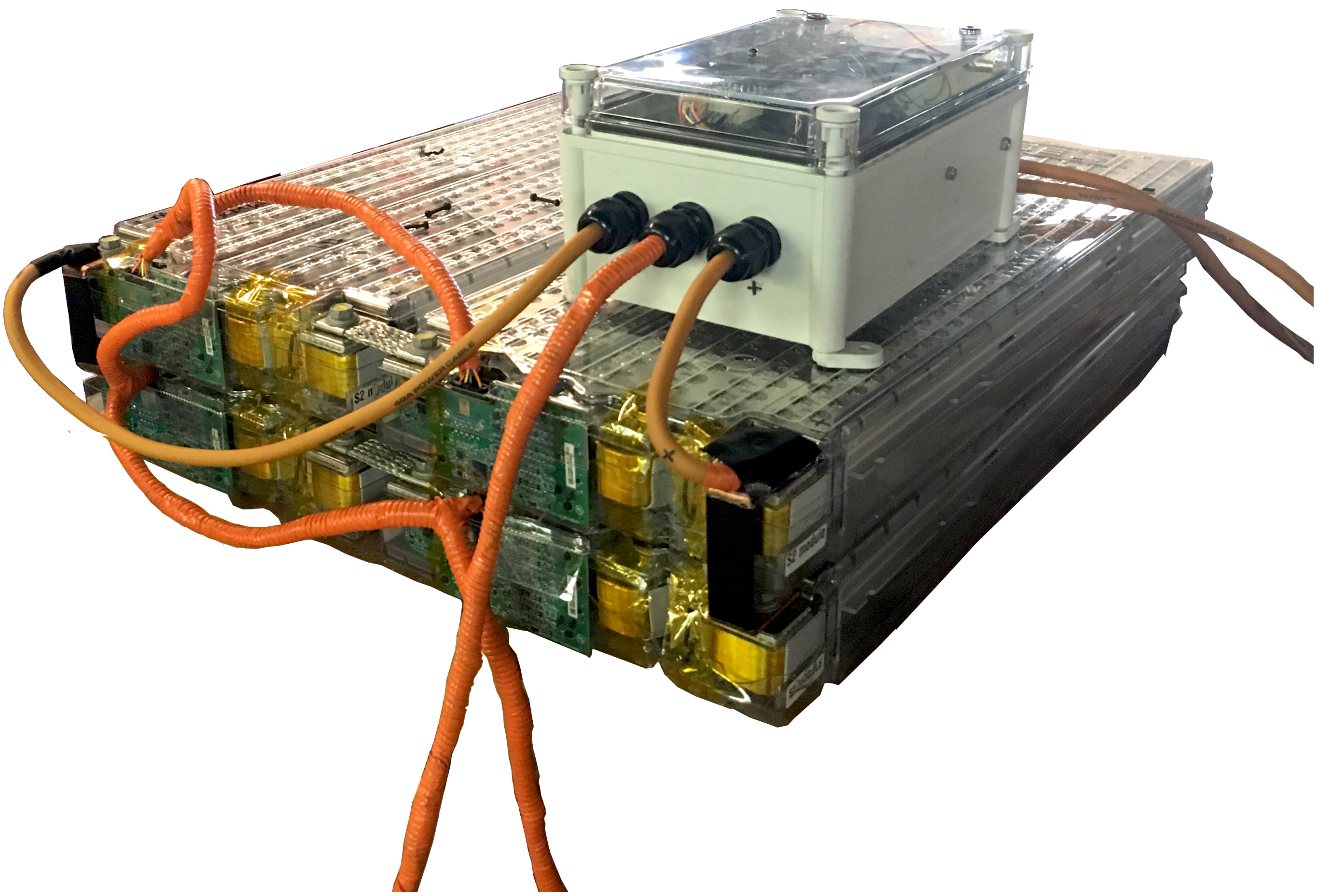
EVTV Monitor/Controller



For Tesla Model S Battery Modules

INTRODUCTION

This document describes the installation and use of the EVTV Tesla Battery Module Controller.

In 2012, Tesla Motors Inc. introduced the Tesla Model S, and electrically powered sedan that operated from an 85 kWh battery pack and featured a range of 275 miles – rather beyond what was available from competing vehicle manufacturers.

The batteries that enabled this were highly engineered modules consisting of 7104 individual 18650 format Lithium Nickel Manganese Oxide ionic cells readily available as the battery of choice for laptop computers and some cameras.

These cells were manufactured in very high quantities and featured a very high energy density, but were problematic in terms of safety and thermal issues.

Tesla invested heavily in engineering and development to incorporate these cells into a battery system suitable for electric vehicle use. This involved advanced thermal management systems with a liquid cooling/heating system and electronic monitoring of each individual cell voltage, current, and temperature.

Despite the somewhat mercurial features of these cells, Tesla managed to develop a system that was reasonably safe for vehicle use.

In the years since, a large number of Tesla vehicles have been wrecked making the Tesla batteries readily available inexpensively from salvaged wrecks – often with very low time/miles on the batteries.

Inevitably, this was picked up by the do-it-yourself home hobbyist/inventor/experimentor as an inexpensive way to obtain lithium batteries for vehicles and home solar projects.

Unfortunately, the use of the Tesla Battery Management System and thermal controls was not understood. Often they would disassemble the 1330 lb battery component and remove the 16 individual 21v battery modules from the package.

Without the controls and thermal management provided in the Tesla vehicle, these modules proved inherently unsafe and there were a number of vehicle fires and explosions as well as several dwellings burned to the ground.

Toward the end of 2016, Jack Rickard of Electric Vehicle Television (EVTV) began investigating the reverse engineering requirements to use the Tesla Battery BMS

and the individual BMS boards featured on each module. He was joined by Collin Kidder of Sparta Michigan and Jarrod Tuma of Tualatin Oregon.
The mission was to develop software and hardware to "control" the Tesla Model S battery pack as well as software and hardware to control individual battery "modules" from the battery. These "controllers" would feature contactors to allow precharge and connection, as well as a failsafe "disconnect" in the event any thermal or voltage limits were exceeded, and CAN communications allowing them to be incorporated in other systems.

This document describes the controller developed for the individual battery modules. As these modules are 230Ah and weigh 56 pounds each, it would actually require the 16 original modules to power a vehicle and at an impractically large volume and weight for most vehicles.

And so the assumption is that most of the interest in using these modules is for backup purposes for home solar installations.

HOME SOLAR

Residential solar installations are not precisely new. In 1998 I installed a 15kW photovoltaic array at my residence in Morrison Colorado at an expense of approximately $275,000. Everyone involved was interested and excited about such a project including the local utility company. At that cost, it posed little threat to their business model.

Today, such systems can be installed for as little as $20,000. The components have evolved somewhat slowly over time but today with massive interest in these systems the pace of innovation has picked up considerably. This is complicated by increasing regulatory activity and an increasingly hostile utility industry desperately seeking to maintain the status quo as an act of gravity defiance.

The result is the distinction between "off-grid" and "grid-tie" systems is blurring as new products become available with increasing utility and more features at ever lower cost.

Because of this, the very nature of photovoltaic panels, combiner boxes, charge controllers, and inverters is very much in flux and the pace of new product introductions is brisk.

But let's discuss some aspects of the "ideal" home solar installation. First, the problem with harvesting energy from sunshine revolves around the concept that the sun doesn't always shine. Particularly, it does not shine at night. So as the planet revolves, your source of energy goes away, every single day, for roughly half the day.

Power is also greatly reduced on days when it is overcast, or rainy, and is reduced to zero when the panels are covered in snow.

1. It would use the output of photovoltaic panels to power the home during the day.

2. It would use power from the photovoltaic panels stored in batteries to power the house at night or during inclement weather.

3. It would always produce exactly the amount of power needed.

Item 3 is a little problematical. Not only does the source of energy vary, but so does the amount of energy needed vary. On hot sunny days, the largest use of electric energy goes to air conditioning. Similarly on cold winter nights it would go to heating.

So both loads and source are widely variable, and if the two actually matched, it would be briefly and accidentally.

For this reason, most installations retain a connection to the "grid" or traditional utility connections. So we can add that feature:

4. It would have the ability to draw needed power from the conventional electric grid.

What about a really GOOD sunny day when we aren't using much electricity and our batteries are already full?

5. It would store excess energy produced back INTO the grid and reduce the charges incurred for power draws FROM the grid.

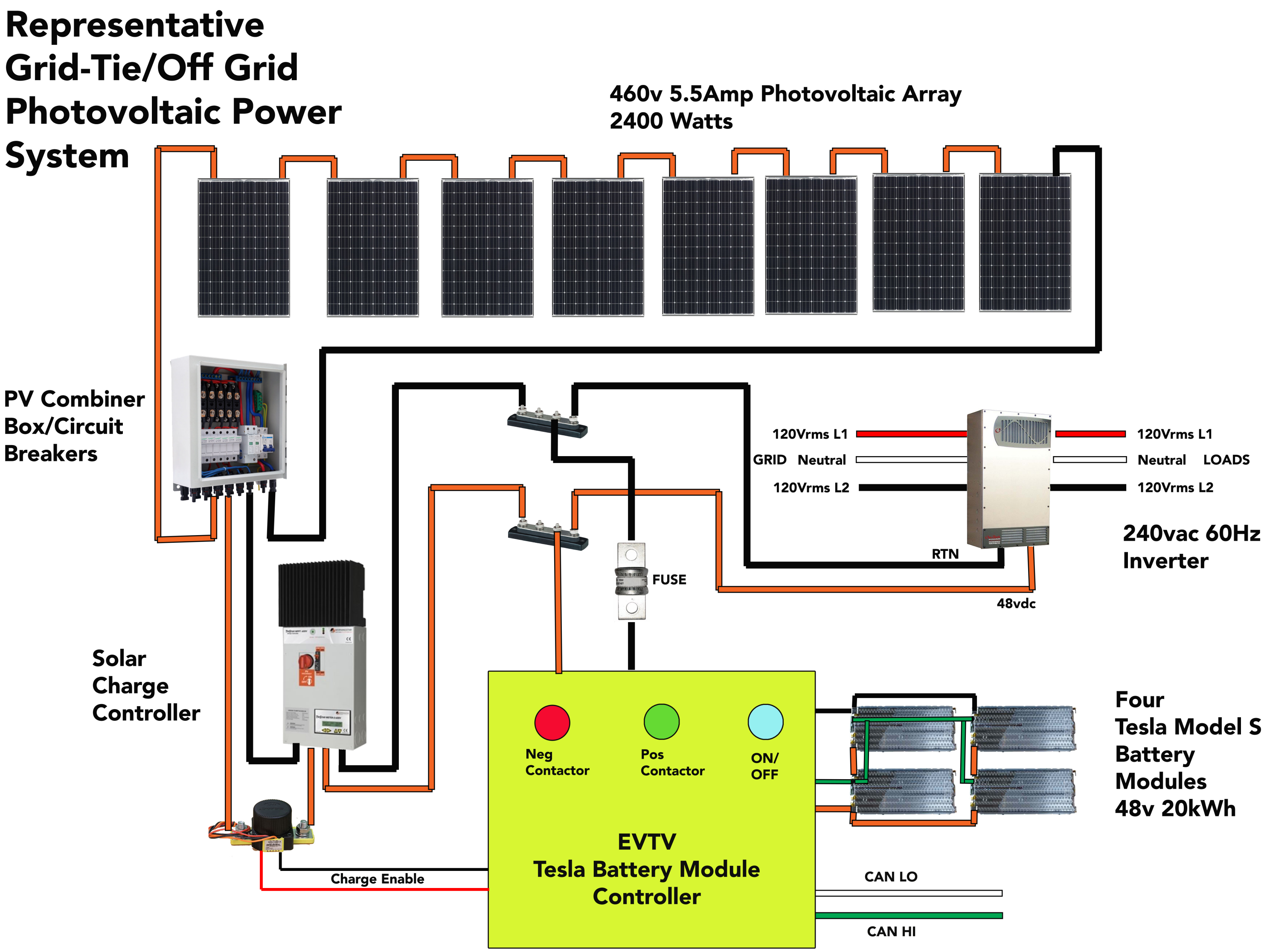
In many states, laws have been enacted to require NET METERING in that the utility companies have to run the meter backwards if you PRODUCE energy defraying your costs from when you USE energy from the grid. In most cases, they will actually pay some reduced amount for any you produce beyond your needs.

