Thursday, 10/19/23

Charge Controllers

1) Review of the Pb-Acid Battery Charging Scheme

The charge controller determines the charging stage of the battery by measuring the voltage across the battery, V_{bat}:

a. Initial Boost Charge

All available current is supplied to the battery.

This stage is performed until the battery is close to 100% State Of Charge (SOC).

Which is up to about $V_{bat} = 14.4$ V.

b. Absorption Charge

This stage is performed at constant voltage and low current.

The current into the battery decreases over time.

This is performed with V_{bat} around 14.1 V.

c. Float Charge

The stage is performed to keep the battery gently topped off.

This is performed with V_{bat} around 14.0 V.

Some battery chargers, called <u>trickle chargers</u>, just operate in this state.

d. Equalization Charge

This charging stage is only used with flooded (wet) Pb-acid batteries.

Gassing is induced with a higher voltage applied across the battery to stir up the electrolyte to prevent acid stratification in the electrolyte solution.

A voltage across the battery of up to 14.7 V is sufficient for this.

2) Purpose of the Charge Controller

(1) To protect the battery from overcharging when the PV energy supply exceeds the load energy demand.

(2) To protect the battery from over-discharging when the load energy demand exceeds the PV energy supply.

(3) Performs other system control functions, such as occasional equalization charging of flooded batteries.

(4) Performs system operation display/logging functions.

3) Charge Controller Challenges

a. Determining SOC

This cannot be accomplished by just measuring V_{bat}.

The SOC depends on the history of the battery too.

Example 1: Power a load off of the battery for a while and V_{bat} drops. Disconnect it and V_{bat} will slowly recover <u>without</u> recharging.

Example 2: Charge the battery and V_{bat} will rise. Cease charging the battery and V_{bat} will slowly fall back to a lower voltage.

Therefore, the charge controller must record battery history and make use of this information to correctly determine SOC.

b. Hysteresis

We want to minimize charging/use hysteresis.

Example 1: Charge the battery until V_{bat} reaches its maximum value. Disconnect the battery from the charging source to prevent overcharging. Without a load connected to the battery, V_{bat} starts to drop. So, how low do you let V_{bat} get before you begin charging again?

Example 2: Disconnect the load from the battery when V_{bat} gets too low. Without recharging, V_{bat} slowly increases. So, when do you reconnect the load to the battery?

We desire to minimize the hysteresis without undercharging or overcharging the battery.

4) Charge Controller Topologies

a. The Simple Charge Controller

For applications up to maybe 100 W.

For use with a 12 V rechargeable battery.

It has 6 terminals: PV (2), battery (2), load (2).

It is low-cost.

It is good for home use.

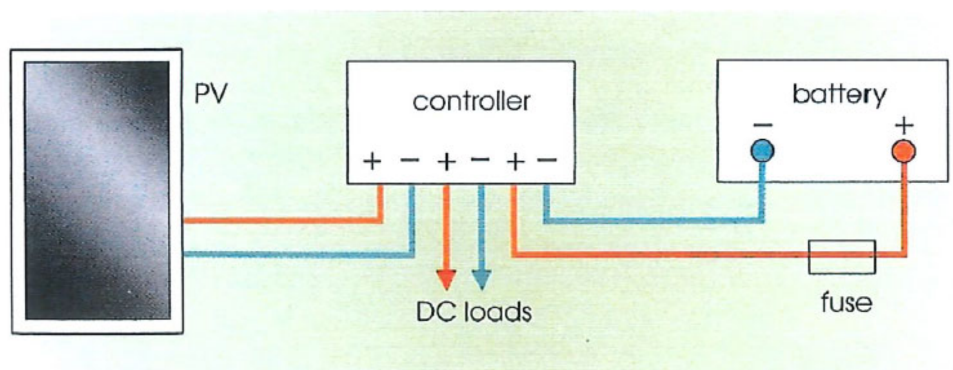


Figure 5.5 A simple scheme for a low-power solar home system (SHS).

The fuse protects the battery in case a fault occurs where the battery gets shorted.

b. Charge Controllers for Higher Power Systems

These charge controllers often have more features than the simple charge controller:

(1) User choice of flooded or sealed Pb-acid batteries.

(2) Protection against reverse polarity connection of the PV modules or the batteries.

(3) Automatic selection between boost, absorption, float, and equalization charging based on estimated SOC and type of battery.

(4) Battery protection against overcharging, over-discharging, excessive load currents, and shorting.

(5) Prevention of discharging the battery through the PV module at night.

