Introductory Note: *Methods of charging lead acid batteries will be explored at a very fundamental level. Many manufacturers make a wide range of battery chargers that work just fine with a particular type of battery, when used in a specific application. There are few chargers, if any, that work very well with all types of lead acid batteries in all types of applications. This should come as no surprise. If something sounds too good to be true, then it probably is. The ultimate question is: How good is good enough?*

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What happens to a battery when it is charged and discharged?

The chemical reactions on discharge convert lead, lead oxides, and acid into free electrons (good stuff), water (also good stuff), and lead sulfates (bad stuff). The chemical reactions on recharge reverse the process. The tricky part is to recharge the battery in such a manner so that the sulfates are eliminated by recombining with water to re-form into acid without loosing the hydrogen and oxygen gasses that make up the water. Oxygen and hydrogen gas will be released at recharge voltages between 13.8 V (2.30 volts per cell) and 14.2 V (2.37 vpc). You will see later that virtually all battery chargers have output voltages during some portion of the charge algorithm that are higher than the gassing voltage. Battery construction plays a very large part in determining what happens to the oxygen and hydrogen gas after it is released as a by-product of the recharge chemical reaction.

What is a charge algorithm?

The battery charger controls the voltage that is applied to the battery, the amount of charge current that is supplied to the battery, and depending on the level of sophistication in the charger technology, the timing associated with what may be multiple voltage and current levels. The following paragraphs provide an overview with some significant detail of the different charging modes, or stages that may be included in a charging algorithm. Basically, a charge algorithm is a collection of all of the software controls over electrical parameters and timing that are applied sequentially to the charging system hardware for the express purpose of recharging a discharged battery. Stated a little more directly, the charging algorithm is what controls the battery charger behavior as measured at its electrical output terminals.

Battery Charging Algorithm Fundamentals:

There are 4 distinct charging modes, or stages, within a battery charging cycle. Not all of these modes are essential in every battery application. The software that controls the charge cycle modes is often referred to as an algorithm.

The General 4 Step Charging graph shows the 4 distinct charging stages or modes that will be described in detail later. The alpha indicators on the axes indicate general values for time, charging voltage, or charging current.

