Design Study: Steca Solarix MPPT

Kapitel 5

solar charge controller with Maximum Power Point Tracking

Off-grid photovoltaic installation for residential use

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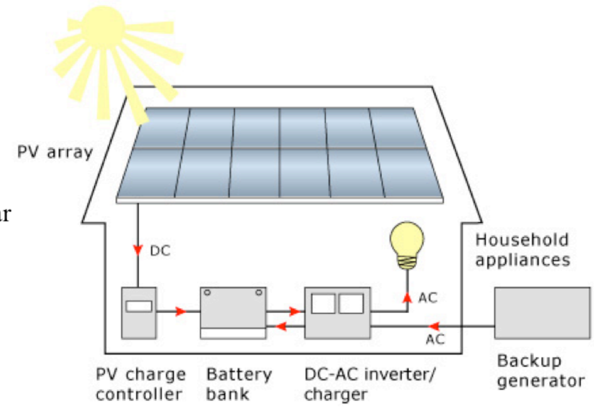
- The photovoltaic (PV) array captures photons from the sun and converts them to DC power.
- An MPPT charge controller monitors PV output and the battery charge level to maximize use of available solar energy to keep your batteries charged.
- A DC-to-AC inverter transforms the DC electricity from the panels into 120/240-volt AC power to run standard appliances, lighting and electronics.



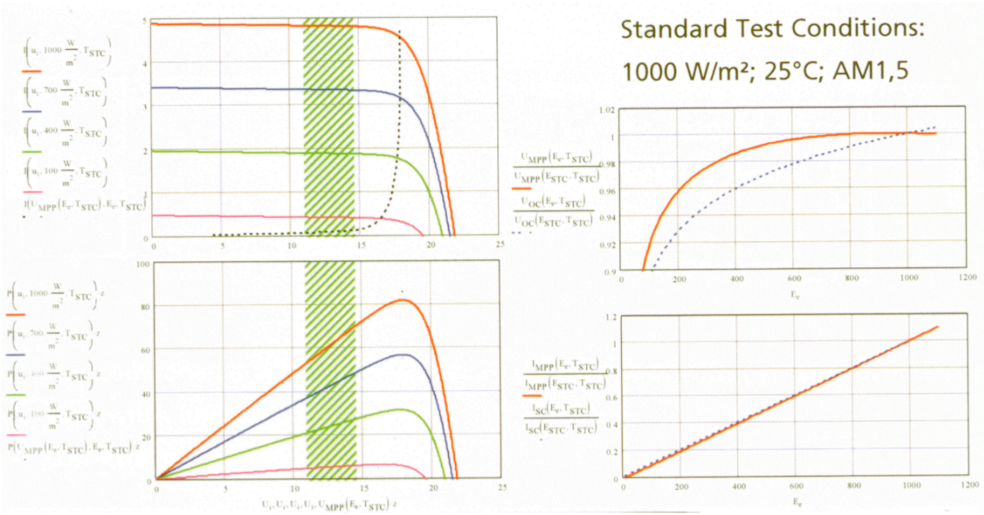
source: http://independentpowerllc.com/off-grid-solar.html

PV Installations by Application and Country

Not surprisingly, the split between off-grid and grid-connected photovoltaics differs from country to country. Off-grid pv applications offer a real alternative especially in countries with vast expanses (like Canada, Australia) or a less reliable national grid (Mexico).

IV-Curves of a solar module for different irradiations

3



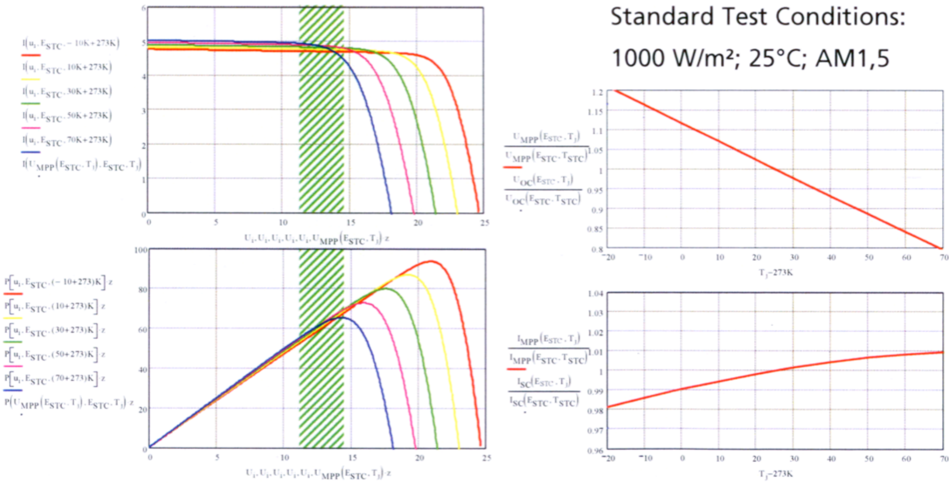
E_e: irradiations

AM1.5: terrestrial solar spectrum with suns position vector 48.3° away from ist perpendicular position

source: Fraunhofer, Institut Solare Energiesysteme: Power Electronics for Photovoltaics