(6) Display of system information.

c. The Series Charge Controller

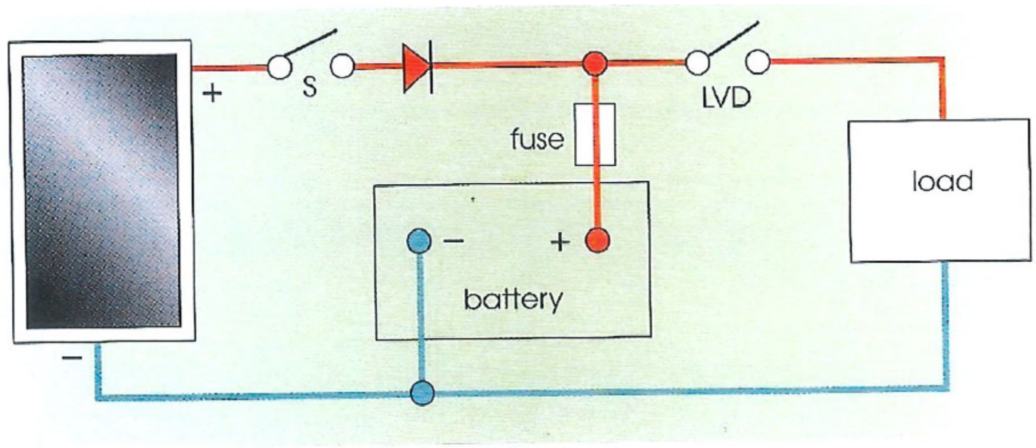


Figure 5.6 Series charge control.

The LVD is the Low Voltage Disconnect switch. It protects the battery from over-discharging. It will disconnect the load from the battery when V_{bat} drops to around 11 V.

The series diode is a blocking diode to prevent the battery from being discharged through the PV module at night. Note: this diode might be included in the PV module itself.

The switch, S, a MOSFET, controls charging of the battery using a PWM signal with SOC determination to set the average (DC) current delivered to the battery, using an optimized control algorithm.

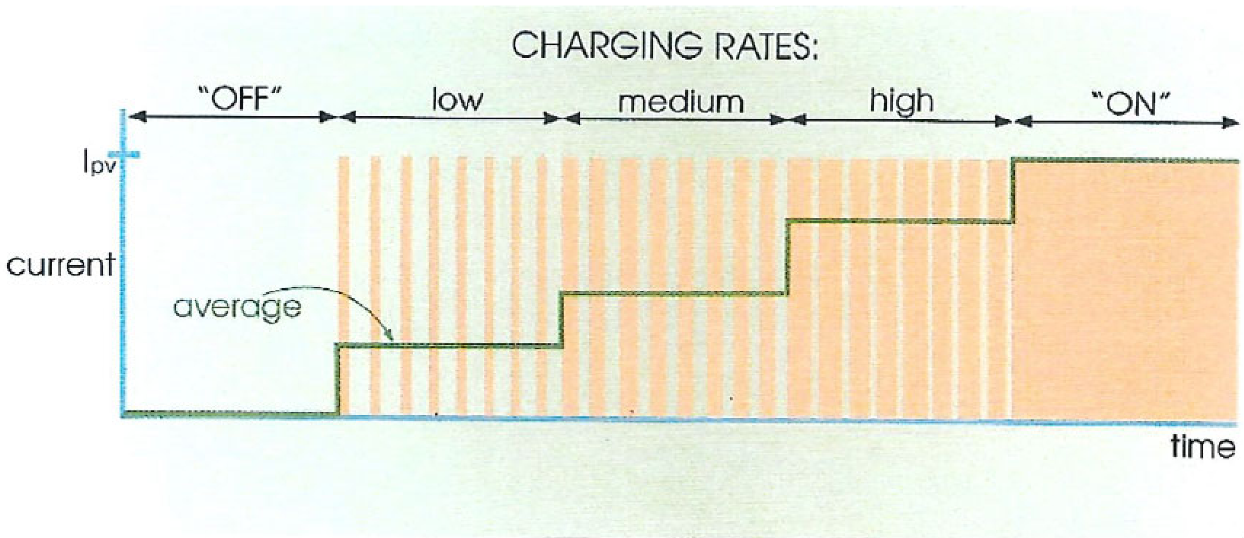


Figure 5.7 Battery charging with pulse-width modulation (PWM).

