Maximum Power Point Tracking Solar Charge Controllers
Or
MPPT Solar Charge Controllers
What are they ?
How Do they Work ?
Are they worth the Extra Expense ?

Well to explain how MPPT Charge Controllers work we must first know the core function of any solar charge controller in a off grid solar battery based system. A Solar Charge Controller is placed in between the Solar Panel Array and the Battery Bank. Its core function is to make sure that the batteries are fully charged then to control the power coming from the solar array so that the batteries are not overcharged and damaged. This is done by diverting the extra power away from the fully charged batteries being produced by the solar array usually by burning off excess power as heat. As and when the batteries become depleted the charge controller returns power to the batteries from the solar array making sure the batteries remain as full as possible till, the solar array stops producing power. The most common quality solar chargers on the market (non MPPT) are know as PWM (Pulse Width Modulation) Solar Charge Controllers . Some famous PWM controllers are made by Xantrex C series, Stecca and Morning Star.

The most important thing you need to know about this type of controller is that it operates at all times at the voltage of the battery bank and locks your solar panel array to this voltage .
So if you have a 24 volt system which is at 24 volts in the morning the PWM Charge Controller will start working when power is produced from your solar panels at 24v locking your panels at 24v and this only increases as the batteries are being charged and the battery voltage rises.
We will call this Key Point 1 or KP1

Next we need to understand a small basic amount electrical knowledge and Maths and a simple formula and how the power of a solar panel is calculated

Volts, (V) A unit of measure of the force or pressure, volts symbol is always V
Amps (A) A unit of measure of the current or flow, Symbol is A or I
Watts (W)A unit of measure for electric power, Watts is calculated via a simple Formula Watts = Volts x Amps W=V x A or W=VI
Or Power = VI P=VI

In everyday domestic electrical use here is a example. A 1500 watt hair drier in the UK using 230 volts would use 6.52 amps of electric flow to work. 1500 watts = 230v x 6.52 amps
Getting the most power from your solar panels is important so remember
Power is Volts x Amps P=VI

Still with me so far ? The next short lesson is understanding the technical parameters of your solar panel. Every Solar Panel has its most 5 important Electrical Specifications listed, usually in the company spec sheets and on the rear of the panel. The specifications are listed under STC conditions. Standard Test Conditions, so that each panel can be compared fairly. STC are set using specific rules as such as set temperature (25 ·C) and set solar irradiance. These conditions are considered optimum .

The table below lists a standard 12v panel rated at 130 watts of power

Electrical Performance under Standard Test Conditions (STC)	
Maximum Power (Pmax)	130W
Maximum Power Voltage (VMP)	17.6
Maximum Current (IMP)	7.39
Open Circuit Voltage (VOC)	21.9
Short Circuit Current (ISC)	8.02

Remember Power (watts) is Volts x Amps P=VI
Max Power Pmax => Vmp x Imp = Watts => 17.6 x 7.39 = 130 Watts.

OK, so we know that if the panel can produce the maximum voltage at the maximum current we will get every ounce of power from the panel. However welcome to the real world things are not so simple. For this exercise we will assume you have perfectly sized cables on short runs in your solar system and its a clear sunny day. Remember my Key point 1 KP1

So you hook up you 130 watt solar panel through your standard PWM Charge controller to your 12 volt battery bank which is sat at 12 volts every thing seems perfect but your display on your controller (if your have one) reads 89 watts of power being generated by your 130 watt panel. Where has the 41 watts gone ? That's over 32% of you generating power from your panel missing !

Back to KP1 Remember that Standard non MPPT charge controllers using standard PWM technology on its own, lock the solar panel voltage to the battery voltage, i.e. they drag the Vmp down to the batteries system voltage in our case 12v, thus we see max amps coming from the panel Imp at 7.39 amps but the panel is locked at 12v thus
P (watts) is P=VI thus 7.37 a x 12 volts = 89 watts.

Even when your 12 volt battery is nearly fully charged close to absorption at 14.4 volts You are only getting 7.37 a x 14.4v = 106 watts still loosing 24 watts from your panel !

The table at the top of the next page shows you relationship between the dept of discharge of your battery with its standing voltage and the voltage that it will move to under charge and also under and load. You will note how close the voltage remains to the overall state of charge on the battery.

% OF CHARGE	(V) AT REST	(V) CHARGING	(V) UNDER LOAD
100%	12.73	14.75	12.50
90%	12.62	13.75	12.40
80%	12.50	13.45	12.30
70%	12.37	13.30	12.25
60%	12.24	13.20	12.15
50%	12.10	13.10	12.00
40%	11.96	12.95	11.90
30%	11.81	12.75	11.70
20%	11.66	12.55	11.50
10%	11.51	12.25	11.25

Table representative for a 12 volt battery

So, why not make panels that put out a lower voltage and higher current ?

Well I said this was a typical spec for a standard 12v panel and it is. The reason why we have 17.6 v Vmp is because the second energy hog is heat, the hotter a panel gets the less voltage it puts out, so our 17.6 volt panel on a very hot day might only put out 15v, so if we started with a 15v panel, on a hot day it would not put out enough to fully charge the battery to 14.4v, and stand no chance of equalizing them to 15.1v.