IV-Curves of a solar module for different temperatures

4



The mismatch between solar cell voltage and battery voltage will guarantee a constant charging power independent from the panel temperature

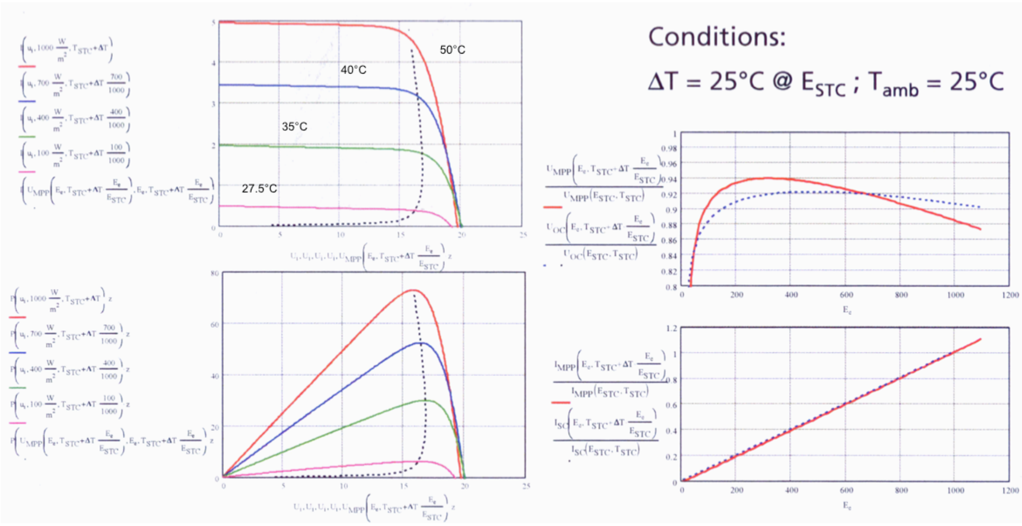
E_e: irradiations

AM1.5: terrestrial solar spectrum with suns position vector 48.3° away from ist perpendicular position

source: Fraunhofer, Institut Solare Energiesysteme: Power Electronics for Photovoltaics

IV_Curves for Different Irradiations and Steady Temperature

5



source: Fraunhofer, Institut Solare Energiesysteme: Power Electronics for Photovoltaics

Lead Acid Batteries: Compact-Power Towerline

Figure 1

Figure 2

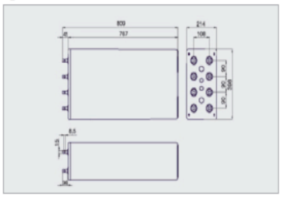
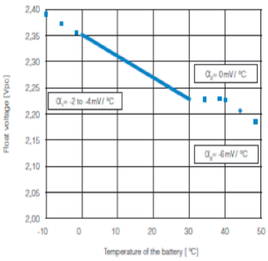


Figure 3



Temperature in °C	Temperature in °F	Percent of the rated capacity
40	104	104.8
35	95	104.2
30	86	103.6
25	77	103.0
20	68	100.0
15	59	97.0
10	50	94.0
5	41	90.0
0	32	84.7
-5	23	77.7
-10	14	69.4
-15	5	60.0
-20	-4	49.6
-25	-13	38.4
-30	-22	25.6
-35	-31	14.1
-40	-40	2.1

