Tuesday, 10/17/23

Stand-Alone PV with Inverter but without Batteries

1) This configuration is sometimes used for agricultural and similar applications

For example, using a water pump with an AC motor.

AC motors <u>can</u> cost less than DC motors, but the cost of the inverter must be considered.

2) Another application could be to power an AC outlet for use only when there is sufficient sunshine.

A PV charging station for phones, laptops, etc. could include this power option:

Full Stand-Alone Systems: PV + Batteries + Inverter

1) Introduction

This PV system has multiple components:

(1) PV array

(2) MPPT

(3) Charge controller

(4) Rechargeable batteries

(5) Inverter

(6) Loads

(7) Possibly secondary electricity producing systems (windmill, gas/diesel generator, etc.)

2) Rechargeable Batteries

The standard rechargeable battery technology is lead-acid (Pb-acid).

New rechargeable battery technologies include NiCd, NiMH (nickel metal hydride), and Li-ion (lithium ion).

a. Battery Efficiency

There are three primary metrics for measuring battery efficiency:

(1) Columbic or Charge Efficiency

The percent of charge put into the battery that may be retrieved from the battery.

For lead-acid batteries, 85% is typical.

(2) Voltage Efficiency

How close the discharging voltage is to the charging voltage.

For lead-acid batteries, 90% is typical.

(3) Energy Efficiency

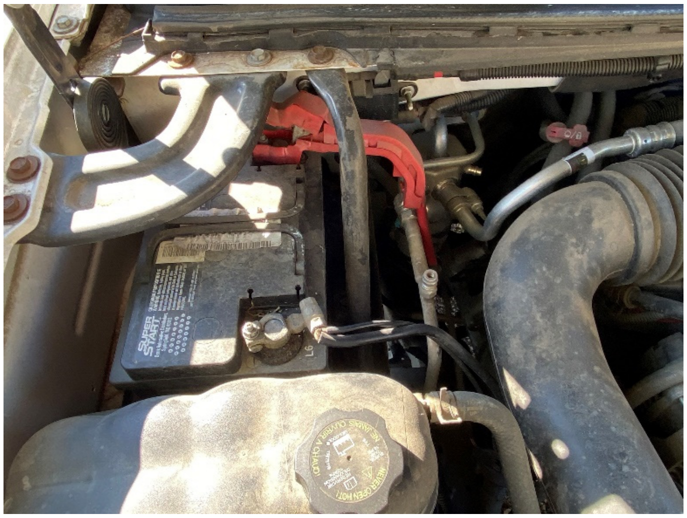
The product of charge efficiency and voltage efficiency.

For lead-acid batteries, 75% is typical.

With battery storage, there is significant loss in the energy storage/retrieval process.

b. Lead-Acid Batteries

12 V lead-acid car batteries are designed for short bursts of high current to start the engine.



They are not designed to be substantially discharged.

For PV applications, the batteries need to be cycled many times without damage.

These are called Deep-Cycle batteries.

They must have a low self-discharged rate (~ 3%/mo is typical)

They must have high efficiency.