GENERAL 4 STEP CHARGING ALGORITHM

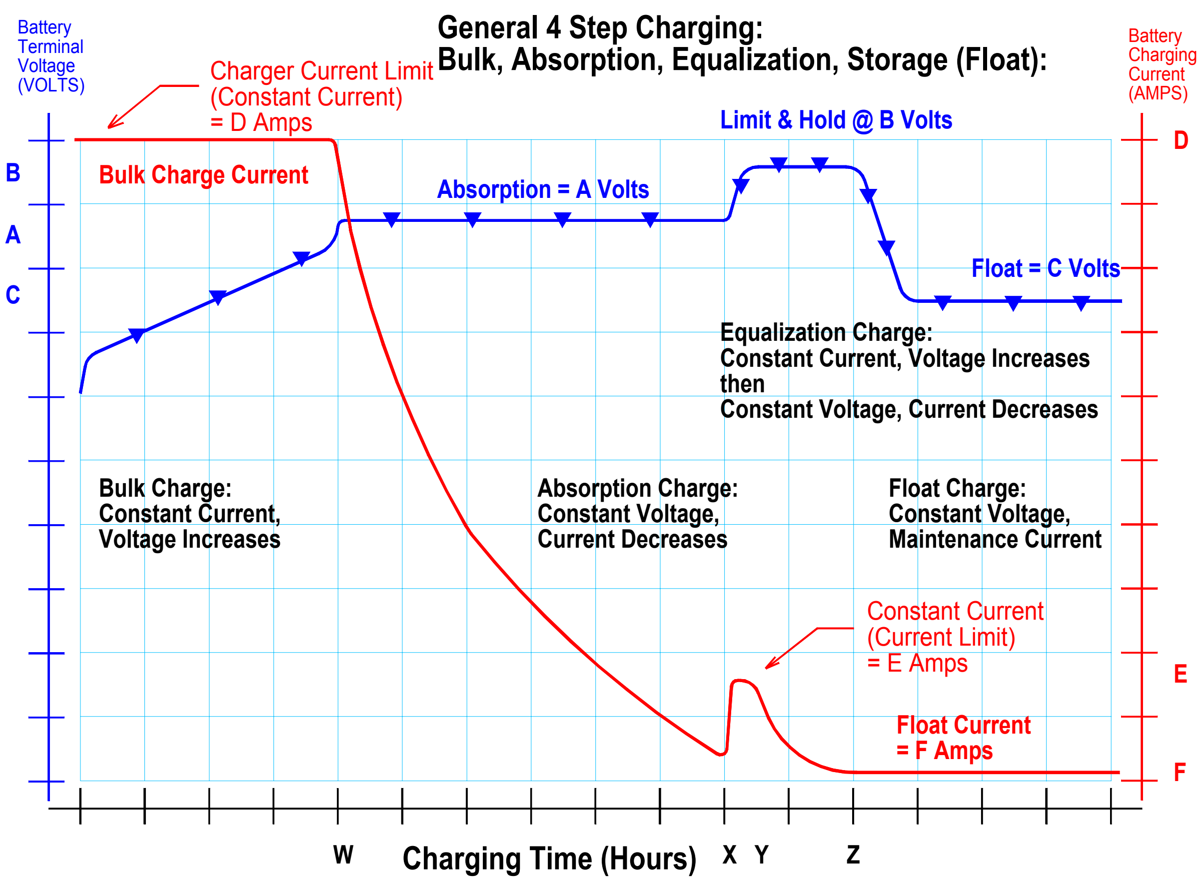

Figure 1 General 4 Step Charging Algorithm

For the voltages: “A” is the voltage value held constant by the charger during the Absorption stage. “B” is the voltage value held constant by the charger during the Equalization stage. “C” is the voltage value held constant by the charger during the Storage or Float stage.

For the currents: “D” is the regulated current limit or the current value held constant by the charger during the Bulk Charge stage. “E” is the regulated current limit or the current value held constant by the charger during the Equalization stage. “F” is the maintenance current value provided by the charger during the Storage of Float stage.

For timing: “W” is the elapsed time for the Bulk Charge stage and is the starting time for the Absorption stage. “X” is the total elapsed time for both the Bulk Charge and Absorption stages. The duration of the Absorption stage is numerically equal to (X – W). “Y” is the total elapsed time from the start to the end of the current limit phase of the equalization stage. “Z” is the total elapsed time from the start to the beginning of the Storage or Float, Maintenance stage. The duration of the Storage or Float, Maintenance stage is indefinite. The duration of the Equalization stage is numerically equal to (Z-W-X).

The charger will remain in float as long as power is applied to the charger, or until some monitored circumstance occurs which resets the charge cycle, or until power is removed from the charger. A typical monitored circumstance that would trigger a charger reset would be if the battery voltage dropped below a certain value. This would indicate that a parasitic load is attached to the battery while it is being charged and that the amplitude of the parasitic load current is greater than the current being supplied by the charger. In that case, the battery is being discharged even while the charger is attempting to maintain its charge level. This circumstance is not at uncommon in industrial applications.

Virtually every battery manufacturer has developed different charging algorithms to optimize the recharge characteristics of a given style of battery in a given application. Sometimes the differences between these charging algorithms seems to be fairly insignificant, but depending upon the battery application, even seemingly slight differences in the charging algorithm can have a significant impact on the cycle life of the battery.