Type	2CP3000	
Part number	6136 3000	
Electrical Data		
Nominal voltage	2 V	
Number of cells	1	
Rated capacity C_{10} to 1.80 Vpc at 20 °C	2800 Ah	
Rated capacity C_8 to 1.75 Vpc at 25 °C	2776 Ah	
Current/Power for 0.5 h back-up time 1.65 Vpc 20 °C	2801 A	5044.4 W
Current/Power for 1.0 h back-up time 1.67 Vpc 20 °C	1940 A	3515.3 W
Current/Power for 2.0 h back-up time 1.80 Vpc 20 °C	1043 A	1908.9 W
Current/Power for 4.0 h back-up time 1.80 Vpc 20 °C	588 A	1106.6 W
Current/Power for 8.0 h back-up time 1.80 Vpc 20 °C	333 A	618.6 W
Current/Power for 10.0 h back-up time 1.80 Vpc 20 °C	280 A	511.1 W
Current/Power for 20.0 h back-up time 1.80 Vpc 20 °C	147 A	277.9 W
Conversion to capacity at 25 °C (77 °F)	20 °C Ah x 1,03 (t > 1 h)	
Internal resistance (± 10%) to IEC/EN 60896-21	≈ 0.08 mΩ	
Short circuit current (± 10%) to IEC/EN 60896-21	≈ 31 kA	
Self discharge at 20 °C to IEC/EN 60896-21	max. 3%/month	
Heat loss during float service at 20 °C	≈ 3 W	
Mechanical Data		
Weight ready for use	180 kg	
Depth of monobloc	767 mm	
Depth over terminal connector	809 mm	
Width	214 mm	
Height (operate horizontally only)	398 mm	
Number of terminals	4⊕/4⊖	
Dimension of connector screw hole	M8	
Suggested/maximum cable cross-section	8 · 185 mm²	
Connection torque	25 Nm	
Terminal insulation class according to IEC/EN 60529	IP20	
Diameter of diagnostic hole for voltage probe	4.0 mm Ø	
Connector (copper, tin-coated) rigid and insulated	8 · 180 mm²	
Complete connector and terminal connection accessoires	available	
Environmental Data		
Shelves, cabinets and racks	available upon request	
Installation	only horizontally	
Distance for cooling and ventilation (preset with the rigid connectors)	10 mm	
Flame retardancy rating case/cover according to Underwriters Laboratories (UL) USA	ABS-PC – UL 94 V-0 with LOI > 32%, halogen-free	
Flame barriers at vents	installed	
UL file number	MH 26065	
Service life expected at 20 °C	15 years	

Lead Acid Batteries

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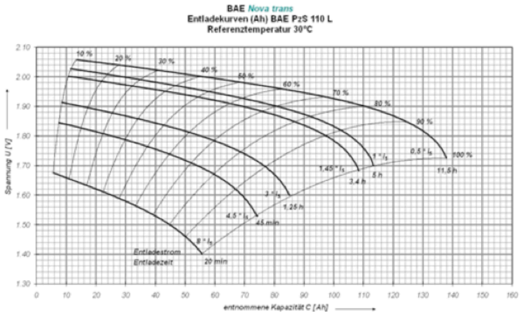
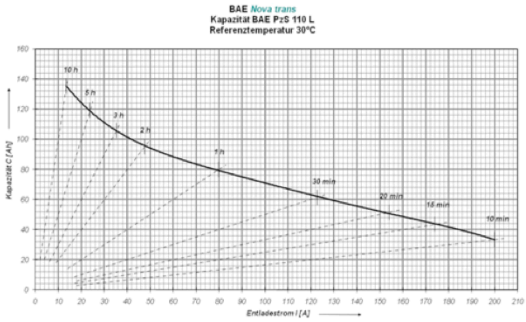
source: http://www.iea-pvps.org/products/download/rep3_06.pdf

- In normal operation of a storage battery there are four major reasons for the ageing process:
  - deep discharge (this gives irreversible sulphation)
  - overcharge (this increases the corrosion velocity)
  - low electrolyte level exposing the electrodes to air (this reduces the capacity permanently and increases the corrosion velocity)
  - high battery temperature (this increases the corrosion velocity)
- In most cases a modern controller in the PV (Photovoltaic) system will take care of the these and therefore a good PV charge controller is a very cost-effective investment.





How to size the battery for a certain system and load.

As an example one can take a small 12V PV solar home system with 2 lamps of 11W used 5 hours a day and a 15W Television set used 3 hours per day.

1. First calculate the daily energy use or load in the system:

The daily energy use will be < Number of appliances * Power consumption * operating per day >. Example with data from above: 2 * 11W * 5h + 1 * 15W * 3h = 155 Wh per day.

