Thursday, 10/5/23

Maximum Power Point Tracking (MPPT)

1) MPPT Architecture

To accomplish maximum paper point tracking, a DC-DC converter can be used:

The switching frequency of the transistor switch may be in the 10s of kHz.

The duty cycle (percent on-time of the transistor switch for each switching period) determines the average output current drawn from the PV module.

From the duty cycle and present output capability of the PV module, an average MPPT input current and voltage can be calculated.

The average load the PV module experiences is then the average MPPT input voltage divided by the average MPPT input current.

Changing the duty cycle of the switch changes the load impedance the PV module experiences.

A controller is required to adjust the duty cycle to maintain operation at the MPP.

The controller monitors the output power delivered by the PV module and then adjusts the duty cycle to maximize the received power as the output characteristics of the PV module change (from varying insolation level, angle of the sun, operating temperature, aging, bad PV cells, etc.)

2) MPPT Controller Techniques

Various control algorithms have been developed for adjusting the switch duty cycle to maintain operation at the PV module's MPP.

a. Perturb and Observe

Adjust the average output voltage of the PV module by a small amount and observe the effect on output power.

If the output power increased, adjust the output voltage a little more in the same direction and observe the result.

If the output power decreased, adjust the output voltage in the opposite direction and observe the result.

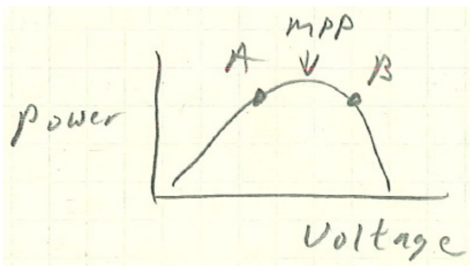
Do this continuously or periodically (repeat the steps until the MMP has been reached).

This is also called the "hill climbing method."

This technique can result in oscillations in power output.

If the perturbations are too small, it can take a long time to reach the MPP.

If the perturbations are too large, the MPP can be missed:



Adaptive Perturb and Observe algorithms are sometimes used.

This is the most popular MPPT technique.

b. Incremental Conductance

The controller measures incremental changes in the PV module's output:

V and I → ΔV and ΔI.

It then uses these measurements to predict the effect of changing the duty cycle.

This technique typically requires more computation than the Perturb and Observe technique.

c. Current Sweep

The controller does an I-V sweep of the PV module's output to determine the I-V plot for the current conditions.

From the I-V plot, the controller locates the MMP.

Then the MPPT's duty cycle is set to achieve MPP operation.

This would be done at fixed time intervals.

d. Constant Voltage

Several different techniques use this method.

For example, in one method, V_{oc} is measured and from that measurement, the PV module's operating voltage is set at a fixed ratio of V_{oc}.

3) Additional Considerations with MPPTs

All of the controller techniques require voltage and/or current sensing, signal processing, and a controller to implement the MPP tracking.

MPPTs can be used with inverters in PV-to-AC systems, or with PV-DC systems with or without storage batteries.

Stand-Alone PV Systems

These are PV systems *not* connected to the AC power grid.

Technically, this includes applications such as:

(1) Satellites (really a specialty application)

(2) Calculators and toys

(3) Cellphone/flashlight rechargers for camping

(4) Pumping water for farm animals, powering emergency phones, powering road signs, etc.

Most of the (2) – (4) applications are low power applications

However, the term "Stand-Alone PV" is generally thought of as a replacement for AC grid power in homes and other buildings.

There are several reasons why homes and other buildings might be powered by PV alone:

(1) The home or building is located too far from the AC grid to connect to it or to connect to it at a reasonable price.

(2) PV could replace other non-grid power sources, like a diesel generator.

(3) Some people just do not want to be connected to the grid: "off-the-grid" living.

1) Example Off-the-Grid Application

Consider Fig. 5.1 below:

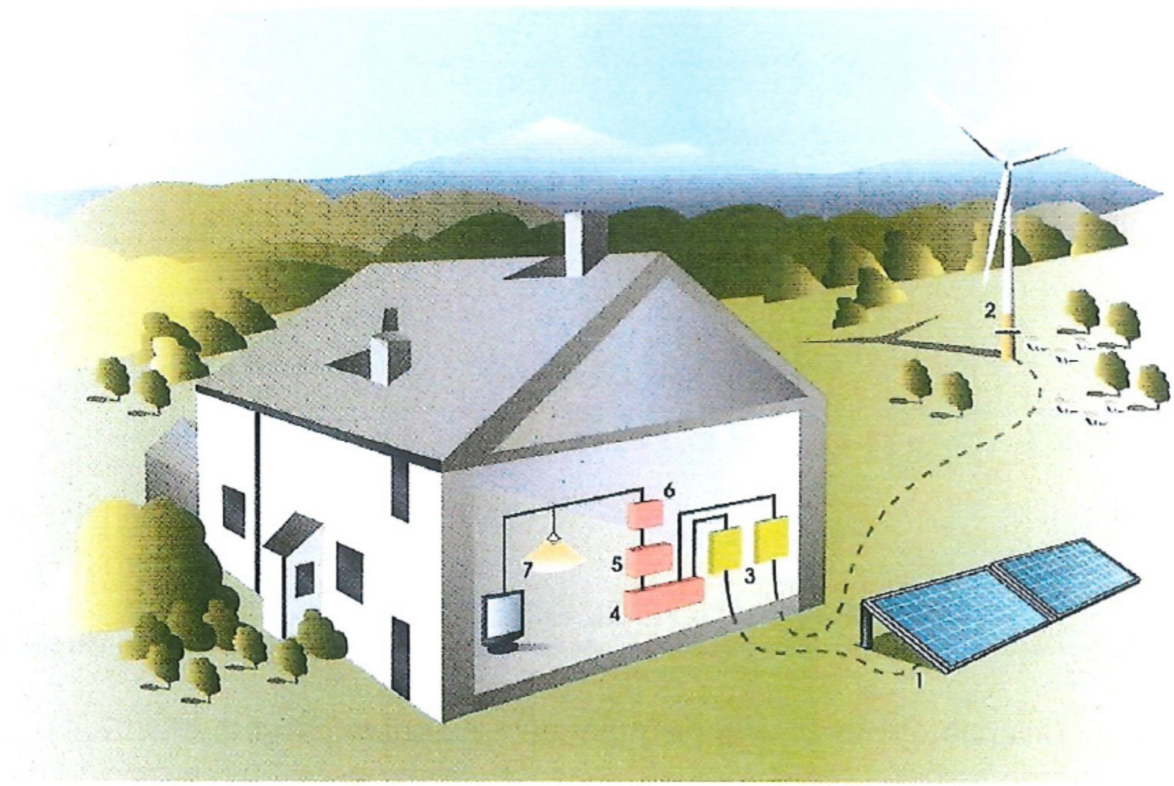


Figure 5.1 Remote and independent: a stand-alone system for a farmhouse.

In the figure, there are 7 major components:

(1) Box #1 is the PV array mounted to face toward the sun at an optimal angle

Note: the figure shows underground cables from the PV array to the building.

(2) Box #2 is a small windmill.

Often, in stand-alone PV systems, other electricity producing systems are used with the PV array, such as wind, a diesel or gas powered generator, small hydroelectric, etc.

An example might be wind and PV: wind might blow at night when PV is unusable.

(3) Box #3 is a charge controller, which regulates the flow of charge into the rechargeable battery bank.

Each electricity producing device has its own charge controller.

(4) Box #4 is the rechargeable battery bank, which is typically 12 V or 24 V.

However, it could be a higher voltage battery bank.

(5) Box #5 is an inverter.

Note: the inverter used here does not have to synchronize itself to the AC power grid and is therefore simpler.

Also, islanding is not an issue here. However, similar safety concerns remain.

(6) Box #6 is a fuse or breaker box.

(7) Box #7 represents the electrical loads.

a. Electrical Loads in PV Powered Off-the-Grid Systems

In stand-alone PV (or wind powered) systems, electricity is a precious commodity and is normally not used for power hungry applications for which other technologies exist:

(1) Building heating → thermal solar or wood/gas burning heating could be used.

(2) Cooking → wood/gas stove could be used.

(3) Heating water → solar or gas water heating could be used.

(4) Air conditioning → electric fans or underground forced air could be used.

b. Typical Uses for Electricity in Off-the-Grid Applications

(1) Lights

(2) Refrigeration

(3) Consumer electronics

(4) Pumping water

(5) Air movement

c. Other Aspects of PV Powered Off-the-Grid applications

(1) It is possible to run everything off 12 V DC.

In this case, an inverter is not needed.

12 V DC power systems are often used in cars, small boats, and some campers.

(2) Pre-1990, when stand-alone PV systems were the majority of applications, most PV modules were designed for charging 12 V batteries.

(3) A SC or MC Si PV module with 36 PV cells in series yields about 20 V for V_{oc} and 17 V for V_{mpp} in bright sunlight.

This is sufficient for charging 12 V batteries.

Typical 12 V lead-acid batteries approach 14.5 V at full charge.

The “extra voltage” from the PV module is used up by the blocking diodes and charge controller, and to ensure sufficient operation in reduced sunlight or at elevated module temperature.

(4) Note: AC grid connected systems favor higher PV module output voltages than battery charging systems.