GENERAL 3 STEP CHARGING ALGORITHM

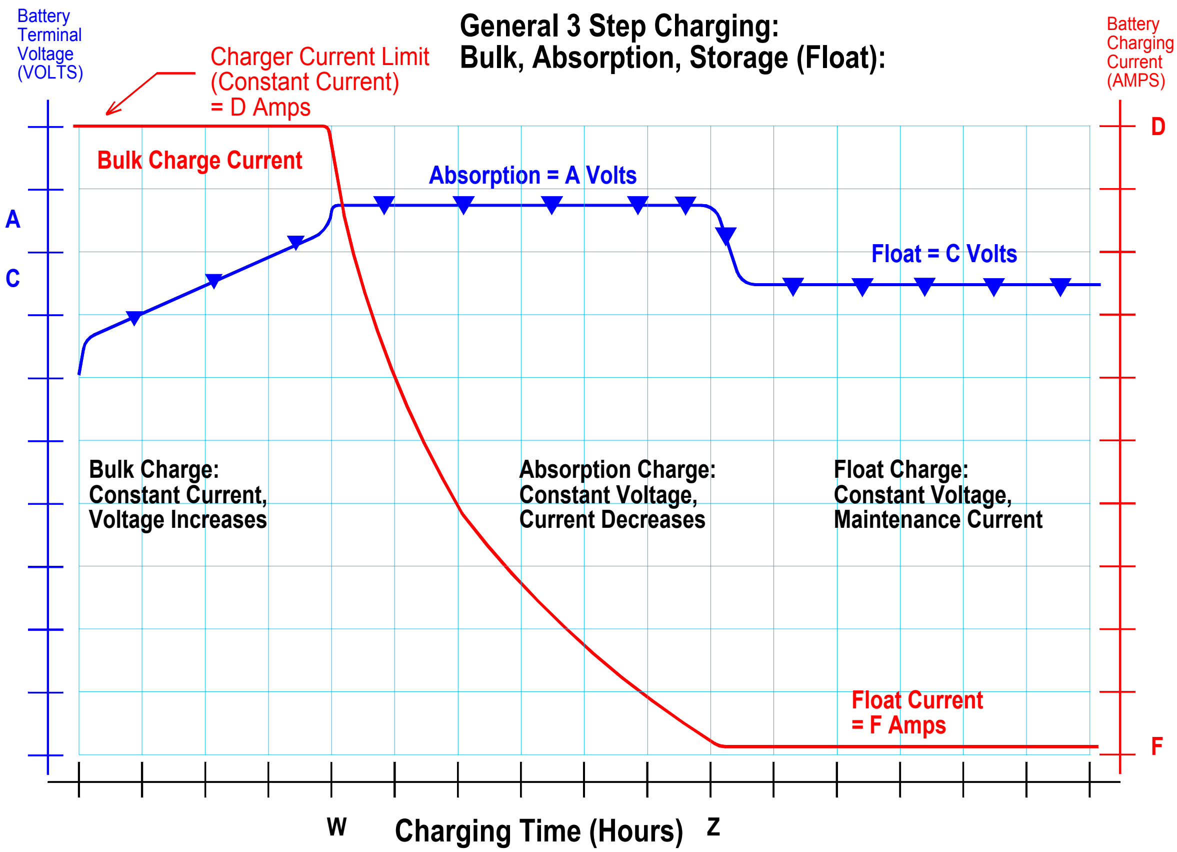

Figure 2 General 3 Step Charging Algorithm

The General 3 Step Charging graph above shows the 3 charging stages. The descriptions are identical to the General 4 Step Charging Algorithm, except that there is no equalization charge stage. The alpha indicators on the axes indicate general values for time, charging voltage, or charging current.

For the voltages: "A" is the voltage value held constant by the charger during the Absorption stage. "C" is the voltage value held constant by the charger during the Storage or Float stage.
For the currents: "D" is the regulated current limit or the current value held constant by the charger during the Bulk Charge stage. "F" is the maintenance current value provided by the charger during the Storage or Float, Maintenance stage.

For timing: "W" is the elapsed time for the Bulk Charge stage and is the starting time for the Absorption stage. "Z" is the total elapsed time for both the Bulk Charge and Absorption stages. The duration of the Absorption stage is numerically equal to (Z – W).

"Z" is the total elapsed time from the start to the beginning of the Storage or Float, Maintenance stage. The duration of the Storage or Float stage is indefinite

ADAPTIVE 4 STEP AGM CHARGING ALGORITHM:

