MPPT v PWM Charge Controllers

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PV Charge Controller History

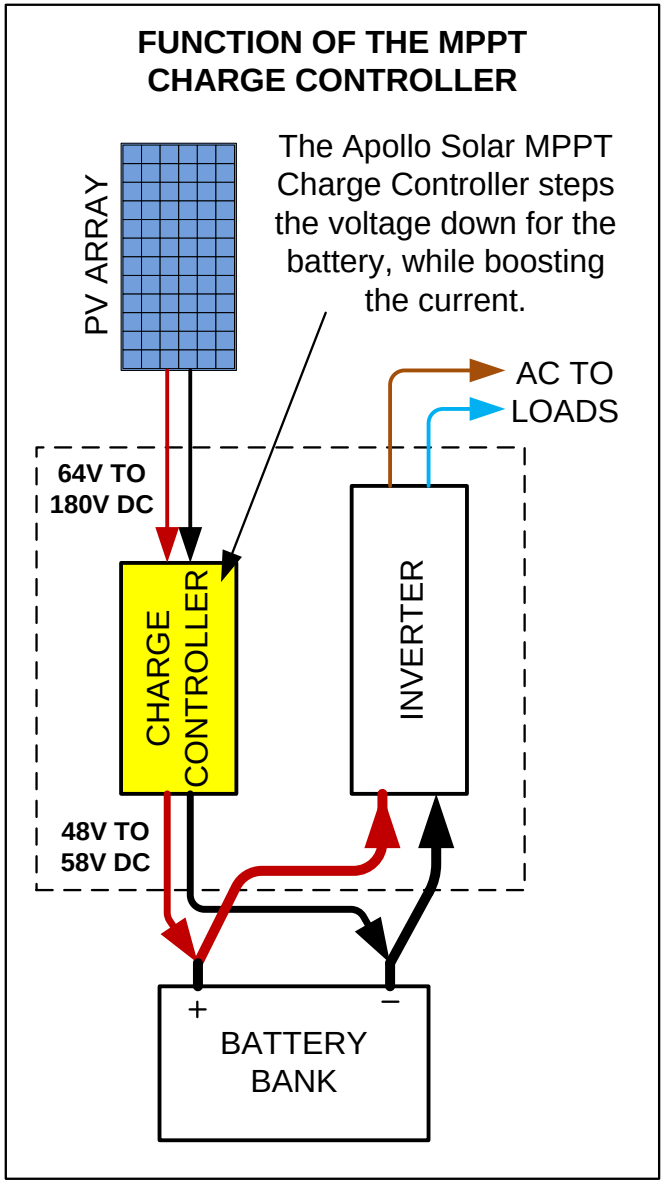
The MPPT Charge Controller is the 3rd Generation of PV charging technology.

1. **RELAYS:** The first PV battery chargers used relays to connect the PV array directly to the battery and then disconnect it when the battery was full. This method reduces the life of the battery and throws away much of the PV energy. They have been replaced.

2. **PWM:** The 2nd generation was PWM (Pulse Width Modulation). PWM also connects the PV array directly to the battery, but it turns on and off quickly so the battery is usually not damaged. PWM also throws away much of the PV energy. PWM is still used on small systems below 500 watts where wasted PV energy is not critical.

3. **MPPT:** Maximum Power Point Tracking Charge Controllers are based on a DC to DC converter. They include software which adjusts to the optimal voltage and current of the PV array as it changes during the day. 100% of the PV energy is harvested. The output to the battery automatically adjusts to precisely what the specific battery needs for optimum charging and longest battery life.

