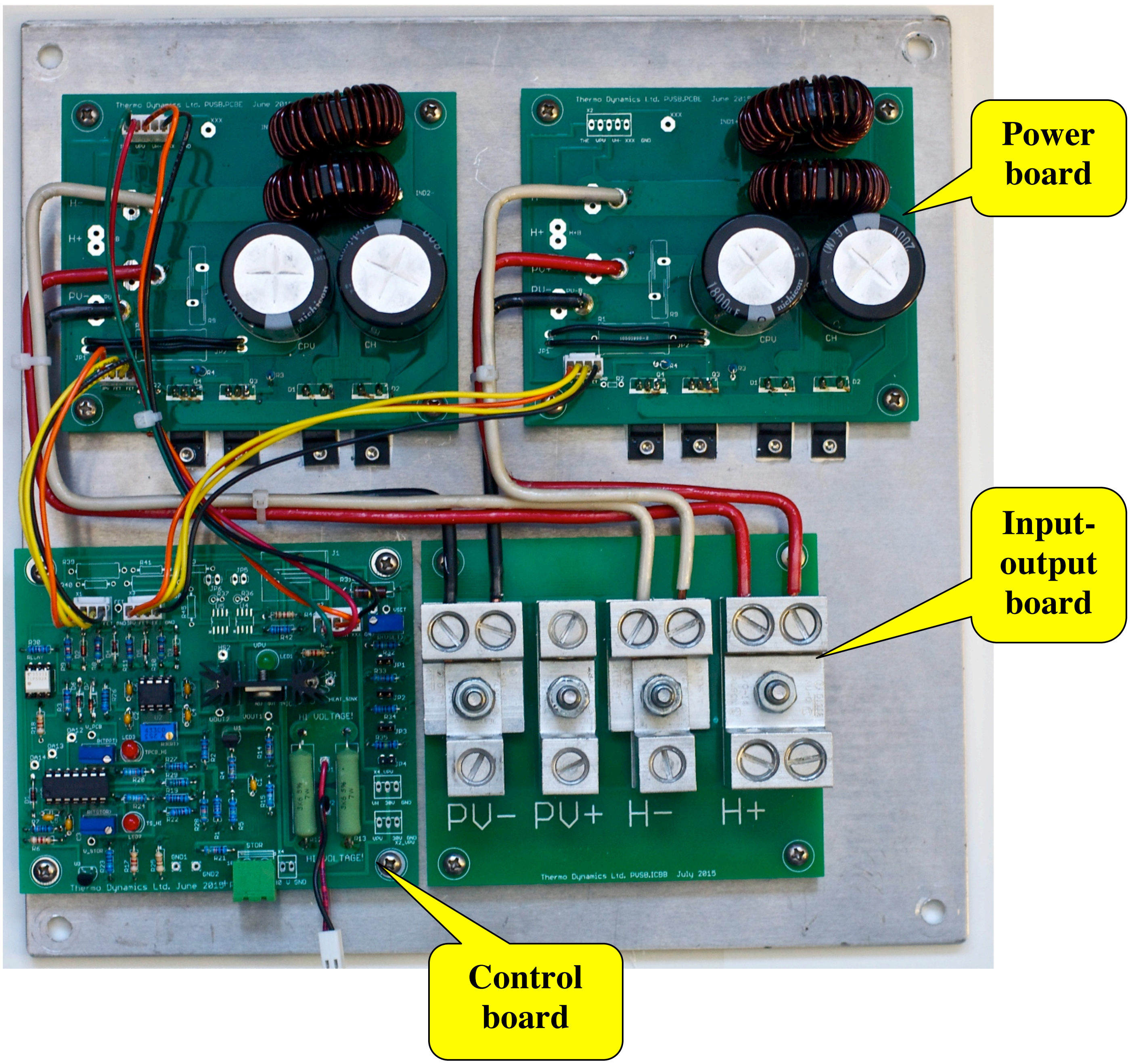
The Control Box (PV) module

The PVSB (photovoltaic Solar Boiler) control panel consists of 1. one or two power boards, 2. a control board and 3. an input-output board. The control panel regulates the voltage of the array of PV modules. While in operation the control panel maintains the voltage of the PV array at a fixed value, while varying the voltage to the heater as the intensity of the solar radiation increase and decreases. In other words, the control panel acts as a DC- DC transformer, with a fixed primary voltage (the PV array voltage) and a variable secondary voltage (the heater voltage).

