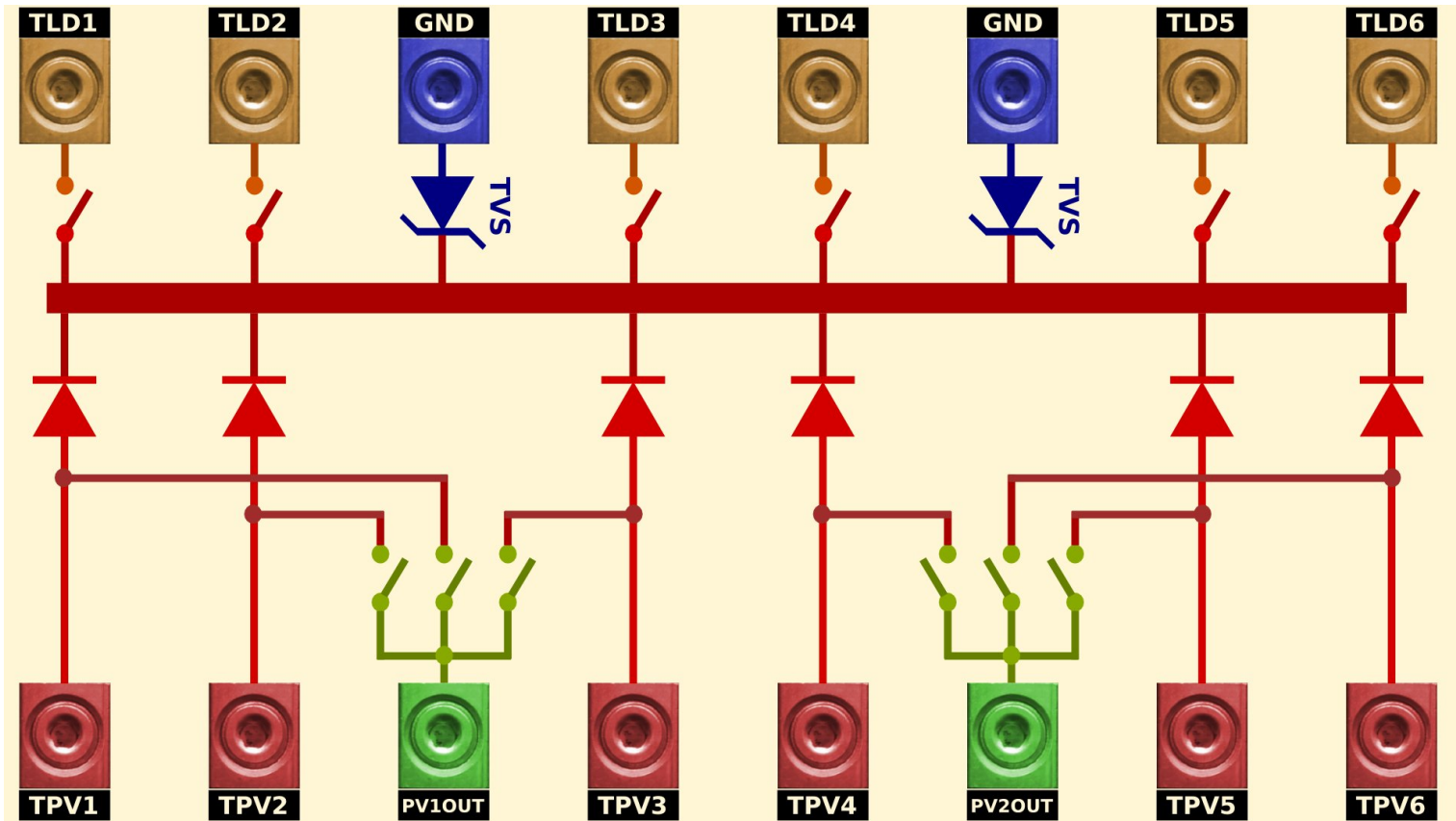


Specification

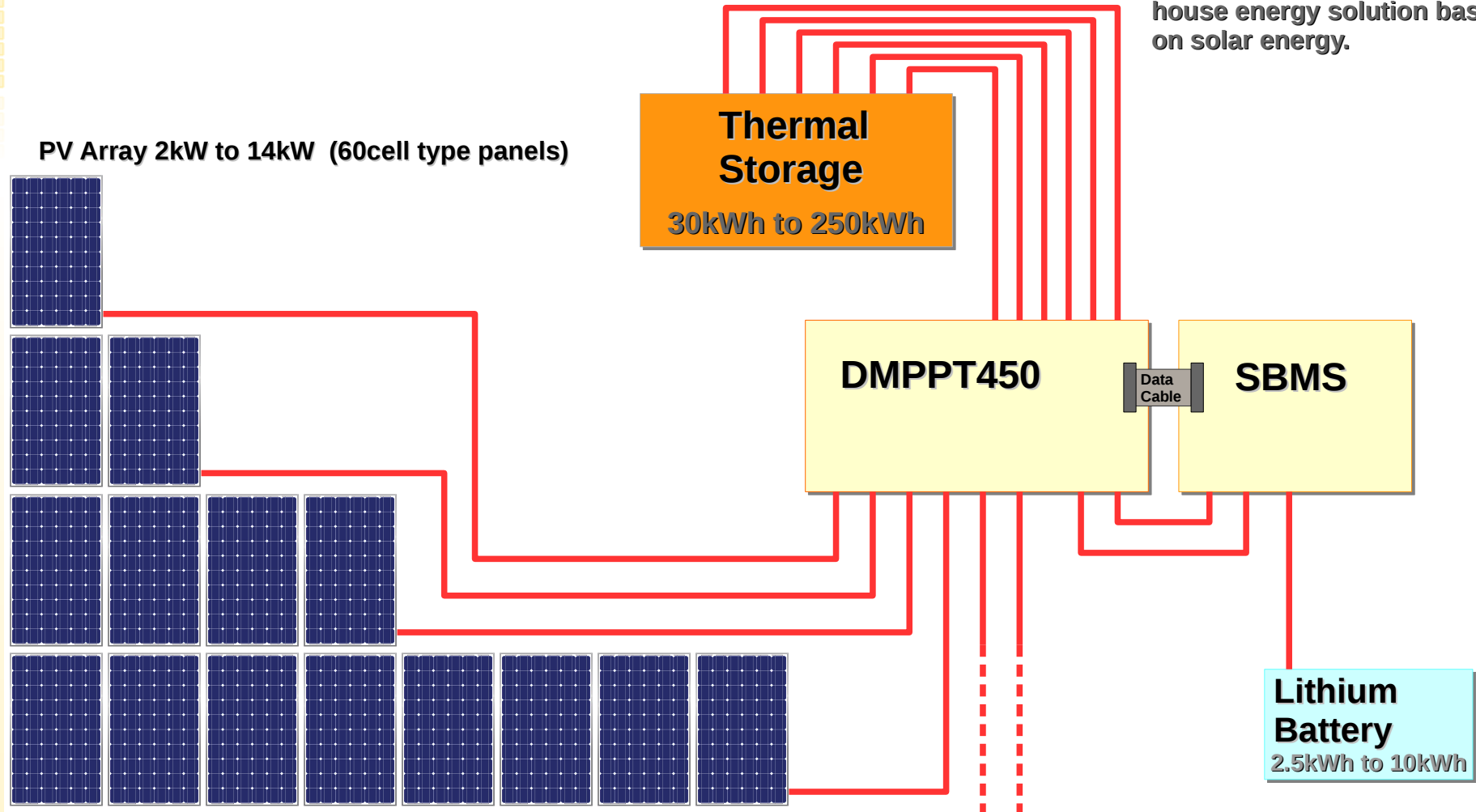
TPV2, TPV5	50A max (5x 60 cell PV panels)
TPV3, TPV4	75A max (7x 60 cell PV panels)
TPV1, TPV6	100A max (10x 60 cell PV panels)
TLD2, TLD3, TLD5	50A max resistive heating elements only
TLD1, TLD4, TLD6	100A max resistive heating elements only
Max PV Open Circuit voltage	40V STC (mono or polycrystalline panels with 60 cells)
TPVx inputs	separate current measurement and ideal diode's
ET1 (TLD2, TLD3, TLD5)	NTC 10kOhm B3950 temp sensor (default +60°C without SBMS)
ET2 (TLD1, TLD4, TLD6)	NTC 10kOhm B3950 temp sensor (default +60°C without SBMS)