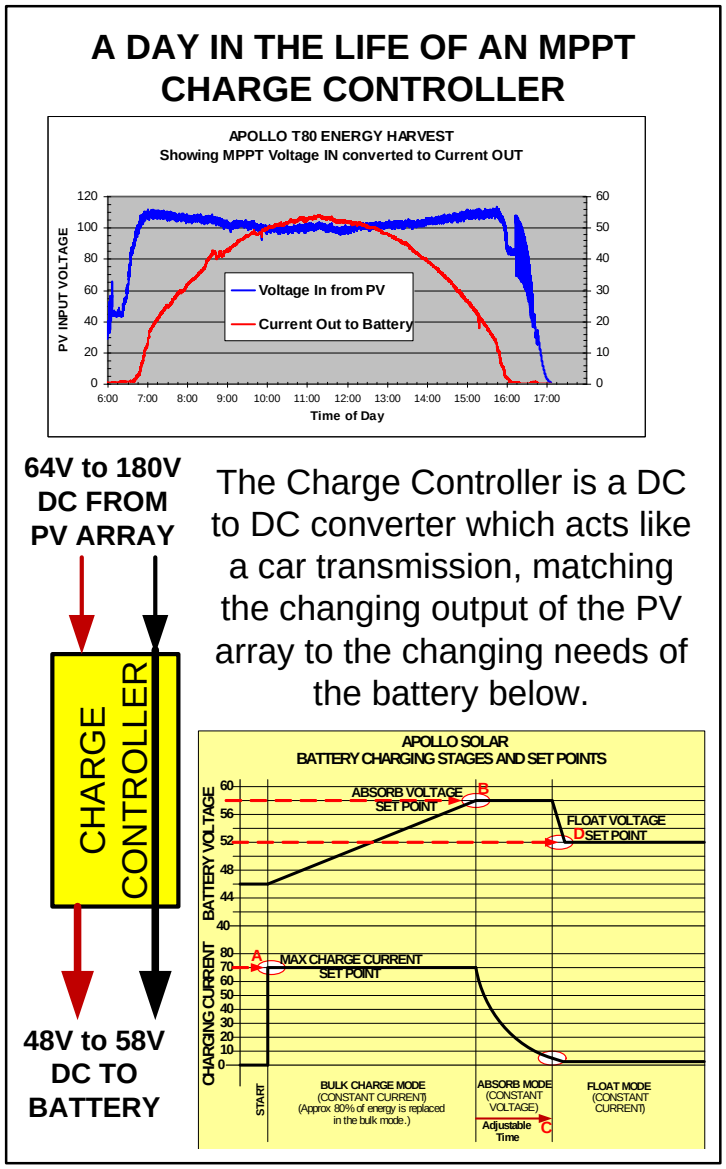
Off-Grid Basics – The Charge Controller



The job of the Charge Controller:

1. Harvest as much energy as possible from the PV array using Maximum Power Point Tracking (MPPT)
2. Provide the Battery with a full charge as soon as possible every day
3. Protect the battery from over-charge
4. Optimize the efficiency of the entire process (including wiring from the array)
5. Report the Battery State-of-Charge and other system parameters for remote maintenance

