DYNAMIC BOOST™ [1] BATTERY CHARGING
A New System That Delivers Both Fast Charging & Minimal Risk of Overcharge

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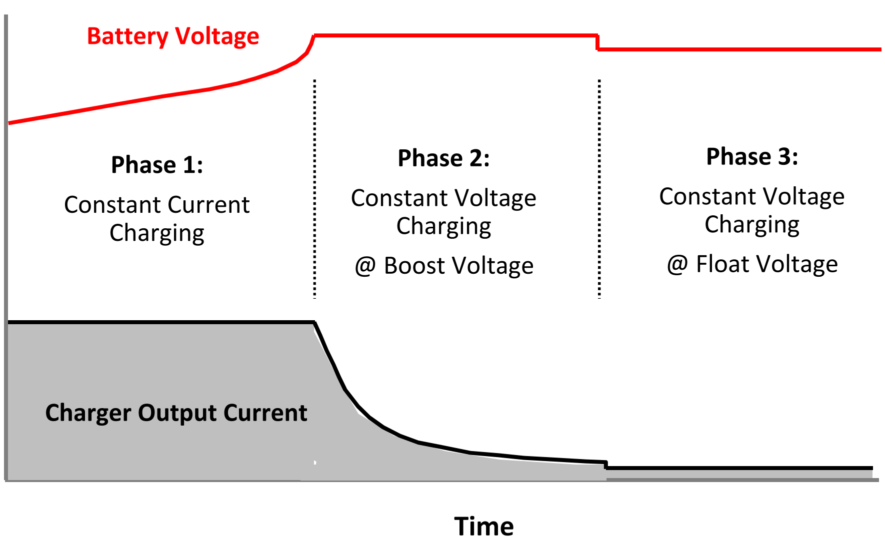
Introduction

The fastest generally accepted way to charge a conventional (lead-acid or ni-cd) battery is with a constant voltage, current limited battery charger that is capable of both "boost" and "float" output voltages. "Boost" charging applies a higher than normal voltage to the battery early in the charge cycle to charge the battery as quickly as possible. Later, once the battery is charged, charging voltage is reduced to a lower value called "float" that is suited for maintaining the battery at a full charge. Appendix 1 explains in detail why these two different charging voltages are necessary.

The following description of the recharge cycle refers to Figure 1 below:

- **Phase 1:** Early in the cycle of recharging a fully discharged battery the charger operates at its maximum current. This is Phase 1 of the recharge cycle. During this phase the battery's voltage increases.
- **Phase 2:** Once battery voltage rises to a pre-set "boost" voltage value the charger's voltage control system takes over to maintain voltage at the boost value for a time that, ideally, is just sufficient to finish the job of recharging the battery. This is Phase 2 of the recharge cycle.
- **Phase 3:** At the end of Phase 2 the charger's voltage control system reduces the charger's output voltage setpoint to the float voltage, which is Phase 3 of the recharge cycle. Although the bulk of the battery's capacity is replenished in Phases 2 and 3, charge current continues to taper off during Phase 3.

Figure 1
Multi-rate Battery Recharge Diagram



[1] Dynamic Boost is patented under multiple US patents. Other patents pending.

What is the right duration of Phase 2?

The duration of Phase 1 is determined by the battery's depth of discharge, the ratio of charger ampacity to battery capacity, and whether there are parasitic DC loads connected to the system. Although the duration of Phase 1 does vary, we are not concerned with this variation since, once the battery capacity, charger output and DC loads are installed, we have no means to change the duration of Phase 1.

The duration of Phase 2, however, is of great concern to us, because the elevated voltage at which the charger operates in Phase 2 has the ability to achieve either good (charging batteries faster), or bad (overcharging batteries and causing rapid water loss and shorter battery life). Phase 2 is the area where applying more knowledge and better technology can pay big dividends.

The charger needs to operate in the boost voltage mode just long enough for the battery to reach a high state of charge, but no longer. Too much time in boost mode overcharges the battery, causing excessive water loss, excessive emission of flammable hydrogen gas, accelerated grid corrosion and shorter battery life. Too little time in boost mode significantly extends charging time such that UL and NFPA mandated recharging performance might not be achieved.[2] In the case of some ni-cd batteries, insufficient boost charging prevents the battery from achieving its full rated capacity.

Unfortunately, there is no easy answer to how long the charger should operate in boost mode. The optimal solution changes each time the battery is charged. Differing depths of battery discharge, the health of the battery, the presence or absence of DC loads in parallel with the battery and charger, and differing ratios of battery capacity to charger output all affect how long the battery charger should remain in boost mode.

Problems With Prior Automated Boost Control Methods

Table 1 summarizes boost control methods, in order of oldest to newest. To understand the new Dynamic Boost system (Method E) we need to review why the other two more recent boost control systems, Methods C and D, are deficient.