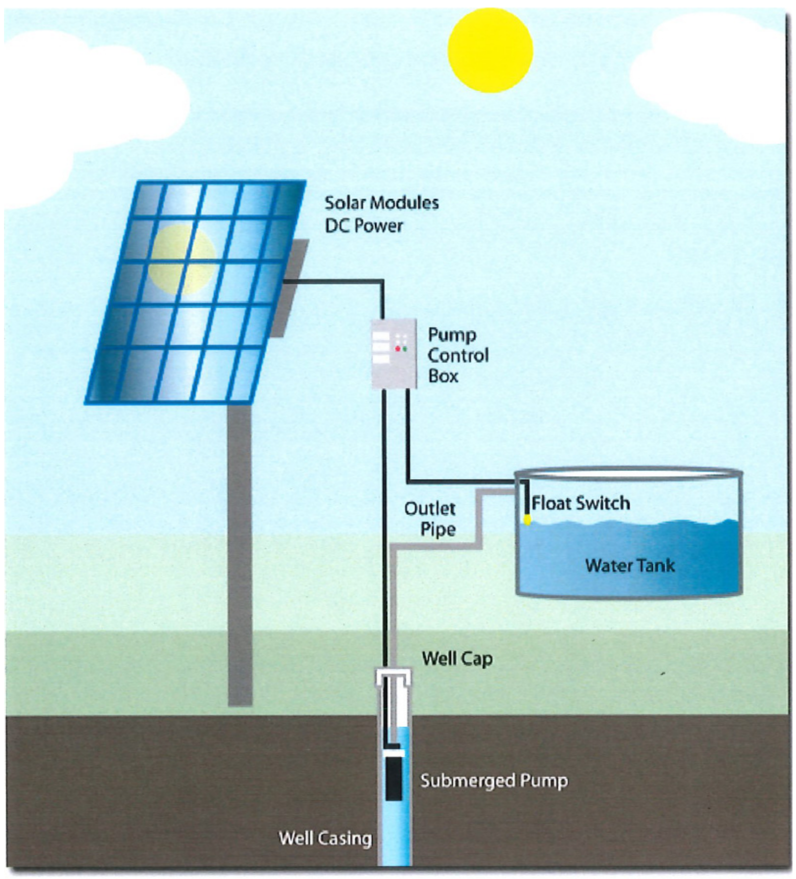
Therefore, carefully select an appropriate PV module for a battery recharging application.

2) Stand-Alone PV Without Battery Storage or Inverter

Here, the PV module supplies DC power directly to the load and only when the insolation is sufficiently high.

A common application is agricultural, such as using a PV array to power an irrigation pump or a livestock watering pump.

The pump only operates when there is sufficient sunlight and a kill switch is not tripped (such as when a livestock watering tank is full):



http://milestonesolar.com/solarwater.html

For this type of application, PV has an advantage over wind power in that a windmill system has a lot more moving parts compared to the PV system, requiring more maintenance.

a. Advantages of not having batteries in the system:

(1) Using batteries creates additional electrical loss, which reduces overall system efficiency.

(2) Batteries (along with the required extra cables, the charge controller, and the battery enclosure) increase system cost.

(3) Batteries require care and maintenance:

If they freeze, they can be damaged.

Overcharging or high temperature can reduce battery operating lifetime.

b. Some Additional Agricultural Applications

Key to these applications is to store enough water during sunshine operation to last until the next opportunity to pump more water.

http://www.sunup-solar-power.com/images/Optimized-Solar_Water_Pump.jpg

http://www.sunpump.com/_photos/_apps/solar-irrigation-trailer.jpg

3) Stand-Alone PV with Batteries but Without an Inverter

The architecture is: PV → Battery → DC Load

a. PV to Recharge Consumer Electronics

Portable PV chargers are available for charging consumer electronic devices such as smartphones and flashlights.

Consider the Anker solar phone charger I used on a 3-day thru-hike of the Pine Mountain Trail in 2021:

Larger PV systems also exist for charging several smartphones at once:

b. PV to Recharge Battery Operated Vehicles

Although this has historically been vehicles like golf carts, in the future it might include EVs.

http://www.spheralsolar.com/products/Solar-Powered-Golf-Cart-Charging-System.html