This poses a couple of corollary technical issues. First, the AC power we produce in our system must match the grid power exactly – not only in voltage but in phase and frequency.

Secondly, if the grid power GOES DOWN you want to be able to rely on your solar panels and batteries to power your house. But if it goes down, utility workers are likely to be out working on the system repairing downed lines and so forth. And so it has to have some means of GRID DISCONNECT to prevent our local system from powering external lines or trying to serve the load of the neighbor's house as well.

REPRESENTATIVE SYSTEM

The figure below depicts a typical home solar installation using commonly available components.



PHOTOVOLTAIC ARRAY

The photovoltaic array is the heart of the home solar installation. These are simply a series of photovoltaic panels arranged with access to the sun (on the roof usually) that produce electricity.

A very short course on how they do that: Photovoltaic panels are themselves an "array" of individual silicon cells in both series and parallel usually. Cells in series exhibit the sum of their voltages while cells in parallel present the sum of their currents.

The cells are actually very thin slices of pure silicon that has been doped with phosphorous on one side and boron on the other to produce what is termed a semiconductor.

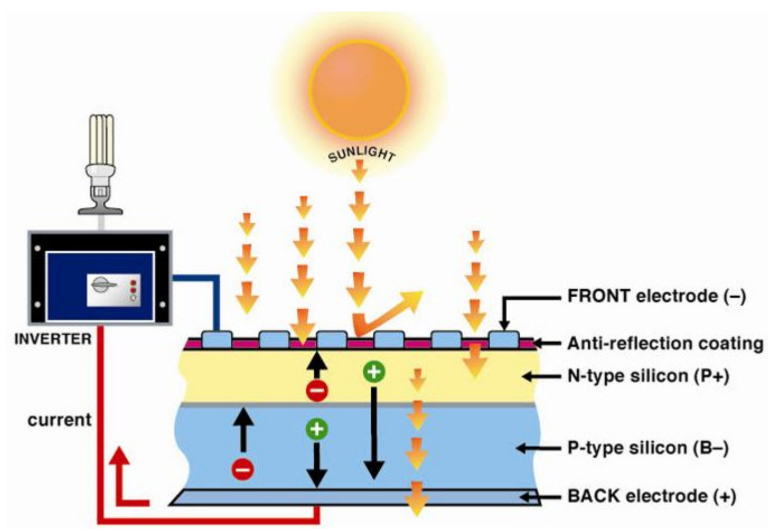
The Silicon atom features four outer valence band electrons. Phosphorous features five outer valance band electrons and Boron features three.

And so Phosphorous CAN become covalent with Silicon and so part of the Silicon crystalline structure, but it has ONE EXTRA electron that doesn't really fit.

Boron can also be covalent with Silicon and so become part of it's crystalline structure but it has one MISSING electron, which for lack of a better term let's call it a "hole".

And so the Phosphorous side is negative in charge (N type) with extra electrons not needed to form a crystalline structure. And the boron side is positively charged with holes (P-type).

At the JUNCTION where the boron doped silicon meets the phosphorous doped silicon, the extra electrons from phosphorous find the holes in the boron and fill them. This material then forms a P/N junction which is greatly resistant to the flow of electrons in one direction, and NOT resistant to the flow of electrons in the other. This is due to the electrostatic field established with a negatively charged material and positively charged material separated by a barrier – the PN junction.



At that point, if we direct sunlight to the phosphorous surface, photons striking the phosphorous atoms will transfer energy to them, causing the promotion or "release" of the extra electron from the orbit of the atom and into free conduction.

And so the negative charge of the surface of the solar cell increases with respect to the charge on the back of the cell. In order to recombine with a "hole" on the boron doped side, it HAS to go through an external circuit.

More sunlight causes an increase in this charge differential or pressure we can call voltage.

And if we do connect the surfaces through an external circuit, then electrons will flow and this is termed "current". Increased voltage causes an increase in current. An increase in current causes a decrease in voltage.

Each panel consisting of dozens of these cells produces a certain voltage and a certain current for a given amount of sunlight.

Panels in series present the sum of their voltages.

Panels in parallel present the sum of their currents at the same voltage.

Often multiple series strings are used.

Each panel will produce maximum power when it is matched to the a load. At Zero current, you will have maximum voltage. If you connect the terminals with a wire to produce MAXIMUM current, this will reduce the voltage to a minimum.

Current in amperes multiplied by voltage in volts gives us power in watts. At some point on the curve, the ideal voltage and current output for the given amount of sunlight received will produce the maximum amount of power. This is a function of the "resistance" of the circuit. And so by varying this resistance, or load, we can maximize the amount of power produced.

And by using electronics to monitor and produce this, we are basically accomplishing Maximum Power Point Tracking or MPPT which you will see described ad infinitum. It is simply regulating the output of the panels every few milliseconds to adjust for the amount of sunlight striking the panel, to produce maximum power.

For example, if you measure the voltage of a Panasonic HIT 325 watt photovoltaic panel in full sunlight, with no load connected, it will measure 69.6 volts. If you short the two output terminals, it will measure 0 volts but will produce 6.03 amps of current.

The maximum power point is at 57.6 volts and 5.65 amperes of current producing 325.44 watts of power. And using ohms law we can see that 57.6volts/5.65 amperes would indicate a load resistance of 10.194 ohms. But of course, those values vary wildly when the sunlight is reduced. We can still seek and "find" the ideal power point for any given amount of sunlight electronically.

And so our series string of eight panels in the figure, in full sunlight, could produce 460.8 volts at 5.65 amps for 2603.2 watts of power.

If we arranged these panels all in parallel, it would produce 45.2 amperes of current at 57.6 volts for exactly the same 2603.2 watts of power.

So why series? We must use conductors to interconnect the panels, and sometimes to reach quite a distance from the roof to where our other equipment is, sized for the CURRENT it will carry much more so than the voltage. And so a very small diameter wire can carry 6 amperes at a high voltage, compared to a much larger diameter wire to carry 45 amperes at 57 volts.

To produce MORE power than this, we would typically add a second or third or fourth or fifth string of eight panels. All the wires would run separately down to our combiner box.

COMBINER BOX

This is a simple device that accepts the wiring for one or more strings of photovoltaic panels and provides a disconnect circuit breaker for each string. On the other side of the circuit breaker, all the strings are added together in parallel to form the output.

In this way, the outputs of multiple strings can be "combined" while retaining control through the circuit breakers of each string.

SOLAR CHARGE CONTROLLER

The solar charge controller is where the conversion from rooftop voltages to battery voltages occurs. This is also where Maximum Power Point Tracking is performed.

This is basically just a switching power supply. The input is switched through an inductor that can increase or decrease the voltage of the output based on the pulse width of the switch. In this way, we can take the 460 volts of the photovoltaic array and step it down in voltage, and consequently up in current, to our battery storage system.

But this offers an opportunity. Switching power supplies are usually used to carefully regulate the output voltage no matter what the input voltage is. But in this case, the battery doesn't care how fast or slow it is charged and so within certain limits, we don't CARE what the output voltage and current is.

By measuring the input voltage and current, and then changing the width of the switch pulse, we of course vary the output voltage and current. If we try this at several different slightly different pulse widths, we can compare the voltage/current input measurements to find the pulse width that produces the maximum power from the solar array.

And the switching frequency of these switched power supplies is such that we can do this sampling hundreds of times per second. And so we refer to this as "tracking" the maximum power point.

MPPT charge controllers provide a minimum of a 15% increase in efficiency of your photovoltaic array power output and in some cases significantly more.

The charge controller also fairly well controls the voltage and current to the battery while observing the battery voltage. In lead acid batteries, this was referred to as absorption, equalization, and float phases of the charge cycle.

Absorption put as much current as possible into a battery until it reached a certain voltage.

During equalization, this was allowed to rise in voltage for a defined period of time to the point that all cells in the batteries were overcharged to the point that they began to produce electrolysis – the separation of hydrogen and oxygen from the electrolyte. By doing this, they were "top balancing" the individual battery cells.

The charge controller then enters the "float" phase where it simply maintains the batteries at a certain voltage by allowing small values of current to replace energy lost to internal discharge.

But different batteries have different charging requirements for absorption, equalization and float phases. And so these charge controllers employ various means to allow you to select different profiles. Most of these efforts are both comically and heroically bad – complicated, confusing and error prone.

Worse, lithium batteries do not have any noticeable internal discharge and don't need a "float" phase. They also not only cannot be equalized by overcharging, but it actually destroys them – often catastrophically with fire and explosion. And the voltages for absorption are often quite different from lead acid or AGM cells.

INVERTER

Probably the most important control hardware for a photovoltaic system is the inverter.

At heart, the inverter converts DC power from either solar panels or batteries into the standard 60 Hz AC power useable by our appliances, lights, motors, etc. This is a 60 Hz sinusoidal waveform of 120vrms.

The standard wall plug features this 120vac single phase power. The waveform actually varies between + 170 and – 170 volts. The "root mean square" value of this waveform is 120 volts – similar to an "average" voltage.

US homes are fed two phases of this 120vrms power that are exactly 180 degrees out of phase. And so at any one point in time, if you measured BETWEEN the two phases at the peak of the waveform, you would see 340v instantaneously. But again, the RMS value of this would be about 240vac.

Your circuit breaker panel simply has one phase on each side. And so any circuit you connect to either side receives 120vac. And if you need 240vac for a heater, stove, or large airconditioner, you simply use 240vac circuit breakers that bridge BOTH sides of the panel.

One phase is termed L1 while the other is labeled L2. And both are 120vac with respect to a NEUTRAL return. A ground often ties the appliance housing, the circuit breaker panel housing, and true earth together as well so you cannot be electrocuted by touching the chassis of the appliance.

So a 120vac wall socket has two blades, L1 and Neutral, plus a third pin for ground.

A 240vac wall socket has three and sometimes four pins, L1, L2, Neutral, and ground. In practice, neutral and ground are connected within the circuit breaker panel.

Today's modern inverters accomplish several things:

1. Convert solar/battery DC to AC power matching the grid in phase, frequency and voltage.

2. Disconnect from the grid in the event of grid power loss.

3. Prioritize whether grid power is normally passed through, and solar/battery power used in the event of loss, or solar/battery power normally used, and grid power tapped if batteries are depleted and solar unavailable or inadequate.