[2] Battery charging performance in emergency generators and fire pumps is governed by the NEC, UL and NFPA standards. NFPA-110 and UL 1236 mandate that fully discharged batteries of Level 1 emergency generators must be fully recharged in less than 24 hours. UL 1236 includes specific tests to verify this performance.

Table 1
Summary of Boost Charge Control Systems

	Method	Termination	Pro	Con
A	Toggle switch	Manual by human operator	None	Human controlled. Accurate operation is impossible, as operator can forget to turn on or off boost.
B	Manually initiated timer	Automatic, based on timer setting	Improvement over toggle switch because boost termination is automatic.	Boost duration is set by operator, who has no way to determine correct boost time.
C	Automatic timer	Automatic, based on pre-programmed time	Improves over manual timer because boost is initiated automatically.	Operates correctly only under one use case. All other use cases are suboptimal and cause the battery to be either overcharged after a partial discharge, or charged more slowly than optimal when there is a large connected load or after a full discharge.
D	Current-sensing automatic initiation and termination	Automatic, based on charger output current dropping below a pre-determined threshold	Improves over automatic timer because termination is made dynamically based on current demanded of charger	Operates correctly only under one use case. All other use cases are suboptimal. The addition of DC loads can cause the charger to remain in boost too long, unless the charger is programmed with loads in mind – in which case boost terminates too soon when there is no DC load
E	Dynamic Boost™	Automatic, based on charger current and analysis of charging performance	Improves over current-sensing automatic system because termination decision takes all factors into account	None. Charging system is not fooled by changes in DC load, battery capacity, depth of discharge or battery age

Shortcomings of automatic boost timers (Method C) and current-sensing automatic systems (Method D)[3]
In the automatic timer control scheme the duration of boost charger is pre-programmed into the charger's control system. Chargers equipped with automatic boost timers may, under very specific circumstances, provide just the right duration of boost charging. Under all other circumstances, however, such as a different depth of discharge, or when the connected DC load changes, the pre-programmed and fixed boost time will be either too long or too short. As a result, most recharge cycles will either overcharge the battery or charge it much more slowly than possible with a more sophisticated control system. Over the course of a battery's lifetime, the conditions it faces will change. Changing conditions guarantee that chargers employing automatic boost timers will at times both overcharge the battery and, at other times, charge it too slowly. In other words, automatic timers assure both shortened battery life and inadequate state of charge sometimes. Unfortunately, these two conditions do not average out; undercharging a battery does not undo the damage done by prior overcharge.

Method D, current-demand controlled automatic boost, is more advanced than the automatic timer because the duration of boost charging is not pre-programmed. Instead, the charger automatically adjusts the duration of boost charging to differing depths of battery discharge. This system, however, is not foolproof. The only information available to the charger is current demand, which the charger uses as a proxy for the battery's state of charge. Adding a DC load -- as in increasingly occurring with gensets -- to a charging cycle using this approach fools the charger because the charger's control system cannot differentiate between current demanded by the battery or by the DC load. Adding a DC load thus causes the charger to operate at boost voltage longer than the charger would if there were no DC load. As with the automatic timer, the consequence of this relatively simple control scheme is batteries that are either overcharged, or that are charged more slowly than possible with a more sophisticated system.

[3] Manual boost control schemes (Methods A and B) deliver worse performance than even the crudest automatic systems, and should be avoided.

The problems inherent with both automatic timers and current controlled automatic boost systems force designers of chargers employing these systems to choose between aggressive recharge profiles that optimize charging speed under ideal conditions, or less aggressive charge profiles that result in slower charging, but improve battery safety and longevity. The former choice typically results in overcharged, short-lived batteries. The latter choice typically results in slower charging than ideal, putting the next engine start at risk.

Dynamic Boost (Method E) overcomes the shortcomings of both these systems.

What Is Dynamic Boost, and Why Does It Work?

As with the current-controlled automatic boost system, Dynamic Boost includes no pre-programmed boost timer. Unlike the current-controlled automatic boost system, however, Dynamic Boost automatically adjusts boost duration to take into account differing parasitic DC loads and other variables discussed above.

The principle behind Dynamic Boost is simple and straightforward. Refer back to Figure 1. For each and every recharge cycle, Dynamic Boost measures how long the charger operates in current limit (Phase 1), and retains this information in its memory. Once the charger transitions from Phase 1 to Phase 2, the charger maintains boost voltage for a ratio of the time that it remembers operating in Phase 1. In other words, the longer the charger operates in Phase 1, the longer it operates in Phase 2, before reverting to float voltage (Phase 3).

The following examples illustrate how Dynamic Boost adapts to changing conditions:

- When a battery is only partially discharged the transition from Phase 2 to Phase 3 should occur sooner than would be optimal if the battery were fully discharged beforehand. This is because fewer ampere-hours need to be returned to a partially discharged battery than a fully discharged one. Dynamic Boost recognizes and adapts to a more shallowly discharged battery because the duration of Phase 1 of a shallowly discharged battery will naturally be shorter than with a battery that had been fully discharged. Dynamic Boost measures the relatively shorter duration of Phase 1 and shortens Phase 2 accordingly.

