Giving Batteries a Second Life

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Isidor Buchmann

CEO & founder of Cadex Electronics Inc.
www.BatteryUniversity.com; answers@cadex.com

Are batteries replaced too soon or too late? The answer lays in reliability concerns, service strategies and economics. While most batteries are replaced too late, Dr. Imre Gyuk, manager of the Energy Storage Research Program at DOE, says that every year roughly one million usable lithium-ion batteries are sent in for recycling with most having a capacity of up to 80%.

Dr. Gyuk is not alone. Mobile phone providers learned that 90% of returned warranty batteries have no problem. Packs are replaced on the slightest complaint without testing; installing a new pack seldom resolves the perceived problem. In the medical industry batteries are often replaced through date-stamping regardless of condition. Some packs are hardly used and are still in excellent health. A leading battery manufacturer discovered that 200 of 400 returned starter batteries had no problem. These organizations question the reason for the returns and the test methods used.

While lead and cadmium-based batteries pose the largest environmental concerns, lithium-ion is being added to the list of pollutants for the first time. This chemistry was classified as only mildly toxic, but the sheer volume of Li-ion batteries in consumer products requires tighter scrutiny.

Ingenious entrepreneurs have discovered a business model in giving discarded batteries a second life. Refurbishment centers have sprung up in the USA, UK and Israel. A service center in Texas handles up to 700,000 mobile phone batteries per month. They purchase surplus batteries by the ton and check them with battery analyzers. Reports reveal that customers using these B-Class batteries serviced by Cadex battery analyzers have identical performance records to new packs; there are no recorded increases in returns. Figure 1 shows a box of incoming batteries to be serviced.

Figure 1: Discarded mobile phone batteries are tested and redistributed

Modern rapid-test methods enable quick service of incoming batteries. Storefronts also utilize these technologies as part of customer service.

With the advent of the electric powertrain, more batteries are becoming available for refurbishing. Although less than at 100% capacity, these rugged industrial batteries have plenty of life left to serve less demanding applications. GM and ABB are already using Chevrolet Volt battery packs to store electrical energy for grid use. A medical technician working in a large Michigan hospital uses spent batteries from patient heart pumps to cut the grass with an electric lawn mower. This makes green energy even greener.

The leading health indicator of a battery is *capacity*. Capacity determines the energy a battery can hold and suggests the price on a refurbished battery. Even if faded, an otherwise healthy Li-ion battery has a higher capacity than a new lead acid. Li-ion batteries for industrial use have a specific energy of about 120Wh/kg; lead acid is only at 40Wh/kg. A Li-ion battery dropping from 100% to 60% still has 72Wh/kg, a capacity that is substantially higher than lead acid. Furthermore, Li-ion will outlive lead acid if continuously cycled in a renewable energy application.

Battery test methods

Battery diagnostics has not advanced as quickly as other technologies and still appears to dwell in medieval times. No instrument is capable of estimating the state-of-health of a battery in a single measurement. Similar to a doctor examining a patient, or the weatherman forecasting the weather, battery testing entails looking at multiple attributes to get a clear health assessment. Although capacity is the leading health indicator, internal resistance and self-discharge also play a role. Suitable test equipment, understanding batteries and intuition are essential to make a refurbishing business viable.

Rapid-testing would be most desirable, but this only works for a designated battery population for which a matrix has been developed. A matrix is a multi-dimensional lookup table against which readings are compared. Text recognition, fingerprint identification and visual imaging operate in a similar principal. Mobile phone batteries fit the bill for rapid-testing and these packs can be checked with QuickSort™.

Developed by Cadex, QuickSort™ uses *electrochemical dynamic response* to check the flow of ions between the cathode and anode of Li-ion. A digital load simulating a mobile phone excites the battery and the generic matrix classifies the battery into *Good*, *Low* and *Poor*. The test takes 30 seconds, is 90% accurate over a broad range of Li-ion systems and can be performed with a state-of-charge of 40–100%. The system does not rely on internal resistance as this would produce unreliable readings. Modern Li-ion keep low resistance with cycling, and Figure 2 illustrates this relationship.

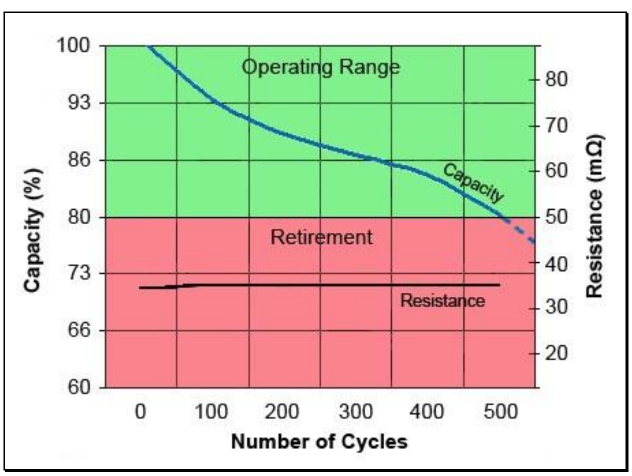

Figure 2: Relationship between capacity and resistance as part of cycling

The resistance of modern Lithium-ion remains low while the capacity gradually drops. Resistance measurements alone do not provide reliable results.

