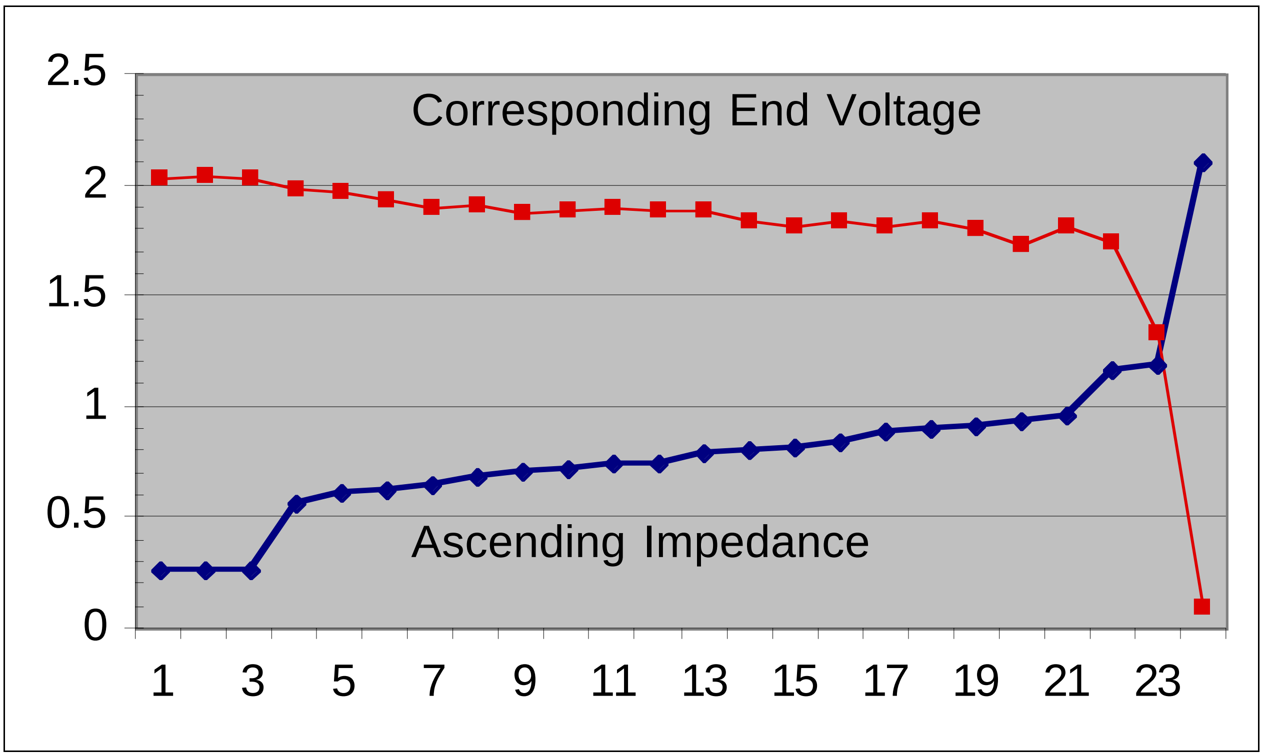
IMPEDANCE: IT CORRELATES TO BATTERY CAPACITY

There has been much talk about whether impedance (and other internal ohmic tests) truly correlates to battery capacity. To date, there is no mathematical equation that when impedance is entered as the variable, capacity is calculated, for example in an equation like:

$$y=m_1x_1 + m_2x_2 + b$$

where y = battery capacity
m_1 is a constant of the first term
x_1 is measured variable such as impedance
m_2 is a constant of the second term,
x_2 is another measured variable (like temperature) and
b is the y-intercept.

However, there has been much testing performed showing a strong correlation to battery capacity as evidenced by in the graph below.



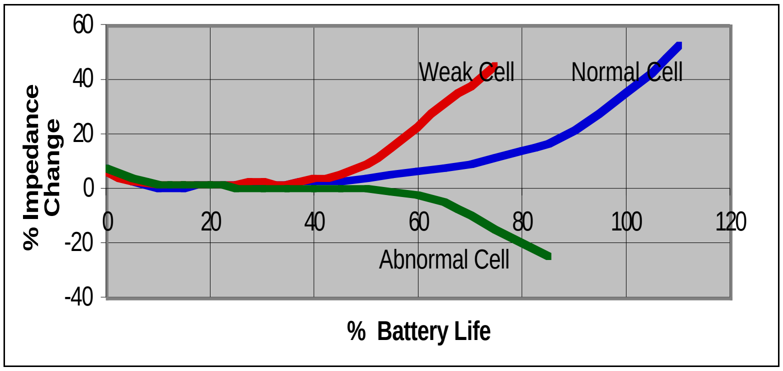
This graph shows ascending impedance with corresponding end-of-capacity voltage. It clearly shows a solid correlation between impedance and capacity. This graph is of an actual telecom battery. We know for example that the lowest three cells were recently replaced while the others date to the original installation.

Batteries are complex chemical mechanisms. No matter how well batteries are manufactured, there is still some amount of black art to them (and all chemical processes).