Increased PWM duty cycle from left to right

d. The Shunt Charge Controller

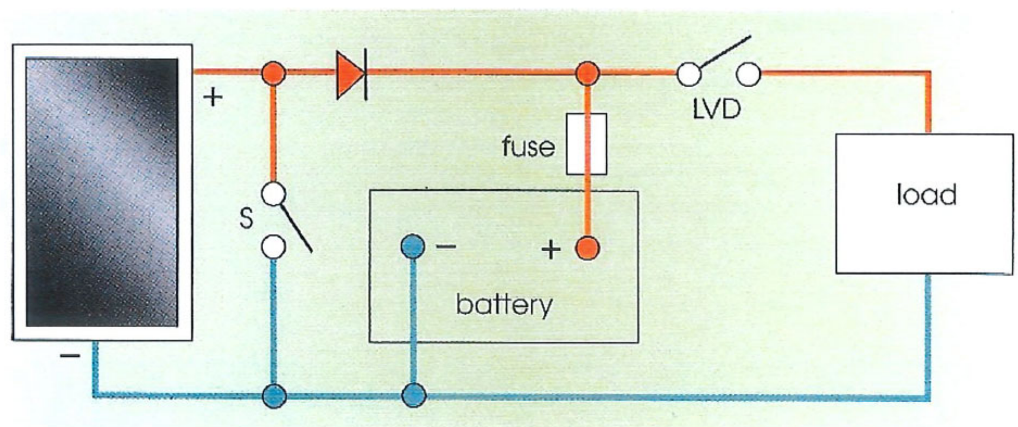


Figure 5.8 Shunt charge control.

The LVD and the diode serve the same purpose as in the series charge controller.

MOSFET switch S is connected across the PV module terminals and functions as follows:

On → the PV module is shorted: the battery receives no current.

Off → the battery receives current from the PV module.

Additionally, the diode prevents the battery from being shorted when S is on.

PWM switching of S is also used to control charging of the battery.

The shunt charge controller has lower switching losses than the series charge controller.

These losses only occur when PV energy is being rejected with this topology.

With the series charge controller, switching losses occur when PV energy is being sent to the battery. Regardless, these should be small losses anyway.

Note: the MOSFET switch must be able to dissipate the full power from the current flowing through it. There are therefore thermal considerations for the circuit.

Shorting PV modules, as is done with this topology, can exacerbate hot-spot problems due to bad PV cells or partial module shading.

Series charge controllers are more prevalent than shunt charge controllers.

e. Series/Shunt Hybrid Charge Controller

This charge controller topology is sometimes used.

It is a combination of the features of the series and the shunt charge controllers.

f. MPPT Charge Controllers

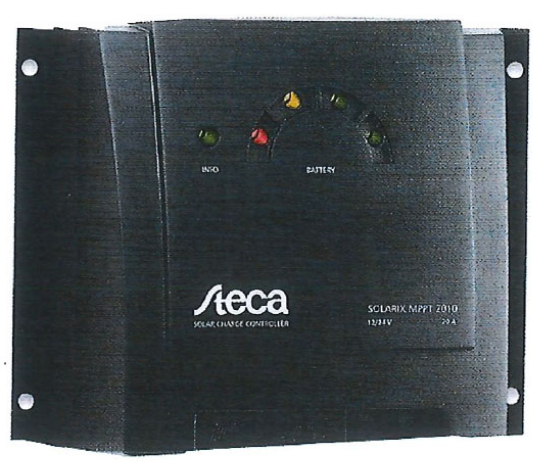


Figure 5.9 This MPPT controller can control a 12 or 24 V system with PV array power up to $500\,W_p$ and MPP voltages up to 100 V. With dimensions 19 × 15 × 7 cm, it weighs 900 g (Steca Elektronik GmbH).

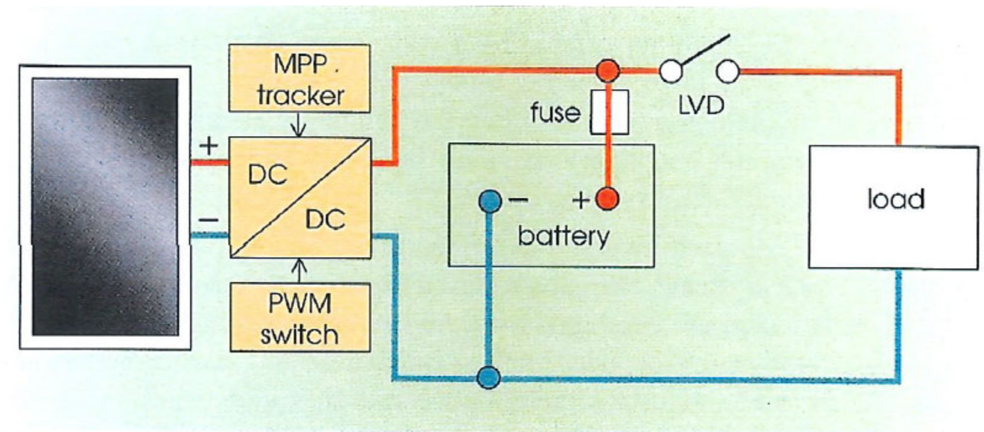


Figure 5.10 Extracting the most from a PV array: the MPPT charge controller.