One power board is used for systems employing up to 1500 watts-peak (W_p) of PV power. A second power board is employed for systems employing from 1500 to 3000 W_p of PV power.



Photovoltaic (PV) module voltage

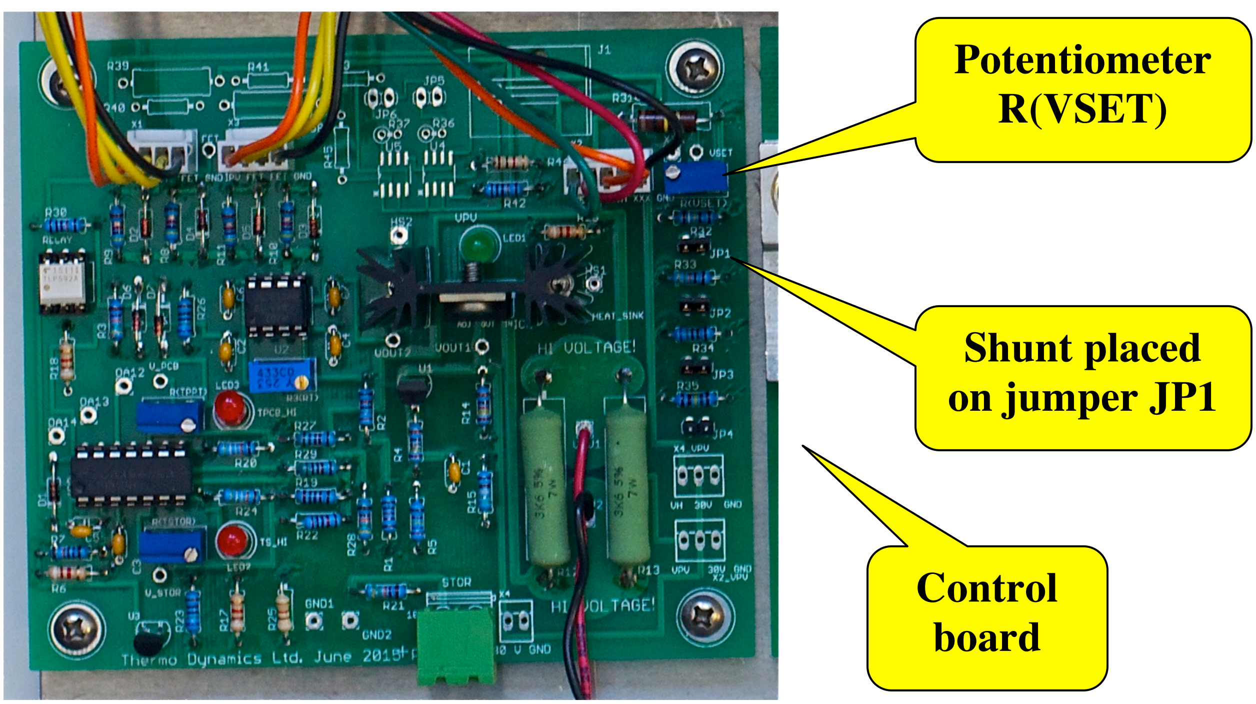
The choice of PV array voltage depends on the number, arrangement and maximum power point voltage (V_{mp}) of the PV modules. The PV array voltage will also depend on the temperature of the PV modules. The table to the right shows suggested PV array voltages for PV module temperatures of 25°C (wintertime operation) and 50°C (summertime operation).

Once the nature of the PV array has been established (number in series, number in parallel, number of cells in each module) then the PV array voltage can be selected. Adjustments can be made, if desired, as the seasons change and the average outside air temperatures changes. For example, if there were 5 modules in series in the array (60-cell modules) then the PV array voltage could be set for 135 VDC in the summer (ambient temperatures of 30°C) and 150 VDC in the winter (ambient temperatures of -5°C). Alternatively, the voltage could be set at 140 to 145 VDC and left at this value year round.