So now we have the MPPT 'intelligent' charge controllers to the rescue!

MPPT or Maximum Power point Tracking is an algorithm that's included in charge controllers used for extracting maximum available power from PV solar module under certain conditions. The voltage at which PV modules can produce maximum power is called 'maximum power point' (or peak power voltage Vmp). Maximum power varies with solar radiation (sunshine & cloud), ambient temperature and solar cell temperature. Our Typical PV solar module produces power with maximum power voltage of around 17 V when measured at a cell temperature of 25°C, (STC) it can drop to around 15 V on a very hot day and it can also rise to 18 V on a very cold day.

The basics of Maximum Power Point Tracking (MPPT) Solar Charge Controller is electronic tracking, and has nothing to do with moving the panels with a mechanical solar tracker. Instead, the controller looks at the output of the panels, and compares it to the battery voltage. It then calculates what is the best power that the panel can put out to charge the battery. It takes this and converts it to the best voltage to get maximum AMPS into the battery. Using technology called a buck-boost feature (Remember, it is Amps or flow or into the battery that counts). Most modern MPPT's are around 93-97% efficient in the conversion. You typically get a 20 to 45% power gain in winter and 10-15% in summer over a standard PWM controller. Actual gain can vary widely depending weather, temperature, battery state of charge, and other factors.

How MPPT works ?

MPPT or maximum power point tracking can optimise the power going into your battery. Assuming your battery is low, at around 11.3 volts. A MPPT takes that 17.6 volts at 7.39 amps and converts it, so that what the battery gets is no longer 7.39 amps at 17.6 volts,. but 10.16 amps at about 12.3 volts. Now you still have almost 130 watts, and that's what you paid for! All going into your batteries. Satisfaction !

MPPT is most effective under these conditions

Cold weather, cloudy or hazy days: Normally, PV module works better at colder temperatures and MPPT is utilized to extract maximum power available from them.

When battery is deeply discharged: MPPT can extract more current and charge the battery if the state of charge in the battery is lowers. The quality MPPT charge controllers such as the original Outback MX60 and its successor the FM60 and FM80 are DC to DC converters which operates by taking DC input from PV module, changing it to AC and converting it back to a different DC voltage and current to exactly match the PV module to the battery.

The main advantages of the MPPT charge controller are:

Extracting the maximum power from PV module; it forces PV module to operate at voltage close to maximum power point to draw maximum available power.

MPPT solar charge controller allows users to use PV module with a higher voltage output than the operating voltage of battery system. For example, if PV module has to be placed far away from charge controller and battery, its wire size must be very large to reduce voltage drop. With a MPPT solar charge controller, users can wire the PV array for 24, 48 or up to 140V (depending on charge controller and PV modules) and bring power into 12 24 or 48 V battery system. This means it reduces the wire size needed while retaining full output of the PV solar modules It has been mentioned and claimed by others that the extra cost of a MPPT charge controller over the cost of a standard PWM CC can be offset on the savings made on cabling alone when long wire runs are required from you PV to your Controller

A MPPT solar charge controller reduces complexity of a system while increasing output of system components at higher efficiency. Additionally, it can be applied to use with more energy sources. Since PV output power is used to control DC-DC converter directly.

Increased functionality of the current mainstream MPPT charge Controllers

The most popular MPPT Charge Controllers on the market today including Outback's FM60,FM80 and Xantrex XW60 MPPT come as standard with many features that are simply not found on most PWM controllers. Such as a Comprehensive Digital display and extensive programming options. Data logging and programmable relays.

Future New MPPT Charge controllers are coming to market very soon with the long awaited Midnite Classic in last production testing very soon of which I am looking forward to being part of. This 2nd Generation MPPT charge controller will have even further functionality, with easy on screen set up allowing you to programme in your longitude and latitude , remote system monitoring with built in Ethernet. The future is bright for MPPT Charge Controllers -

A 3 year comparison with a standard PWM Charge Controller v MPPT Controller

I've been living off grid for 5 years now originally with 8 x 200 watt of Mono Crystalline Panels then upgrading 4 yrs ago to 12 identical panels giving me 2400 watts of PV Solar Array

12 x 200w Mono Panels (2400w) wired all in parallel to 2 Xantrex C40 PWM Charge Controllers (24v nominal)

Here you can see my original 2x C40 (PWM) charge controllers each handling 1200 watts of PV Panels each

Then came the upgrade to a Xantrex XW60 MPPT Charge Controller. This was wired to 1200 watts of the PV Array removing one of the C40 units from service. The 1200 w of panels for the XW60 MPPT was rewired from 6 strings of panels in parallel (nominal 24v) to 3 strings of 2 panels in series (nominal 48v) then in 3 parallel strings to the XW60-MPPT charge controller. So now we have a perfect test bed for the comparison of Standard PWM Charge Controllers The Xantrex C40 against the same companies MPPT offering the Xantrex XW60-MPPT--Combined with 12 identical solar panels of which 6 feed each controller. The location in Eastern Spain gives high summer temps and reasonable low winter temps

Here is the new XW60-MPPT sat to the right of the 2 x Xantrex C40 controllers. You can see that it is physically a lot larger the C40 range. The 3 Silver cans wired to the Charge controllers are Delta LA302DC lightning arrestors.