Internal temperature limit	+70°C (measured inside the microcontroller so reading a bit higher)
All 16 power connectors	max AWG #1/0 (50mm2) use flexible cables (minim hundred's of strands)
UARTTX (pin 2 on 8pin side connector)	115.2 Kbps (you need to add external optical isolation)
16pin connector	For firmware update and I2C communication with SBMS trough included cable
Total size of PV array (60 cell panels 250W to 300W)	1 to 44 PV panels (15 to 39 is the most practical and economical)
Self consumption	1W to 3W directly from PV array
Max TDP	52W (full configuration) so add large passive heatsink
Dimensions	245mm x 120mm x 32mm
Weight	1070g

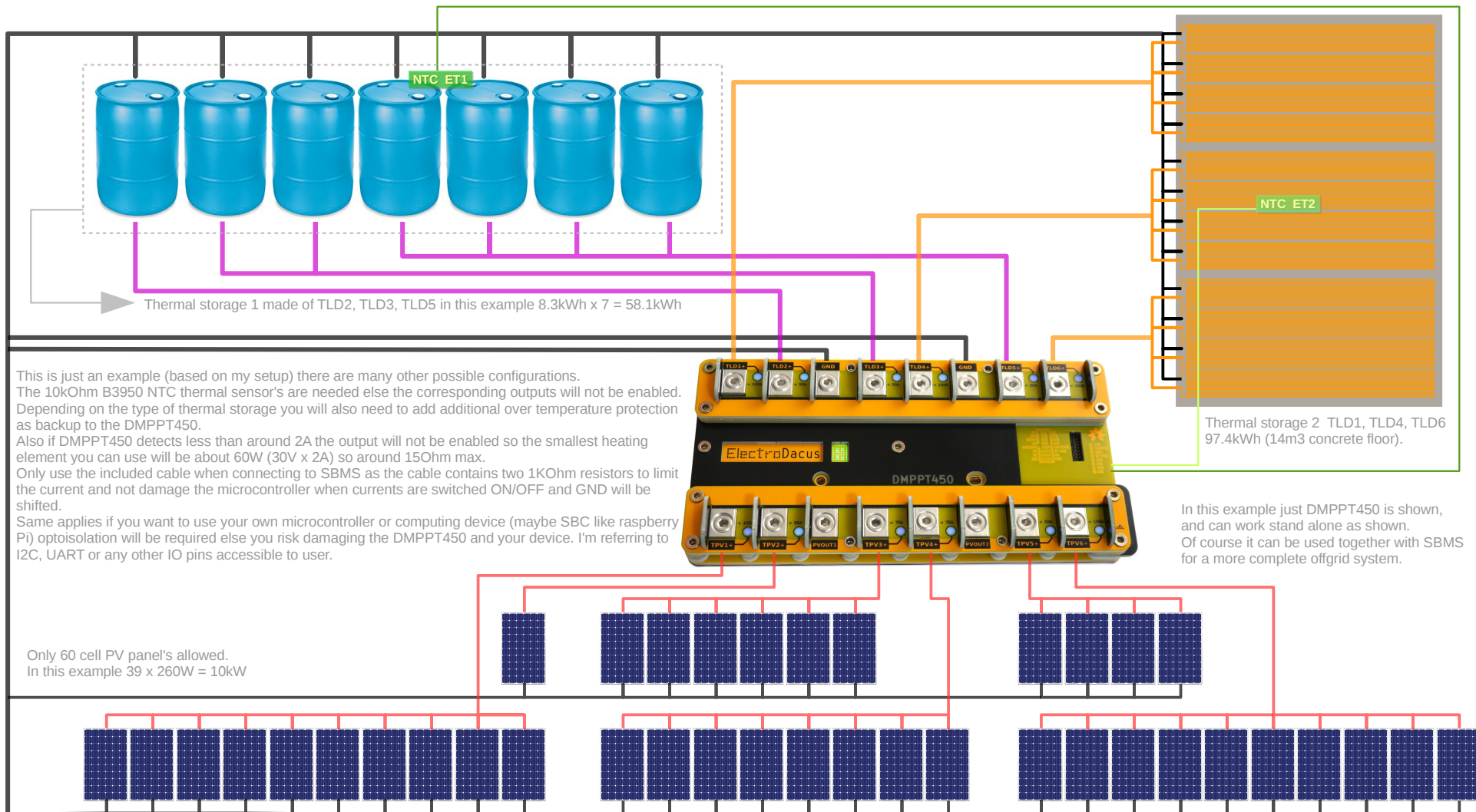
DMPPT450 simplified internal diagram.