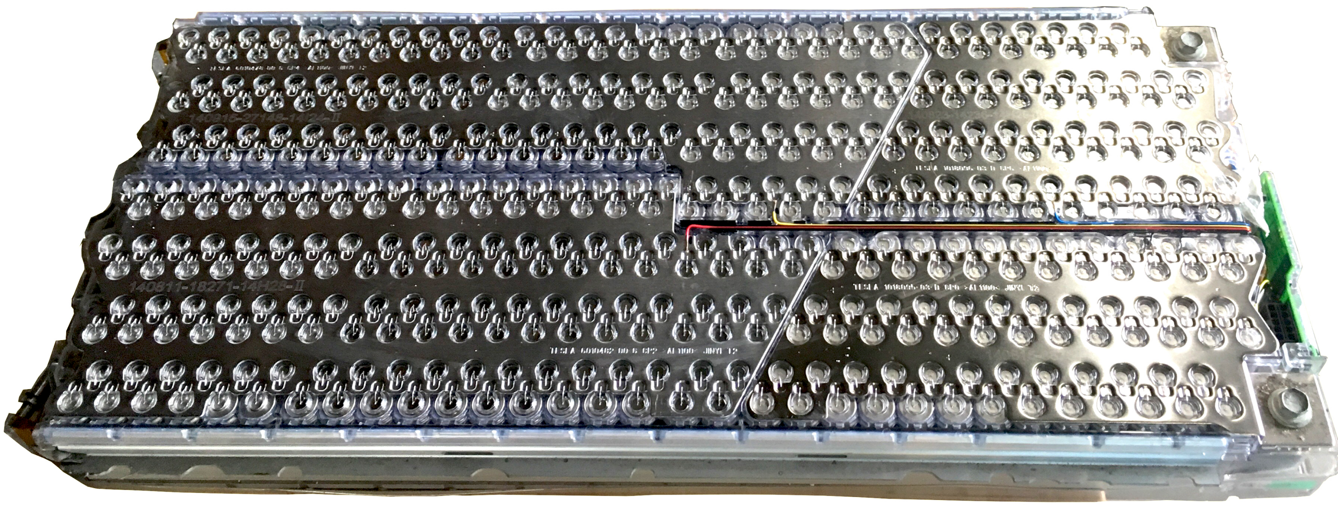
In the past, inverters were primarily designed entirely for off-grid use, or entirely for grid use – actually requiring the grid to be present in order to operate at all.

Today we are seeing more "hybrid" inverters appear that can work intelligently with the availability of grid power, but maximizing the use of solar and battery systems.

Indeed, increasingly we see some of these "hybrid" inverters add the role of battery charge controller to the mix as well, allowing the batteries to actually be charged by the grid as well as by solar.

THE TESLA BATTERY MODULE

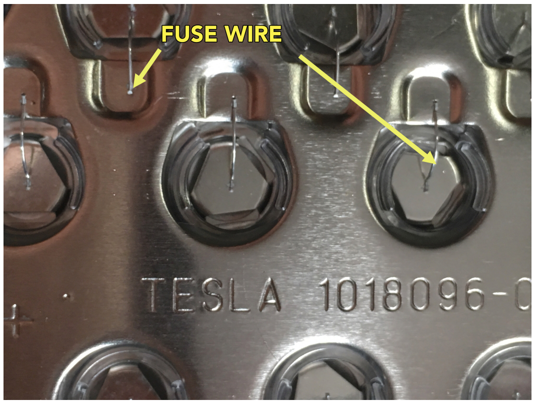
The Tesla Model S battery system consists of 16 individual modules. Each are 27 by 11.5 by 3.5 inches in dimension and weigh 55.8 pounds. They consist of 444 individual 18650 battery cells with 74 cells in each voltage cell and six of these voltage cells in series.



The battery cells are most likely Panasonic NCR18650BE cells or close equivalent of nominally 3200 mAh capacity and 3.6vdc. These cells are of a nickel cobalt manganese aluminum oxide cathode and a graphite silicon anode.

This gives the module a 74 x 3.2Ah or 237 Ah capacity at the nominal voltage of 3.6v for a total power storage capacity of 5115 watt hours and a module nominal voltage of 21.6 volts. These modules are designed to produce up to 1155 amperes of current for brief periods.

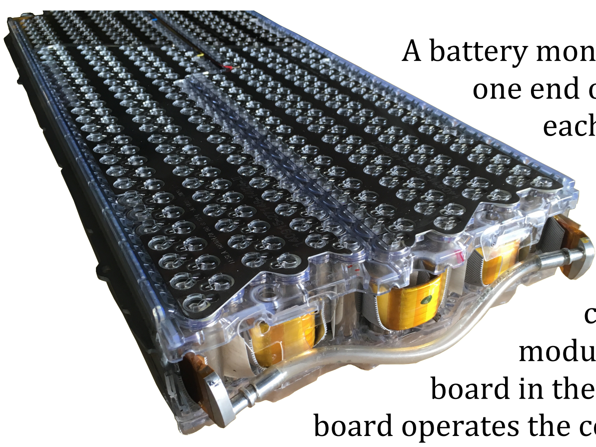
The cathode chemistry of these cells is such that gives off free oxygen at a fairly low thermal temperature of perhaps 180C –



very low by lithium battery standards. Without adequate monitoring, they can easily be driven to thermal runaway by overcharging or overdischarging and can be explosive. The resulting fires are extremely hot and since they produce their own oxygen from cathode materials, extremely difficult to extinguish.

The individual batteries are interconnected by thin plates on top and bottom with holes at the cell terminals. Small wires are welded from the plates to the center of the cell terminals. These wires are designed to act as fuses in the event of the short failure of any particular battery cell.

A series of flat fluid conduits winds between the rows of battery cells. These are connected to two pipe fittings on the end of the module. In the battery assembly these fittings are connected to clear tubing from one module to the next and to some external fittings to allow the circulation of fluid that can be externally heated or cooled as necessary.



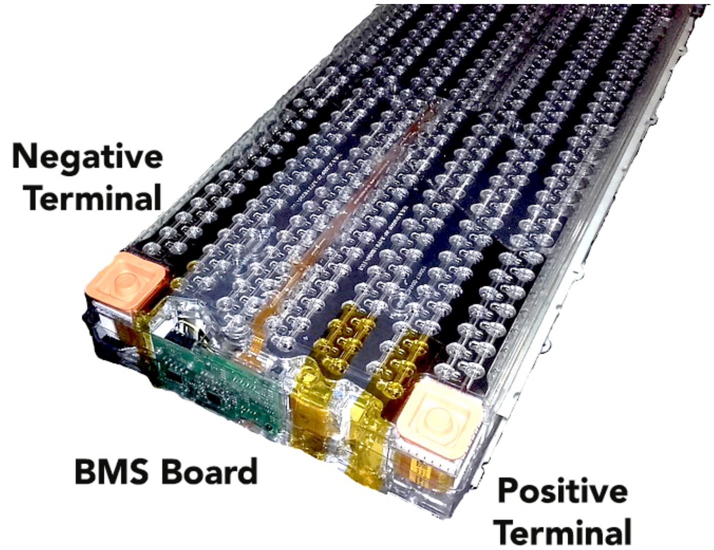
A battery monitoring printed circuit board is mounted on one end of each module. It measures the voltage of each individual voltage cell and the temperature of positive and negative module terminals.

A 10 pin molex connector at the top of this module board allows connection to a daisy chain cable assembly connecting all the modules to a central battery management system board in the end of the main battery assembly. This main board operates the contactors in the battery assembly and communicates with other vehicle components via Controller Area Network CAN bus.

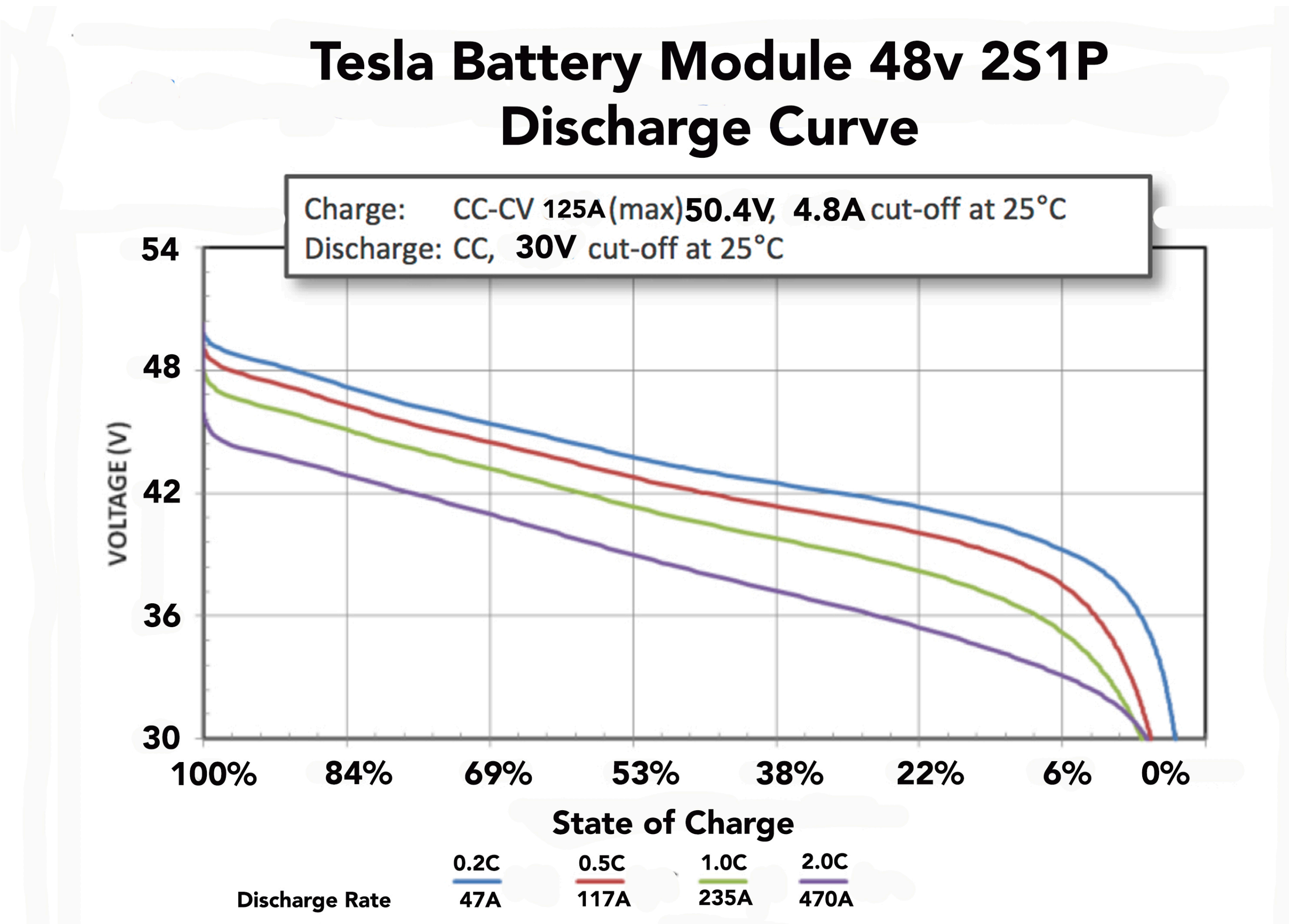
The modules are designed to be charged to a maximum voltage of 4.2 volts per cell for 25.2 volts per module and it is extremely important that this voltage never be exceeded.

The cells are essentially 100% discharged at a static resting voltage of 3.0 volts or 18 volts per module. Under high current loads, this lower voltage may of course be much less, but it is important that in a static condition, 3.00v is essentially fully discharged. Overdischarge can similarly cause damage to the cell and it will not normally be readily apparent until the next charge cycle, which can then be catastrophic.