2. Then calculate the design energy content of a suitable battery available locally:

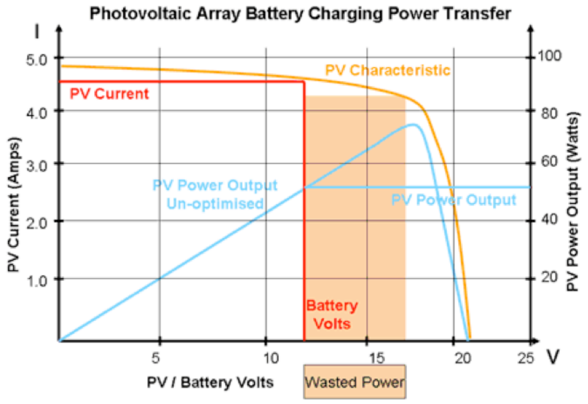
For example a 12V / 75Ah battery contains nominally about 1 kWh. More exactly 75Ah * 12V = 900Wh if fully discharged. According to the rules given above only 80% of the capacity can be counted on in the long run. Further more to extend the battery life only 50% of that should be discharged each day at the most. Totally only 0.8 * 0.5 = 0.4 or 40% of the nominal energy content should be base for sizing. In this case 40% of 900Wh = 900 * 0.4 = 360Wh. The design energy content of this battery is 360Wh or 0.36 kWh.

3. Calculate the number of batteries needed:

Normally the sizing of a small system is done so that the battery has enough energy for 3-7 days energy use without sunshine. In this case one 12V / 75 Ah battery has an energy content of about 2 days use (360Wh / 155Wh/day = 2.3 days). At latitudes close to the equator (± 40° latitude) with more even annual distribution of the solar energy, 2 batteries should be enough in this example giving (2 * 2.3 = 4.6 days autonomy). At latitudes higher than 40° 3-4 batteries can be recommended giving 7-9 days autonomy in this case. In a real application there will be a close connection between the service you can get and the battery size and installed PV module power, but also the user interaction can have a large influence. With a modern controller the user can read the battery state of charge and the load can be adjusted to the available energy stored in the batteries. This means that more energy than design can be used during sunny weather and less during very cloudy or rainy periods.

Maximum Power Point Tracking

- Needed to reach maximum output power of photovoltaic module independent of
  - load impedance
  - module temperature
  - Irradiance
- Increase of energy yield between 15-30% for off-grid battery chargers
- Tracking algorithm requires
  - Measurement of at least two of the module values: electrical values (V, I) and temperature (T)



source: http://www.mpoweruk.com/solar_power.htm

Maximum Power Point Tracking (MPPT)

A power source will deliver its maximum power to a load when the load has the same impedance as the internal impedance of the power source. (Jacobi's Law). Unfortunately, batteries are far from the ideal load for a solar array and the mismatch results in major efficiency losses.

A typical PV array designed to charge 12 Volt batteries delivers its maximum power at an operating voltage around 17 Volts. Lead Acid batteries are normally charged up to 14 Volts though the voltage quickly drops to 12 Volts as they start to deliver current and lower still as the depth of discharge (DOD) increases.
In its simplest form, charging is carried out by connecting the PV array directly across the battery. The battery however is a power source itself and presents an opposing voltage to the PV array. This pulls the operating voltage of the array down to the voltage of the discharged battery and this is far from the optimum operating point of the array.

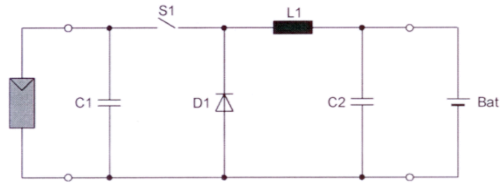
The diagram below shows the performance of a17 Volt, 4.4 Amp, 75 Watt PV array used to top up a 12 Volt battery. If the actual battery voltage is 12 Volts, the resulting current will only be about 2.5 Amps and the power delivered by the array will be just over 50 Watts rather than the specified 75 Watts: an efficiency loss of over 30%.
Maximum Power Point Tracking is designed to overcome this problem.

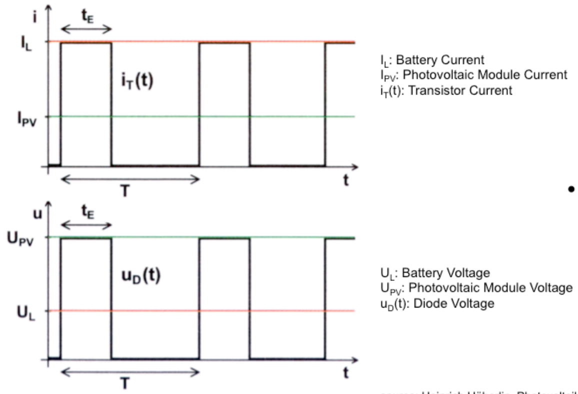
The power tracker module is a form of voltage regulator which is placed between the PV array and the battery. It presents an ideal load to the PV array allowing it to operate at its optimum voltage, in this case 17 Volts, delivering its full 75 Watts regardless of the battery voltage. A variable DC/DC converter in the module automatically adjusts the DC output from the module to match the battery voltage of 12 Volts.
As the voltage is stepped down in the DC/DC converter, the current will be stepped up in the same ratio. Thus the charging current will be 17/12 X 4.4 = 6.2 Amps and, assuming no losses in the module, the power delivered to the battery will be 12 X 6.23 = the full 75 Watts generated by the PV array.
In practice the converter losses could be as high as 10%. Nevertheless a substantial efficiency improvement is possible.

