BATTERY POWER
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# Enhance Battery Pack Performance With the Optimal Charger

**Lon Schneider, Director of Product Development**
*Nexergy, Inc.*

To assure that the rechargeable battery you provide with your product operates safely and gives the customer the performance that is expected, it is important that it be charged properly. Sufficient charge, at an appropriate rate, must be supplied so that the cell can deliver its rated capacity. Capacity, essentially the product of the magnitude and duration of the current it supplies, is expressed in units of milliampere-hours or Ampere hours. As the units suggest, reduced capacity results in reduced run time for the battery-powered device. If too little charge is delivered per cycle, the product cannot deliver its expected run time. Additionally, batteries incorporating several cells in series can be permanently damaged as a result of insufficient charge.

The other side of the coin is excessive charge. Overcharge can cause permanent damage to batteries, even those composed of only one cell. At the extreme, damage can result from a single, severely excessive overcharge. More often, however, the degree of overcharge is less severe and the result more subtle and gradual. The result is that the battery becomes unusable well before its expected lifetime has expired. For some types of cells, excessive charge can also make them unsafe. Thus, proper charging requires knowing when to deliver charge and when enough has been delivered.

The most widely used rechargeable batteries include a variety of cell chemistries, primarily nickel cadmium (NiCd), nickel metal hydride (NiMH), sealed lead acid (SLA), and lithium ion (Li-ion). There are two fundamentally different approaches to charging these different chemistries. First, the nickel based chemistries (NiCd and NiMH) will be discussed. These can be charged at low rates without great complexity. Overnight charge of NiCd is often accomplished without termination control. NiMH can be addressed similarly, though it is not recommended that low rate charging be sustained for long periods of time. The problem is that users are not satisfied to wait for 12 or more hours for a product to be charged. Customers want charge in as short a time as possible, often one or two hours or less. NiCd and NiMH batteries are designed to accept some degree of overcharge, but cannot sustain overcharge at the rates needed for fast charge. The charge current must be shut off or reduced to a prescribed level when the battery is full.

Typically, when a battery is installed in its charger, its state of charge is not evident. As a result, chargers must be designed to use external parameters to indicate when the battery is full. (The exception is "Smart" batteries, which include on board electronics to keep track of charge state and conditions.) Figure 1 is a graph of battery voltage, pressure, and temperature versus charge delivered. It is based on a charge at rate of 1C.

The charge rate of 1C is a normalized rate equal to the nominal capacity of the cell. For a 1.5 aH battery, a 1 C charge rate would be 1.5 amps. At that current, representing a 1-hour charge rate, it is evident that as full charge is approached, pressure continues to rise steeply. If charge is not terminated in time, the pressure will become high enough to damage the cell. The safety valve will open, venting gas and electrolyte to minimize danger, but the cell will be permanently damaged. This scenario illustrates the need for proper charge termination.

Generally, the charger cannot measure the pressure buildup inside the cell, but the voltage profile offers a clue. While the absolute value of the voltage is not a good indictor of charge level, the peak beyond 100 percent charge is a good indicator.

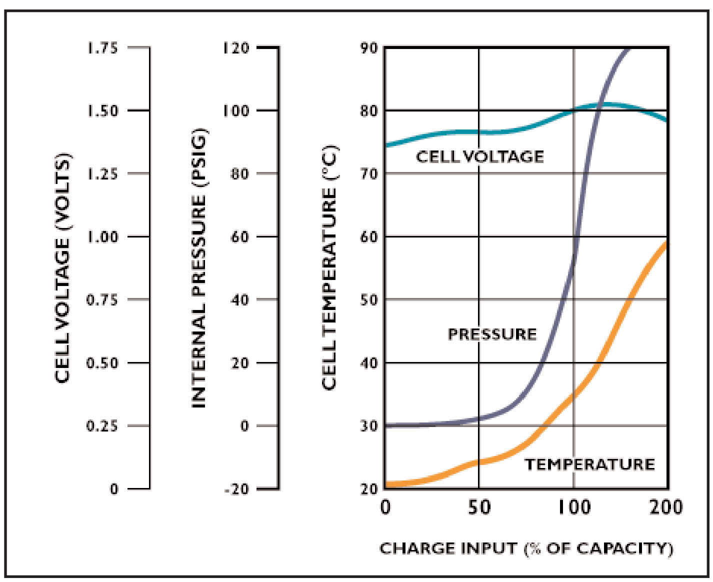


**Figure 1. Cell voltage, pressure, and temperature versus charge level (NiCd cell charged at 1C rate)**

Chargers for NiCd frequently use this characteristic to determine when charge is complete. They compare successive readings of battery voltage to determine when the voltage peak has been passed and subsequent values begin to fall. The method is called $-\Delta$ V, (minus delta V), corresponding to the small negative change in voltage which signals that charge is complete.