The cells have a fairly flat discharge curve making it difficult to determine state of charge by voltage alone.

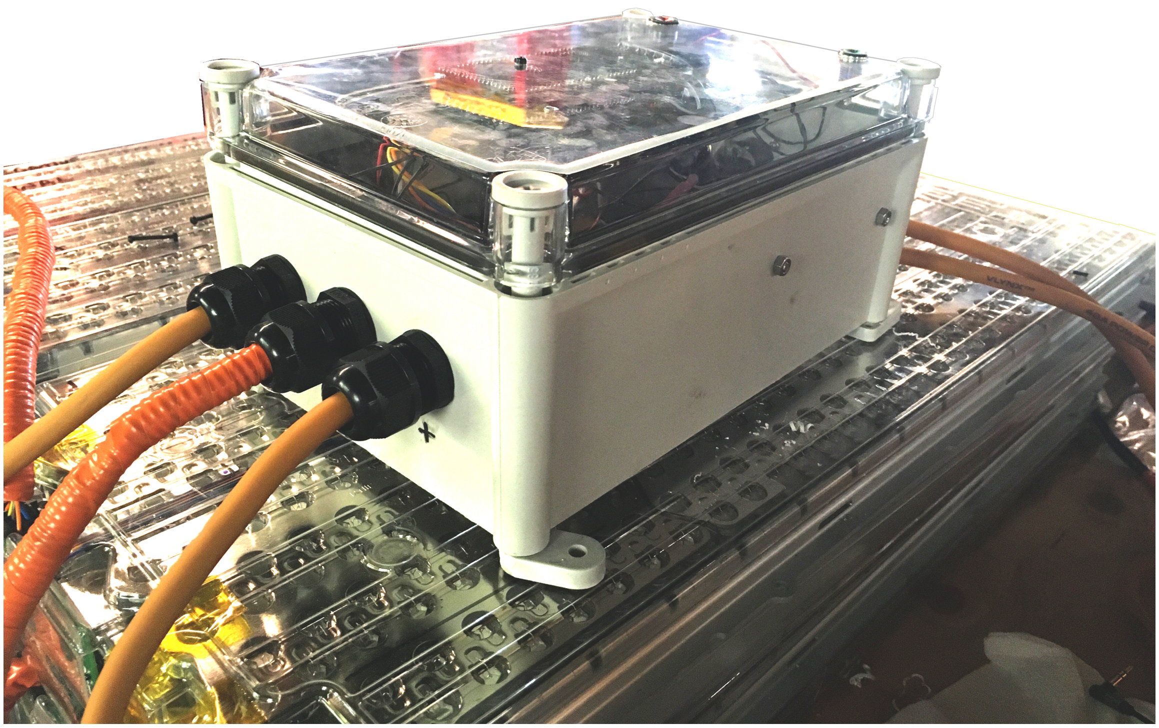


It is very important that NO charging of a Tesla Module S battery module be performed at an ambient temperature below freezing - 0C or 32F. Charging at cold temperatures leads to lithium dendrite formation on the anode and eventually failure of the plastic separator in the battery cell. If you need to charge these modules in extremely cold weather, you must make provisions for heated fluid circulation through the modules.



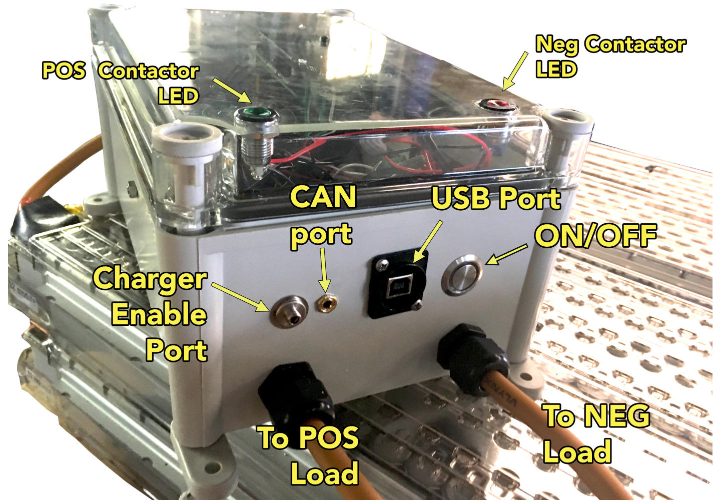
EVTV MONITOR/CONTROLLER

The EVTV Monitor/Controller is at attempt to design a replacement for the Tesla Battery System BMS that communicates with the individual battery modules and controls a set of high current relay contactors to connect the battery to external equipment. These contactors are quite important as the key to averting catastrophe is to DISCONNECT the battery from outside charging or discharging in ANY event where the voltage or temperature of cells is determined to be "abnormal".



One corollary process is that of "balancing" the cells. By using many small cells, Tesla largely alleviates the problem of capacity inconsistency from cell to cell. But unlike lead acid cells, you cannot simply overcharge them into electrolysis to get all the cells to the same voltage state.

The BMS board ON the module actually has provisions for cell balancing by switching small resistors in parallel with each cell causing a very tiny "bleed off" of some 125-200 milliamps across the cell. By applying this to "high" cells they can be brought down to the level of lower voltage cells and the cells balanced.



An important function of the battery system controller is to communicate battery state to other equipment in the vehicle over CAN bus. Increasingly, Solar equipment is also adopting CAN communications, so the Tesla Battery Module Controller does support CAN communications.

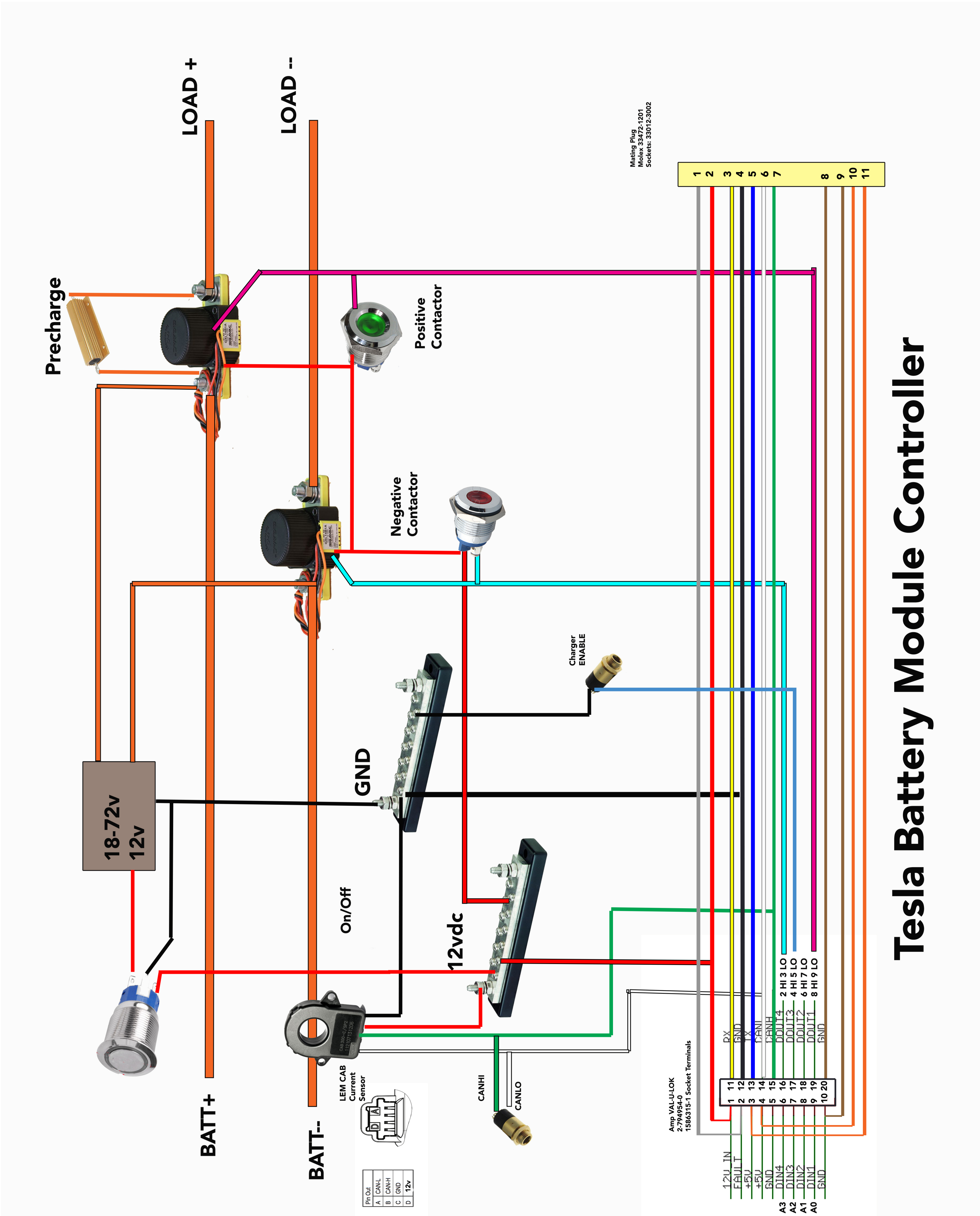
Solar Charge Controllers, as previously discussed, are notoriously poor at allowing configuration for different battery chemistries. To deal with this, the Tesla Battery Module Controller features a separate external CHARGER ENABLE output that can drive an external contactor to control the charge process.

The charge controller can monitor and control 1 to 63 Tesla Battery Modules and in this way support enormous battery banks all from a single controller.

Most home solar equipment today is designed around 12v, 24v, 36v, or 48v battery banks based on the standardized 12vdc lead acid battery. Increasingly 48v systems seem ascendant and we expect to see higher voltage battery systems in the future.

Two Tesla battery modules provide a nominal voltage of 43.2 volts and 237 ampere-hours for a backup capacity of 10.238 kWh. Naturally four of these modules would double that to a 20.476 kWh capacity. These packs would be charged to 50.4 volts and would be considered fully discharged at a static voltage of 36vdc.

The diagram below depicts the Tesla Battery Module Controller hardware.



LOAD +
LOAD --
Precharge
Positive Contactor
Negative Contactor
Mating Plug
Molex 33472-1201
Sockets: 33012-3002
Charger ENABLE
GND
18-72v
12v
On/Off
12vdc
BATT+
BATT--
LEM CAB Current Sensor
CANHI
CANLO
Amp VAL-U-LOK
2-794954-0
1586315-1 Socket Terminals
RX
GND
TX
CANL
CANH
DOUT4
DOUT3
DOUT2
DOUT1
GND
12V_IN
FAULT
+5V
+5V
GND
DIN4
DIN3
DIN2
DIN1
GND
A3
A2
A1
A0
2 HI 3 LO
4 HI 5 LO
6 HI 7 LO
8 HI 9 LO
Tesla Battery Module Controller

CONTROLLER

The heart of the Tesla Battery Module Controller is the controller electronics consisting of an EVTV Due microprocessor board and a Tesla Module Controller shield. The shield provides level shifting for the 612.5 kbps serial communications with the Module BMS boards.

It also provides four MOSFET outputs capable of switching either high side 3 amp/12vdc or low side 3 amp ground outputs to control two onboard contactors as well as other devices.

In addition to the CAN0 bus provided by the EVTV Due, it provides a second CAN1 bus.

It also provides a separate 12v to 5v voltage converter to ensure sufficient 5v supply voltage for up to 63 Tesla Battery Modules.