Off-Grid Basics – The Charge Controller

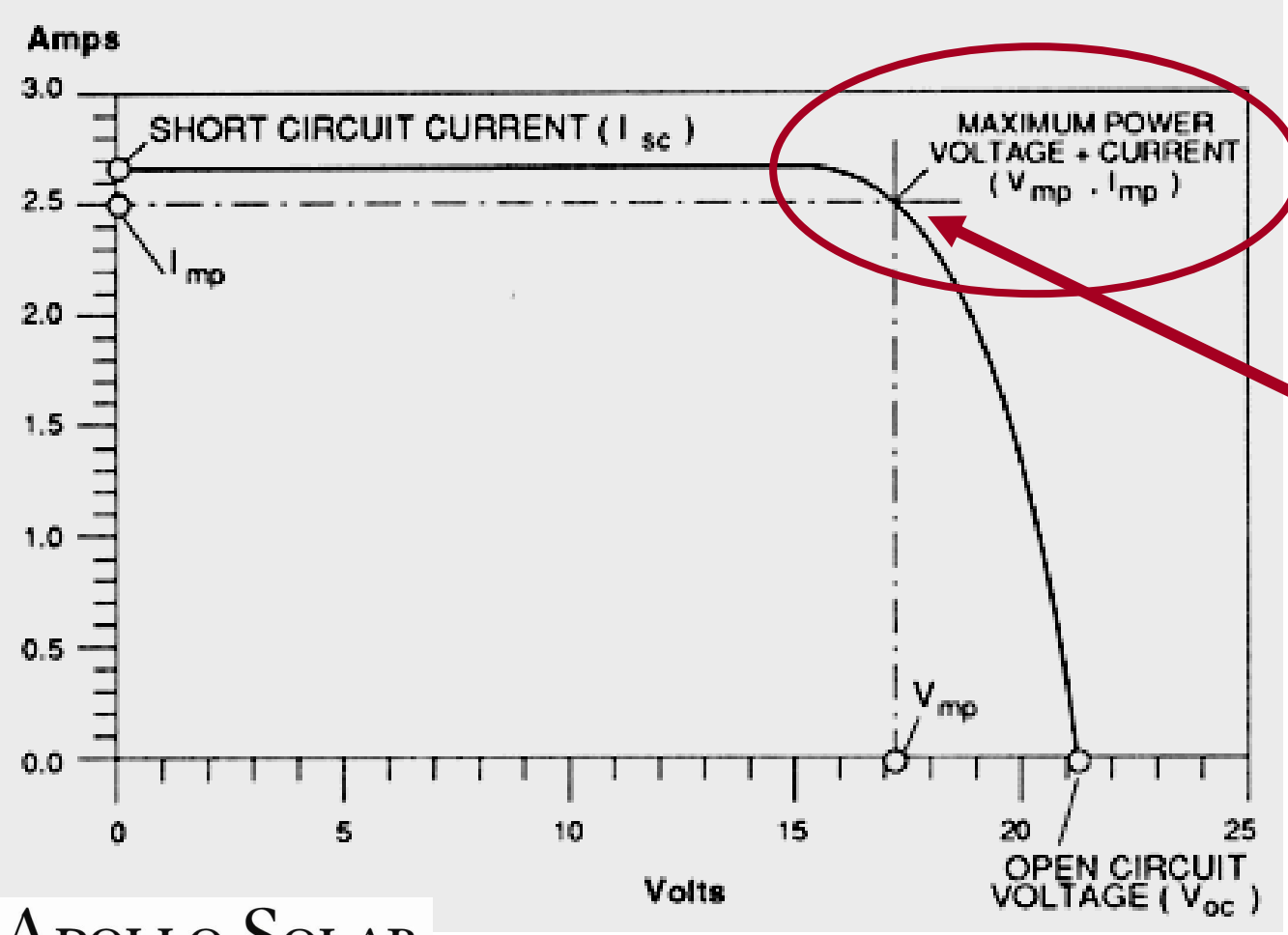


A day in the life of an MPPT Charge Controller:

1. The MPPT (Maximum Power Point Tracking) Charge Controller adjusts to the optimal voltage and current of the PV array as it changes thru the day.
2. Higher voltage in the wires from the PV array allows for lower current which cuts losses by the square of that current.
3. As a 4kW example, a 100 volt DC input at 40 Amps is converted to 50 volts output to charge the battery with 80 Amps.
4. The battery charging curve is followed using the Bulk, Absorb and Float stages.

Maximum Power Point Tracking

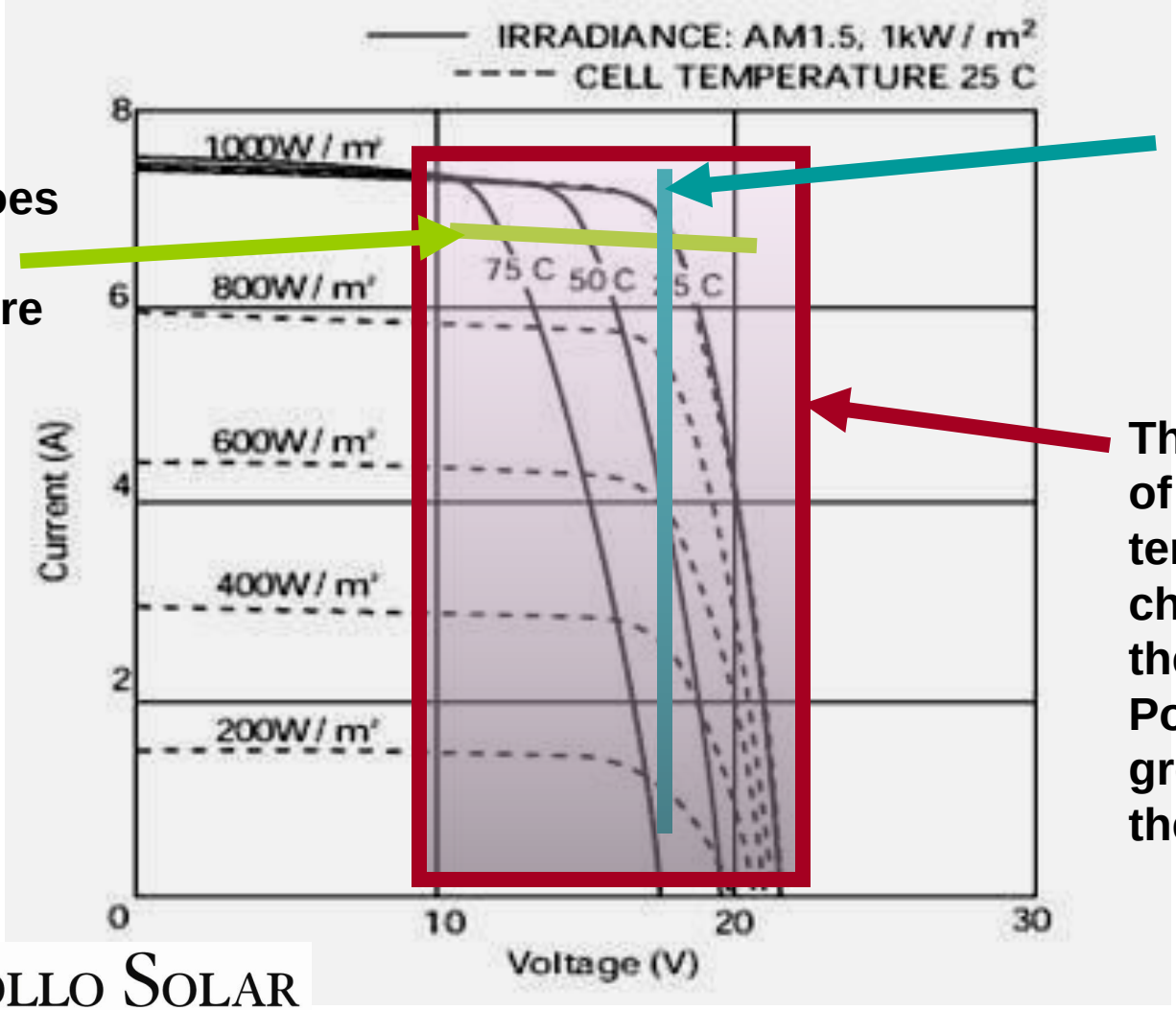
Fact 1: To get the full power from any PV module, the load must be set at a specific current (the Imp) and specific voltage (the Vmp). The Current x the Voltage is the Maximum Power Point of that PV module.