Some NiMH chargers use this same technique, but the shallower peak characteristic of NiMH makes this more difficult to resolve. Another characteristic shown on Figure 1 is the acceleration in the temperature rise as full charge is approached. Temperature rises as a result of overcharge. Excessive temperature will damage the cell in addition to the corresponding increase in pressure. So temperature rise is more than a clue. It is a parameter to control. Termination methods based upon reaching a prescribed rate of temperature rise is called dT/dt, a Calculus expression for the rate of charge of temperature versus time. This technique addresses the problems NiMH may have with $-\Delta$ V, and is suitable for either chemistry. Because the cell mass has specific heat, and temperature is measured on the cell surface, there is some delay in the temperature rise. Faster techniques are available which use other characteristics of the charge voltage profile to locate the point of full charge. These are useful on NiCd cells which can be charged at rates much faster than one hour.

The chemistries not discussed so far are SLA and Li-ion. These share a similar charge profile which is very different from that required for NiCd or NiMH. Though chemically very different, SLA and Li-ion both require that the charger terminate when the cell EMF approaches a prescribed value.

For SLA or Li-ion packs, the charger is a voltage regulated source with intentionally limited output current. During the early portion of the charge cycle, charge current reaches the limited value while battery voltage is below the regulated value. As charge proceeds, battery voltage rises until the regulated value is reached. Then, as that voltage is maintained and the battery internal EMF rises, charge current begins to fall. Ideally charge could terminate when the current reaches zero. But that is impractical as it would take a very long time. Also, real batteries have internal current leakage, preventing current ever reaching zero. Fortunately, as charge current falls, its contribution to total capacity becomes less significant. Therefore, rapid charge is terminated when the falling magnitude of charge current reaches a predetermined fraction of the initial value.

Some SLA chargers completely shut off at this point. Others reduce the value of the regulated voltage to a float level. This reduced, float level is applied to offset internal leakage current and keep the battery full without overcharge during prolonged waiting periods.

Figure 2 shows the same charge profile as applied to Li-ion. For Li-ion, the voltage level to be regulated is determined not only for reasons of capacity, but especially for safety. The positive plate in the Li-ion battery is a structure of lithium and transition metal oxide. As the cell is charged, lithium ions leave the positive plate and travel to the negative plate. The positive plate is most stable chemically when it holds a high degree of lithium. Charge reduces the amount of lithium in the positive plate. Excess charge removes too much lithium, making the structure less stable. Even at full charge, batteries are designed to keep a minimum level of lithium in the structure. This corresponds to a voltage level that must not be exceeded. The result is that chargers for Li-ion must accurately limit the battery voltage to the prescribed limit. For additional protection in case of a charger fault, Li-ion battery packs include internal circuitry to disconnect the battery in the event of overcharge.

The charge functions described above apply to normal conditions. These assume that the temperature is within the proper range for charging, the cell's depth of discharge is not excessive, and no shorted cells are present. But, conditions are not always ideal. Chargers must include accommodation for temperature, deeply discharged cells, etc. Prequalification tests should be applied to the pack to verify that the voltage is within the normal range before applying full charge, or to apply a reduced charge rate to bring the voltage within that range. Backup termination after a prescribed elapsed time, or above a prescribed cell temperature, addresses the possibility that damaged cells might not terminate normally.