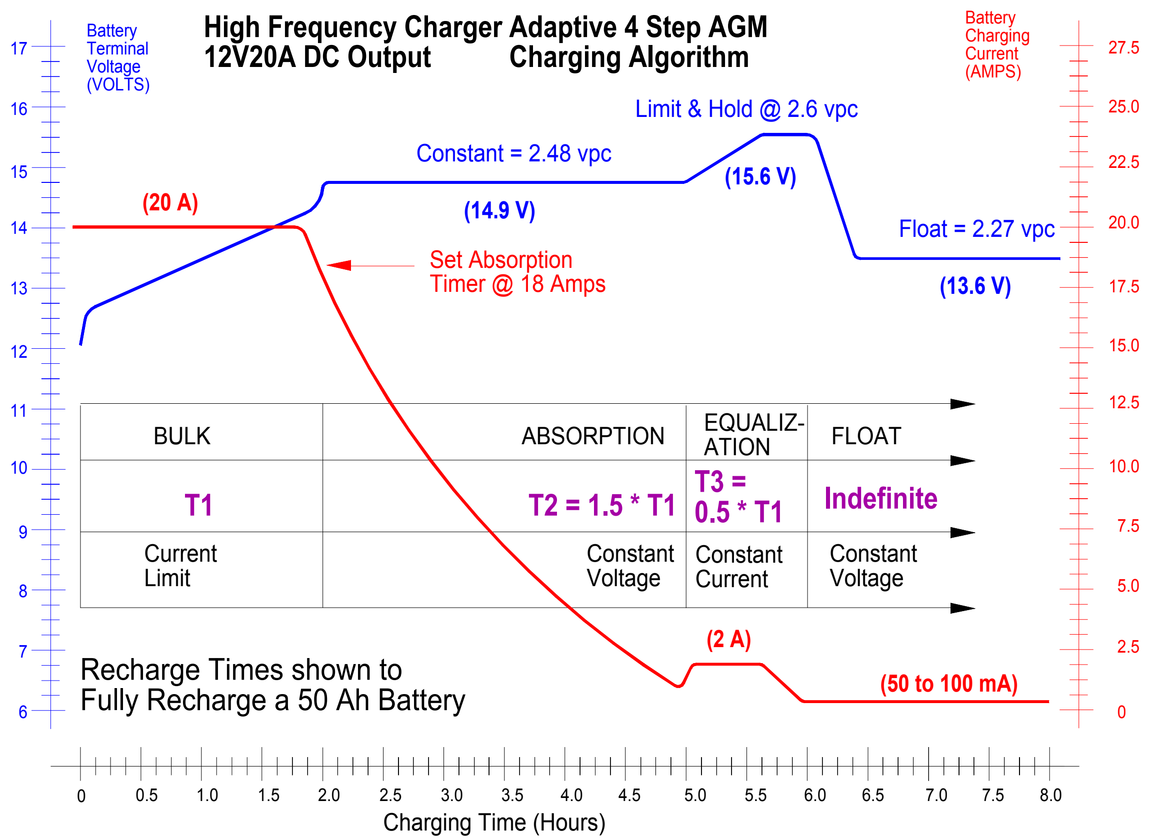

Figure 3 Adaptive 4 Step AGM Charging Algorithm

For illustration purposes, each time interval corresponding to each charging mode will be highlighted on the above graph immediately preceding the description of the charging mode.

The previous graph shows voltage and charge current time profile for the most sophisticated charging algorithm available in Deltran chargers. This charging profile was developed by Deltran engineers in conjunction with manufacturers of Sealed, AGM (Absorbed Glass Matte), Lead Acid batteries. This particular algorithm, the Adaptive 4 Step AGM Charging Algorithm is only available on the higher-powered Battery Tender® products: the 300 and 600-Watt SuperSmart® High Frequency (Golf Cart style) chargers, and the High Powered, DVD and DVS dual and single output portable chargers.

