Understanding Battery Charging

Introduction

When using batteries for energy storage, whether an off-grid or grid-tie with back-up power, the renewable energy system used to charge the batteries and the metering systems to monitor performance must be properly configured for optimal performance. While there is a relatively large amount of information for programming the correct values in the battery charging systems, whether a charge controller or inverter/charge, with the advent of more sophisticated metering systems, e.g., the Pentametric, additional information is required.

Most batteries used in renewable energy systems use lead-acid chemistry, whether flooded or sealed. Therefore, the following discussions are for this basic technology, i.e., not lithium-ion or metal-hydride, given one must get the specific values for each battery type and manufacturer.

There is a lack of common terminology for concepts and operations regarding batteries, i.e., the battery manufacturer uses a different terminology than the renewable energy battery charger manufacturer or the battery meter manufacturer. The following are some terms and definitions that are used with in this document and can be used to interpret descriptions in various manufacturer documents.

Terms and Definitions

absorb charge: The second phase during the battery recharging cycle where the voltage is fixed at the bulk/absorb limit and the charging current decreases to an arbitrarily low limit.

ampere-hour (amp-hour; AH): A measure of current over time, used to measure battery capacity and state of charge.

anode: The positive electrode within a battery cell that during charging undergoes the chemical process of oxidation.

battery: a device that stores energy.

NOTE 1 Electrical batteries consist of a liquid, paste, or solid electrolyte, a positive electrode and a negative electrode to convert chemical energy into electrical energy, rechargeable batteries also convert electrical energy into chemical energy.

NOTE 2 The electrolyte is an ionic conductor; one of the electrodes will react, producing electrons, while the other will accept electrons. When the electrodes are connected to a device to be powered, called a load, an electrical current flows.

NOTE 3 Batteries in which the chemicals can be reconstituted by passing an electric current through them in the direction opposite that of normal cell operation are called secondary cells, rechargeable cells, storage cells, or accumulators.

NOTE 4 The electrolyte is a dilute solution of sulfuric acid, the negative electrode consists of lead, and the positive electrode of lead dioxide. In operation, the negative lead electrode dissociates into free electrons and positive lead ions. The electrons travel through the external electric circuit, and the positive lead ions combine with the sulfate ions in the electrolyte to form lead sulfate. When the electrons reenter the cell at the positive lead-dioxide electrode, another chemical reaction occurs. The lead dioxide combines with the hydrogen ions in the electrolyte and with the returning electrons to form water, releasing lead ions in the electrolyte to form additional lead sulfate. A lead-acid storage cell runs down as the sulfuric acid gradually is converted into water and the electrodes are converted into lead sulfate. When the cell is being recharged, the chemical reactions described above are reversed until the chemicals have been restored to their original condition.

battery capacity: The total maximum charge, expressed in ampere-hours that can be withdrawn from battery under a specific set of operating conditions including discharge rate temperature, state of charge, age, and cutoff voltage.

battery life: The time during which a battery is capable of operating above a specified capacity, typically end-of-life occurs when a fully charged cell can deliver only 80% of the rated capacity

bulk charge: The first phase during the battery recharging cycle when charging current is only constrained by the limits of the charging system and the voltage rises from the discharged battery voltage to the bulk/absorb voltage limit.

cathode: The negative electrode within a battery cell that during charging undergoes the chemical process of reduction.

charge controller: A component of renewable energy systems that controls the charging of the battery to protect the batteries from overcharge and over-discharge.

charge rate: The current applied to a battery to restore its available capacity, specified in relation to total battery capacity.

NOTE A C/20 charge rate is 1/20th of the total battery capacity measured in amp-hours, e.g., if the capacity were 100 amp-hours, a C/20 would be 5 amps taking at least 20 hours of bulk charging to recharge.

deep-cycle battery: A battery designed to regularly discharge 50 to 80 percent of the battery capacity before requiring recharging, with minimal impact on battery life.

depth-of-discharge (DOD): The ampere-hours removed from a fully charged battery, expressed as a percentage of rated capacity.

discharge rate: The current removed from a battery measured in amps.

equalization: When required, the process of restoring all cells in a lead-acid battery to an equal state-of-charge, typically for a duration longer than normal recharging.

float charge: A trickle charge to keep a battery fully charged at a safe voltage level with minimal gassing.

NOTE The float voltage is slightly higher than the intrinsic open-circuit voltage of a fully charged battery.

gassing: When a battery is overcharged, the production of oxygen gas at the cathode and when severely overcharged of hydrogen gas at the anode from electrolysis of water in the electrolyte.

intrinsic battery voltage: The open circuit voltage of a fully charged battery after the gassing within the electrolyte from the charging operation has stopped and the resulting polarization of the battery plates has dissipated.

