.com/manuals/sec1260-1280-2440.pdf>) (2009)
2. US Battery Charging Recommendations (<http://www.trojanbattery.com/pdf/U.S.%20Battery%20Charge%20Profile%20Full%20%2011-12-13.pdf>)
3. Exide battery charging and storage guidelines (http://www.exide.com/Media/files/Downloads/TransAmer/Battery%20Care%20and%20Maintenance/Battery%20Charging%20&%20Storage%20Guidelines%20%2005_9_13.pdf) (2013).

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