The diagram is an oversimplification to show the way it operates. For example the diodes are ideal diodes made out of mosfet's and ideal diode drivers and the switches are solid state relays made up of mosfet's and high side mosfet drivers. Many other parts are not represented to keep the diagram clean like current shunt sensors are placed on all TPVx inputs and the two PvxOUT followed by current sense amplifiers and going in to a 16-bit ADC to be used in DMPPT algorithm by the cortex M4 based MCU.



Simplified Diagram of a complete house energy solution based just on solar energy.





This is just an example (based on my setup) there are many other possible configurations. The 10kOhm B3950 NTC thermal sensor's are needed else the corresponding outputs will not be enabled. Depending on the type of thermal storage you will also need to add additional over temperature protection as backup to the DMPPT450. Also if DMPPT450 detects less than around 2A the output will not be enabled so the smallest heating element you can use will be about 60W (30V x 2A) so around 150Ohm max. Only use the included cable when connecting to SBMS as the cable contains two 1KOhm resistors to limit the current and not damage the microcontroller when currents are switched ON/OFF and GND will be shifted. Same applies if you want to use your own microcontroller or computing device (maybe SBC like raspberry Pi) optoisolation will be required else you risk damaging the DMPPT450 and your device. I'm referring to I2C, UART or any other IO pins accessible to user.

In this example just DMPPT450 is shown, and can work stand alone as shown. Of course it can be used together with SBMS for a more complete offgrid system.

DMPPT advantage when both heating and off-grid electricity is needed.

Below you can see a) 39x 260W PV panel array exactly as I will be using for my off-grid house. Lithium battery has priority for charging and as many as needed from the 39 panels will be redirected to battery charging and all the energy not needed for electrical appliances and battery charging will be stored in the much larger and less expensive thermal mass.

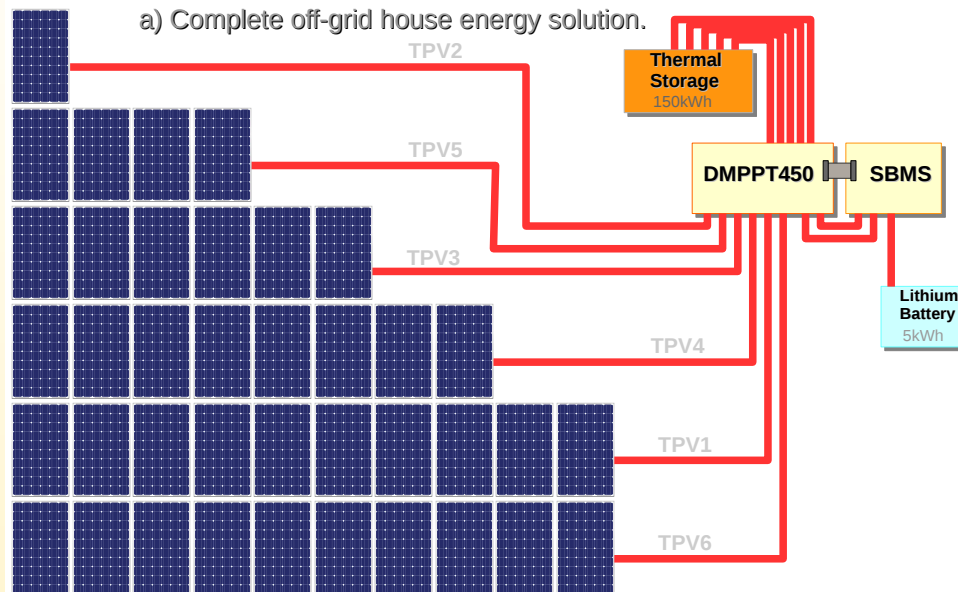
The 5kWh LiFePO4 battery will cost around \$2000 (at the current price of \$400/kWh) and in real use case scenario that will have a cost amortization over the life of the battery of about 25 cent/kWh while the much larger 150kWh thermal mass will cost around or even less than \$2000 (so less than \$14/kWh) and if just 25 years life is considered the cost amortization will be well below 0.5cent/kWh so extremely low compared to electricity storage in Lithium battery and ideal for heating and or cooling (cooling is more complex will need the use of custom build peltier cooling devices).

Solar PV panels have a cost amortization of 2.4cent/kWh (based on acquisition cost of 80cent/Watt, 25 years amortization period and amount of sun at my location).

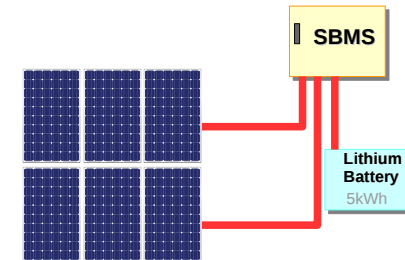
So based on this thermal mass storage is the most cost effective 0.5cent/kWh so the use of that needs to be maximized next is solar PV solar at about 2.4cent/kWh and last as the most expensive in terms of cost amortization is Lithium battery storage so that needs to be kept as small as possible (but all 3 are needed for a cost effective complete energy solution). Having the large PV array for heating will allow much more electricity use with the same battery size compared to just b) simple PV array and Lithium battery as seen in the graph on the next page.