- When DC loads are attached in parallel to a given battery and charger, and the battery must be recharged, the duration of both Phases 1 and 2 must become longer than if there were no attached load. This is because the DC loads are consuming some of the charger's capacity, leaving less capacity to charge the battery. The time to achieve full recharge must therefore increase. Dynamic Boost recognizes and adapts to the DC load because it measures an increase in the duration of Phase 1. This causes the charger to lengthen the duration of Phase 2.

Because most modern systems experience variation of both the connected DC loads current and battery depth of discharge, it should be clear that chargers equipped with Dynamic Boost deliver more accurate real-world charging results than earlier generation chargers. "More accurate charging" means faster charging with lower risk of overcharge for every recharge cycle.

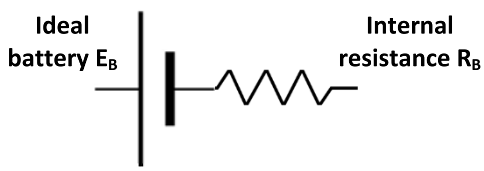
The benefits of more accurate charging enabled by Dynamic Boost include a more reliable battery-backed application, reduced need for battery maintenance, lower risk of premature battery failure, longer battery life and lower costs.

APPENDIX 2
Review of Charging Basics – Why Boost Charging is Necessary

The following example helps illustrate two facts about reducing battery recharge time:

- Cutting recharge time in half is more complex than using a charger that delivers twice as many amperes.
- Multi-rate charging is necessary when attempting to charge quickly.

Because no battery materials are superconducting, and because ions must physically move through the battery, all batteries to some degree resist current flow. Therefore any storage battery can be thought of as an ideal battery in series with electrical resistance. Assume in the example below that ideal battery E_B is connected in series with resistance R_B.



We will compare the battery's state of charge when it is charged with a 20A charger versus a 40A charger. We assume for purposes of this example that R_B is .001 ohms (this is an oversimplified value as the internal resistance will vary with type of cell and state-of-charge). The equation below states that a voltage applied to an ideal battery (E_B) equals the voltage delivered by the charger at the battery terminals, minus the voltage lost in the battery's internal resistance (R_B) as heat.

<u>If we apply a charge current of **20 amps**</u> that is voltage limited to 2.25 volts/cell, E_B (which corresponds to the state of charge of the battery) will be:

$$\mathbf{2.25 = E_B + (20 * R_B)}$$
$$\mathbf{2.25 = E_B + (20 * .001)}$$
$$\mathbf{2.25 = E_B + (.02)}$$
$$\mathbf{2.23 = E_B}$$

When charged by the 20A charger, the ideal battery sees 2.23 volts/cell.

<u>If we apply a charge current of **40 amps**</u> that is voltage limited to 2.25 volts/cell, E_B will be:

$$\mathbf{2.25 = E_B + (40 * R_B)}$$
$$\mathbf{2.25 = E_B + (40 * .001)}$$
$$\mathbf{2.25 = E_B + (.04)}$$
$$\mathbf{2.21 = E_B}$$

When charged by the 40A charger, the ideal battery sees 2.21 volts/cell. At this voltage the ideal battery is able to accept less current than it would at 2.23 volts/cell. In other words it will take longer to recharge the battery at 2.21 volts/cell than it would at 2.23 volts/cell.

In other words, although doubling charging current reduces charging time, it cannot cut charging time in half because the battery's resistance converts a portion of the additional charging current into waste heat.

In fact, this model understates the problem of resistance losses, because it does not include the significant resistance of cables that connect the charger to the battery. The comparison shows that in order to fully exploit the current capacity of both the 20A and 40A chargers, charging voltage must be elevated such that higher charging voltage offsets resistance losses both in the battery and in charging cables external to the battery. This elevated voltage is known as "boost" charging.

Let us assume that the charger's voltage has in fact been increased to a "boost" voltage to enable faster charging. As the battery's state of charge increases during the course of charging the ideal battery accepts decreasing current. As current diminishes less voltage is lost to heat in the battery's internal resistance. This exposes the ideal battery to increasing voltage from the constant voltage charging source[4]. If not corrected, this excess voltage would overcharge and damage the ideal battery. To avoid this problem, charging voltage must be reduced as state of charge increases. Although this reduction could be achieved in several steps as current acceptance drops, it is typically achieved in single step to a lower voltage charging value called "float" that allows the battery to accept just enough current after becoming charged to offset its self-discharge rate.

Charging a battery at maximum speed and with maximum safety means that the transition from boost charge voltage to float charge voltage must occur at the correct time. The correct time is the point at which the battery achieves near full charge, but before damaging overcharge occurs.

[4] The term constant voltage charging means that the charger's DC voltage is maintained at a fixed value. In this example the voltage presented to the ideal battery varies not because the charger's DC voltage is varying, but because battery resistance is converting some of the charger's voltage into heat.