The shield is connected to a wiring harness out of the controller box with a 12 pin Molex Connector. This connector allows you to plug in the actual Tesla BMS module cable assemblies for any size battery pack of up to 63 modules.

CONTACTORS

The controller features two GIGAVAC EPIC GX14BD contactors. These are single-pole, single-throw normally open high voltage high current relays capable of breaking current flows of up to 900 volts. These are hermitically sealed IP67 UL listed contactors mechanically rated for 1 million cycles.

These contactors are rated for 350 amperes continuous load.

The positive contactor has a 500 ohm 50 watt precharge resistor wired across the terminals.

Both contactors are wired to switched grounds from the controller board in parallel with LED indicators on the enclosure. The RED LED indicates negative contactor closure while the GREEN LED indicates positive contactor closure.

In normal operation, on startup the controller will close the negative contactor completing the circuit between the battery and the load through the precharge resistor, which acts to limit current flow to about 100 milliamps. This allows the input capacitors for the load to fill before connecting the battery.

After a user configurable **PRECHARGE TIME**, the positive contactor is closed completing the circuit and connecting the battery to the outside system.

If at any time the controller determines that the voltage for any cell in the system exceeds the user configurable limits (**VOLTHI**, **VOLTLO**, **VARIANCE**), or that the terminal temperatures of any module exceed user-configurable limits (**TEMPHI**, **TEMPLO**), the controller will disengage both contactors, isolating the battery from any load and effectively disconnecting the battery.

DC-DC CONVERTER

An onboard DC-DC converter is connected across the battery side terminals of the two contactors. This DC-DC converter can convert input voltages of 18 tp 72 volts to a steady 12vdc at up to 50 watts for use in powering the controller electronics, LEDs, and contactors. In this way, the system is powered by the battery itself.

But note that this also means the battery is under continuous drain any time the controller power switch is in the ON position, even though the contactors are disengaged, a very small drain on the battery will continue until the power switch is set to OFF.

LEM CAB CURRENT SENSOR

The controller also features a LEM CAB current sensor that reports currents of up to 300 amperes in either direction via CAN message to the controller electronics.

CHARGER ENABLE CONNECTION

A 3.5 mm stereo jack is provided on the enclosure side to provide 12vdc (tip) and ground (ring) any time the control electronics determines charging of the battery should be allowed. This will be switched OFF if battery voltage exceeds user configurable voltage **CUTOFF** limits.

It will also switch back to ON if battery voltage falls below a user configurable **RESUME** voltage limit.

Note that in our home solar system diagram, we use this charge enable to power an external GIGAVAC EPIC contactor that switches high voltage solar array power to the charge controller. In this way, the MPPT charge controller could be set with limits both higher and lower than the Tesla Module Controller limits, and would still only be allowed to charge by the Tesla Module Controller.\

CAN CONNECTION

A second 3.5 mm stereo jack is provided with CAN HI on tip and CAN LO on ring. This is a 500 kbps CAN connection that can be connected to any 500kbps CAN bus. Messages to request and receive Tesla Battery Module data are described later in this document.

USB PORT

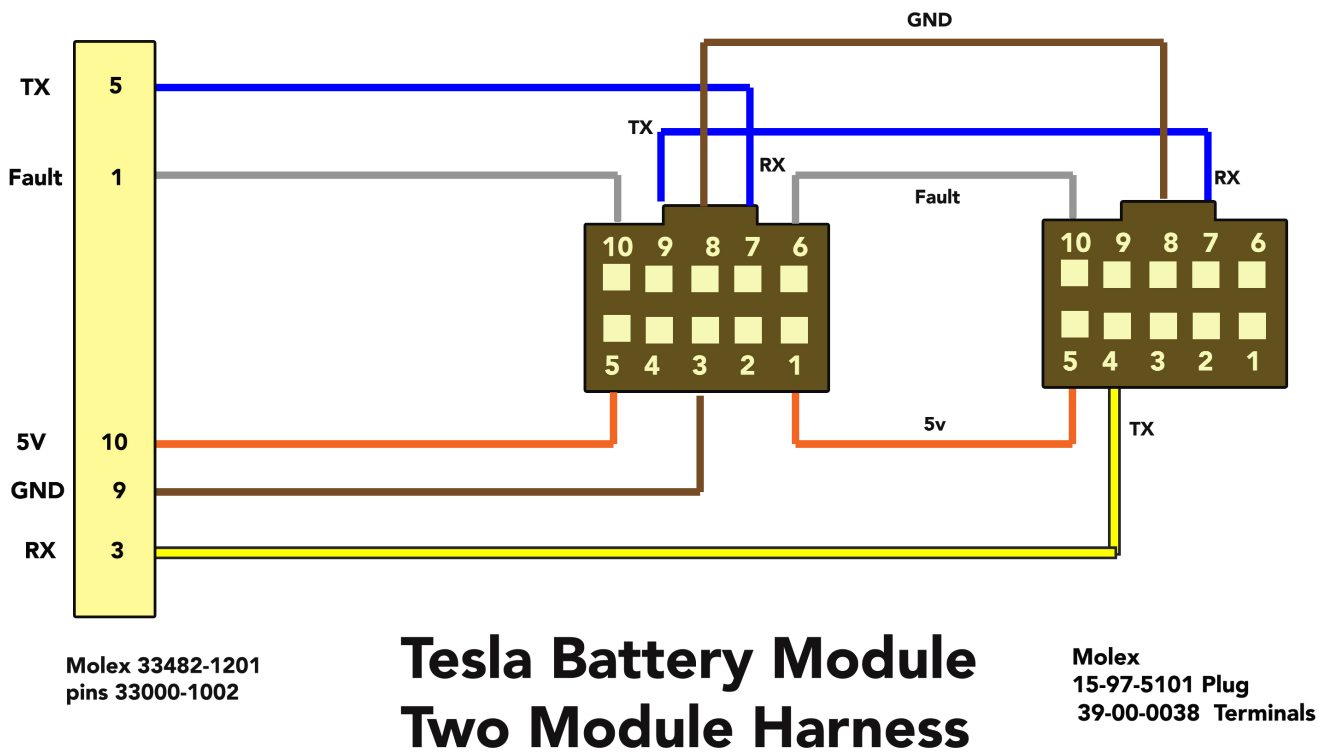
A standard USB mini-b printer port is provided on the end of the controller enclosure. This is connected to the Native USB port of the EVTV Due microcontroller board .

You can connect a laptop of any operating system to this port to view the configuration and monitor screens provided by the controller software. You wlll need an ASCII terminal program such as CoolTerm or Putty to do so.

Communications parameters are 115.2 kbps, 8 data bits, no parity, 1 stop bit. Your terminal program must be set to append either a line feed, carriage return, or both to all commands.

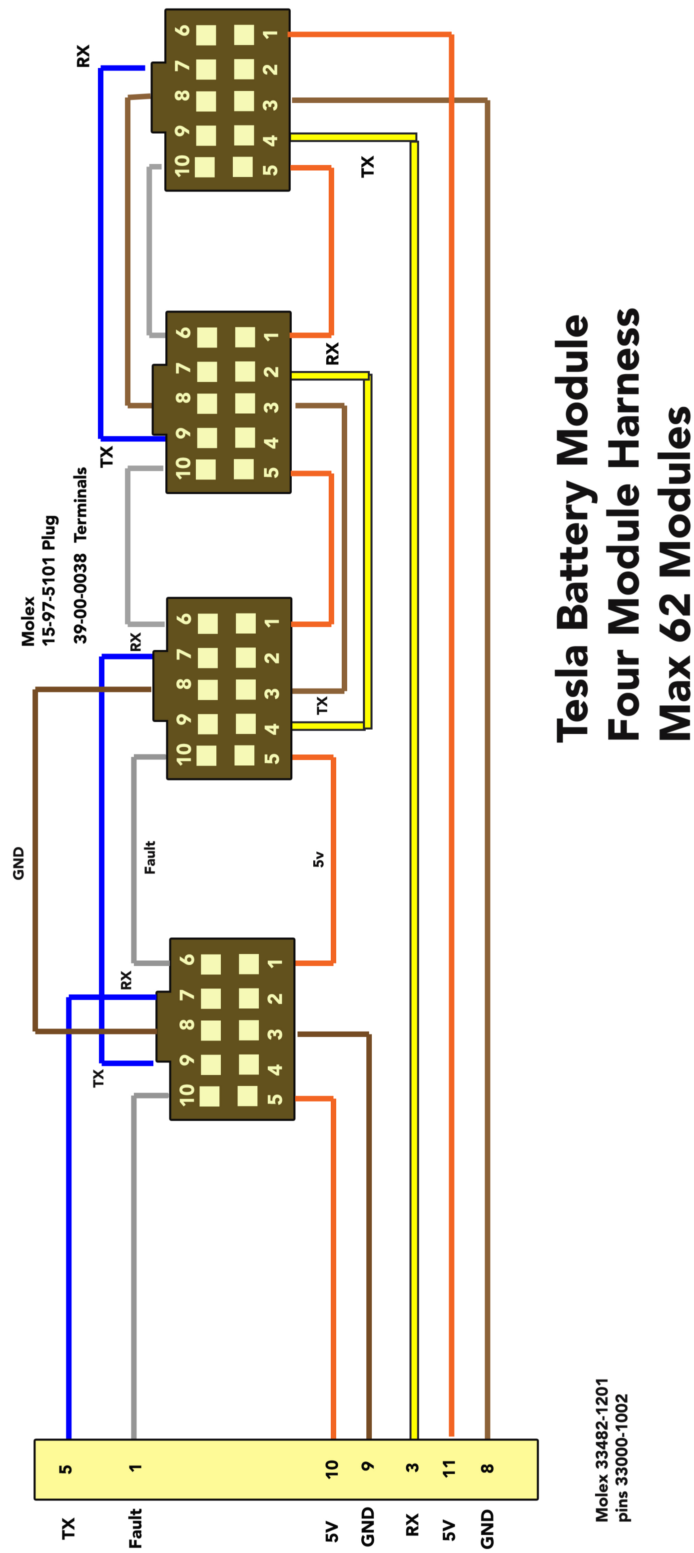
TESLA BATTERY MODULE CONTROLLER CONNECTIONS

The diagrams below illustrate the wiring necessary to connect the Tesla Battery Module Controller to Tesla Battery Modules for control and monitoring.



Note that both two module and four module cables are available from EVTV at http://store.evtv.me.

For larger strings of modules, EVTV makes available a kit with the mating controller interface connector and as many Tesla Battery Module connectors as desired for custom wire harness assembly.


Tesla Battery Module
Four Module Harness
Max 62 Modules
Molex
15-97-5101 Plug
39-00-0038 Terminals
Molex 33482-1201
pins 33000-1002
GND
Fault
5v
RX
TX
TX
Fault
5V
GND
RX
5V
GND

BATTERY TERMINAL CONNECTIONS

The EVTV controller provides approximately 2 feet of 1AWG shielded cable to connect to the positive and negative terminals of the Tesla Battery Module.

To interconnect the modules, our 76mm battery straps are the ideal length for two adjacent/side-by-side modules and provide adequate current capacity.

The EVTV controller also provides approximately 2 feet of 1AWG shielded cable to connect to the positive and negative terminals of the load – typically a solar inverter and a solar charge controller.