BULK CHARGE MODE:
Constant Current, Increasing Battery Voltage

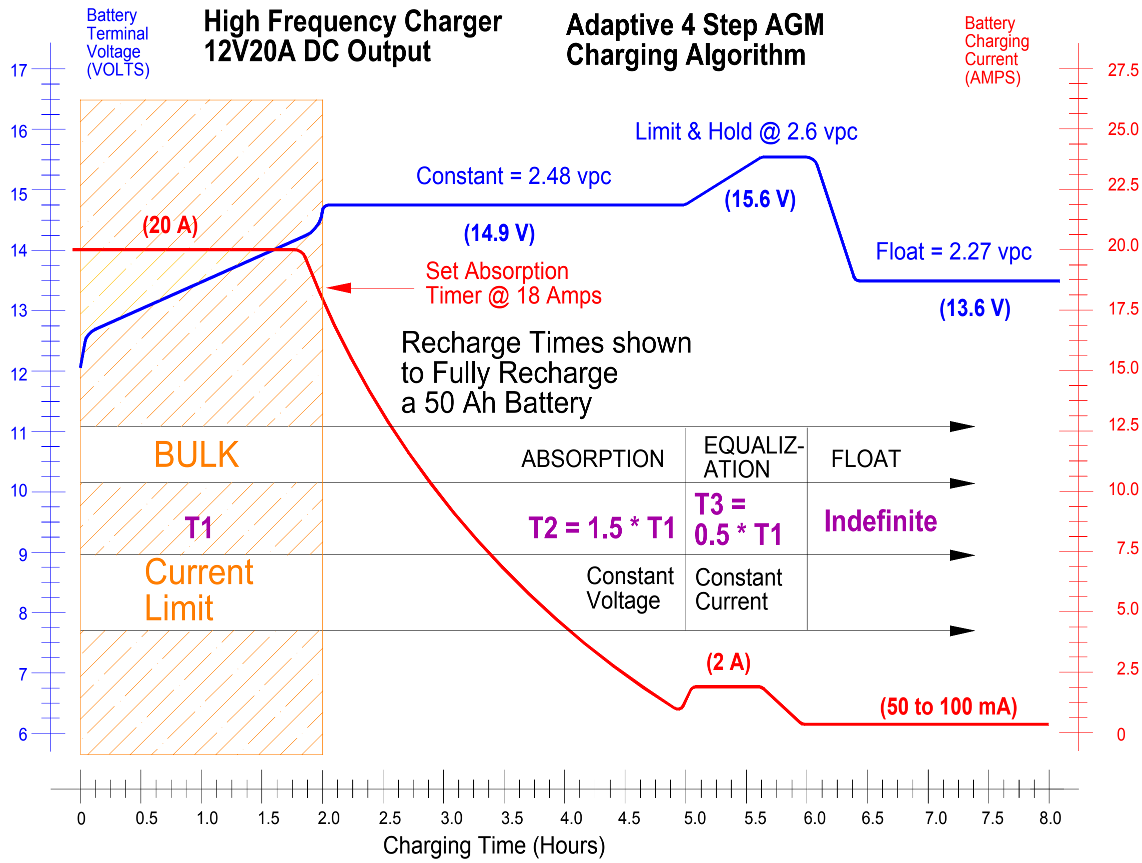

Figure 4 BULK Charge Mode

STAGE 1) BULK CHARGE MODE: During this time, the battery is fully or partially discharged, in some state of charge less than 100%. On a 12 volt battery, the no load battery voltage is between 11.4 VDC, fully discharged, and 12.9-13.0VDC, fully charged. When the battery charger is connected to the battery and then turned on by plugging it into the 110 or 220VAC power source (wall socket), the charger will attempt to bring the battery voltage up to the level required to be in stage 2), the absorption charge mode. Sometimes this voltage level is called the "quick charge voltage". Typically, this voltage is in the 14.2 to 15.0VDC range. The battery voltage rises because the charging current that is provided by the battery charger is replenishing its internal charge capacity. **During bulk charge mode, the charger current is flat (constant) and the battery voltage is rising.**

ABSORPTION CHARGE MODE:

Constant Battery Voltage, Decreasing Charge Current

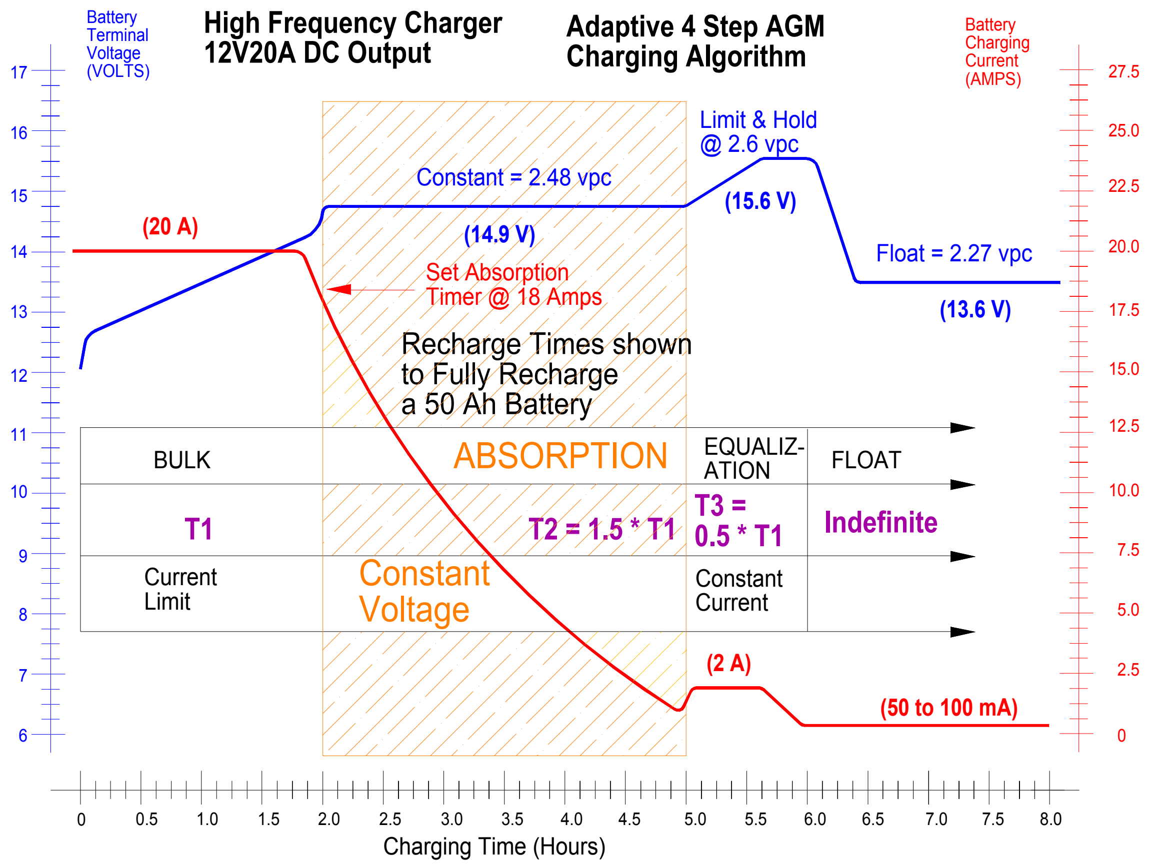

Figure 5 ABSORPTION Charge Mode

STAGE 2) ABSORPTION CHARGE MODE: At this time the battery is approximately 80% recharged. The charger will now attempt to hold its output voltage constant while the battery continues to absorb charge (draw charging current) from the charger. The rate at which the battery continues to absorb charge in this mode gradually slows down. The amplitude of the charger current is gradually decreasing. **During absorption charge mode, the charge current is falling and the battery voltage is flat (constant).**

The transition from absorption charge mode to the next stage is determined either by a timer, or by the charger sensing the value of charge current and then switching over when the charge current drops below a certain threshold. For example, the Battery Tender® Plus (part of a different product line) switches out of absorption mode when the charge current falls below 100 milliamps (or 0.1 amp) or when the absorption mode has lasted for 8 hours. With properly set timers or charge current switch thresholds, the battery should be charged to more than 95% at the end of absorption mode. Ideally it would be at 100%, but there are some practical limitations that usually prevent full recharge.

EQUALIZATION CHARGE MODE:
Constant Charge Current, Increasing Battery Voltage

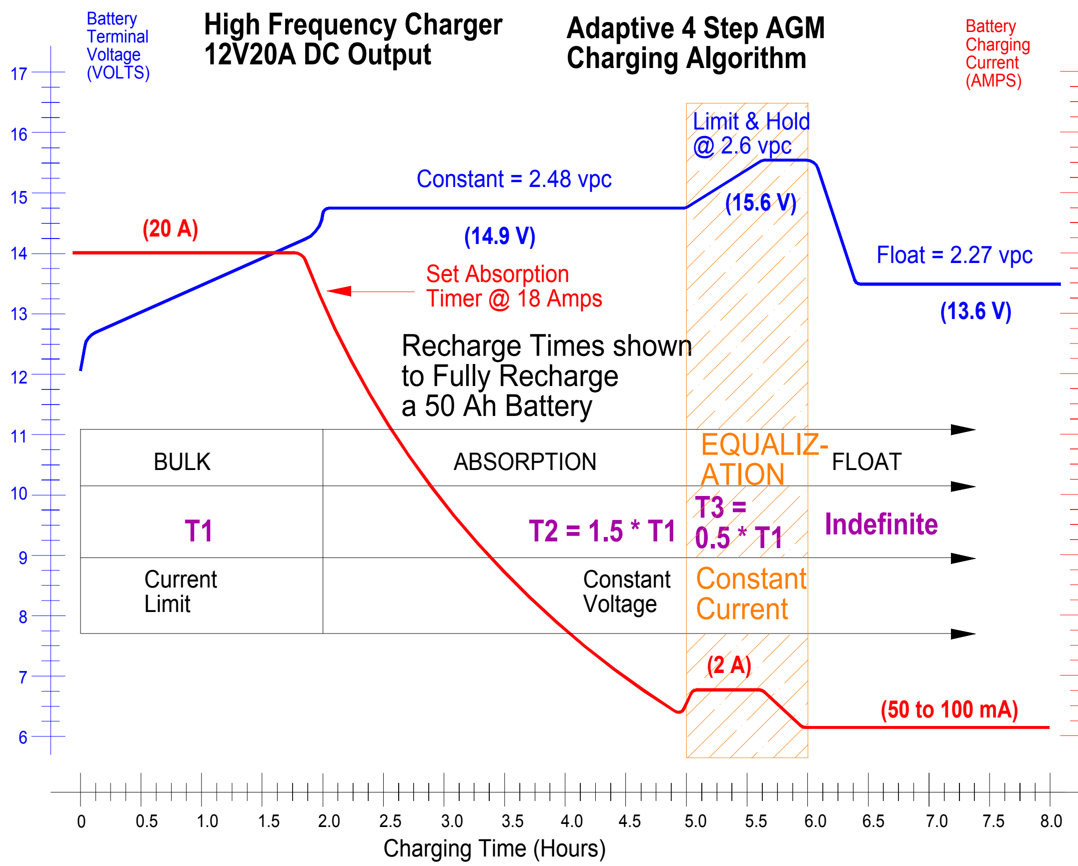

Figure 6 EQUALIZATION Charge Mode

STAGE 3) EQUALIZATION CHARGE MODE: ***The equalization charge mode is optional and usually only included at the request of a specific battery manufacturer.*** At this time the battery is approximately 95% recharged. To speed up the delivery of the last 5% of the recharge, one of two things usually happen.