It is not enough however to match the voltage at the specified maximum power point (MPP) of the PV array to the varying battery voltage as the battery charges up. Due to changes in the intensity of the radiation falling on the array during the day as well as to changes in the ambient temperature, the operating characteristic of the PV array is constantly changing and with it the MPP of the PV also changes. Thus we have a moving reference point and a moving target. For optimum power transfer, the system needs to track the MPP as the solar intensity and ambient temperature changes in order to provide a dynamic reference point to the voltage regulator.

Off-Grid – Battery Charger: MPPT Regulator

source: Fraunhofer, Institut Solare Energiesysteme: Power Electronics for Photovoltaics

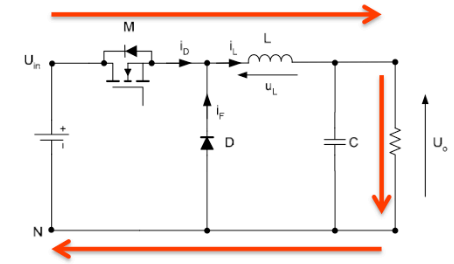


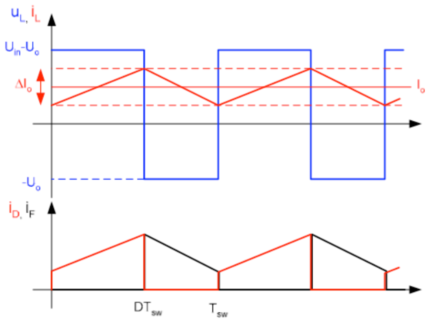


- Simple Buck Circuit
  - Input Switch acts as overcharge protection
  - Systems also include discharge protection
- Features
  - + MPP-tracking
  - + fits all module type
  - - more complex control
  - - EMC-behavior
  - - more circuit losses
- Suppliers
  - Morningstar: SunsaverMPPT
  - Outback: MX60
  - Phocos: MPPT 100/20-1
  - Steca: Solarix MPP
  - Würth: Controla Maxi Power

source: Heinrich Häberlin, Photovoltaik, , AZ Verlag 2007

Step-down (Buck) Converte: on-phase





Output current:

$$I_o = \frac{P_o}{U_o}$$

Duty cycle in continuous conduction mode:

$$D = \frac{U_o}{U_{in}}$$

Output current ripple:

$$\Delta I_o = \frac{(1-D)U_o}{L \cdot f_{sw}}$$

$$I_{Don} = I_o - \frac{\Delta I_o}{2}$$

$$I_{Doff} = I_o + \frac{\Delta I_o}{2}$$

$$I_{Drms}^2 = D \cdot I_o^2 = (\sqrt{D} \cdot I_o)^2$$

$$I_{Fav} = (1-D) \cdot I_o$$

$$I_{Frms}^2 = (1-D) \cdot I_o^2 = (\sqrt{1-D} \cdot I_o)^2$$

Circuit description

The three basic dc-dc converters use a pair of switches, usually one controlled (eg. MOSFET) and one uncontrolled (ie. diode), to achieve unidirectional power flow from input to output. The converters also use one capacitor and one inductor to store and transfer energy from input to output. They also filter or smooth voltage and current.

The dc-dc coverters can have two distinct modes of operation: Continuous conduction mode (CCM) and discontinuous conduction mode (DCM). In practice, a converter may operate in both modes, which have significantly different characteristics. Therefore, a converter and its control should be designed based on both modes of operation. However, for this course we only consider the dc-dc converters operated in CCM.

Circuit Operation. When the switch is on for a time duration DT, the switch conducts the inductor current and the diode becomes reverse biased. This results in a positive voltage vL = Vg – Vo across the inductor. This voltage causes a linear increase in the inductor current iL. When the switch is turned off, because of the inductive energy storage, iL continues to flow. This current now flows through the diode, and vL = -Vo for a time duration (1-D)T until the switch is turned on again.