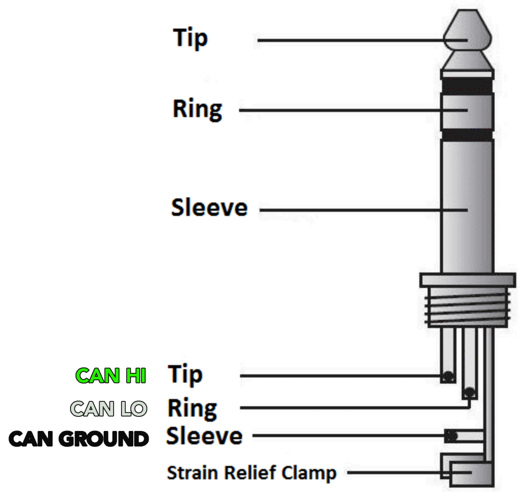
Solar installations differ markedly from those in electric vehicles in that higher currents are encountered in electric vehicles but for shorter duration. Solar applications use lower currents in the 100-200 ampere range but often do so for extended periods of time.

It is important to use copper cables of sufficient cross section to carry the load efficiently over time. 1 AWG is appropriate for a couple of feet. But longer runs require heavier cabling. A number of online calculator sites exist to calculate cable sizes based on current and length. http://www.solar-wind.co.uk/cable-sizing-DC-cables.html

Additionally, the output of your battery should be fused. EVTV provides a variety of fuses at http://store.evtv.me, along with terminal bars, and shielded cabling.

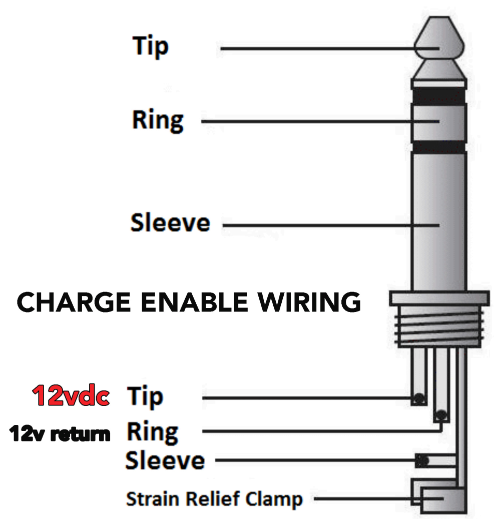
CAN WIRING

The EVTV Controller provides a CAN port using a 3.5mm stereo receptacle. You can fabricate any type of CAN connection using a 3.5mm audio plug as shown.



CHARGE ENABLE WIRING

The EVTV Controller provides a CHARGE ENABLE port using a 3.5mm stereo receptacle. This receptacle provides 12v and a return to energize an external relay or contactor as illustrated here.



TESLA BATTERY MODULE CONTROLLER SOFTWARE

The original core software we developed to actually communicate with Tesla Battery Modules over the serial port is available open source at https://github.com/collin80/TeslaBMS.

The expense and effort of developing this were substantial. But we think it's important to share this with the community to enable innovation in the use of these very capable battery modules.

It does work with the EVTV Tesla Battery Module Control hardware. But it is very basic. It handles the hard parts of dealing with the Tesla Battery Module BMS boards. But it does not take advantage of many of the other features in the provided hardware. It is intended as a basis for those with a better idea, or with different needs regarding functionality. You can use this as the basis for developing your own more advanced application.

On the other hand, we are not going to spend a lot of time providing product support or coding lessons on either the open source software or the EVTV Controller hardware with unknown code.

The software included with the controller device is more fully featured and quite user configurable. It should serve the needs in most applications and is updated regularly and supported.

MODULE CONTROLLER OPERATION

The EVTV Controller for the Tesla Model S Battery Module is an entirely automatic system to connect a series of 1 to 63 Tesla Model S battery modules to a load – typically a home solar installation.

The basic operation is extremely simple. You connect the batteries in one end and the load out the other and press ON/OFF to turn it on. After a brief precharge sequence, this connects the battery to your system.

To disconnect it, press ON/OFF again. You're done and that is really all the operation required. Thank you for shopping at EVTV.

The device monitors battery voltage and temperature hundreds of times each second, and as long as all fall within preset limits, it just works. The limits are already configured before it leaves our shop. And as long as the battery modules do net exceed certain voltage and temperature limitations, you can use the batteries at will.

BUT – how whom so ever, EVTV viewers tend toward curiosity, obsessive compulsive disorder, and an overweening desire to control everything within their purview. Not to cast aspersions on the show's host and producer and first wizard deluxe.

And so the EVTV controller provides a USB port and a CAN port.

The USB port allows a serial connection for a common standard American Standard Code for Information Interchange (ASCII) terminal. While a bit shy of an iPhone application, this elderly communications technique allows a very simple interface to ANY device of any operating system, Linux, Windoze, Mac OSX, et al. But it DOES require the use of a "terminal program" such as HyperTerm for Windoze, CoolTerm for Mac OSX, or the Arduino MONITOR program, part of the Arduino IDE.

Communication parameters are 8 data bits, no parity, 1 stop bit, and nominally at 115 kbps data rate.

Any commands entered to the system must be an ASCII text line terminated with a carriage return (CR), line feed (LF) or both.

On connection, the system will send the ASCII text of the MONITOR screen several times per second. If your terminal program recognizes the ASCII Form Feed command, it will be easier to read.

MONITOR SCREEN

The basic MONITOR screen is shown below:

```
===========================================================================================================
*****************  EVTV Tesla Battery Module Monitor Version 1.07  Runtime: 00 Days 00:00:50  *************
===========================================================================================================

PACK STATUS:No Faults Modules:4 Battery Voltage:46.02 Avg Cell Voltage:3.86  Avg Temp:27.37

Module1:22.93V 27.09/27.03C  Cell1:3.850V  Cell2:3.852V  Cell3:3.853V  Cell4:3.853V  Cell5:3.853V  Cell6:3.855V
Module2:23.13V 27.72/26.76C  Cell7:3.866V  Cell8:3.865V  Cell9:3.866V  Cell10:3.866V Cell11:3.888V Cell12:3.798V
Module3:23.04V 27.95/27.36C Cell13:3.853V Cell14:3.853V Cell15:3.855V Cell16:3.853V Cell17:3.852V Cell18:3.855V
Module4:22.94V 27.76/27.26C Cell19:3.855V Cell20:3.856V Cell21:3.858V Cell22:3.857V Cell23:3.857V Cell24:3.858V

        Battery SOC:98.35% Battery Current:-34.14 A  Battery Power:-1570.86 Watts
        Battery Watt Hours:-313.53 Wh Battery Lifetime Charging:0.00 kWh  Battery Lifetime Discharging:-0.31 kWh
        Battery Capacity:410.00 Ah Ampere-Hours:-6.78 Ah
        Max System Discharge Current:-207.72A Max System Charge Current:0.21A
        Highest Cell Voltage:3.8882V  Lowest Cell Voltage:3.7981V

        Negative Contactor:ON
        Positive Contactor:ON
         Temperature Alarm:OFF
             Voltage Alarm:OFF
   Charging Enabled Output:ON


Enter ? for Configuration Menu......
```

It is refreshed with new data several times per second.

TITLE BAR

```
*****************  EVTV Tesla Battery Module Monitor Version 1.07  Runtime: 00 Days 00:00:50  *************
```

This line shows the current software version number and the runtime since the system was powered up. The runtime will rollover after about 49 days.
The version number can be used to verify you have the latest software operating anytime you upgrade the software.

PACK SUMMARY

```
PACK STATUS:No Faults Modules:4 Battery Voltage:46.02 Avg Cell Voltage:3.86  Avg Temp:27.37
```

The pack summary line shows whether or not the system has received ANY sort of fault indication from the BMS board on ANY battery module.

It indicates how many modules were discovered by the software. This should of course match the number you have provisioned. If it does not, there is a wiring problem in your wiring harness.

Batttery voltage is the total voltage of all battery modules summed, divided by the number entered in PARALLEL indicating the number of parallel strings your battery configuration contains. The default is two strings of two modules for a 48vdc

system. But you can have any number of modules arranged anyway you like up to the 63 module maximum. PARALLEL should contain the number of parallel strings you configured.
Average Cell Voltage is an average of ALL cells in ALL modules in the system.

Average Temperature is the average temperature in degrees Centigrade, of ALL positive and negative terminals of ALL modules in your system.

INDIVIDUAL MODULE DISPLAY

The next set of lines is variable from 1 to 63 with one line per module.

```
Module1:22.93V 27.09/27.03C  Cell1:3.850V  Cell2:3.852V  Cell3:3.853V  Cell4:3.853V  Cell5:3.853V  Cell6:3.855V
Module2:23.13V 27.72/26.76C  Cell7:3.866V  Cell8:3.865V  Cell9:3.866V  Cell10:3.866V Cell11:3.888V Cell12:3.798V
Module3:23.04V 27.95/27.36C Cell13:3.853V Cell14:3.853V Cell15:3.855V Cell16:3.853V Cell17:3.852V Cell18:3.855V
Module4:22.94V 27.76/27.26C Cell19:3.855V Cell20:3.856V Cell21:3.858V Cell22:3.857V Cell23:3.857V Cell24:3.858V
```

Each line lists the assigned module number, the module voltage, the negative terminal temperature followed by the positive terminal temperature, and the actual voltage reading of each of the six “cells” in that module to the thousandth of a volt.

SOC/CURRENT/POWER

The next line provides the battery state of charge, current, and power.

```
Battery SOC:98.35% Battery Current:-34.14 A  Battery Power:-1570.86 Watts
```

Battery SOC is expressed as a percentage from zero to 100%. It is actually a function of the entered configuration parameter CAPACITY and the measured number of ampere hours charged or discharged from the battery. If you have set CAPACITY to 100 amp hours, and the system has measured 12.5 ampere hours discharged from the pack, it will show an SOC value of 87.50%.

You can ZERO out the ampere hours measured by entering the single character command “Z”. This has the effect of zeroing SOC as well to 100%.

Battery current is shown in amperes. Negative values indicate the battery is currently DISCHARGING into the load. Positive values indicate current INTO the battery via charging.

Battery Power is a simple instantaneous calculation of current power by multiplying pack voltage in volts times the current in amperes. Again, negative values indicate discharge and positive values indicate power while charging.

WATT HOURS

```
Battery Watt Hours:-313.53 Wh Battery Lifetime Charging:0.00 kWh  Battery Lifetime Discharging:-0.31 kWh
```

The next line displays usage in watt hours. A watt hour is a measurement of power over time. If you use one watt of power for an hour, you have extracted a watt hour from the pack. Each Tesla Model S battery module provides about 5000 watt hours of storage capacity.

The first indication of battery watt hours indicates the number of watt hours charged (positive) or discharged (negative) SINCE the system was last powered on.

The second and third elements on this line are the TOTAL watt hours charged or discharged since the last software upgrade in kilowatthours (1000 watt hours). This is a running total that is carried from one powered on session to the next. In this way, you can monitor the lifetime number of kilowatt hours going into and out of the battery pack.

CAPACITY/USE

The next line displays battery **CAPACITY** and use.

```
Battery Capacity:410.00 Ah Ampere-Hours:-6.78 Ah
```

CAPACITY is an entered variable indicating the number of Ampere-Hours in the battery pack. A typical Model S Battery Module from an 85kWh pack holds about 235 ampere-hours while a similar module from a 60kWh pack holds about 205 ampere hours. If you have two strings in parallel using 85kWh battery modules, you would enter 470 as your capacity. Of course if you had four strings in parallel this would be 940 amp hours. This is an important configuration element in that it determines state of charge.