Maximum Power Point Tracking

Fact 2: The Maximum Power Point changes rapidly as the temperature of the module changes and as the irradiance or amount of sunlight changes.

PV output voltage goes down as temperature increases.



PV output current goes up as irradiance increases.

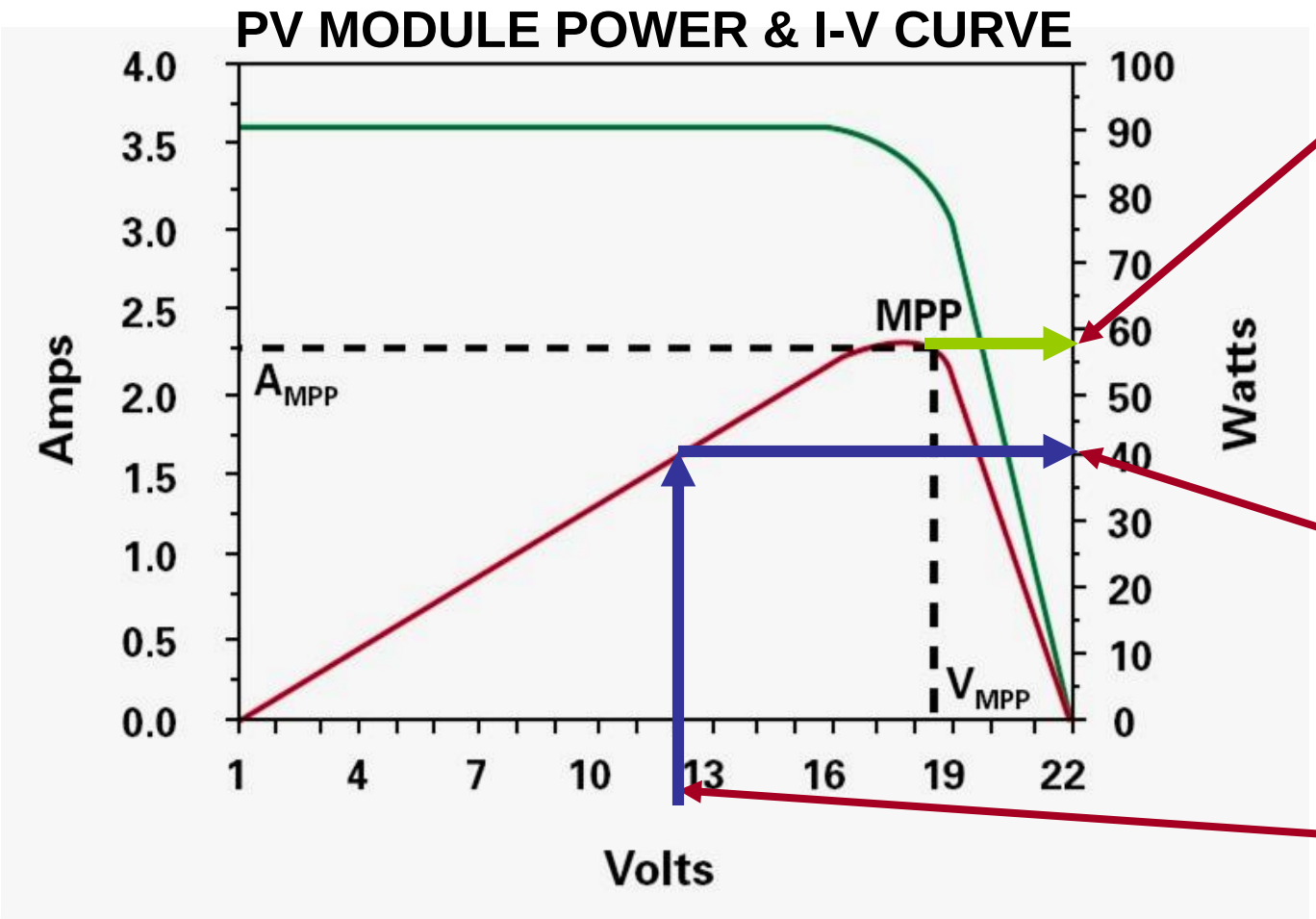
The combination of irradiance and temperature changes cause the Max Power Point to vary greatly during the day.