NOTE Sometimes called the battery rest voltage.

open circuit voltage: The voltage across the battery terminals with no load or charger attached.

self-discharge: The tendency of all batteries to lose energy to internal chemical reactions within the cell.

state-of-charge (SOC): The ampere-hours remaining in a battery, expressed as a percentage of rated capacity.

sulfation: The formation of lead-sulfate crystals on the plates of a lead-acid battery, which decreases battery capacity by impeding the opportunity for chemical reaction within a cell, typically caused by leaving the battery in a discharged state for long periods of time.

NOTE An equalization is often performed to mitigate sulfation.

temperature compensation coefficient: The value that the charging voltage must be changed as a function of the difference in temperature between the standard test condition and the battery.

NOTE 1 The temperature compensation coefficient is usually stated as V/ºC-cell (volts per ºC for each cell).

NOTE 2 When calculating the compensation voltage, the ΔT is positive for colder battery temperatures and negative for hotter battery temperatures, e.g., one adds the ΔV when cold and subtracts when hot.

usable battery capacity: The number of amp-hours that are available for use on an ongoing basis.

NOTE The usable battery capacity at a given discharge rate is typically 50% of the maximum battery capacity at that discharge rate. The usable battery capacity is measured from the intrinsic battery voltage level to the minimum recommended battery voltage level, while the maximum capacity is measured from the intrinsic battery voltage level to the minimum allowed battery voltage.

Operations

All renewable energy systems with batteries, will regularly charge and discharge the batteries. Given the cost of batteries and the limited lifetime of the batteries (relative to the other system components), one will want to maximize the performance of the batteries and extend the lifetime as long as possible. The two major components of extending the lifetime of batteries is to limit the amount of discharge and properly recharge.

The two ways of controlling the amount of discharge are to:

1. Properly size the battery bank, such that the amount of discharge between recharge periods is no more than the recommended maximum discharge of the battery, typically 50%. Thus, one needs to consider both the loads and capacity of the charging source. For example, if one is using a photovoltaic source and one has 6 hours/day of sunlight, then the ideal usable battery capacity would be the number of bulk charging hours available, (e.g., 6 hours) minus the minimum absorb time. However, since one must still consider loads and another charging source, e.g., a generator, may be available, the battery bank size is generally more in keeping with the load demand for the expected use period.
2. Install a metering system so that a warning signal is available when the batteries approach the maximum recommended safe discharge level. Many inverter/chargers and charge controllers have the capability to automatically start a generator or initiate an alarm. Meters, such as the Pentametric, have even more sophisticated sensors, allowing preventive actions, prior to reaching the discharged state.

Batteries are usually characterized using essentially unconstrained recharging sources, i.e., no limitations on current availability. In general, renewable energy systems have current charging limitations, whether because of component capability or changing resource availability, e.g., a cloudy day for a photovoltaic (PV) system. Thus, monitoring the state-of-charge (SOC) of the batteries becomes very important, in order to maximize the lifetime of the batteries.

In order to properly recharge the batteries (see figure 1), one must use the battery recommended settings. Sometimes this is not always possible, e.g., the bulk/absorb timer on many charge controllers does not allow the batteries to fully meet the desired recharge time during a short winter day. If batteries cannot be regularly charged for the full absorb cycle, then a quarterly equalization charge may be appropriate, assuming the battery manufacturer allows equalization charging. The following uses a Concorde SunXtender battery for illustration, noting different batteries and manufacturers will have different values. The examples use a nominal 2-volt battery, for higher nominal systems, just use the appropriate multiplier, e.g., for a nominal 48 V system multiply by 24.

The battery manufacturer often specifies a recharge voltage and a time for a 50% discharged battery. The charge controller (or inverter/charger) manufacturer specifies a bulk and absorb voltage. Once the recharge cycle is initiated, e.g., when the charge controller turns on sometime after sunrise, the system provides the maximum available current at the battery voltage until the battery voltage reaches the bulk/absorb voltage setting. For example, if the battery is 30% discharged and the bulk current is limited to C/10, then the bulk time will be 3 hours. The absorb timer then initiates the absorb cycle for the duration of the timer, which may be fixed or programmable. During this time, the current will gradually decline to a negligible value.