Ampere-hours shows the actual number of NET ampere hours in the current session. Charging energy is positive and is added to the total while discharging current measured over time is negative and subtracted from the total. Note that this value indicates the sum of BOTH since the system was last powered on.

Actually, the AH value is retained BETWEEN sessions as well. It can be zeroed out at any time using the single character **Z** command.

MAXIMUM CURRENT

```
Max System Discharge Current:-207.72A Max System Charge Current:0.21A
```

The next line displays an interesting metric in that it represents the PEAK charge or discharge current measured this session. It is an instantaneous value that is continuously updated to show the maximums encountered. This can provide valuable information about your wiring sizing and other considerations based on the maximum current the system will encounter.

These values are reset each time the system is powered up.

HIGH AND LOW CELLS

Highest Cell Voltage:3.8882V Lowest Cell Voltage:3.7981V

The next line displays the highest cell voltage in the entire pack and the lowest cell voltage in the pack. This is an instantaneous measurement and does not indicate WHICH cell is highest or lowest, simply the value of the highest cell measured and the lowest cell measured.

CONTACTOR STATE

Negative Contactor:ON
Positive Contactor:ON

One of the most important functions of the EVTV controller is to connect, and more importantly, disconnect the pack from the load in event of a detected error in the pack. This is accomplished using two very high quality Gigavac contactor relays capable of continues currents of 350 amperes. One is provided for each battery terminal.

On power up, the system checks all voltages and temperatures and if there are no anomalies it closes the NEGATIVE contactor. This is also indicated by lighting the RED LED on the top panel of the controller.

The battery is actually then connected to the load through a 500 ohm 50 watt precharge resistor. While connected, this severely limits the amount of current through the system, allowing input capacitors on the load to **PRECHARGE** at a very low current rate. This is to prevent huge current surges when connecting to inverters with large input capacitors.

After expiration of a configurable **PRECHARGE** period in seconds, the controller then closes the POSITIVE contactor, indicated by the GREEN LED on the top panel. At this point the battery can provide full current to the system.

ALARMS

There are two things monitored by the controller to determine battery state of health, voltage and temperature. If either are out of limits, it sets an alarm and disconnects both contactors.

```
Temperature Alarm:OFF
    Voltage Alarm:OFF
```

The voltage alarm is determined by three configuration items, **HIVOLT**, **LOVOLT**, and **VARIANCE**.

HIVOLT sets the maximum allowable voltage ANY cell in the pack is allowed to achieve before the alarm is triggered. Any time ANY cell exceeds **HIVOLT**, the system is presumed to be overcharging and it is shut down.

LOVOLT sets the minimum allowable voltage ANY cell in the pack is allowed to achieve before the alarm is triggered. Any time ANY cell falls below **LOVOLT**, the system is shut down.

Note that the voltage of the cells will be lower under high current discharge and so you may set **LOVOLT** to a lower voltage than what would be considered fully discharged under no current conditions. If you set it to the 3.0 volts normally considered fully discharged in a static no load condition, you will trip the **LOVOLT** alarm prematurely when discharging 300 amps for example.

VARIANCE sets the maximum allowable variance between the highest voltage cell and the lowest voltage cell. The normal cell failure indication would be at a very low voltage or a very high voltage and very much out of line with the other cells. By setting a low variance, you ensure early detection of cells that are just beginning to develop problems. Default here is 0.2volts.

The system does provide for automatic cell balancing that should be able to keep EVERY cell in the pack to within a few millivolts of each other. But under load, a weak cell will exhibit a higher internal resistance than the others and so it's voltage will dip rather more than the healthy cells. This is a very good way to detect problem cells EARLY and before they fail utterly and catastrophically. If you are getting a lot of voltage alarm shutdowns and all the cells seem good with no load, this is probably the reason. Investigate further. Set this variance to a wider value and put the system under load WHILE MONITORING THE VOLTAGES and you may see one cell seriously out of line with the others.

CHARGE ENABLE

`Charging Enabled Output:ON`

There is a slight problem with using Tesla Model S power modules with most home solar equipment designed for 48vdc battery storage.

The lead-acid battery was invented in 1859 by French physicist Gaston Plante' and it is the oldest type of rechargeable battery. There have been numerous advances in battery technology since, but most of the home solar equipment vendors have apparently not received the word.

And so their systems are designed for use with Pb chemistry battery cells. Lead-acid cells feature a nominal voltage of 2.1v per cell. Six cells make up the standard lead-acid "battery" and the nominal voltage is then 2.1 x 6 or 12.6 volts each. In a 48 volt system, four of these would be used for a nominal voltage of 50.4 volts.

The charging of lead-acid cells is relatively complex compared to Lithium ion cells, though they do share some similarities. Let's go through four basic phases used in lead-acid charging and usually referred to in the operating instructions of most home solar equipment.

BULK CHARGE PHASE

This refers to the constant current stage of charging where power is simply added to the battery at the maximum rate until it reaches some preset value. For lead acid cells this tends to be about 2.3 volts per cell or 55.2 volts for a 48v pack.

ABSORPTION PHASE

This would correlate to the constant voltage phase of lithium batteries. The batteries are held at a constant voltage. As energy is added to the cells, the voltage tends to creep up. The charging system then lowers the current applied to the cell to bring the voltage back down to the absorption voltage. As this is a continuous process it is "held" at the absorption phase voltage. This is typically 2.4 volts per cell or 57.6 volts per 48v pack.

EQUALIZATION PHASE

Lead acid batteries discharge even when left unconnected to a load. This "internal" discharge is based on internal resistance and varies from cell to cell. Because of this, even a sitting battery will decrease in state of charge over time, and each cell will do so at a different rate. This leads to inequality in the state of charge of the cells.

To bring these cells into balance such that all are at the SAME state of charge, they simply overcharge the cells. This is handy in that lead-acid cells actually cannot BE overcharged. If you continue to add energy to a fully charged lead-acid cell, it will increase to about 2.5v per cell. But it will not go beyond that. The additional energy puts the cell into electrolysis, much as extra energy added to water beyond 212F does not raise the temperature, it simply causes it to boil. Similarly lead cells "boil" by separating hydrogen and oxygen from the water in the electrolyte, giving off quite dangerous hydrogen and oxygen gasses and depleting the water level in the cells.

But it DOES bring all of them to the same state of charge – 100% at 2.5volts per cell or 60 volts for a 48v pack of 24 cells. This is usually done for a time limited period, ostensibly bringing all cells in the battery pack to the same 2.5v limit. At that point, they have been "top balanced" at 2.5v per cell.

FLOAT PHASE

After the cells have been fully charged, the charge voltage is removed and they will immediately drop to about 2.25 volts per cell or 54 volts per 48v pack. But they immediately begin to decrease from there, even if not used, due to internal discharge. And so the "float phase" referred to by most charge controllers is simply to maintain the cells at a constant 2.25v per cell level.

All of these voltages and phases vary with temperature. And with the advent of absorbed glass matt and gel cells, pressure. And so each battery manufacturer has a slightly different set of voltages ideal and recommended for battery charging and maintenance.

And so to simplify this, most charge controller manufacturers provide an absolutely nonsensical menu of battery types for you to select from, with very little actual control of the voltages involved. Unfortunately, none of them really provide anything close to what is used for lithium batteries and even there, the Tesla Model S battery modules vary greatly from most lithium batteries.

TESLA MODEL S BATTERY MODULE CHARACTERISTICS

The Tesla Model S battery is quite different featuring a nominal voltage of 3.6v rather than 2.1. That means a SIX cell module has a nominal voltage of 21.6v and two of them would be 43.2v.

This is generally close enough to 48v to operate a 48v battery inverter. But barely.

The fully charged voltage of the Tesla module is a little over 4v per cell or 24v per module giving you the 48v ideal to start with.

We would normally charge the Tesla module to 4.2v per cell as an absolute maximum voltage corresponding to 25.2v per module or 50.4v per two-module pack.

Lead acid cells really MUST be fully charged periodically or all manner of sin befalls them. Indeed equalization is really quite necessary.

Lithium cells NEVER have to be fully charged AT ALL. No penalty is incurred in not fully charging them and indeed cycle life is SERIOUSLY extended by undercharging them. We would advocate charging to a maximum of 4.1 volts per cell and 4v per cell would be even better.

Lithium cells cannot be top balanced by overcharging and in fact overcharging is generally CATASTROPHIC for lithium cells. It causes gassing of the electrolyte, and often thermal runaway accompanied by fire and/or explosion. So you see the basic disconnect here.

So let's summarize the mismatch between Lithium and lead at a 48v pack basis related to the charging phases presented for a typical charge controller.

PHASE	**LITHIUM**	**LEAD**
Bulk	**3.9 x 12 = 46.8v**	**2.3 x 24 = 55.2v**
Absorption	**4.1 x 12 = 49.2v**	**2.4 x 24 = 57.6v**
Equalization	**4.1 x 12 = 49.2v**	**2.5 x 24 = 60.0v**
Float	**4.0 x 12 = 48.0v**	**2.25 x 24 = 54.0v**
Fully Discharged	**3.0 x 12 = 36.0v**	**1.70 x 24 = 41.0v**

And so what we see here is that in **all four charge phases** of a lead acid battery cell, the voltages used are CATASTROPHIC for the Tesla Model S battery module. They would GROSSLY overcharge the cell inevitably leading to fire and/or explosion.

And so you see the problem with individuals trying to use Tesla cells for home solar energy storage. The charging equipment, which often does provide SOME variance within a range, is essentially NEVER suitable for Lithium cells generally, and absolutely not for Tesla's battery modules. LiFePo4 cells, for example, are nominally

3.2v and it is fairly easy to match them mathematically to the lead acid batteries. 4 LiFePo4 cells just happen, by coincidence, correspond very closely to 6 lead acid cells.

But the Tesla battery modules higher 3.6vdc nominal voltage and a fixed 6 cells per module make it very difficult to match a system to existing equipment.

Of course, we have a HIVOLT setting that would prevent this by tripping its internal alarm and disconnecting the battery from the system by opening both contactors. Very effective. But a poor strategy.

At that point, we are disconnected from the system and the fully charged battery is totally useless because it is disconnected.

If we automatically reconnect, it will again reach the HIVOLT mark and disconnect again. This would lead to a cycle of hysteresis where we continually connected and disconnected until indeed the battery caught fire.

So once HIVOLT is reached, you must MANUALLY reconnect using the power switch on the controller or a command via the USB terminal port.

It is true that SOME charge controller vendors are becoming more aware of lithium issues. Sunny Island for example, allows lithium batteries but it REQUIRES an external Battery Management System for the lithium cells and it MUST communicate by CAN with the Sunny Island inverter/charger to set the charge termination voltage.

The Magnum Power inverter/charger allows a wider range of adjustment of its voltages, but only with an optional remote control device.

For these reasons, it is important that the EVTV controller be able to control the charge process externally. We do this in two ways – by CAN communication and by the external charge enable signal.

CAN communications will be discussed later in the chapter on CAN COMMUNICATIONS.

But more directly the EVTV controller provides an external contactor signal via a 3.5mm stereo receptacle. This receptacle carries a 12v energize voltage on TIP and a return ground on RING. This can easily accommodate up to 4 amps to energize a contactor and the 200ma necessary in most cases to hold a contactor closed.

This voltage is available anytime charging is allowed for the Tesla battery modules.

And this CHARGER ENABLE output is controlled by two simple variables CUTOFF and RESUME

The CUTOFF variable simply provides the pack voltage at which the CHARGER ENABLE output will go to zero.