Maximum Power Point Tracking

1. To get the most out of a PV array, the Maximum Power Point must be found, saved and then re-calculated often or “tracked” all day. (Hence the name MPP**T** for Tracking.)
2. The Apollo Solar MPPT charge controllers re-calculate the maximum power point 500 times every second, then average the findings and lock onto a new point every 1.25 seconds. (Competitors do this every 3 minutes or more.)
3. The result is that the Apollo Solar MPPT charge controllers harvest all the energy available from the PV array in conditions from bright sun to cloud cover or changing shade conditions at any temperature.

PWM v MPPT Operating Voltage

PWM regulators connect the PV array directly across the battery, forcing the PV voltage to be at the battery voltage thus limiting the power possible from the PV array.



3) 57 Watts from MPPT controller (42% increase over PWM)

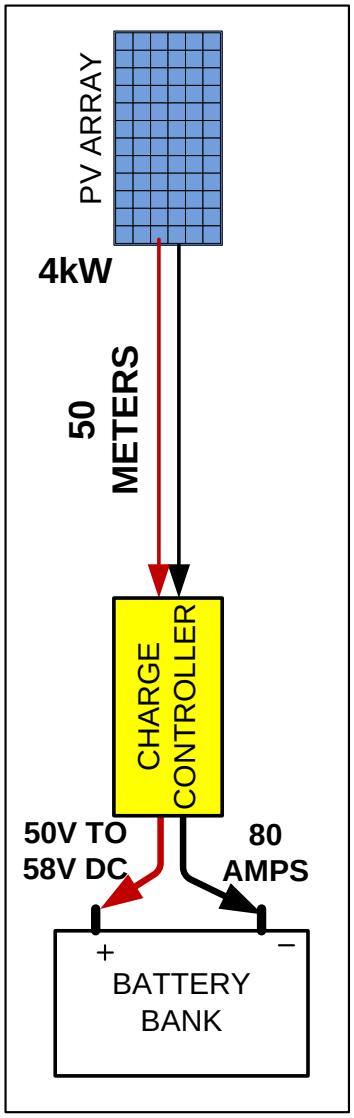
2) 40 Watts from PWM Controller

1) 12 Volt Battery limits voltage of PV module

Technical Benefits of MPPT over PWM

1. Added energy harvest because all of the PV array voltage range is used, not just a narrow voltage slightly above the battery voltage. No power is thrown away using MPPT if the load or battery can us it.
2. Added energy harvest because the PV array is used at the maximum power point at all temperatures.
3. MPPT has added energy harvest because the PV array can be used early in the morning, late in the day and during cloudy days, even when the voltage or current is very low.
4. The PWM chargers produce zero power if the PV array does have sufficient sunshine. This has been measured at > 25% difference in favor of MPPT.
5. With MPPT, the higher voltage and lower current in the wiring from the PV array has lower losses and can use thinner gauge wire which is lower cost.
6. Since the energy harvest is greatest when the PV temperature is low and when the batteries are deeply discharged, MPPT produces more energy in the morning when it is needed most to extend battery life.