The hardware needed to deliver charge and provide charge control for normal and abnormal conditions, is represented in Figures 3 and 4. They show a linear power supply, though an off-line switch mode (OLSM) supply can also be used. Analog to digital circuitry converts analog voltages to digital form so the microcontroller can read them. (Or, for Li-ion or SLA, analog controls can interface with those signals directly.) One such signal is battery voltage. Additionally, a negative temperature coef-

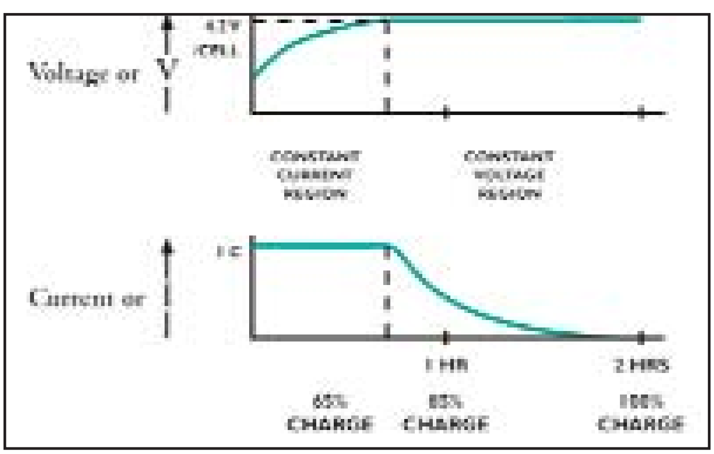


**Figure 2. Li-ion charge profile**

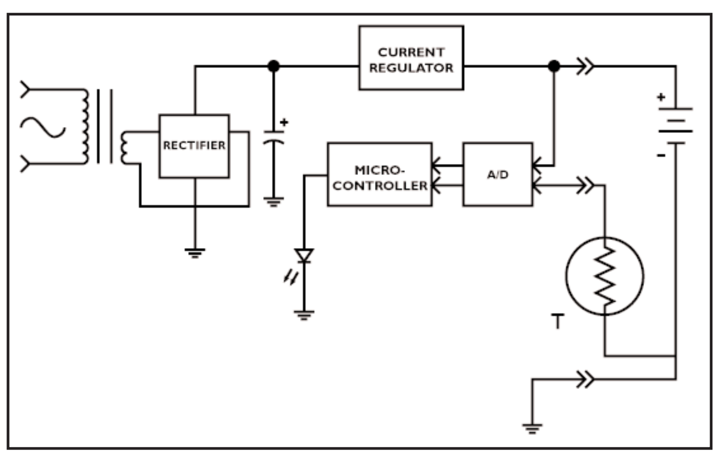


**Figure 3. NiCd, NiMH Charger**

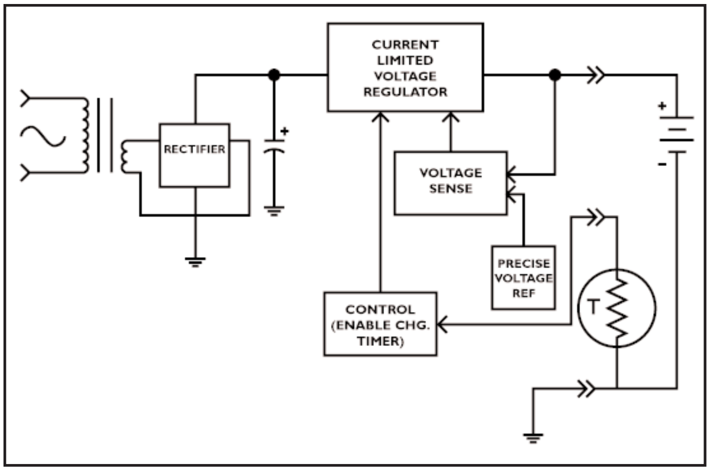


**Figure 4. Li-ion, SLA Charger**

ficient (NTC) thermistor, in thermal contact with the cells, signals the cell temperature. Throughout the charge cycle, the charge controller monitors battery voltage and temperature, and uses that data to perform the appropriate action: enable charge, apply a conditioning charge, terminate, or wait. Charge status is also signaled via LED indicators.

Selecting the right circuit topology and optimizing the selection of parameters that determine charge rate as well as initiation or termination of charge, assures optimum charger performance. This is best performed when the battery and charger characteristics can be optimized together.

Proper charging of a battery pack is essential to ensure safe operation of portable electronics devices. Value-added battery pack manufacturers may be able to provide a custom portable power source, but very few can design and manufacture a custom charger that takes full advantage of the capabilities of the battery cell. By optimizing both battery pack and charger during the design phase, manufacturers can take into account all relevant considerations for their portable power source, including charge rate, accurate determination of full charge, and charge termination.

*Lon Schneider, Director of Product Development, manages the design of Nexergy's standard and custom battery chargers, and all battery management electronic circuits.*

*Mr. Schneider can be reached at lschneider@nexergy.com.*