Lead-acid (flooded) Failure Modes

- Positive grid corrosion,
- Sediment (shedding) build-up,
- Top lead corrosion,
- Plate sulphation,
- Hard shorts (paste lumps).

The normal designed failure mode is positive grid corrosion. The grids are lead alloys (lead-calcium, lead-antimony, lead-antimony-selenium) that convert to lead oxide over time. Since the lead oxide is a bigger crystal than lead metal alloy, the plate grows. Battery manufacturers design for extra space in the jars to account for this growth. At the designed end-of-life the plates will have grown sufficiently to pop the tops off of the batteries. But excessive cycling, temperature and over-charging can also increase the speed of positive grid corrosion.



Sediment build-up (shedding) is a function of the amount of cycling a battery endures. This is more often seen in UPS batteries but can be seen elsewhere. Shedding is the sloughing off of active material from the plates, converting to white lead sulfate. Sediment build-up is the second reason battery mfrs. have space at the bottom of the jars to allow for a certain amount of sediment before it builds-up to the point of shorting across the bottom of the plates rendering the battery useless. The float voltage will drop and the amount of the voltage drop depends upon how hard the short is. Shedding, in reasonable amounts, is normal.

Some battery designs have wrapped plates such that the sediment is held against the plate and is not allowed to drop to the bottom. So sediment does not build-up in wrapped plate designs. The most common application of wrapped plates is UPS batteries.

Top lead corrosion, like slivering, is more of a mfg defect. This is hard to detect even with a visual inspection since it occurs near the top of the battery and is hidden by the cover. Nearing a full failure, impedance may find this defect. But it will surely fail due to the high current draw when the AC mains drop off. The heat build-up when discharging will most likely melt the crack open and then the entire string drops off-line — a catastrophic failure.

Plate sulphation is one of the easiest failure modes to find with impedance. A thorough visual inspection can sometimes find traces of plate sulphation. Sulphation is the process of converting active plate material to inactive white lead sulfate. Since impedance finds electrical path failures (rather than mechanical failures unless they are manifested as electrical path failures) very well, and sulphation is one of the electrical path problems, it is easily found. Sulphation is due to low charger voltage settings or incomplete recharge after an outage. Sulfates form when the voltage is not set high enough.

Lead-acid (VRLA) Failure Modes

- Dry-out (a.k.a. Loss-of-Compression)
- Plate Sulphation (see above)
- Soft and Hard Shorts
- Post leakage
- Thermal run-away
- Positive grid corrosion (see above)

Dry-out is a phenomenon that occurs due to excessive heat (lack of proper ventilation), over charging, which can cause elevated internal temperatures, high ambient (room) temperatures, etc. At elevated internal temperatures, the sealed cells will vent through the PRV. When sufficient electrolyte is vented, the glass matte no longer is in contact with the plates, thus increasing the internal impedance and reducing battery capacity. In some cases, the PRV can be removed and distilled water added (but only in worst case scenarios and by an authorized service company since removing the PRV may void the warranty). This failure mode is easily detected by impedance and is one of the more common failure modes of VRLA batteries.

Soft (a.k.a. dendritic shorts) and Hard shorts occur for a number of reasons. Hard sorts are typically caused by paste lumps pushing through the matte and shorting out to the adjacent (opposite polarity) plate. Soft shorts, on the other hand, are caused by deep discharges. When the specific gravity of the acid gets too low, the lead will dissolve into it. Since the liquid (and the dissolved lead) are immobilized by the glass matte, when the battery is recharged, the lead comes out of solution forming dendrites inside the matte. In some cases, the lead dendrites short through the matte to the other plate. The float voltage may drop slightly but impedance can find this failure mode easily but is a decrease in impedance, not the typical increase as in dry-out. See Figure 1, abnormal Cell .

Thermal run-away is when a battery internal components melt-down in a self-sustaining reaction. Normally, this phenomenon can be predicted by as much as four months (which is one of the reasons why AVO International recommends quarterly VRLA impedance testing.) The impedance will increase in advance of thermal run-away as does float current. Thermal run-away is relatively easy to avoid, simply by using temperature-compensated chargers and properly ventilating the battery room/cabinet. Temperature-compensated chargers reduce the charge current as the temperature increases. Remember that heating is a function of the square of the current.

Nickel-Cadmium Failure Modes

NiCd batteries seem to be more robust than lead-acid. They are more expensive to purchase but the cost of ownership is similar to lead-acid, especially if maintenance costs are used in the cost equation. Also, the risks of catastrophic failure are considerably lower than VRLA.

The failure modes of NiCd are much more limited than lead-acid. Some of the more important modes are:

- Gradual loss of capacity
- Carbonation
- Floating Effects
- Cycling
- Iron poisoning of positive plates
- Service at elevated temperatures

Gradual loss of capacity occurs from the normal aging process. It is irreversible but is not catastrophic.

Carbonation is reversible and is gradual. But without proper maintenance, this can cause the load to not be supported. This can be reversed by exchanging the electrolyte.

Floating Effects are the gradual loss of capacity due to long periods on float without being cycled. However, through routine maintenance, this can be avoided and is easily found by impedance testing. Floating Effects are reversible by deep-cycling the battery once or twice.

Iron poisoning is caused by corroding plates and is irreversible.