Reduced Wire Gauge - Large Cost Saving



Example: 4kW PV Array 50 meters from the Charge Controller.

Using MPPT Controller:

4kW = 25 Amps at 160 volts

Using 16mm² wire, the resistance for 100m is .1077 ohms.

The power loss is I^2R = 25 * 25 * .1077 = 67.31 watts which is 1.68% loss and is considered a good installation.

Using PWM Controller:

4kW = 71.4 Amps at 56 volts

Using 16mm² wire, the resistance for 100m is .1077 ohms.

The power loss is I^2R = 71.4 * 71.4 * .1077 = 549 watts which is 13.73% loss which is a very poor installation.

The wire size must be at least 95mm² at .0181 ohms for 100m.

The power loss would be 71.4 * 71.4 * .0181 = 92.27 watts which is 2.31% loss and is considered an acceptable installation.

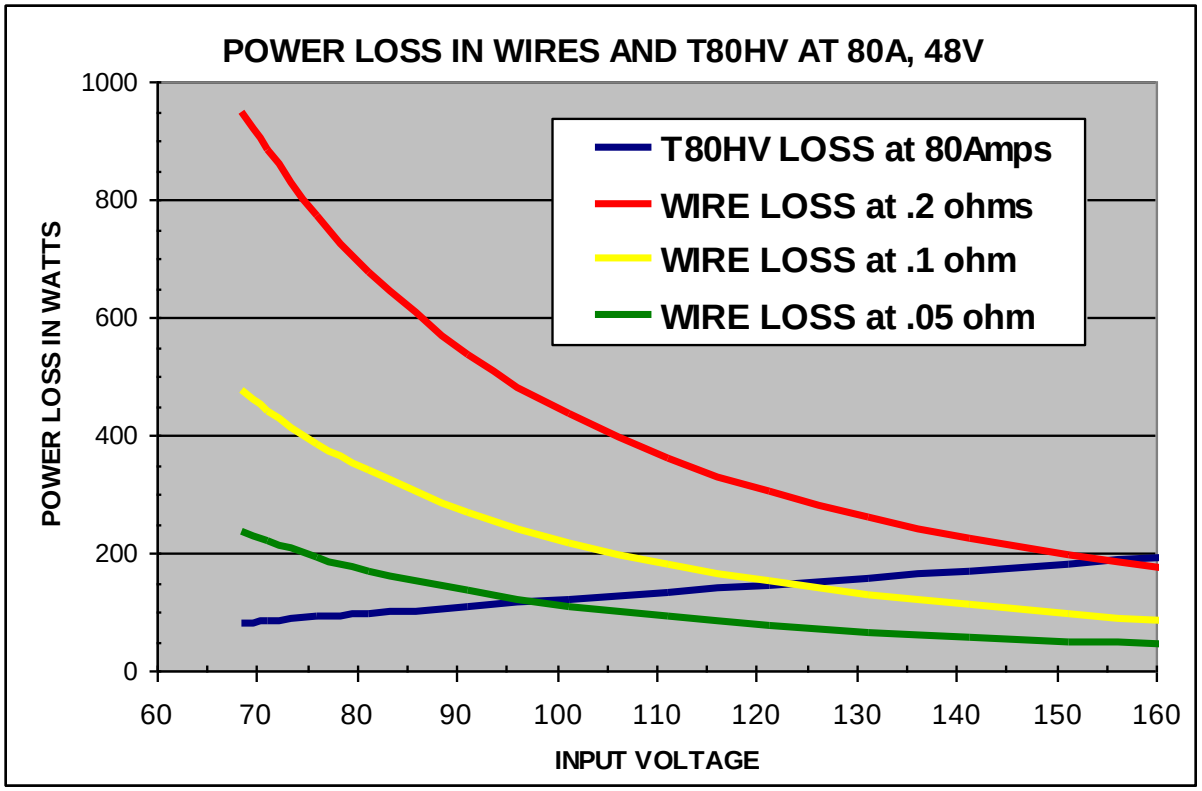
Costs: For 100m, 95mm² wire = $6100, 16mm² wire = $1030.

Savings: Each MPPT controller saves $5070 with 100m of wire.

At 15 meters the cost of wire pays for the MPPT charge controller.

Wire Loss and the T80HV

The higher PV voltage into the T80HV easily overcomes the loss in the PV wires.



The difference in the cost of the wire can often pay for the T80HV.