Step-down (Buck) Converter: off-phase

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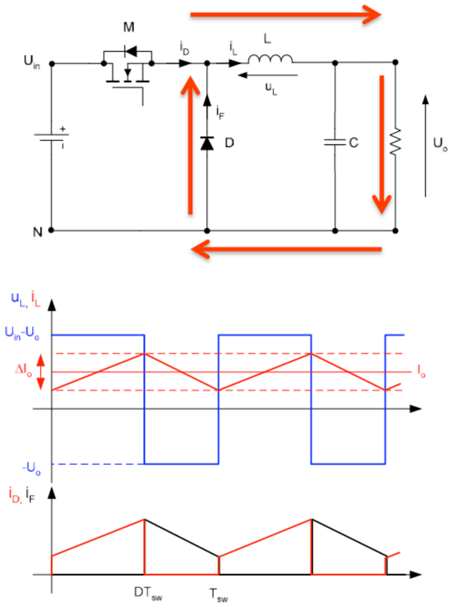

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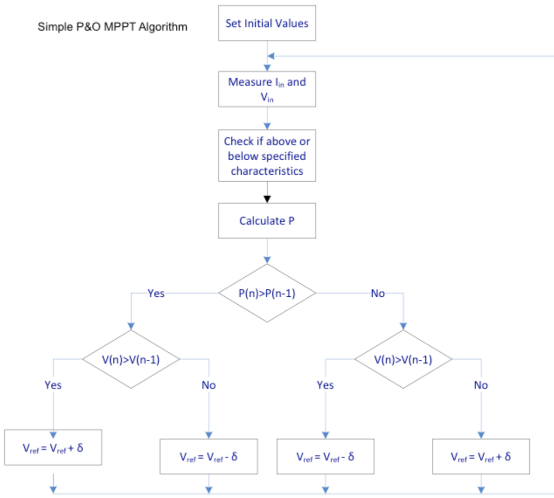
Simple P&O MPPT Algorithm



source: BFH TI, MPPT Air Design Description, Simonin/Vezzini, 2006

High performance MPPT modules may incorporate software algorithms to take account of the variations in insolation and temperature. A typical job for fuzzy logic or a neural network. Alternatively the optimisation can be accomplished in hardware by means of a perturbation signal incorporated in a feedback loop which drives the system operating point to the MPP.

A small dither voltage is superimposed on the PV voltage and its affect on the regulator output current feeding the battery is monitored. If the current drawn by the battery increases when the dither voltage increases, then the operating point has moved towards the MPP and therefore, the operating voltage must be increased in the same direction. On the other hand, if the current into the battery decreases, then the operating point has moved away from the MPP and the the operating voltage must be decreased to bring it back.

Design Study: Steca Solarix MPPT

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Product features

- Maximum Power Point Tracker (MPP tracker)
- Voltage and current regulation
- PWM control
- Temperature compensation

Electronic protection functions

- Overcharge protection
- Deep discharge protection
- Reverse polarity protection of load, module and battery
- Short circuit protection

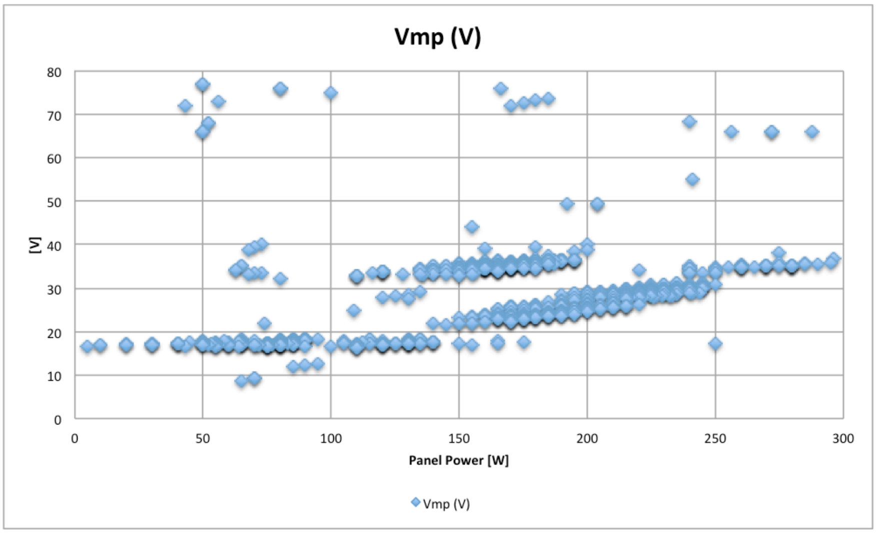
	MPPT 1010	MPPT 2010
Characterisation of the operating performance		
System voltage	12 V (24 V)	
Nominal power	125 W (250 W)	250 W (500 W)
Max. efficiency	> 98 %	
Own consumption	10 mA	
DC input side		
MPP voltage	15 V (30 V) < V_{module} < 75 V	15 V (30 V) < V_{module} << 100 V
Open circuit voltage solar module (at minimum operating temperature)	17 V ... 75 V (34 V … 75 V)	17 V ... 100 V (34 V … 100 V)**
Module current	9 A	18 A
DC output side		
Charge current	10 A	20 A
Load current	10 A	
End of charge voltage*	13.9 V (27.8 V)	
Boost charge voltage*	14.4 V (28.8 V)	
Equalisation charge*	14.7 V (29.4 V)	
Reconnection voltage (LVR)*	12.5 V (25 V)	
Deep discharge protection (LVD)*	11.5 V (23 V)	
Operating conditions		
Ambient temperature	-25 °C … +40 °C	
Fitting and construction		
Terminal (fine / single wire)	16 mm² / 25 mm² - AWG 6 / 4	
Degree of protection	IP 32	
Dimensions (X x Y x Z)	187 x 153 x 68 mm	
Weight	approx. 900 g	