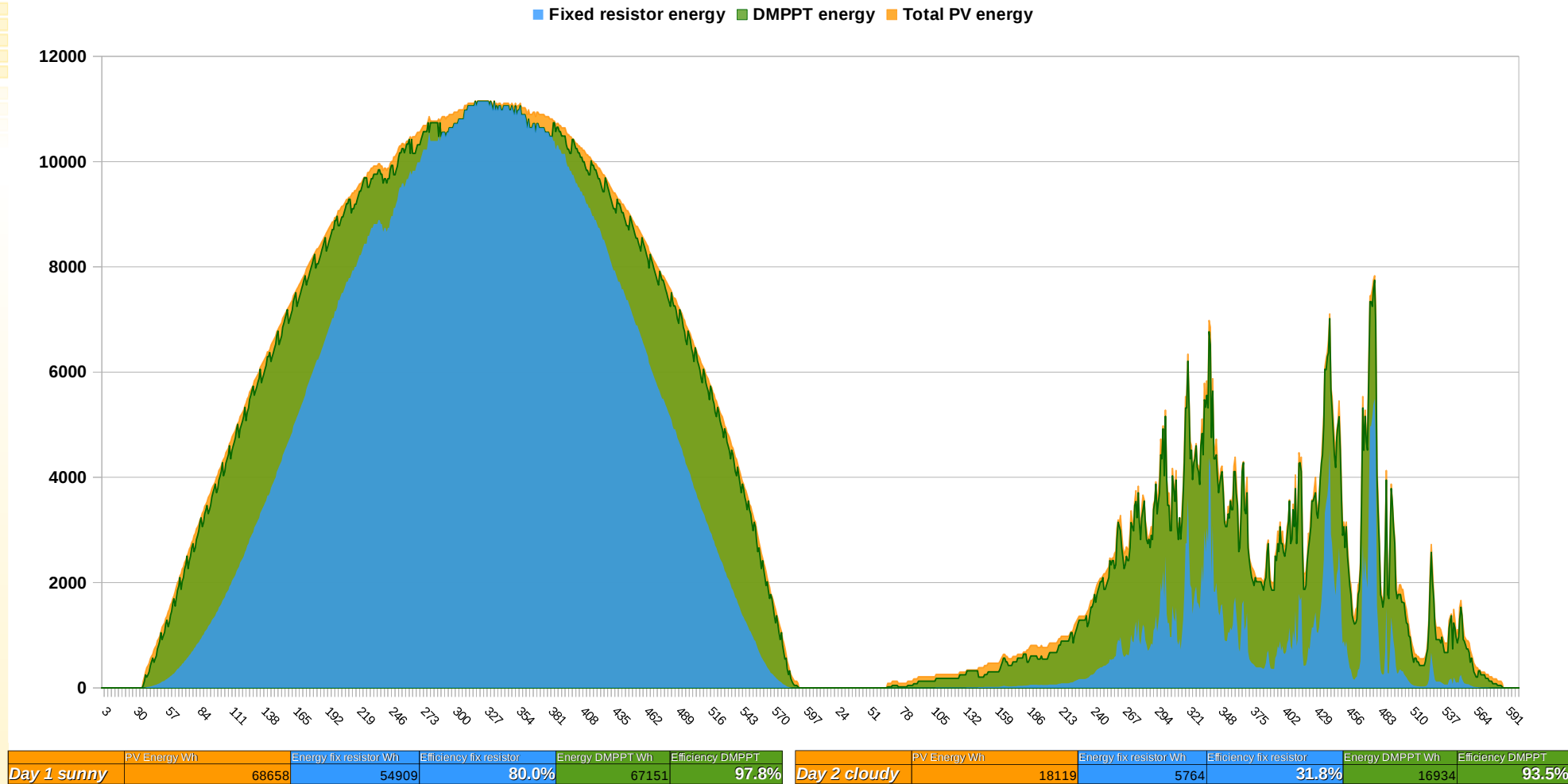
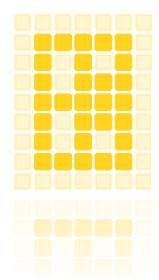
In winter with solution b) at my location you can expect to use around 100kWh/month while with a) 200kWh are possible for electric appliances all the rest will be used for heating.

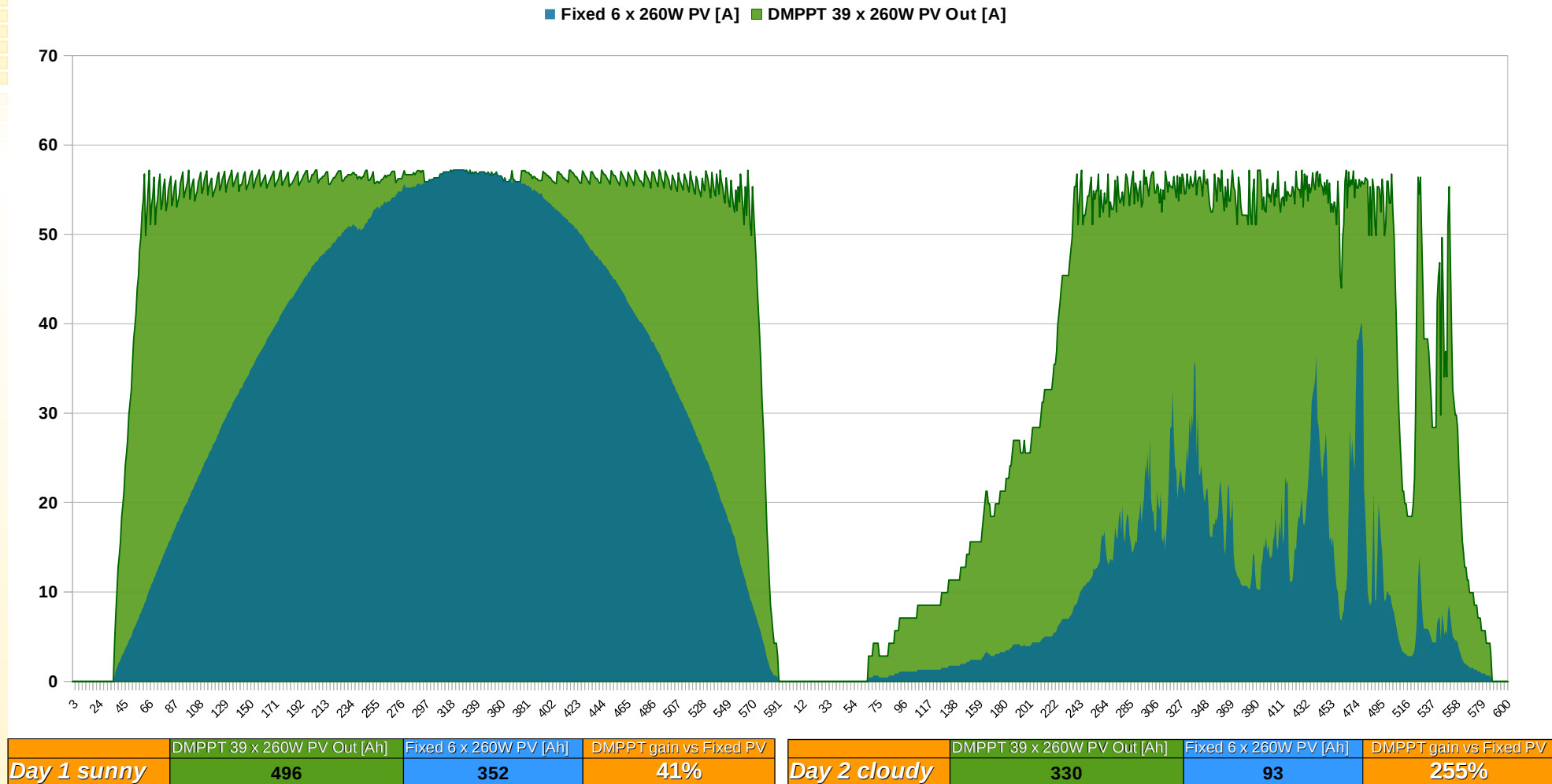
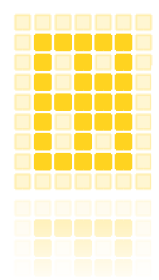
So if you want 200kWh with solution b) at my location in winter then PV array will need to be double 12x 260W panels and battery will also need to be increased to 10kWh.



b) Off-grid electricity only.