1) The charger switches over to a true constant current mode where the value of the charge current is a small percentage, usually never more than 20%, and typically in the 5% to 10% range, of the numerical value of the battery's 10 or 20-hour capacity in amp-hours. Since the charger circuitry does not have the ability to directly sense the battery capacity, these relative percentages will only be true for a specific range of battery capacities. There is also a safety timer engaged and there is often a safety voltage limit, a "lid" or "ceiling" that performs an automatic shutoff or switch to stage 4) if the battery

voltage attempts to rise higher than the safety limit. In either case, the higher constant voltage, or the lower true constant current perform a similar recharge function. That is to safely replenish the last 5% of the battery's charge, in a minimum amount of time.

2) The charger voltage is set high, maybe 3 to 4 volts above the battery no load fully charged voltage with a safety timer. The battery then draws current until the timer shuts off. The reaction of the battery during this time is first to force the charger to deliver its maximum current. Then the amplitude of the charger current gradually decreases until the timer forces the charger to switch to the next charging mode. It's almost like repeating the bulk and absorption charge modes together in a compressed time frame, with different voltage limits.

FLOAT, MAINTENANCE CHARGE MODE:
Constant Battery Voltage, Minimal Charge Current

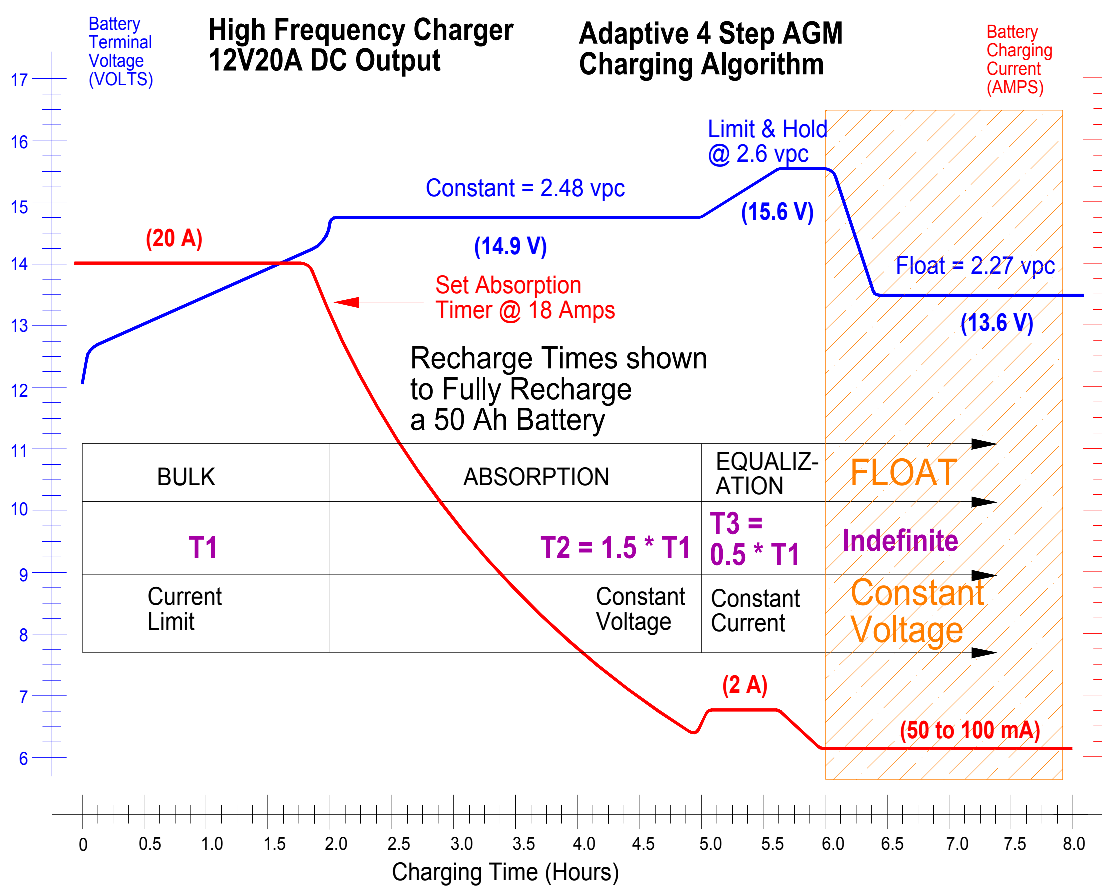

Figure 7 FLOAT, MAINTENANCE, or STORAGE Charge Mode

STAGE 4) FLOAT, STORAGE, OR MAINTENANCE CHARGE MODE: ***The float charge mode is also optional on many battery chargers. However, ALL Deltran chargers have a float, maintenance charge mode.*** Basically a couple of features can be implemented in a float charge mode. The first is to simply put the charger in a constant (flat) voltage mode. The magnitude of the voltage should be a few tenths of a volt above the no load, fully charged battery voltage, typically between 13.2 to 13.6 VDC. The second is to turn off the charger, and monitor the no load battery voltage. When the no load battery voltage drops below a present threshold, the charger comes on for a short period of time in a constant voltage mode. The numerical value of the voltage is usually somewhere between the typical float voltage and the manufacturer's recommended quick charge voltage. That was the constant voltage value used in the absorption charge mode, usually between 14.2 and 15.0 VDC. This second method is sometimes called "hysteresis charging" or "window charging".

Traditionally, the entire Battery Tender® product line has incorporated a constant voltage float charge mode. The 70W product line implements a somewhat unique combination of the two general methods just described. In float mode the charger output voltage is a constant, somewhere between 13.2 and 13.6 VDC, depending on the specific model number. Also, the charger continues to monitor the battery voltage. If the battery voltage drops below a threshold, usually set at between 12.0 and 12.5 VDC, the charger will reinitialize its charging cycle. The Battery Tender® response to low battery voltage is more effective than the traditional hysteresis charging method because it allows the battery to be fully recharged more quickly.