60-cell modules	Vmp	imp	Pmp		
	30	8.0	240		
Number in series	V-array 25°C	V-array 50°C	Number in parallel	Total number	Max current
2	60	54	1	2	8.0
3	90	81	1	3	8.0
4	120	108	1	4	8.0
5	150	135	1	5	8.0
3	90	81	2	6	16.0
4	120	108	2	8	16.0
5	150	135	2	10	16.0
3	90	81	3	9	24.0

72-cell modules	Vmp	imp	Pmp		
	36	8.0	288		
Number in series	V-array 25°C	V-array 50°C	Number in parallel	Total number	Max current
2	72	65	1	2	8.0
3	108	97	1	3	8.0
4	144	130	1	4	8.0
5	180	162	1	5	8.0
3	108	97	2	6	16.0
4	144	130	2	8	16.0
5	180	162	2	10	16.0
3	108	97	3	9	24.0

The voltage of the PV array is set using the 2-kohm potentiometer, labeled R(VSET), located at the top right of the control board. The setpoint is adjusted by turning the potentiometer. **Clockwise** rotation will **decrease** the PV. The 2-k pot is used for fine tuning of the PV voltage. Rough adjustment of the PV voltage is handled by a set of four shunts placed just below R(VSET). The shunts are placed on jumper pins JP1, JP2, JP3 and JP4, located just below R(VSET).



No shunt is required for operation at 60 volts (the voltage of the PV array). Shunts are added as the PV array voltage is increased. A first shunt, if required, is placed on JP1. A second shunt, if required, is placed on JP2, while leaving the shunt on JP1. A third shunt, if required, is placed on JP3, while leaving the shunts on JP1 and JP2. A fourth shunt, if required, is placed on JP4, while leaving the shunts on JP1 and JP2 and JP3.

The PV array voltage must be verified with a digital voltmeter used to measure the voltage between the terminals marked PV- and PV+ on the input-output board The PV voltage should be adjusted and verified after the control board and power boards have become warm. The PV array voltage will drop by 3 – 5% as the boards warm up.

The PVSB control board, once set, does not vary the PV array voltage. Changes in the PV array voltage must be made manually using R(VSET).

Operation at PV array voltages less than 100 VDC

If only two or three 60-cell modules are employed in series, or only two 72-cell modules are employed in series, then the PV array voltage will be in the range 54 – 90 VDC. In this case a resistor must be added to the control board between resistors R12 and R13. This resistor should be 1.8 kohms and rated for 4 – 7 watts of power dissipation. There are two through-hole connections labeled VPV1 and VPV2, located between R12 and R13, for the addition of this resistor. This resistor can be installed at the factory if you indicate to the factory that you wish to operate the PV array at less than 100 VDC.

Heater Selection

The heater to be employed with your PVSB depends on the following parameters:

1. The power of the individual PV module in watts-peak (W_p)
2. The number of modules in parallel, typically 1 - 5
3. The number of modules in series, typically, 1, 2 or 3.
4. The operating voltage of the PV module, which depends on the number of cells, typically 60 or 72.

The heater employed with the PVSB is a resistive device. Most commonly available resistance heaters are designed for 120 or 240 VAC (voltage, alternating current) operation. Typically they are rated as 3000 W at 240 VAC, or 1500 W at 120 VAC, or something similar to this. The ratings may also be given in terms of kilowatts (kW, where 1 kW = 1000 W). There are also a few heaters that are rated at 208 VAC.

A resistance-type heater can be employed with AC or DC (direct current) electric power. There is no need to employ a heater that is specifically rated for DC power.

The resistance of the heater can be measured using a digital ohmmeter, or calculated using the equation

$$R = \frac{V_{rated}^2}{P}$$

V_{rated} is typically 120 VAC, 208 VAC or 240 VAC and P is the rated power in watts (W). For example, a 6 kW heater rated for 240 VAC should have a resistance of

$$R = \frac{V_{rated}^2}{P} = \frac{240^2}{6{,}000} = 9.6 \text{ ohms}$$

The tables below indicates the heater that should be used for a particular system. As an example, consider a system that employs eight 250-W_p modules. An 8-module array should have 2 parallel sub-arrays with 4 modules in series in each sub-array, and should incorporate a 6.4-ohm heater, which is a 9-kW heater rated at 240 VAC. This type of heater is commonly available.