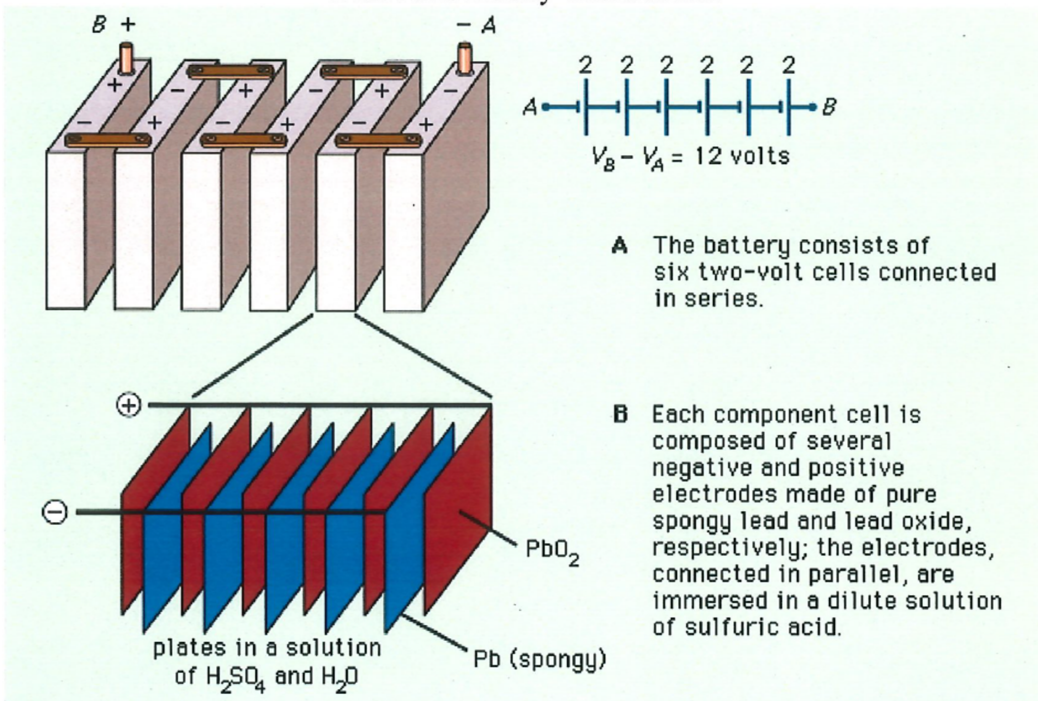
Example deep cycle Pb-acid battery:

https://www.renogy.com/deep-cycle-agm-battery-12-volt-100ah/?Rng_ads=f7608be5e93fa6bb&msclkid=d2980ee91c1713b072756bc45f22bf2a

(1) Lead-Acid Battery Structure

A 12 V lead acid battery is made up of six 2 V cells connected in series:

Lead Acid Battery Construction



http://www.kollewin.com/blog/lead-acid-batteries/

Each 2 V cell is composed of interleaved positive and negative electrodes.

(2) When the battery is discharging

When the battery is fully charged:

Pos. electrode → lead oxide (PbO_2)

Neg electrode → spongy lead (Pb)

Electrolyte → dilute sulfuric acid ($H_2SO_4 + H_2O$)

When the battery is discharging:

Both electrodes → become lead sulfate ($PbSO_4$)

Electrolyte → becomes mostly water

Negative plate reaction:

$$Pb(s) + HSO_4^-(aq) \rightarrow PbSO_4(s) + H^+(aq) + 2e^-$$

Positive plate reaction:

$$PbO_2(s) + HSO_4^-(aq) + 3H^+(aq) + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l)$$

Conduction electrons go from the negative plate, through the external circuit, to the positive plate.

When discharged, the electrolyte solution is mostly water.

The discharged battery is subject to freezing in low temperatures.

(3) When the battery is charging

The negative plate becomes Pb:

$$PbSO_4(s) + H^+(aq) + 2e^- \rightarrow Pb(s) + HSO_4^-(aq)$$

The positive plate becomes PbO_2

$$PbSO_4(s) + 2H_2O(l) \rightarrow PbO_2(s) + HSO_4^-(aq) + 3H^+(aq) + 2e^-$$

The electrolyte becomes about 35% sulfuric acid (H_2SO_4) and about 65% H_2O.

During charging, the externally applied voltage forcibly removes electrons from the positive plate and forcibly introduces them to the negative plate.

Overcharging (with high voltage) generates oxygen and hydrogen gas by electrolysis of the water.

NOTE: $O_2(g) + H_2(g)$ + energy → water <violently>. So, if the Pb-acid battery enters into electrolysis, this is potentially dangerous!