WIRE SIZE AWG	OHMS PER 100ft	$ / 100ft USE-2 APRIL 2012
14	0.25250	$ 45.00
12	0.15880	$ 80.17
10	0.09989	$ 120.15
8	0.06282	$ 164.40
6	0.03951	$ 248.64
4	0.02485	$ 376.16
3	0.01970	$ 435.91
2	0.01563	$ 610.94
1	0.01239	$ 825.48
1/0	0.00983	$ 1,030.97
2/0	0.00779	$ 1,295.95
3/0	0.00618	$ 1,619.45
4/0	0.00490	$ 1,849.41

The price of copper wire was quoted by Encore Wire Corp in April 2012.

Ideally, we keep both the loss in the Wire and the T80HV below 200 watts, so the wire should have less than 0.1 ohms and the input voltage is about 160 volts.

Cost Benefits of MPPT over PWM

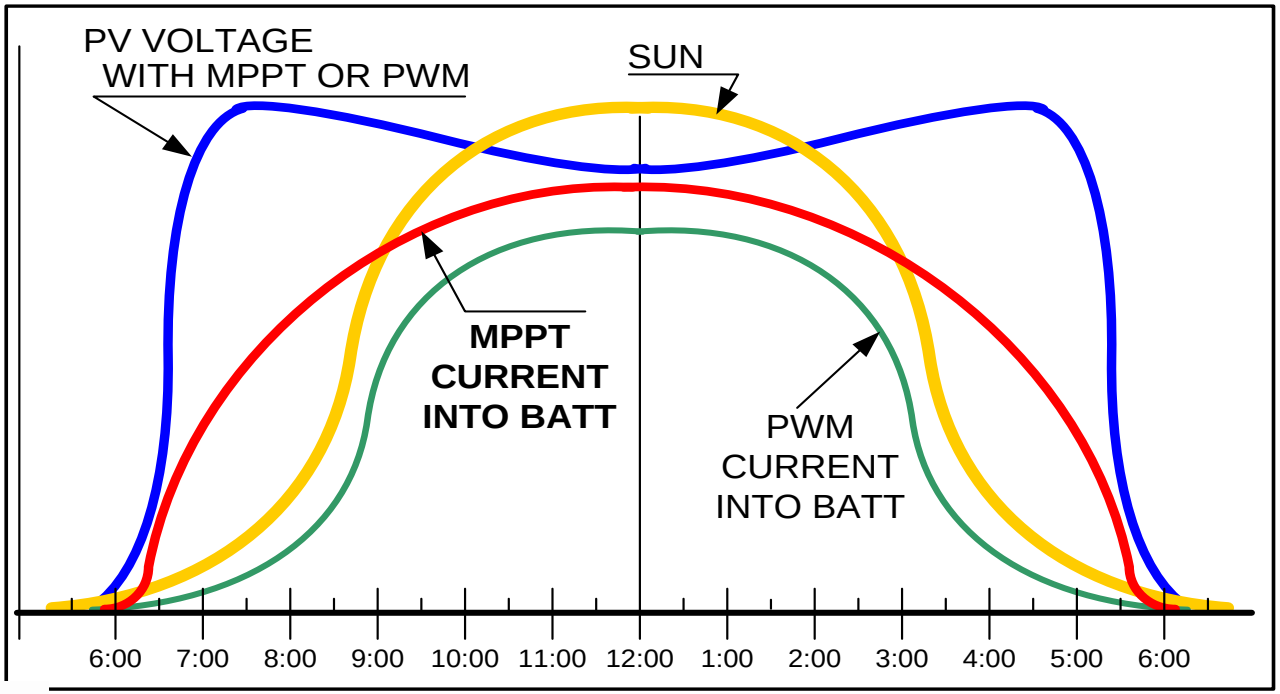
1. The additional power captured by using MPPT charge controllers allows the PV array size to be reduced by up to 30%. Hugh savings.
2. MPPT allows higher voltage in the wires from the PV array meaning lower current which cuts losses by the square of that current. The wire size can be reduced – large saving in cost of copper and labor.
3. Since good MPPT charge controllers protect and extend the life of the batteries by making sure they are charged well early each day, large long-term savings are realized by extending the battery life.
4. MPPT controllers allow the use of higher voltage and lower cost PV modules made for the large grid tie market. Many of the "12 volt" modules for off grid battery charging have been discontinued. Freedom from supply limitations is a major technical, logistical and cost benefit of MPPT.

The MPPT charge controllers do cost more than the PWM units. That higher cost is more than paid for by the reduction in PV modules, and/or lower wiring costs. The extended life of the batteries is a long term benefit.