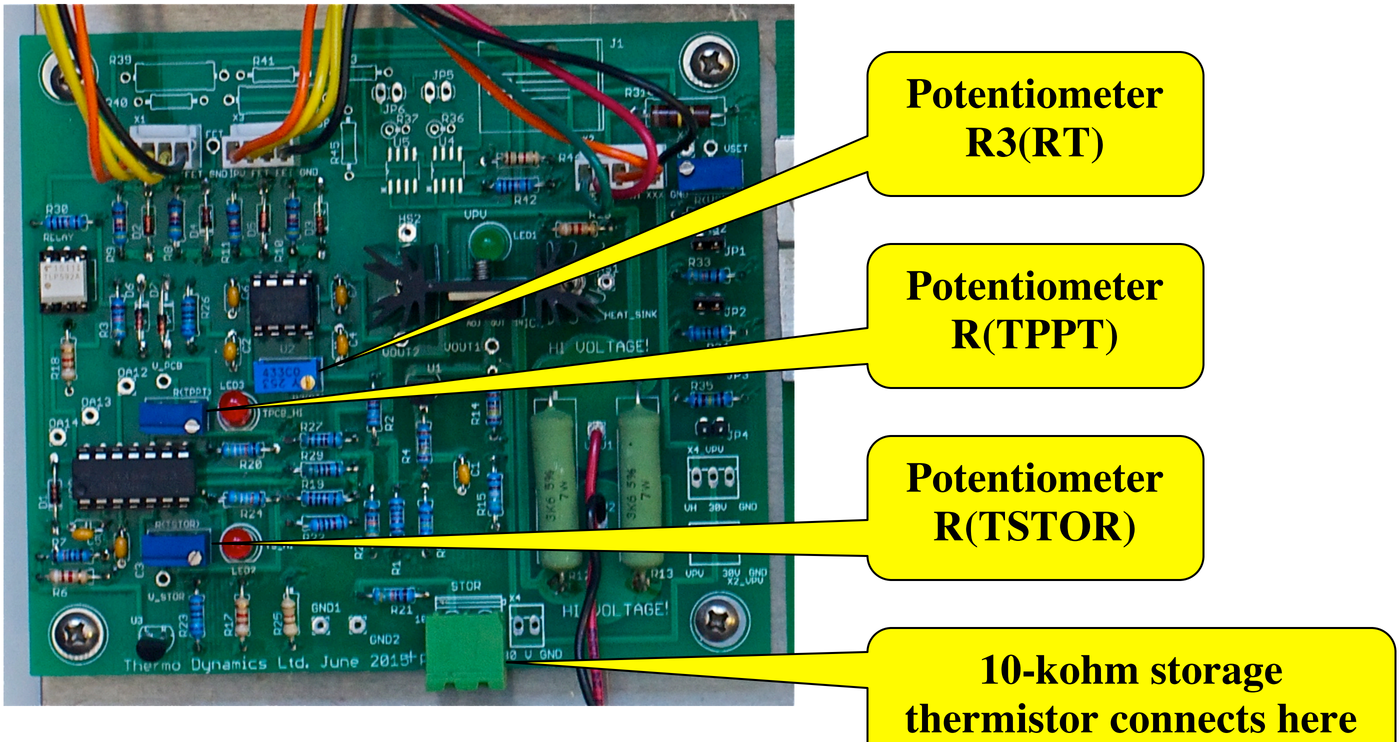
Pmod	250	watts	**Vmod**	29	volts				
Nmod	3	4	4	5	6	8	9	10	12	
Npar	1	1	2	1	2	2	3	2	3	
Nser	3	4	2	5	3	4	3	5	4	
Varray	87	116	58	145	87	116	87	145	116	volts
Parray	750	1000	1000	1250	1500	2000	2250	2500	3000	watts
iMAX	9.5	9.5	19.0	9.5	19.0	19.0	28.4	19.0	28.4	amps
R	9.6	12.8	4.1	16.5	5.0	6.4	4.1	8.2	4.1	ohms
Prating	6.0	4.5	14.0	3.5	11.5	9.0	14.0	7.0	14.0	kW 240 VAC
Prating	1.5	1.1	3.5	0.9	2.9	2.3	3.5	1.8	3.5	kW 120 VAC