If you look closely at the top right-hand corner of the LCD display you can see a PK1248W . That was a one day peak recording of 1280 watts being sent to my batteries .Which considering my array is rated 1200 w STC is proof of the Electronic Magic that MPPT offers . I have seen a recorded peak of 1440 watts, honestly !

I could bore you with lots of table and facts but I wont. I used the Xantrex C40 Display to compare outputs with the XW60 and used a very expensive DC Clamp Meter to confirm readings on both displays. Here is my condensed findings over 3 years .

1. A minimum 10% extra harvest of power even in summer with the MPPT Unit.
2. Winter time, cold panels batteries low a peak of 1440 watts registered on the MPPT unit.
3. Regularly observed over 1300 w of power entering batteries in Winter from a 1200 w STC Array !
4. Never saw above 1080 w being generated on the C40 PWM in Winter
5. Winter time harvest yield between 20% and 40% in favour of MPPT Unit
6. Your greatest harvest yield comes in Winter when the sun shines for less time !

Are they worth the Extra Expense ?

At the time I write this answer to this question August 2010, solar panel prices have dropped over 40% in the last 2 years in Europe and USA, due to the global recession whilst the prices of hardware such as PWM and MMPT charge controllers has remained fairly constant over this time.

I will make some assumptions which I think are accurate , you may wish to differ, but I'm the author after all

No 1 . Comparing like for like, a quality MPPT 60 amp Charge Controller like Outback's Flexmax 60 and Xantrex XW60-MPPT are approximately double the price of a comparative quality PWM unit when the options of display and BTS (battery temp sensors) are included for Xantrex C series or Morningstar Tri-Star Range.

No 2 PV panel prices are currently around 3 Euros a watt on average in Spain. Mine are currently 2.65 Euros Per watt but I'm always extremely competitive so we will go with the current Spanish average of 3 Euros a watt.

No 3. Its probably fair to say from my findings that in my location a MPPT charge controller will give you a annual harvest increase of 20% over standard PWM controllers. In cooler climates increase harvest will be higher.

No 4. For this first exercise we will compare a 60 amp charger controller a PWM unit 300 Euros and a MPPT unit at 600 Euros PV Panels at 3 Euros per watt and a 20% extra harvest yield for MPPT

No 5. For clarity and ease I have assumed the PWM controller obtains a 100% yield and the MPPT is 120% It could be more accurate to say 70% for PWM and 90% for MPPT but this was easier to work out !

Quality Branded PWM 60a Charge Controller and assumption of 100% Solar Yield www.prismsolar.co.uk				
PV Watts	**Cost 3 euro wp**	**PWM CC Cost 60a**	**PV+ PWM CC**	**Cost Per Watt Generated in Euros for PWM**
100	300	300	600	6
200	600	300	900	4.5
300	900	300	1200	4.0
400	1200	300	1500	3.75
500	1500	300	1800	3.60
600	1800	300	2100	3.50
700	2100	300	2400	3.43
800	2400	300	2700	3.38
900	2700	300	3000	3.33

Quality Branded MPPT 60a Charge Controller and assumption of 120% Solar Yield www.prismsolar.co.uk				
PV Watts +20%	**Cost 3 euro wp**	**MPPT CC Cost 60a**	**PV+ PWM CC**	**Cost Per Watt Generated in Euros for MPPT +20% yield**
120	300	600	900	7.5
240	600	600	1200	5.0
360	900	600	1500	4.17
480	1200	600	1800	3.75
600	1500	600	2100	3.50
720	1800	600	2400	3.33
840	2100	600	2700	3.22
960	2400	600	3000	3.13
1080	2700	600	3300	3.01

So we achieve price parity at low as 400 watts of solar panels. I think the case is made for MPPT over PWM controllers. Remember PV prices are at a 2 year low when I made this comparison and I can only see PV prices increasing making MPPT more attractive. If you lived in the USA where this MPPT equipment comes from it would work out around 600w of panels for parity but even that makes it a no brainer for me and Solar Off Grid Living.

You may argue as you down scale that its not as clear well, that's an argument which is fast loosing any credence as Morningstar have produced a very good VFM 15 amp MPPT unit as well as Others coming to market soon in the 30 amp range.

Yes I know there are inexpensive Chinese controllers out there half the price of Quality Xantrex , Morning Star and Stecca products in the PWM range, but few offer the feature set and reliability of the units that are required. Please also note that a alarming high number of Eastern CC manufacturers are claiming there units are MPPT when its a simple lie, if it looks too good to be true it usually is. Trust me I search the eastern markets and have yet to place any orders for there so called MPPT CC Models !

Hope you found this article Interesting Nigel, Prism Solar.