Thermal storage solutions.

Thermal storage is an important part of the solar PV heating solution but the thermal storage can be done in many different ways and using different storage materials so below I will give a few example so that you can make your calculations based on your own needs.

Almost any solid or liquid can be used for thermal storage but the most common is water and concrete or sand/stone.

a) Water can usually be considered free so the cost in this case is related to storage and I selected in this example a very common 206 Litres (55 Gallon) HDPE barrel than can be had new for about 60 USD or used/recycled for much less.

The water has the highest heat capacity of any liquid and is 4185.5 J/(kg·K) where 1 Joule is actually 1Watt-second to transform this in Watt-hour you just need to divide this by 3600 the number of seconds in one hour. So heat capacity of water is about 1.16Wh/(kg·K) and since water density is about 1 then 1kg of water is the same as 1 litre of water and a delta of 1 Kelvin is the same as a delta of 1 Celsius the calculation of amount of energy stored in that barrel of water is quite simple.

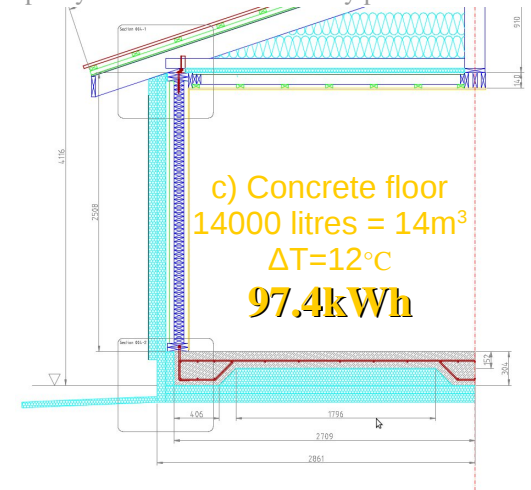
Say that usable temperature range in that HDPE barrel is 20°C to 55°C so usable temperature delta is 55°C-20°C = 35°C then 206 litre * 35°C * 1.16Wh/(litre·°C) = 8363.6Wh = 8.364 kWh this is a large storage capacity for a small cost and almost infinite cycle life so I hope this shows why thermal storage is so important in a solar setup.

b) Second example is based on a generic 1 cubic meter of concrete or sand (they will have about the same storage capacity) 880 J/(kg·K) this looks bad compared to water by weight but since the concrete has higher density 2400kg/cubic meter things are not as bad by volume about half compared to water at 0.58Wh/(litre·°C) (one cubic meter = 1000 litres)

The amount of energy you can store in that cubic meter of concrete depends how large is the usable temperature delta.

If the concrete is actually a floor used for storage as in my house then max delta is probably just 10 to 12°C but if this is a cube maybe thermally insulated and used in a separate space then you can have maybe a temp delta as high as 80 to 100°C or even higher then 1000 litres * 100°C * 0.58Wh/(litre·°C) = 58kWh

c) My house already integrates a 14 cubic meter concrete floor so 14000 litres * 12°C * 0.58Wh/(litre·°C) = 97.4kWh of storage capacity at no cost since is already part of the house structure.



So you may be asking how do you transfer the energy to thermal mass and answer is fairly simple if all you want is heating (yes cooling possible with peltier modules but more complex and maybe I will get in to more details about that in another paper).

Simplest will be the case c) where thermal mass in the house concrete floor thermally insulated from the outside as it is done on my house since then all can be solid state and not much else is needed other than some simple copper wires acting as resistive heat elements embedded in the concrete floor.

The entire floor in my case will be covered with ceramic tiles (it is not as of the time I write this) and the copper cable for heating will be embedded under the ceramic tiles.

Probably almost any type of copper cable will work but my recommendation will be using one of the following 150°C to 200°C silicone insulated cables, enamelled copper wire or Teflon isolated copper wires.

Personally I will be using 200°C rated silicone insulated cables since they are easily available and relatively inexpensive. The cable thickness can be somewhere in the range of 0.3mm² to 0.8mm² (#22 AWG to #18 AWG) since that will give the best length vs resistance at around 30V DC max power point of 60 cell PV panels and at a good cost.

I already got #18 AWG 200°C cable since I got a good deal and I will be using that for my house and in this example.

This #18 AWG 200C cable is rated for a max of 24A in free air and while this will be embedded in concrete where thermal conduction will be much better I do not want to exceed that so since max power point voltage is around 30V the worst case in winter may be higher 33 to 36V possible and the cable resistance is about 21mOhm/m for this cable.

$36V/24A = 1.5\Omega$ so cable will need to be $1.5\Omega/0.021\Omega/m = 71.4m$.

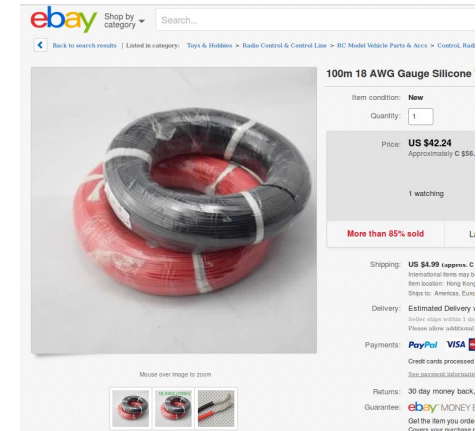
At this worse case scenario $36V \times 24A = 864Watt$ I have about 12W/m of cable but more realistic or typical will be about 32 to 33V max power point in a cold winter day for current generation 60 cell PV panels so $33V/1.5\Omega = 22A$ and $33V \times 22A = 726W$ so about 10W/m of cable.