Steca Solarix MPPT

MPPT 1010, MPPT 2010

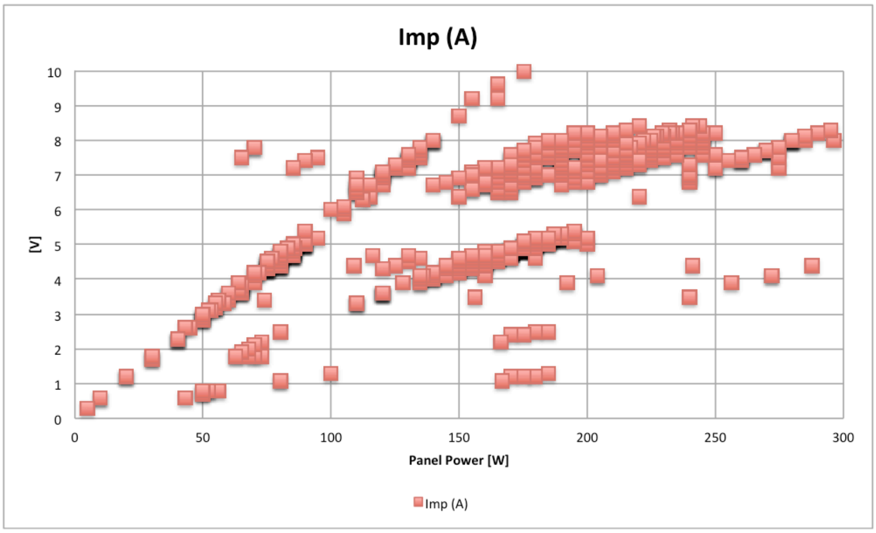
Steca Solarix MPPT is a solar charge controller with Maximum Power Point Tracking. It is specially designed to work with all established module technologies and is optimized for solar systems with module voltages higher than the battery voltage. The Steca Solarix MPPT is especially qualified in combination with grid tied solar modules. The advanced MPP-tracking algorithm from Steca assures that the maximum available power of the solar generator is charged to the batteries. The Steca Solarix MPPT with latest technology ensures full performance in all conditions, a professional battery care combined with modern design and excellent protection.

Panel Analysis: Power vs. Panel MPPT Voltage



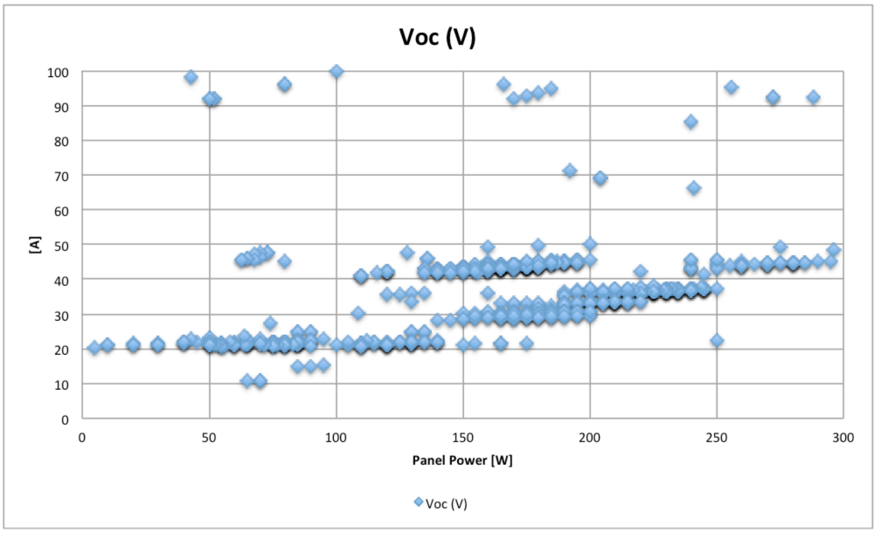
Panels up to 300W available with MPPT-Voltage below 40V, Range: 16-40V