Consider a system that employs 300-W_p modules. For example, an 8-module array, with 2 parallel sub-arrays with 4 modules in series in each sub-array should employ a 7.9-ohm heater, which is a 7.3-kW heater rated at 240 VAC or a 1.8 kW heater rated at 120 VAC. These heaters are not commonly available, however, a standard product is a 5.5 kW heater rated at 208 VAC, which is also a 7.3 kW heater at 240 VAC, or a 1.8 kW heater at 120 VAC.

Pmod	300	watts	**Vmod**	35	volts		
Nmod	3	4	4	6	8	9	
Npar	1	1	2	2	2	3	
Nser	3	4	2	3	4	3	
Varray	105	140	70	105	140	105	volts
Parray	900	1200	1200	1800	2400	2700	watts
iMAX	9.4	9.4	18.9	18.9	18.9	28.3	amps
R	11.5	14.4	4.1	6.1	7.9	4.1	ohms
Prating	5.0	4.0	14.0	9.5	7.3	14.0	kW 240 VAC
Prating	1.3	1.0	3.5	2.4	1.8	3.5	kW 120 VAC

Pulse Width Modulation setpoint

The control board acts as a pulse width modulator (PWM) when controlling the voltage of the array of PV modules. The frequency of the PWM can be adjusted using the 25-kohm potentiometer, labeled R3(RT), which is located just left of the center of the control board. Turning the pot counterclockwise increases the frequency of the PWM. Typically the frequency should be set at 80 kHz. One complete turn of the pot changes the frequency by about 8 kHz. This is factory set and there is no need to adjust this in the field.



Storage tank high temperature setpoint

The PVSB will shut down on a high storage tank temperature. The storage tank temperature is monitored using a 10-kohm thermistor. This thermistor should be mounted near the top of the storage tank, or alternatively on the outlet of the PV-powered sidearm heater mounted on the side of the storage tank. This thermistor is connected to the PVSB control board using a 2-conductor cable, which plugs into the 2-pin connector at the bottom of the control board. This connector is labeled "STOR" on the control board.

The setpoint is adjusted using a 2-kohm potentiometer, labeled R(TSTOR), which is located towards the bottom left of the control board. The setpoint can be verified by measuring the DC voltage at test point "V_STOR", which is just below R(TSTOR). The graph below shows the relationship between V_STOR and the storage tank high temperature setpoint. Turning the potentiometer clockwise will **increase** the voltage at V_STOR, which will **decrease** the high limit.

To **increase** the storage tank high temperature setpoint: turn the pot **counter-clockwise.**
To **decrease** the storage tank high temperature setpoint: turn the pot **clockwise.**

When the storage tank temperature has reached the high setpoint value the red (or yellow) LED2 adjacent to potentiometer R(TSTOR) will be illuminated, and the heater will be de-energised. When the storage tank temperature falls by a few degrees LED2 will be extinguished and the heater will be energized again, if there is sufficient sunlight still available.

Power board high temperature setpoint

The power board contains FETs (field effect transistors), diodes, inductors and capacitors. These devices all carry high current on both the PV input side and the heater output side. The efficiency of the PVSB varies from 80% (at low power) to 96% (at full power). Hence there is some loss of power, which appears as heat. Most of this heat is conducted through the heat sinks in the control box to the control box and then to the tank on which the control box is affixed, therefore, even the losses from the control box are recovered to a high degree to keep the outside of the tank warm.