For the concrete floor I will be using a total of 12 of this 71.4m loops $726W \times 12 = 8712W$ and since my usable floor space inside the house is around 57m² then I will have about $8712/57m^2 = 153W/m^2$

From this (153W/m² and 10W/m) I can calculate what will be the spacing needed for this cable $1/(153/10) = 0.065m$ so the distance between two wires will need to be around 6.5cm.

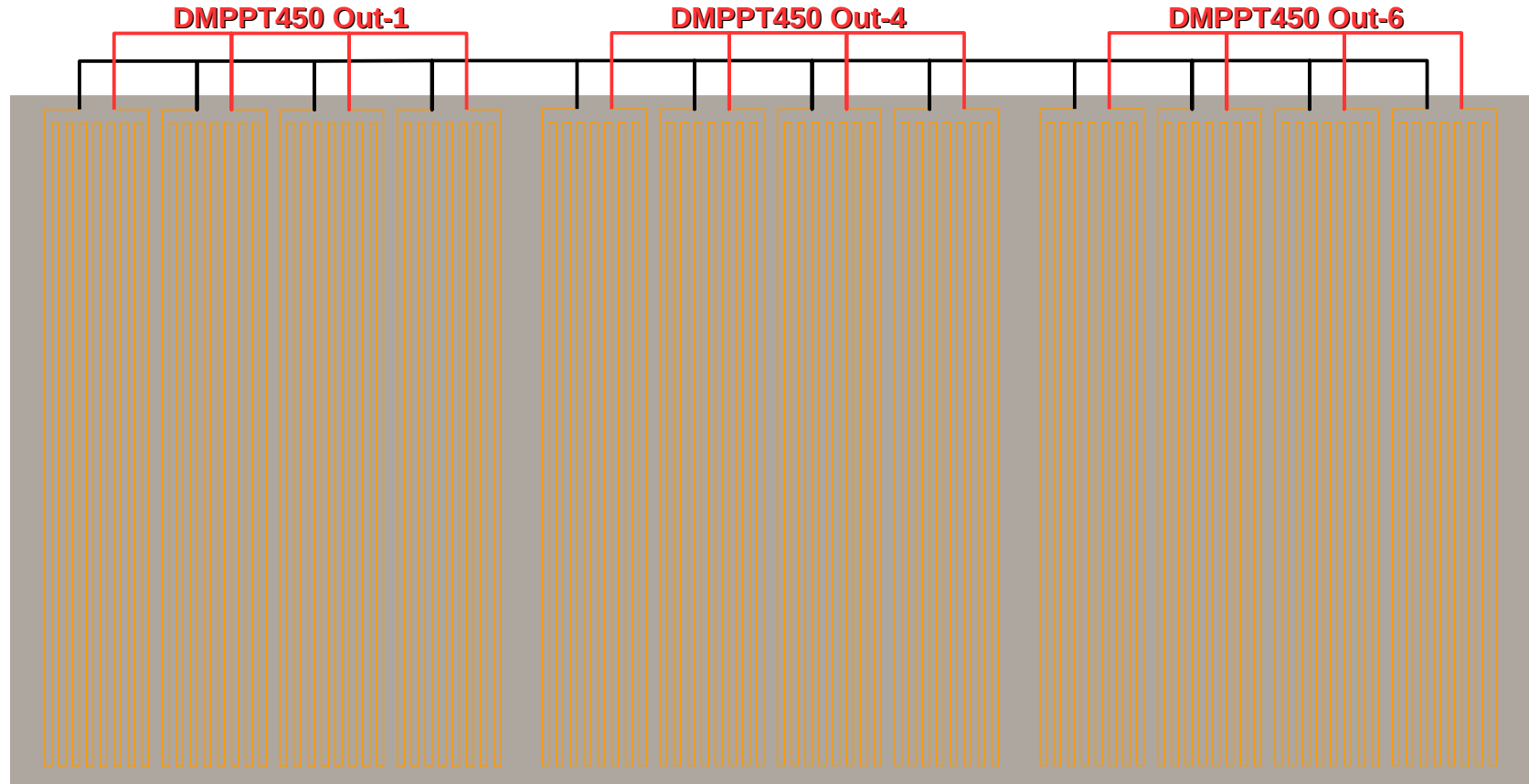
But if the math above is confusing (for sure my fault) no worries since I will provide a tool to simply calculate all this based on your requirements.

Total length for this heating cable will be $12 \times 71.4m = 856.8m$ (rounded to 900m) and total cost will be around 425USD including shipping as you can see in the below eBay screenshot. I think the price is very reasonable so it makes no sense to try and save something here (this should last the life of the house).



Thermal storage example for my house simplified diagram.

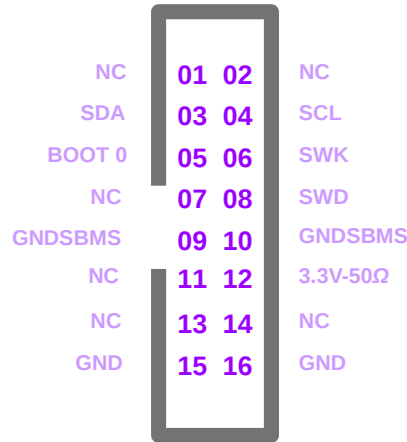
As mentioned in the anterior page there will be 12 resistive heat loops and they are grouped in 3 zone each with 4 parallel groups and each of this 3 groups is connected to one of the DMPPT450 output. The other 3 outputs of the DMPPT450 will be connected to another smaller thermal storage for domestic hot water and to preheat the air getting out of the air heat recovery unit. Those other 3 outputs together will have a lower power than one of this single 3 outputs used for the floor heating/floor thermal mass storage.