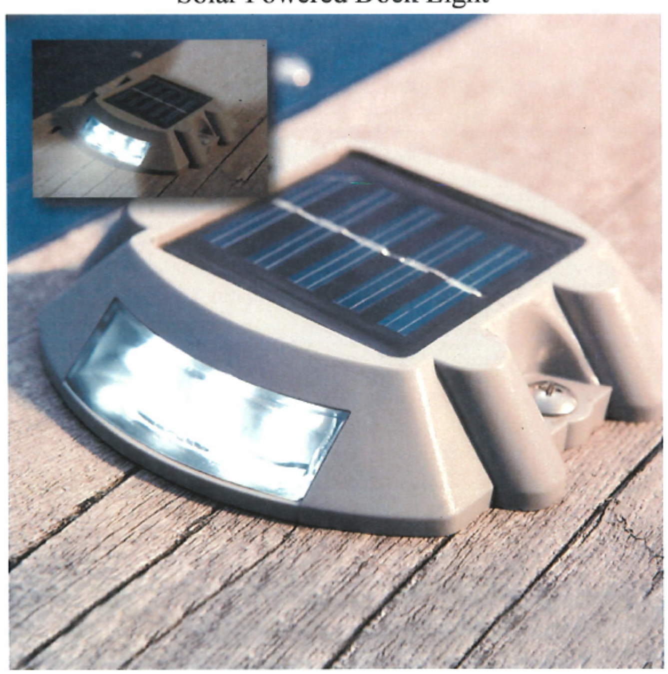
c. To Power Stand-Alone Isolated Systems

This includes applications such as stand-alone emergency phones, railroad crossing signals, road/dock lights, etc.

http://elteccorp.com/images/Gerdau-Am%203.JPG

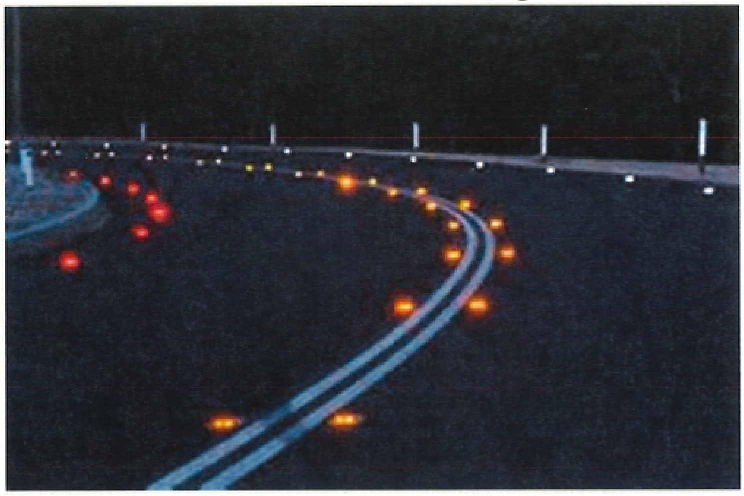
http://www.talkaphone.com/product/etp-mtr-op-solar

Solar Powered Dock Light



http://www.thechandleryonline.com/product_info.php?cPath=8_253&products_id=6313

Solar Powered Road Lights



http://solarpathusa.com/category/traffic-calming-solutions/solar-road-delineation/

d. To Power Garden Lighting Systems

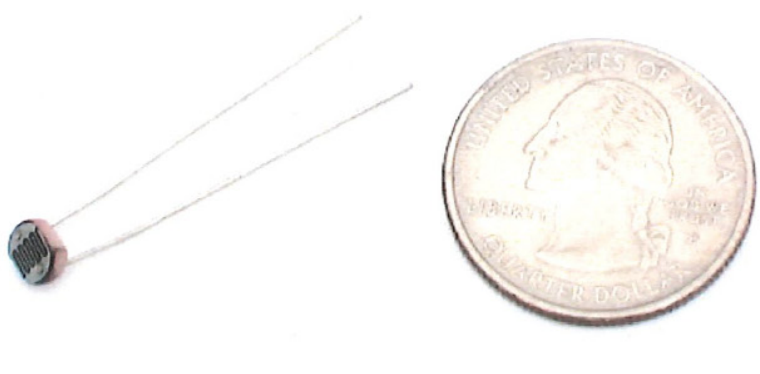
Typically, this type of device uses PV to recharge NiCd battery(-ies) during the day to "fully charged."

A CdS photocell [high resistance in dark (~ 200 kΩ), lower resistance in sunlight (~ 10 kΩ)] is used to turn on a light source (such as a white LED) at night.

The LED fully discharges the NiCd battery(-ies) by morning.

This is a good application for NiCd batteries, because they work best and the longest when fully charged and discharged each use cycle.

Solar powered flood light
www.lowes.com



CdS photocell
http://www.ladyada.net/learn/sensors/cds.html

e. Other Agricultural Applications

An example would be using PV to power a rechargeable electric fence charger.

PV electric fence charger

http://farm4.staticflickr.com/3043/2701996483_aacf768b70_z.jpg

f. Interesting Sailboat Application

Thin film PV integrated into the sail on a sailboat

http://www.yachtingworld.com/gear-reviews/wind-water-and-solar-power-65797