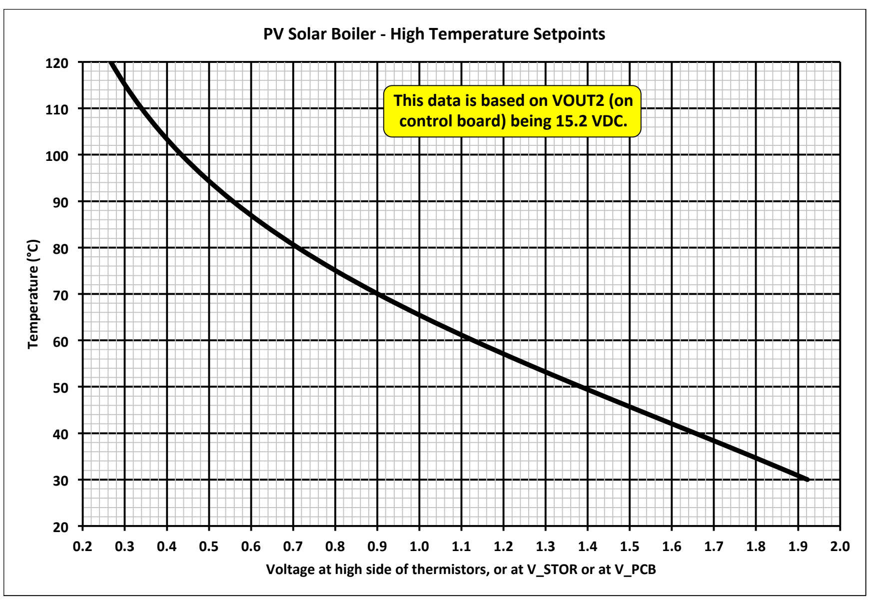
The PVSB will shut down on a high power board temperature. The power board temperature is monitored using a 10-kohm thermistor mounted on the power board directly above the control board. This thermistor is connected to the PVSB control board with the 5-conductor cable, which plugs into the 5-pin connector at the top right corner of the control board.

The setpoint is adjusted using a 2-kohm potentiometer, labeled R(TPPT), which is located towards the left of the control board, just below the center of the control board. The setpoint can be verified by measuring the DC voltage at test point "V_PCB", which is just above R(TPPT). The graph below shows the relationship between V_PCB and the power board high temperature setpoint. Turning the potentiometer clockwise will **increase** the voltage at V_PCB, which will **decrease** the high limit.

To **increase** the power board high temperature setpoint: turn the pot **counter-clockwise.**
To **decrease** the power board high temperature setpoint: turn the pot **clockwise.**

One complete turn of the pot will change the setpoint temperature by approximately 4°C, when the set point temperature is approximately 60°C.