In order to maximize the usage of the DMPPT450 the total heat power that is desired will need to be split between the 6 outputs in the following way. Say you want a 11.25kW output and you have you panels with a 33V max power point in your average winter temperature so about 341A max current. The way you will want the outputs setup will be as the last 3 outputs (Out-6, Out-5 and Out-4) all equal say with x then the other 3 outputs (Out-3, Out-2 and Out-1) will be $1/2x$, $1/4x$ and $1/8x$ respectively in order to maximize the max power point. So total of all outputs will be $3x + 1/2x + 1/4x + 1/8x = 3.875x$ and then $x = 341A / 3.875 = 88A$. Then first 3 resistive elements will have $33V/88A = 0.375\Omega$ and you seen in my example that is made of groups of 4 resistive loops each 1.5Ω in parallel so $1.5\Omega/4 = 0.375\Omega$ and all this are embedded under ceramic tiles on the large floor thermal storage made of concrete and with a capacity of 97.4kWh. The next 3 outputs will have 0.75Ω (so can be made of two of those 1.5Ω loops in parallel) next will be 1.5Ω and last will be 3Ω . This setup will allow for 31 power steps (32 if you include zero) and you can see below how with just 6 outputs you get 31 levels (the SW engineers will get this relay easy) and understand why this is called a Digital MPPT. As you can see in the graph at page 10 this 31 levels are more than sufficient since up to around 98% efficiency can be obtained and increasing the number of steps will only increase HW complexity with very little gain so this in my opinion is the optimum level. As SW people will notice the number of steps can be increased to 63 since there are 6 outputs so number of combination is $2^6 = 64$ but then the max output power will need to be lower since each output is capable of max 100A and if you want 63 levels for slightly more efficiency 99% instead of 98% then max total output power will be limited to $196.875A \times 33V = 6496W$ compared to recommended 31 levels and 3 equal outputs where max is $387.5A \times 33V = 12787W$.

	Resistive heat elements [Ohm]		Resistance level Ohm		Current level [A]
TPV6	1	0.375	1	0.097	341.00
TPV4	1	0.375	2	0.100	330.00
TPV1	1	0.375	3	0.103	319.00
TPV5	1	0.75	4	0.107	308.00
TPV3	1	1.5	5	0.111	297.00
TPV2	1	3	6	0.115	286.00
			7	0.120	275.00
			8	0.125	264.00
Total resistance		0.096774	9	0.130	253.00
			10	0.136	242.00
			11	0.143	231.00
			12	0.150	220.00
			13	0.158	209.00
			14	0.167	198.00
			15	0.176	187.00
			16	0.188	176.00
			17	0.200	165.00
			18	0.214	154.00
			19	0.231	143.00
			20	0.250	132.00
			21	0.273	121.00
			22	0.300	110.00
			23	0.333	99.00
			24	0.375	88.00
			25	0.429	77.00
			26	0.500	66.00
			27	0.600	55.00
			28	0.750	44.00
			29	1.000	33.00
			30	1.500	22.00
			31	3.000	11.00
mppv [V]		33			

The top 16pin connector and side 8pin connector.



16pin connector:

01, 02, 07, 11, 13, 14 Not connected.

03 & 04 I2C port for communicating with SBMS or a custom device see protocol on next page. SBMS needs firmware version 3.2h or higher to support DMPPT450 .

05 Boot 0 connected to pin **12** will put the STM32F373 microcontroller in programming mode.

06 & 08 SWK and SWD programming interface for the STM32F373.

09 & 10 GND through a diode for used with SBMS communication cable.

12 This is a 3.3V supply from the internal DC-DC converter through 50Ω series resistor mostly to be used to pull up BOOT 0 pin to enter programming mode.

15 & 16 GND.

8pin side connector:

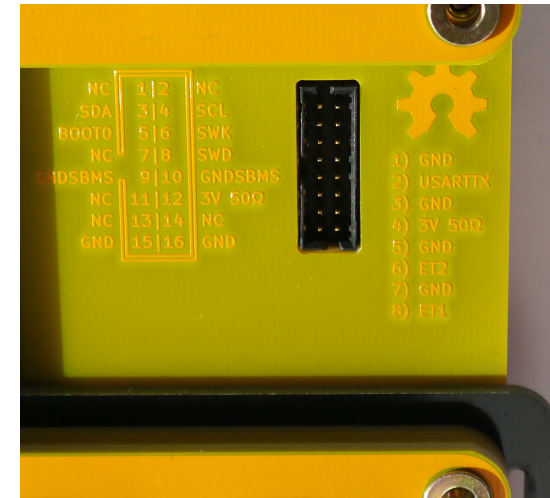
2 USARTTX will transmit every second all relevant DMPPT450 data needs external optoisolation.

4 3V 500hm.

6 ET2 for external 10KOhm B 3950 NTC thermistor controlling TLD1, TLD4, TLD6 .

8 ET1 for external 10KOhm B 3950 NTC thermistor controlling TLD2, TLD3, TLD5.

1, 3, 5, 7 GND.



I2C and UART communication protocol.

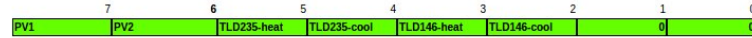
Same dmppt TX data is also send over UARTTX every second

dmppt TX 160

0	software version	10
1	model	45
2	Volt	
3		
4	PV redirect	
5	TPV1	
6		
7		
8	TPV2	
9		
10		
11	TPV3	
12		
13	TPV4	
14		
15	TPV5	
16		
17	TPV6	
18		
19		
20	TPV6	
21		
22		
23	Out PV1	
24		
25	Out PV2	
26		
27		
28		
29	Load ON/OFF	
30	Load R1	
31		
32	Load R2	
33		
34	Load R3	
35		
36	Load R4	
37		
38	Load R5	
39		
40	Load R6	
41		
42	IT	
43	ET1	
44		
45	ET2	
46		
47	reserved	
48		
49	sum of the above 49	
50		

dmppt RX 161

0	max current	40	0 to 100A
1	PV1	A	
2	PV2	A	
3	Batt	A	
4	Flags		
5	ET1 set	-40C to +99C	
6	ET2 set	-40C to +99C	
7	sum of the above 7		
8			





Algorithm description.

As of the current DMPPT v1.0 firmware the behavior is as follow:

As soon as above 5V is available on any of the TPVx input the TPVx LED will be illuminated green (LED will be red if voltage below 5V so you may see this for a few minutes around sunrise and sunset) and the ElectroDacus logo will be illuminated green for about 400ms then off for about 600ms so it will blink at 1 second interval. If there is successful I2C communication between DMPPT450 and SBMS or an external device the logo will also blink red for about 250ms to indicate I2C request so then Logo backlight will be 400ms green then 350ms off (not quite as blue LED is always ON but not that visible through the PCB compared to green and red) and then 250ms red before repeating.

As long as no NTC Thermistor (10KOhm B 3950) are connected to ET1 and or ET2 the TLDx will not be enabled. With DMPPT450 stand alone (not connected to SBMS) the limits for ET1 and ET2 are both set at +60°C and so DMPPT450 will be set for heating applications. If NTC thermal sensors are connected and below +60°C and the TPVx voltage is above 31.5V the DMPPT450 will start scanning TLDx outputs in this order TLD2,TLD3,TLD5,TLD4,TLD6,TLD1.

