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Measuring the state-of-charge (SoC) and equivalent series resistance (ESR) of exhausted alkaline and zinc-carbon batteries for possible recharging using a self-built, open-source Arduino-based tool

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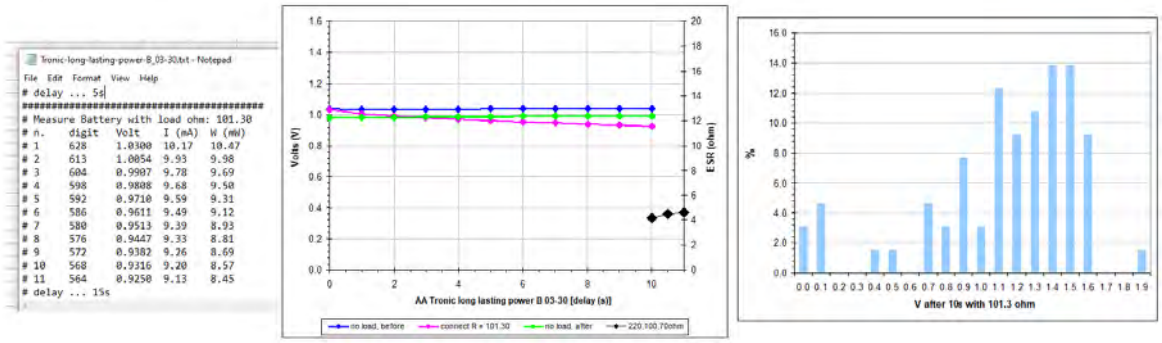
In 2024, global alkaline battery production reached 15 billion units. AA and AAA batteries accounted for 93% of all sales. The average household in developed countries uses about 50 alkaline batteries per year to power portable devices. In 2023, 231,000 tons of portable batteries were sold in the EU but only 117,000 were collected for recycling. Society is increasingly asking us to adhere to the 3Rs, especially for low-cost, mass-produced items. In the case of batteries if even a small percentage were first reused and then recycled, significant environmental savings could be achieved. 65 end-of-life batteries (alkaline and some zinc-carbon) collected from supermarkets and electronics stores were tested to determine their state of charge (SoC) and internal resistance (ESR) in view of their possible recharge. The new measuring device, an evolution of the previous one [1], is based on an Arduino UNO R3 and measures both parameters by subjecting the battery to resistive loads of 220, 100 and 70 ohm.

The figure below shows on the left a screenshot, generated by the software, of the output data for a used Tronal alkaline battery, which shows that it still produces currents of approximately 10 mA and power of approximately 10 mW. In the center is the corresponding graph showing the output voltage trend over 10 seconds with and without load, and in the lower right corner are the three ESR values obtained with the three different resistive loads. Finally, the graph on the right shows the voltage measured at the end of the pink curve (SoC) for the 65 batteries.



The last graph shows that 57.8% of the tested batteries had a voltage under load greater than 1.2 V, thus they are still usable, and 81.3% had a voltage greater than 0.9 V, i.e., above the cutoff declared in the manufacturers' datasheets. At the same time, 53.8% of the batteries had an ESR <5 ohms and 73.8% had an ESR <10 ohms.

Simultaneous measurement of SoC and ESR allows for detailed state-of-charge analysis both before and after a future charging attempt.

The low-cost device is presented as an open-source project under the CC BY-NC-ND 4.0 EN license. The circuit diagram, Arduino software, and all measurements performed with the 65 batteries are available. See the link in the poster.

References

1. G. Visco et al., *Methods Protoc.*, vol.9, no.2, art. 66, 2026.