Panel Analysis: Power vs. Panel MPPT Current



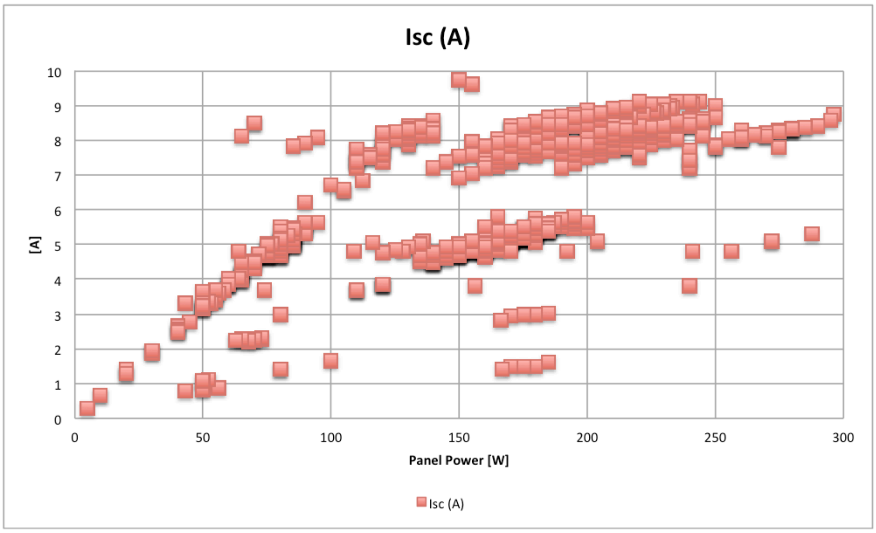
Panels up to 300W available with MPPT-Current below 9A, Range: 4.5 (6) and 9A

Panel Analysis: Power vs. Panel Open Circuit Voltage



Panels up to 300W available with OC-Voltage below 50V, Range: 19-50V

Panel Analysis: Power vs. Panel Short Circuit Current

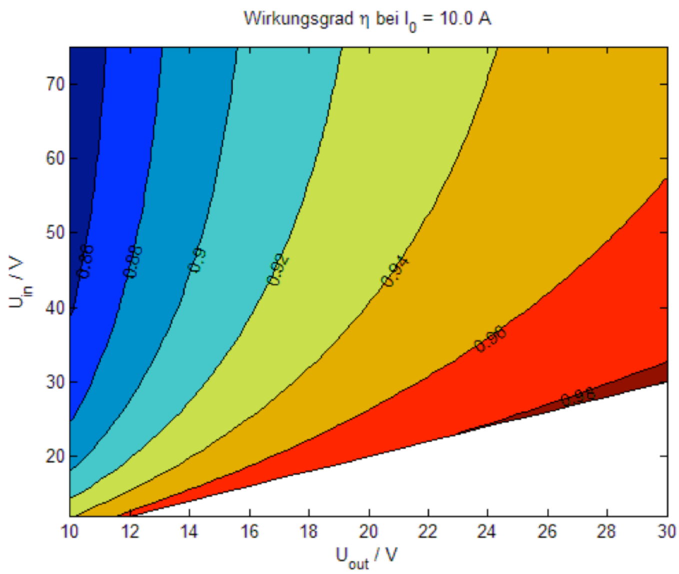


Panels up to 300W available with SC-Current below 9A

Task

- Establish voltage and current range for input and output values of the Steca Solarix MPPT using a simple excel sheet
- For an ideal converter (no losses): In function of the output voltage and the power
  - Establish 3D plots for duty cycle d
  - Calculate the efficiency over the whole input/output range and plot it over the output current range as animated surface plot
  - Draw 3D plot of current ripple Δi and required critical inductor value over the whole input/output range and calculate the minimum required inductor value
- Write a short 5-page report on all the design steps (including capacitor and inductor selection (next 2 weeks topic)

Results


Wirkungsgrad η bei I0 = 10.0 A
0.86
0.88
0.9
0.92
0.94
0.96
0.98
70
60
50
40
30
20
Uin / V
10
12
14
16
18
20
22
24
26
28
30
Uout / V