Cadex continues research to accommodate larger packs using *Time Domain* and *Frequency Domain* methods. Time domain applies a series of pulses (as in QuickSort™) and observes the rate of recovery. A good battery has as a quick recovery; a faded one is slow. An analogy can be made with a dry felt pen that still writes but needs rest to replenish the ink. Figure 3 compares a good battery with quick recovery against a faded one that is sluggish.

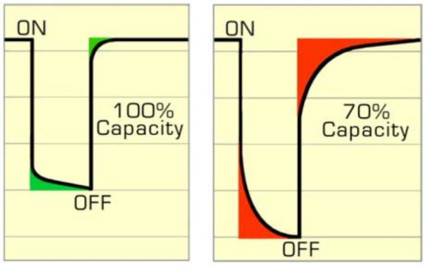

Figure 3: Electrochemical dynamic response

The electrochemical dynamic response measures the ion flow between the positive and negative electrodes. A good battery has a quick recovery; a faded one is sluggish.

Frequency domain is based on *electrochemical impedance spectroscopy (EIS)* and involves scanning a battery with frequencies ranging from several kilohertz down to millihertz. High frequency reveals the resistive qualities of a battery, also known as bird-eye's view, and low frequencies provide insight into unique battery characteristics, including capacity estimation with a suitable algorithm.

Evaluating batteries at sub-hertz frequencies adds to the test time. At one millihertz, a cycle takes 1,000 seconds and several data points are required to assess a battery with certainty. Clever software simulation can shorten the duration to seconds by applying prediction models.

Research laboratories have been using EIS for many years to evaluate battery characteristics, but high equipment cost, long test times and the need for trained professionals to decipher reams of data have limited this technology to laboratory environments. In spite of its complexity, battery scientists believe that advanced battery testing will evolve around this very technology.

Cadex took the EIS technology a step further and developed *multi-model electrochemical impedance spectroscopy* or Spectro™ for short. The handheld Spectro™ test devices developed by Cadex scan the lead acid battery with a 20-2,000 Hertz signal as if to take a landscape, but the heart of the system lays in the patented algorithm that performs 40 million transactions to calculate capacity and CCA readings in 15 seconds.

Not all batteries can be checked with rapid-test methods. For the broad population of larger batteries, Cadex recommends battery analyzers to first establish if a battery is functional or not. A final capacity reading must always be known, and the most reliable method is through a full charge and discharge cycle. This method works well for deep-cycle lead acid, as well as nickel and lithium-based batteries, but should be avoided for starter batteries.

Servicing a broad range of batteries is best done with the Cadex C7000 Series. Figure 4 illustrates the C7400ER, a programmable battery analyzer servicing lead, nickel- and lithium-based batteries with ratings of up to 36V and 6A per channel to accommodate sizes of up to 24Ah. Each of the four stations operates independently. Redundant test algorithms assure safe service of batteries with a known fault.

Figure 4: Cadex C7400ER battery analyzer

Programmable analyzers service batteries of up to 36V. Automated programs recognize a faulty battery and halt the service if necessary. The optional PC-BatteryShop™ enables PC interface.

Connecting batteries has always been a challenge and Cadex solved this with battery adapters. Frequently used batteries are best serviced with a *custom adapter*. Each adapter holds 10 configuration codes to service batteries of same footprint. The parameters can be edited on the analyzer or with the optional PC-BatteryShop™ software.

The *Smart Cable* is best suited for a broad range of diverse batteries, and the *RigidArm*™ (Figure 5) is most convenient for mobile phone batteries. Spring-loaded arms meet the battery contacts from the top down, allowing quick and repetitive testing. The spring-loaded retractable floor holds the battery in a vertical position and a temperature sensor monitors the battery during the test.

Figure 5: RigidArm™ for cellular batteries

Connecting small batteries is simplified with the RigidArm™. This universal battery adapter meets the contacts from the top down, allowing repetitive testing with ease.

Summary

Battery diagnostics and monitoring techniques are not advancing as rapidly as the global battery market demands. Much work lays ahead, and many companies, including Cadex, are making critical advances in the field. These incremental improvements will help extend battery life without sacrificing reliability. This is consistent with protecting our environment by being able to fully utilize the life of each battery and reducing the number of packs discarded.

About the Author

Isidor Buchmann is the founder and CEO of Cadex Electronics Inc. For three decades, Buchmann has studied the behavior of rechargeable batteries in practical, everyday applications, has written award-winning articles including the best-selling book "Batteries in a Portable World," now in its third edition. Cadex specializes in the design and manufacturing of battery chargers, analyzers and monitoring devices. For more information on batteries, visit www.batteryuniversity.com; product information is on www.cadex.com.