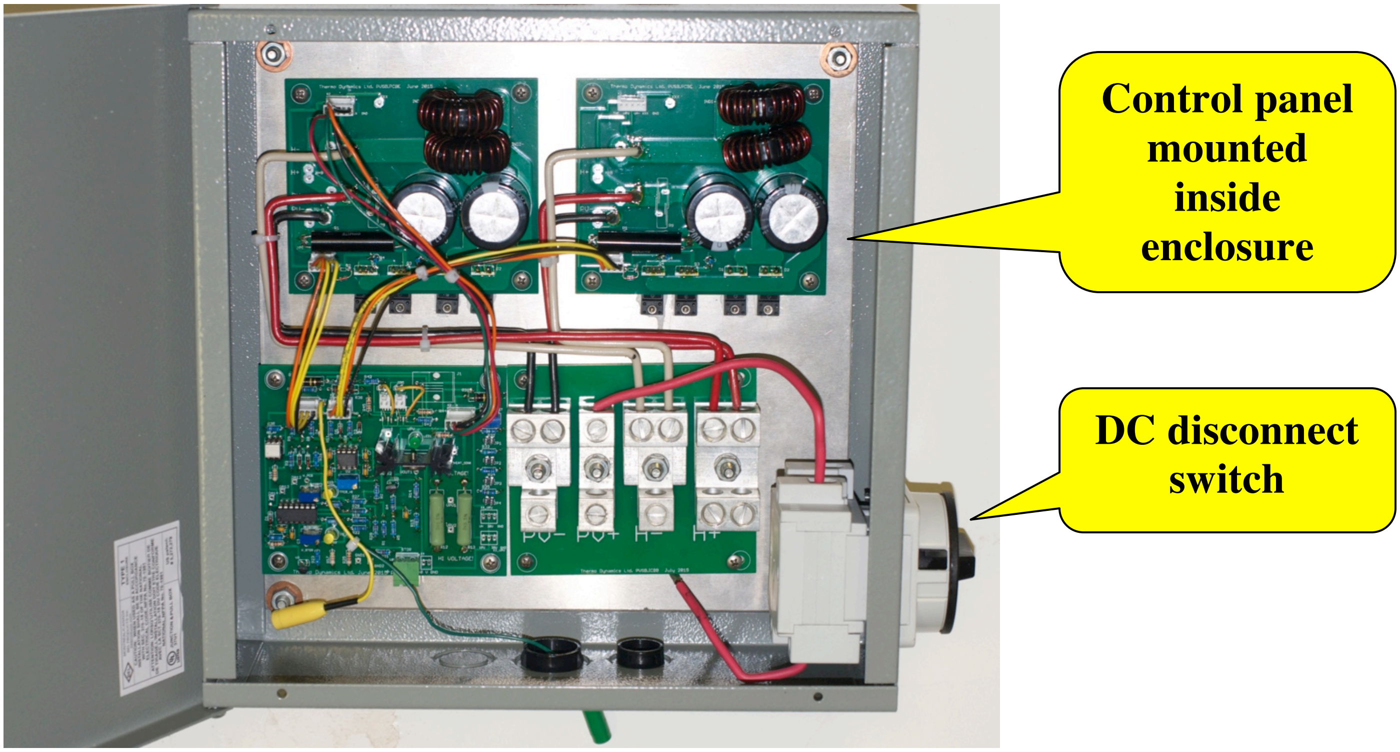
When the power board temperature has reached the high setpoint value the red (or yellow) LED3 adjacent to potentiometer R(TPPT) will be illuminated. When the power board temperature falls by a few degrees LED3 will be extinguished and the heater will be energized again, if there is sufficient sunlight still available.