A mostly discharged Pb-acid battery has a freezing temperature near 0°C.

A fully charged Pb-acid has a freezing temperature of about -68.9°C.

Therefore, it is not good to allow a Pb-acid battery to approach fully discharged in cold conditions.

c. Lead-Acid Battery Structures

There are two primary Pb-acid battery structures.

(1) Flooded Pb-acid battery

Also called "Wet Pb-acid battery."

The liquid electrolyte solution must be regularly topped off with distilled water.

H_2 gas is given off by this battery structure.

Therefore, adequate ventilation is necessary for safe operation.

(2) Sealed Pb-acid battery

Also called "Valve-regulated Pb-acid battery."

The battery case is sealed with a gas-tight valve that only opens in an over-pressure situation.

Since the battery is sealed, O_2(g) and H_2(g) recombine internally for form H_2O:

Therefore, topping off with additional water is unnecessary.

As a result, this structure requires less maintenance than the flooded structure.

However, it requires a strict charging regime to ensure that an overpressure condition does not occur due to overcharging.

An alternative sealed battery structure uses a gel electrolyte.

d. PV Deep Cycle Pb-Acid Batteries

These typically use special tubular plate electrodes.

If it is discharged no more than 30%, it will survive several thousand charge-discharge cycles.

If it is discharged by 80%, it will survive about 1000 cycles.

e. Battery Capacity

Battery capacity is typically measured in Ampere Hours (Ah).

This metric is the product of current supplied and the time it flows.

Example: 12 V 200 Ah battery → 20 A at 12 V for 10 hrs

Energy stored = 200 x 12 = 2.4 kWh

Note: an Ah battery rating is <u>only</u> specified for a particular discharge time:

You get more energy out of a battery when discharging it as <u>slow</u> as possible

→ A 10 hr rate is a typical discharge rate

→ A 100 hr rate is often more appropriate for PV applications

Example: 3 nights + 2 cloudy days

Rated capacity normally applies to 20^{o}C.

Rated capacity reduces by about 1% for every ^{o}C drop in temperature.

f. Considerations for Charging Lead-Acid Batteries

The battery voltage varies while charging according to how charged the battery is:

~ Fully Discharged: $V_{bat} \sim 12$ V

Fully charged: $V_{bat} > 14$ V

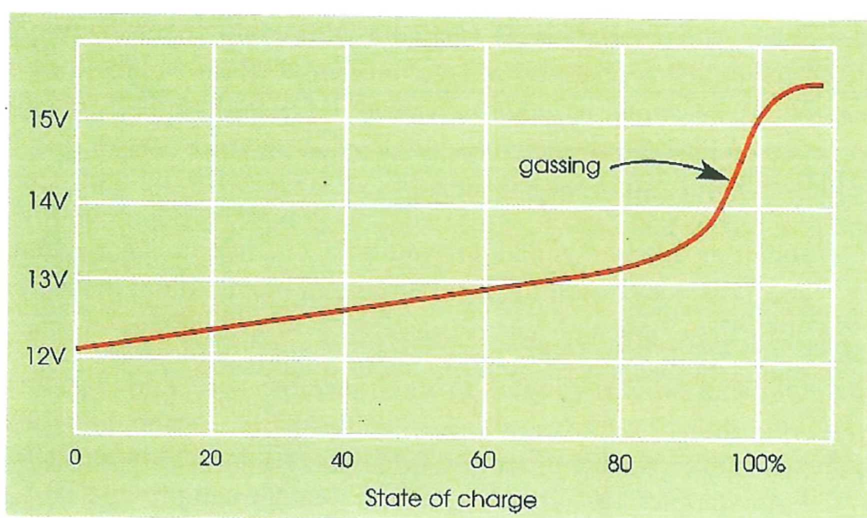


Figure 5.3 Typical charging characteristic of a 12 V lead–acid battery.

The charge controller monitors V_{bat} to regulate charging current flow into the battery.