NOTE: Without some type of battery or charger malfunction, the only way that the battery voltage can go down below the charger output voltage is if the battery is connected to an external load that draws current from the battery. As the battery delivers current, its charge capacity decreases and its voltage drops. When the battery charger is connected to the battery while the battery is under load, and if the load current is large enough, then the charger current is diverted to the load.

As long as they are functioning properly, the Battery Tender® battery chargers can be left connected to the battery indefinitely.

NOTE: The obvious question is: "What happens if the charger is not functioning properly and it is left connected to a battery?" Batteries store a tremendous amount of energy due to their electrochemical composition. As that energy is transferred out of the battery into a load (discharging) and into the battery from a charger (charging), there are some risks involved. The basic chemical reaction occurs between the conductive lead grid, the various oxides and active materials, and the sulfuric acid, which is the electrolyte. Depending on the reaction rates, the sulfuric acid will decompose in to gaseous components. The biggest danger to a battery is water loss, ultimately resulting from the escape of hydrogen and oxygen gasses during recharge. The importance of charging voltage values applied to a battery, and the reason that several manufacturers recommend different charging voltages, is the effect that the charging voltage has on the acid decomposition into gas, or just simply "gassing". The more gas that is generated, the more water that is lost, the quicker the battery dries out, and ultimately wears out.

Now back to the original question. If a battery charger fails during continuous float / maintenance mode such that its output charging voltage is higher than the minimum gassing voltage of the battery, the battery will expel gas and dry out. The other danger is that any mixture of hydrogen and oxygen containing more than 4% hydrogen is potentially explosive. Therefore it is very important to periodically monitor the battery to make sure that there is not a problem. Also, the battery should be recharged in an open area with good ventilation, away from any sources of sparks or combustion, like water heaters and electrical motors.

Deltran Chargers: General Charging Algorithm Summary:

The Battery Tender® Junior implements 2 of the charge cycle stages, Bulk, and Float.
The Battery Tender® Plus implements 3 of the charge cycle stages, Bulk, Absorption, and Float.
Shop Chargers, 5 & 10 Bank units implement the same algorithm as the Battery Tender® Plus only at a higher current.
The International Battery Tender® both the single output unit and 4-Bank Battery Management System implement 3 of the charge cycle stages, Bulk, Absorption, and Float. (Exactly the same as the Battery Tender® Plus)
All 70W Battery Tender® product line models (Lightweight, On-Board, Power Tenders) implement 3 of the charge cycle stages, Bulk, Absorption, and Float.
The high power chargers, DVS, DVD, and SuperSmart® High Frequency (Golf Cart style) chargers implement either 3 or all 4 of the charge cycle stages. The Equalization charge mode is only used on specific models.