After the absorb timer times out, the controller supplies current at the battery voltage. The battery voltage will decay from the absorb voltage to the float voltage over a period of time, typically 2 to 4 hours with no load; with load the system will settle at the float voltage much sooner. After this time, the controller will maintain the float voltage (which is slightly higher than the intrinsic voltage), unless the load is greater than the generating resource. Then the battery will start to discharge, the amount determined by the loads and the generating resource. When the battery is discharging, the controller output voltage will track the battery voltage, maximizing the available current at that voltage.

Typical settings for a 2-V battery would be:

A. Intrinsic voltage: 2.167 V.
B. Float voltage: 2.2 V.
C. Recharge/bulk/absorb voltage: 2.4 V
D. Absorb time: 4 hours
E. Minimum recommended battery voltage: 2.0 V
F. Minimum allowed battery voltage: 1.75 V
G. Minimum charge rate: C/20
H. Maximum charge rate: 2C
I. Temperature compensation coefficient: 0.00375V/ºC-cell referenced to 25 ºC
J. Temperature compensation range: 0 – 40 ºC (32 – 104 ºF)

Chemical reactions, such as charging a battery, are affected by temperature, i.e., increasing the temperature increases the reaction rate, decreasing the temperature decreases the reaction rate. Therefore, for battery temperatures colder than the standard test condition (25 ºC), the charging voltage should be increased by the temperature compensation coefficient value (i.e., the number of cells times the coefficient times the difference in temperature from standard). Similarly, the voltage should be decreased for higher than standard battery temperatures. All charging voltages should be temperature compensated; this is usually accomplished by connecting a battery temperature sensor mounted on the battery (below the electrolyte level) to the charge controller.

Thus, for a PV charge controller, after sunrise and the minimum on current is reached, the charge controller would start the recharge cycle. First, the charge controller would supply maximum available current at the battery voltage until the bulk/absorb (2.4 V) voltage is reached, then stay at 2.4 V for 4 hours. Over the next 2 to 4 hours (no load), the battery voltage will decrease to float level, which will be maintained until the battery has started to discharge or the next recharge cycle begins.

Since there is so much variability in both load and recharging values, a battery monitoring system is strongly recommended. The battery monitoring system should measure both battery voltage and either SOC or DOD. In order to initiate alarms at the proper levels, the battery monitoring system needs to have such values as the upper battery voltage limit, e.g., some value above the bulk/absorb value, the lower battery voltage limit, e.g., the 50% discharge value of 2 V, and usually the float voltage, e.g., 2.2 V.

In order to measure the SOC or DOD, the battery capacity must be entered. Since the battery capacity is a function of the discharge rate, one must know (at least estimate) the discharge rate. For most systems that have properly sized the battery bank relative to usage and generation capability, the discharge rate will be something in the order of 16 to 20 hours, given the battery will start to discharge immediately after the daily recharge cycle. If one only uses a generator, then the discharge time will be the interval between operating the generator, e.g., could be less frequent than once per day.

Given a discharge rate, the usable battery capacity is typically 50% of the stated battery capacity (see Figure 2). The stated battery capacity is usually listed in the manufacturer's documentation as the 100% discharge value; however, in order to obtain the maximum lifetime of the battery, one should never 100% discharge the battery. The usable battery capacity is what one would typically enter into a metering system that monitors SOC or DOD; that way one would not normally over-discharge and potentially damage the battery, e.g., reduce the expected lifetime.