While scanning the current needs to be a minimum of 2A and less than TLDx current limit (either 50A or 100A depending on the output) else the TLDx output will not be enabled. The PV voltage will also need to stay above 28.5V else the TLDx will be disabled in order to stay around the max power point and above battery voltage (only 7s NMC or 8s LiFePO4 are allowed) and only 60 cell PV panels are allowed typical 250 to 300W depending on cell efficiency.

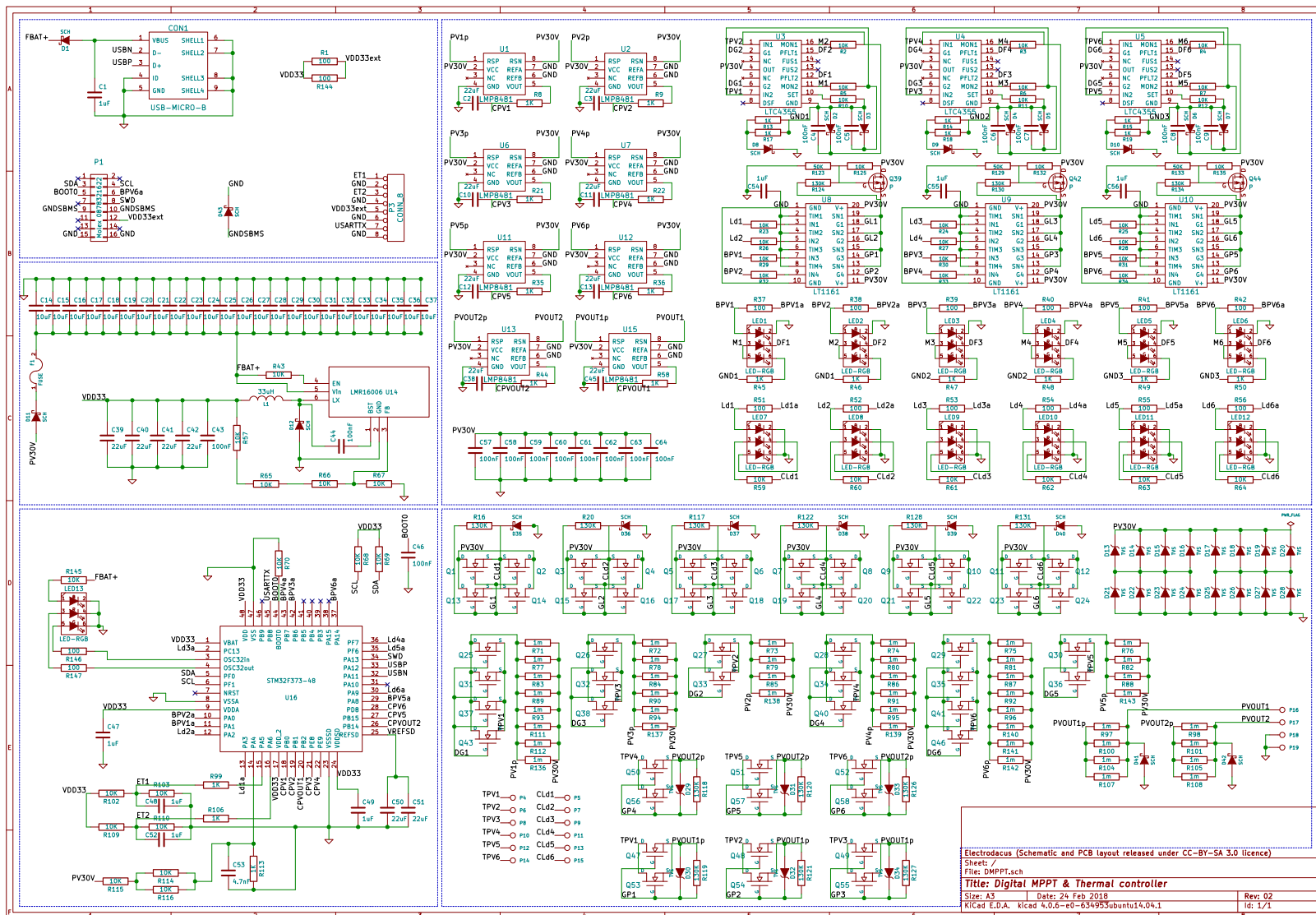
In case SBMS is used the ET1 and ET2 limits can be set in the SBMS menu by user. Also if an SBMS is present an battery is less than fully charged the TPVx will be redirected to PV1 and PV2 on SBMS. The TPVx will be redirected to PVOUT1 and PVOUT2 one at a time while measuring the current (fast scanning) the DMPPT will calculate what is the best combination of the 6 TPVx inputs to be redirected so that current is below but as close as possible to the SBMS requested current set by user in the SBMS DMPPT settings.

The TLDx will be switched off just before scanning the TPVx then once the combination for ideal redirected current is found the TLDx will be scanned to find the max power point for heating elements.

Interaction is more complex but this is a simplified description to get an idea on how the DMPPT450 should look with correct installation.

The RGB LED's will be green for the TPVx and cyan (blue+green) closer to green with a bit of blue for the channels that are redirected to battery charging and they will only be red if ideal diode has failed or there is little light on the PV panels thus just 5 to 6V available.

The TLDx LED's will be warm white (red+green+blue) when ON and no light when OFF. If TLDx LED is blue mosfet failed as open circuit and if is green it failed as close circuit so you should stop using that channel until it is repaired. Only resistive heat elements are acceptable on the TLDx outputs.



Electrodacus (Schematic and PCB layout released under CC-BY-SA 3.0 licence)
 Sheet 7
 File: DMPTT.sch
 Title: Digital MPPT & Thermal controller
 Size: A3 Date: 24 Feb 2018
 KiCad E.D.A. kicad 4.0.6-e0-63495Subunit14.0.1
 Rev: 02
 Id: 1/1



SW and HW files for DMPPT450

HW : http://electrodacus.com/DMPPT450/HW/DMPPT_HW.zip

SW : http://electrodacus.com/DMPPT450/SW/DMPPT_v1.0.zip

Firmware binary : http://electrodacus.com/DMPPT450/SW/DMPPT_v1.0_bin.zip