MPPT vs PWM Energy Harvest

- DC to DC Converter allows all the PV voltage to be converted into useful current into the battery.
- MPPT algorithm finds and tracks the peak product of PV voltage and current as it changes.
- PWM chargers do not have DC to DC converters so can not use the excess voltage or track the peak.

MPPT current (in red) is greater all day than the PWM current (in green).



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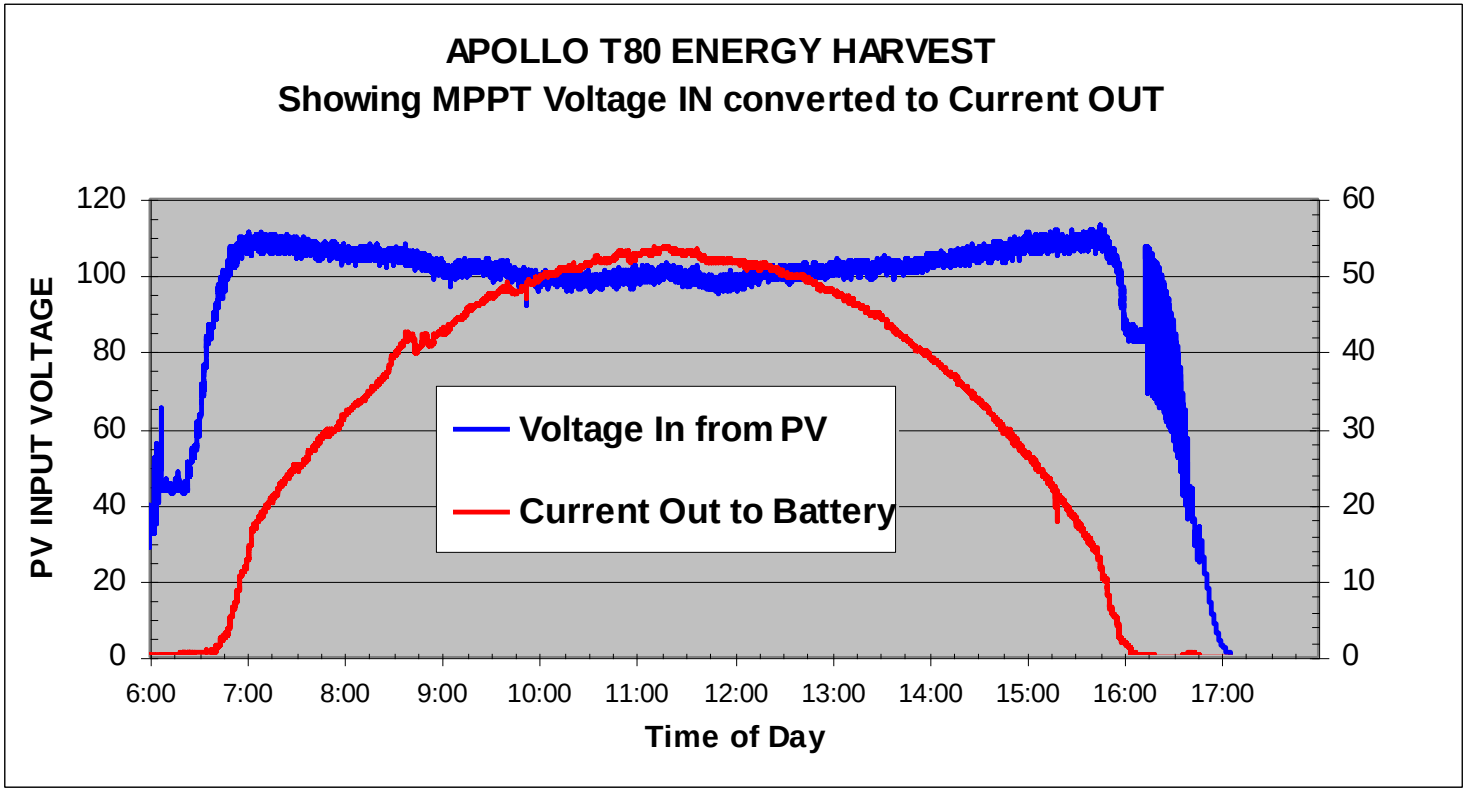
Optimum Energy Harvest

- Unbeatable Apollo Solar MPPT algorithm
- Captures all the energy from the PV array across full range of temperature and irradiance



Actual data captured in SD card and displayed in Excel

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