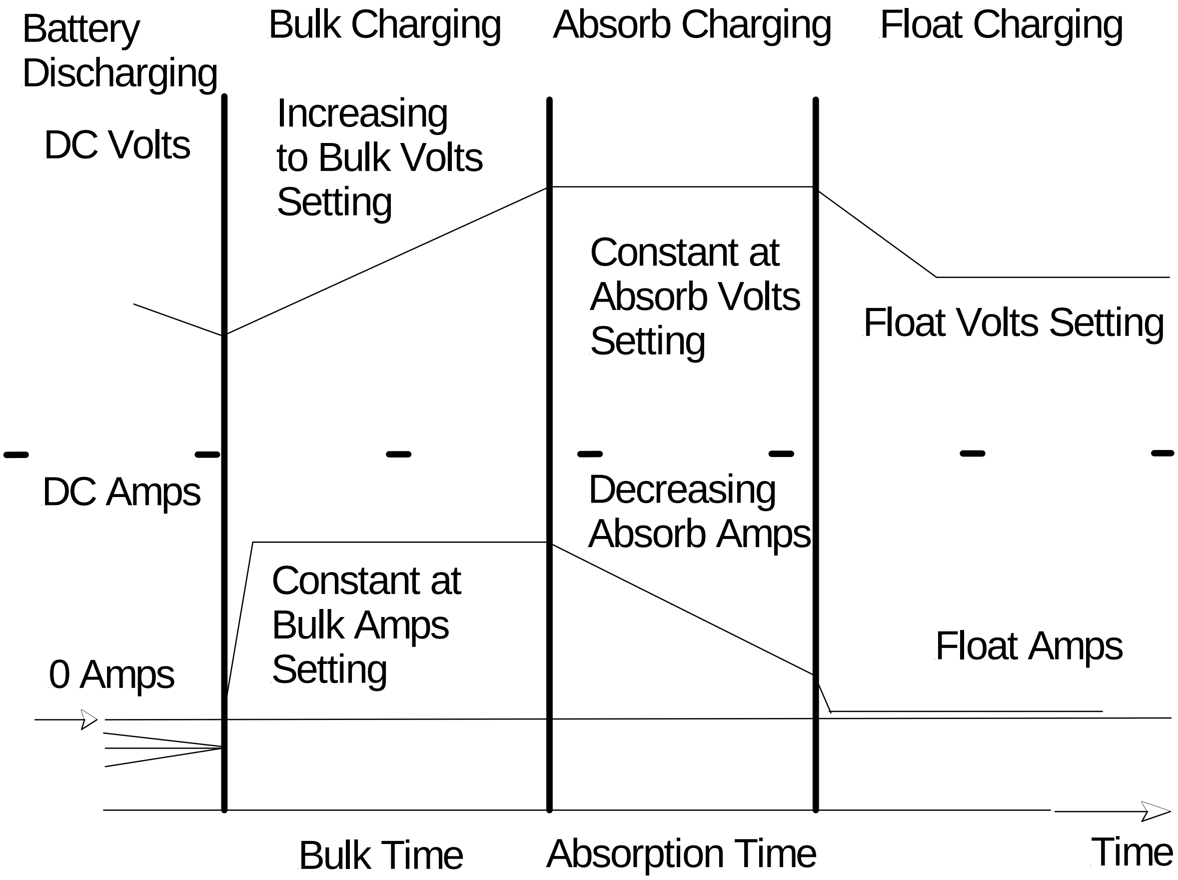

Figure 1 Battery Charging Stages

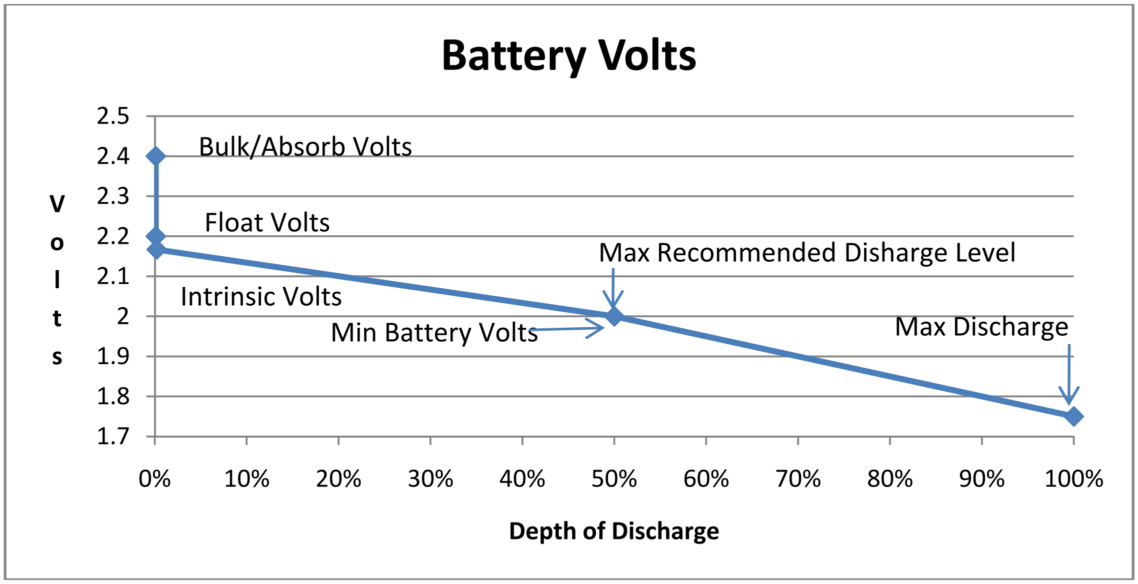

Figure 2 Battery Discharging
(Battery Voltage as function of DOD)