This charge controller topology increases the efficiency of extracting energy from the PV module, since it is not driven by the required battery voltage.

This topology is convenient for the now more common higher voltage PV modules designed for grid-connected applications.

> It uses a DC/DC converter to efficiently step-down the high output voltage of the PV module to a voltage more optimal for charging the battery.

This DC/DC converter subcircuit also works with the MPP tracker to perform MPPT functions.

A multi-stage DC/DC converter might be used:

> The frontend stage connects to the PV module and performs the MPPT operation, generating some intermediate voltage.
>
> The backend stage converts the intermediate voltage to the voltage needed to optimally charge the battery.

This topology could employ the series controller or the shunt controller on the battery side.

This charge controller topology typically costs more than simpler charge controller designs.

Other Types of Rechargeable Batteries for Use in Stand-Alone PV

1) Nickel-Cadmium (NiCd) Batteries

An early version was invented in 1899.

a. Battery Construction

Positive electrode: nickel oxide-hydroxide (also called oxyhydroxide): the battery anode

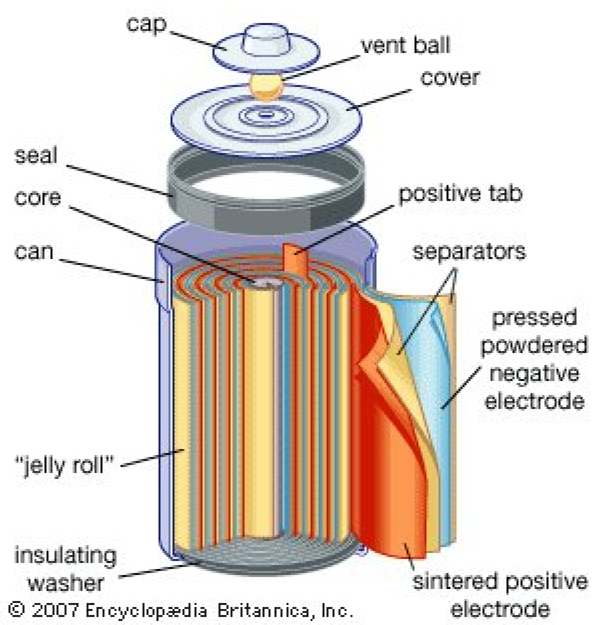
Negative electrode: cadmium: the battery cathode.

Electrolyte: potassium hydroxide (KOH), an alkaline material.

Separator: a permeable membrane between the anode and the cathode.

Nominal cell voltage: 1.2 V

Sealed and vented versions exist.



Curtesy: https://www.britannica.com/technology/nickel-cadmium-cell

b. Comparison with Pb-acid Batteries

(1) The Advantages

NiCd batteries can be overcharged.

NiCd batteries can be fully discharged.

NiCd batteries have excellent low temperature performance.

NiCd batteries can be frozen without damage.

NiCd batteries can be charged at a much higher rate.

NiCd batteries maintain a uniform voltage during discharge.

NiCd batteries have longer life.

NiCd batteries have lower maintenance requirements.

NiCd batteries have low internal resistance.

NiCd batteries have low self-discharge when unused.

(2) The Disadvantages

NiCd batteries are typically 2 to 3 times more expensive.

NiCd batteries have lower storage efficiency (60% to 70%).

NiCd batteries have a "memory effect" and must be fully charged and discharged, or they lose storage capacity.

Cadmium is highly toxic.

2) Nickel-Metal-Hydride (NiMH) Batteries

Work to develop NiMH battery technology began in 1967.

a. Battery Construction

NiMH battery construction is similar to NiCd batteries.

Positive electrode: nickel oxyhydroxide.

Negative electrode: a hydrogen absorbing metal alloy is used instead of Cd.

Two commonly used alloys: AB_5 and AB_2.

AB_5:

A: a rare earth mixture of lanthanum, cerium, neodymium, and praseodymium.

B: Ni, Co, Mn, or Al.

AB_2:

A: Ti or vanadium.

B: Zr or Ni, modified with Cr, Co, Fe, or Mn.

Electrolyte: KOH.

A separator is used.

Nominal cell voltage: 1.2 V (like NiCd batteries).

NiMH batteries have higher storage efficiency than NiCd batteries (80% to 90%).

The memory effect is less pronounced than with NiCd batteries.

They are less tolerant to voltage reversal than NiCd batteries.

Since they have no Cd, they are considered to be less toxic than NiCd batteries.