The flooded battery and the sealed battery have different charging requirements.

(1) Charging Considerations Unique to the Flooded Battery

When the battery is nearly fully charged, the liquid electrolyte gasses

i.e. it produces O_2 and H_2 gas.

Therefore, adequate ventilation is necessary to avoid the risk of explosion.

Occasional, controlled overcharging is helpful:

Gassing stirs up the electrolyte to prevent stratification into different levels of acid concentration

This is called "equalization charging."

However, too much overcharging can cause damage to the plates.

(2) Charging Considerations Unique to the Sealed Battery

Never overcharge a sealed lead-acid battery!

Otherwise, an overpressure condition could result that opens the gas-tight valve.

g. Charging Scheme for Lead-Acid Batteries

Typically, a 3 stage charger is used.

→ keeps the battery in top condition.

(1) Stage 1: Initial Boost Charge

All available current is supplied to the battery.

This is done until the battery is close to 100% SOC.

"SOC" → "State of Charge"

(2) Stage 2: Absorption Charge

Charging continues, but at a constant voltage and low current.

(3) Stage 3: Float Charge

Keeps the battery gently topped off.

The float charge can be done indefinitely without overcharging the battery.

h. Discharging Lead-Acid Batteries

Consider Fig. 5.4 for a typical 12 V 200 Ah battery:

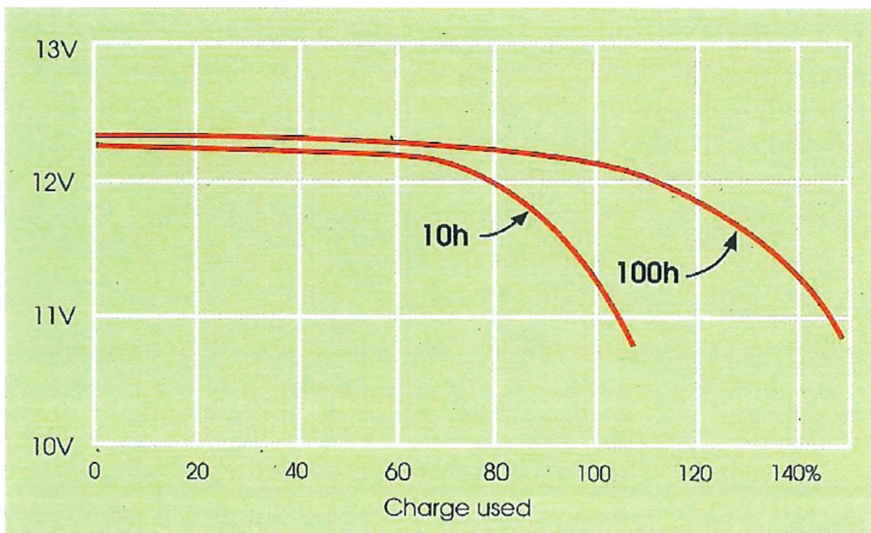


Figure 5.4 Typical discharge characteristics of a 12 V lead–acid battery.

Regardless of how we get to V_{bat} = 11 V, once at that voltage, we must disconnect the load from the battery to avoid damaging the battery.

The charge controller monitors V_{bat} and disconnects the load at that point.

Observe that drawing current at the 2 A for 100 hr rate results in V_{bat} staying higher "longer" than at the 20 A for 10 hr rate.

Here "longer" does not refer to time, but rather to the amount of charge that can be drawn from the battery.

(1) Leaving the Battery in a Low SOC for a Long Time

This can damage the battery through the process of sulfation.

Sulfation is the formation of large lead sulfate crystals on the plates.

This results in loss of battery charge capacity.

(2) PV Lead-Acid Battery Usage

Summer: batteries are more likely to be at a high SOC most of the time.

Winter/cloudy periods: batteries are more likely to have periods of low SOC.

More “battery care” may be necessary during this usage period.