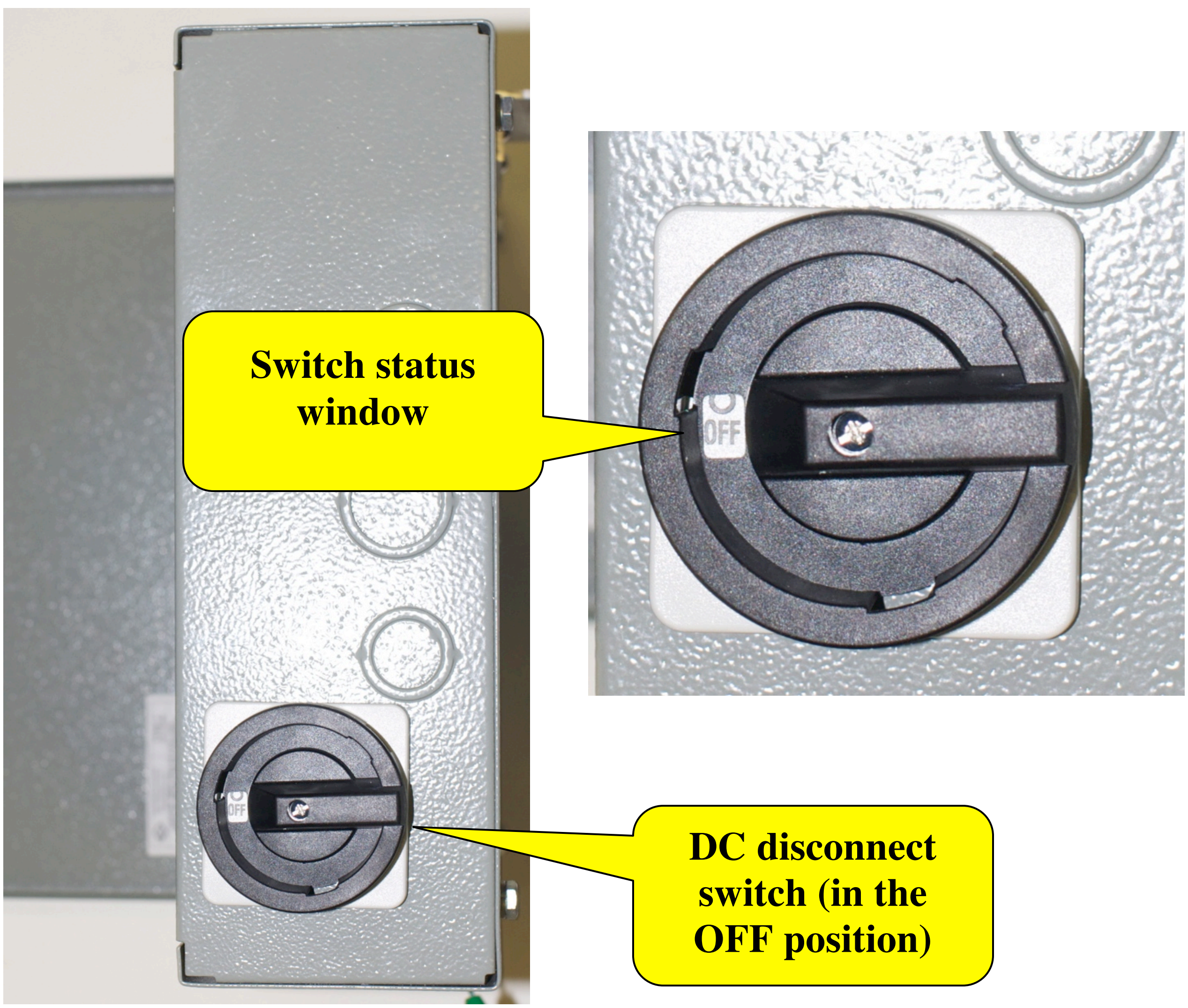


Thermistor.10k.PVSB.TS_hi.xlsx 2015-07-27

Starting up the PVSB

Ensure that the DC-disconnect switch is in the OFF position. The DC-disconnect switch should be in the horizontal position. The switch status can also be checked by confirming that OFF is shown in the status window on the switch.


Control panel mounted inside enclosure
DC disconnect switch


Switch status window
OFF
DC disconnect switch (in the OFF position)

Connect the two wires from the heater to the **H-** and **H+** terminals on the input-output board box. The heater is a purely resistive element and as such has no polarity, however, to be consistent we have labeled the output to the heater as **H-** and **H+**.

Measure the resistance between the **H-** and **H+** terminals to confirm that the heater is connected and that its resistance is correct.

The electrical cable from the PV modules to the PVSB control panel should be stranded, 10-AWG copper wire (7 strands). Connect the negative lead from the PV modules to the **PV-** terminal in the control box.

Using a digital voltmeter measure the open circuit voltage (V_{oc}) from the array of PV modules. If using 60-cell modules the open circuit voltage should be 36 - 38 V per module in series. For example, if there are five PV modules in series then the open circuit voltage should be 5 x 36 to 5 x 38 V (180 – 190 VDC) The higher the outside air temperature, the lower the open-circuit voltage.

Connect the positive lead from the PV modules to the **PV+** terminal in the control box. Once again measure the voltage across the terminals **PV-** and **PV+**.

Remove all shunts from the four jumpers on the right hand side of the control board. These jumpers are labeled JP1, JP2, JP3 and JP4. Turn the switch to the ON position and measure the voltage between the PV- and PV+ terminals once again. The voltage should be close to 60 – 70 VDC. Adjust the voltage using the shunts and the potentiometer R(VSET) so that it is equal to the desired PV array voltage as discussed above.

Measure the voltage at the heater terminals **H-** and **H+**. The voltage here will be lower than the voltage of the PV array. At sunrise in the morning the heater voltage could be quite low. As the sun rises the voltage to the heater will increase, and then decrease again as the sun goes down.

In the morning, prior to sunrise, the PV array voltage will be close to 0 VDC. As the sun comes above the horizon the voltage will gradually increase from 0 to the setpoint value, e.g., 120 VDC. While the PV array voltage is increasing from 0 to the setpoint voltage, no power will be delivered to the heater. The green LED (LED1) on the control board will start to glow shortly after sunrise. When the PV array voltage reaches the setpoint current will flow to the heater.

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