And the RESUME variable is to prevent hysteresis. It establishes the voltage at which charging should RESUME and is typically some value safely below the CUTOFF value.

Defaults would be 4.1v for CUTOFF and 3.8v for RESUME.

By way of example, we have found a **Tristar MPPT 600v** solar charge controller we rather like in that it DOES accommodate a wide range of solar input voltages (100-525v) and battery voltages (16-72v). But it presumes some standard battery types and voltages per the tables below, and requires special software and connections to set "custom" voltages.

Battery Charging Settings

The details of the TriStar MPPT 600V battery charging settings are shown in tables 4-1 and 4-2 below. All voltage settings listed are for nominal 48 Volt battery banks.

Settings Switches 4 - 5 - 6	Battery Type	Absorp. Stage (Volts)	Float Stage (Volts)	Equalize Stage (Volts)	Absorp. Time (Minutes)	Equalize Time (Minutes)	Equalize Interval (Days)
off-off-off	1 - Gel	56.00	54.80		150		
off-off-on	2 - Sealed*	56.60	54.80	57.60	150	60	28
off-on-off	3 - Sealed*	57.20	54.80	58.40	150	60	28
off-on-on	4 - AGM/Flooded	57.60	54.80	60.40	180	120	28
on-off-off	5 - Flooded	58.40	54.00	61.20	180	120	28
on-off-on	6 - Flooded	58.80	54.00	61.60	180	180	28
on-on-off	7 - L-16	61.60	53.60	64.00	180	180	14
on-on-on	8 - Custom	Custom	Custom	Custom	Custom	Custom	Custom

** "Sealed" battery type includes gel and AGM batteries*

Table 4-1. Battery charging settings for each selectable battery type

Shared Settings	Value	Units
Absorption Extension Voltage	50.00	Volts
Absorption Extension Time	Absorption Time + 30	minutes
Float Exit Time-out	30	minutes
Float Cancel Voltage	46.00	Volts
Equalize Time-out	Equalize Time + 60	minutes
Temperature Compensation Coefficient*	- 5	millivolts / °C / cell

** 25°C reference*

As you can see, all the "standard" battery types result in hopelessly high voltages for our battery system.

But not to worry, we can select ANY of them, and install an additional Gigavac Contactor to the Solar array input of the charge controller. We tie the coil connections of this contactor to a 3.5mm stereo plug and connect it to the EVTV controller **CHARGE ENABLE** receptacle. Now, whenever the voltage of the pack is less than the **CUTOFF** variable, the EVTV controller will energize the contactor, connecting high voltage from the solar array to the Tripp charge controller. That controller will then come up and begin Maximum Power Point Tracking and battery charging as designed.

When we reach **CUTOFF**, the contactor de-energizes, removing solar array high voltage from the charge controller. When the voltage in the battery falls to the RESUME point, it will again engage, and again begin charging.

In this way, we do not have to disconnect the battery pack, but instead disconnect the charger. If for some reason this strategy should fail, HIVOLT will still prevent overcharge. And as a third level of safety, we will indeed probably chase down the special software and set appropriate custom battery charging voltages in the Tristar charge controller.

When preventing overcharge of the battery pack, overkill is always appropriate. Overcharging is how to convert a superb Tesla battery module pack into an incendiary device of impressive proportions.

CONFIGURATION SCREEN.

On the EVTV monitor screen, you can enter a question mark at any time to call up the configuration screen.

```
=======================================================
  ************* CONFIGURATION MENU ***************
=======================================================
Enable line endings of some sort (LF, CR, CRLF)

GENERAL SYSTEM CONFIGURATION

   CANSPEED=500000 - set CAN bus speed
   BATTERYID=1 - Set battery ID for CAN protocol (1-14)


MODULE COMMANDS

   C = Clear all board faults
   R = Renumber connected boards in sequence
   Z - Resets State of Charge Values to 100% Currently:96.57%
   O — Cycle contactors OFF and ON.


LIMITS AND CONFIGURATION

   CAPACITY= 410.00 - Battery pack capacity in ampere-hours
   PARALLEL= 2 - Number of series strings in parallel in this configuration
   PRECHARGE= 6.50 - Number of seconds in precharge delay
   HIVOLT= 4.10 - High Cell Voltage limit for Contactor cutoff
   LOVOLT= 2.30 - Low Cell Voltage limit for Contactor cutoff
   VARIANCE= 0.25 - Maximum Allowable Difference Between Cell Voltages
   HITEMP= 65.00 - High Temp limit C for Contactor cutoff
   LOTEMP= 5.00 - Low Temp limit C for Contactor cutoff
   CUTOFF= 4.15 - Charge Enable Output Charging Cutoff Cell Voltage
   RESUME= 3.80 - Charge Enable Output Resume Charging Cell Voltage


Enter ? to return to MONITOR screen......
```

This screen allows you to enter various configuration values used by the system. Most of these have already been discussed. To enter a value simply enter a text line with the name of the value, the equals sign, and the numeric value. Each command line MUST end with a carriage return, line feed, or both.

For example, to change the capacity of the battery:

CAPACITY = 470.00

Indeed, in almost all cases you can abbreviate this to the first three letters of the command

CAP=470

We will provide descriptions for those values not discussed in the Monitor Screen section.

CANSPEED = 500000

CAN=500

CAN speed sets the data rate for the CAN bus available on a 3.5 mm stereo jack on the outside panel of the controller enclosure. Speeds must be between 33,000 bits per second and 1,000,000 bits per second.

BATTERYID=1

The Battery ID refers to an identifier for a CAN protocol we have designed for the system. A battery can consist of from 1 to 63 Tesla Battery Modules and you can have up to 14 batteries in one CAN controlled system. This allows you to control and monitor up to 882 Tesla battery modules in one system for a pretty impressive total capacity of 4.4 MwH. This should be sufficient to power the average American home for 4.86 months. Which should pretty much get you through the Zombi Apocalypse.

This allows you to set the battery number for this particular system.

SINGLE CHARACTER COMMANDS

The following single character commands affect the operation of the device.

```
C = Clear all board faults
R = Renumber connected boards in sequence
Z - Resets State of Charge Values to 100% Currently:96.57%
O – Cycle contactors OFF and ON.
```

C CLEAR ALL BOARD FAULTS

This is a test function. If a fault is reported on the MONITOR screen PACK line, entering a C will clear all board faults. If they return, there is a problem with one of the modules.
Normally anytime you renumber the connected boards, you will also have to clear faults as it uses a fault to detect that all boards have been reached.

R RENUMBER CONNECTED BOARDS IN SEQUENCE

You can connect any number of Tesla Model S battery modules up to a maximum of 63 and you can add or subtract modules at will. R command renumbers all modules in the series for identification purposes.

This process is actually performed EVERY time you powerup the system. The R command simply provides a manual means of resurveying the bus for battery module BMS boards.

Z - Resets State of Charge Values to 100% Currently:96.57%

This command is interesting in that it displays the current battery State of Charge in percent. This is based on capacity and the currently used number of ampere-hours. Entering Z really zeros the ampere-hour value, effectively also restoring state of charge to 100%.

O – Cycle contactors OFF and ON.

This command basically provides a manual disconnect for both contactors. If you enter it a second time, it will engage the negative contactor and initiate the precharge sequence for the positive contactor.

CAPACITY= 410.00 - Battery pack capacity in ampere-hours

This command allows you to enter the capacity of the entire battery pack in ampere-hours. You must take into account the number of strings in parallel to calculate the true amp-hour capacity. For example, four strings in parallel of modules from an 85kWh Tesla battery would be 235 Ah x 4 or 940 ampere-hours.

PARALLEL= 2 - Number of series strings in parallel in this configuration

This command allows you to enter the number of parallel strings in your pack. Strings in series of course sum in voltage. So if you had 16 modules in series it would comprise a battery of nominally 345.6 volts and the system will accurately read that voltage. You would say you had 16S1P pack.
If however, you split it into two strings of eight cells each, it would be an 8S2P pack of 172.8 volts. We can automatically sum the voltages from all reporting BMS boards, but need the number of parallel strings to determine the true pack configuration.

PRECHARGE= 6.50 - Number of seconds in precharge delay

On startup, the system engages the negative contactor, initiating a precharge of the input capacitors on the load equipment. After a period of delay defined by PRECHARGE in seconds, it engages the positive contactor, connecting the battery to the system.

HIVOLT= 4.10 - High Cell Voltage limit for Contactor cutoff

This command allows entry of the highest allowable cell voltage. If ANY cell in ANY module reaches this voltage, even briefly, it triggers a voltage alarm and the system is disconnected. You might want this to be slightly above the charge voltage or any voltage a cell might reach during charging or balancing even briefly.

LOVOLT= 2.30 - Low Cell Voltage limit for Contactor cutoff

This command allows entry of the lowest allowable cell voltage. If ANY cell in ANY module falls below this voltage, even briefly, it triggers a voltage alarm and the system is disconnected.

Note that cell voltages can reach fairly low values during high current delivery, and that this is NOT the same as the fully discharged voltage under static conditions.

You will probably want to experiment with your system under normal full loads, and observe the cell voltages on the monitor screen. You can then set this for something slightly lower, in order to catch failing cells or surge currents beyond what you want to supply.

VARIANCE= 0.25 - Maximum Allowable Difference Between Cell Voltages

This command allows entry of the maximum variation between the HIGHEST measured cell voltage and the lowest measured cell voltage. It is actually key to the most important measurement of cell health in a battery system. When the pack is under high current load, an early sign of cell failure is a lower cell voltage than other cells in the pack. You can set this variance to catch this.

HITEMP= 65.00 - High Temp limit C for Contactor cutoff

The BMS boards on each Tesla battery module report the temperature of both the negative terminal and positive terminal of the pack. This command allows you to set a maximum temperature in degrees Celsius. ANY terminal in the pack exceeding this temperature will trigger a temperature alarm and both contactors will be dis-engaged, disconnecting the pack from the load.

The normal 300 amp loads encountered in home solar at 48v are fairly trivial for Tesla battery modules which must, for brief periods, provide up to 1155 amperes of current for acceleration. But 300 amps over times encountered in solar installations may involve significant heating.

The modules feature liquid cooling ports on the rear edge of the module. If temperature alarms are common, you might consider connecting these using clear plastic tubing to a circulating system for heat removal.

LOTEMP= 5.00 - Low Temp limit C for Contactor cutoff

The BMS boards on each Tesla battery module report the temperature of both the negative terminal and positive terminal of the pack. This command allows you to set a minimum temperature. ANY terminal in the pack falling below this temperature will trigger a temperature alarm and both contactors will be dis-engaged, disconnecting the pack from the load.

NOTE that lithium cells should NEVER be charged at a temperature below 0C or 32F. Doing so causes lithium plating and eventually cell destruction. For this reason, this value should be set at something above 0C.

If you need to operate your battery in cold temperatures, you should either house the battery module in a protected heated environment, or circulate warm fluid through the module temperature loop to heat them.

That said, the battery WILL produce power down to -20C. IF you use the CHARGEENABLE output to control your charging, it is hardwired to disallow any charging if the temperature of either module 1 terminal falls below 5 degrees Centigrade. In this way you COULD set LOTEMP to -20C for discharge, and still inhibit charging if it falls below 5C. But this is only if you control charging using the CHARGENABLE output.

CAN COMMUNICATIONS

The EVTV Controller for Tesla Model S battery modules provides support for Controller Area Network (CAN) communications commonly used in automotive applications and pretty much universally used in electric vehicles. Access is provided via a common 3.5mm stereo receptacle in the end of the controller with CAN HI available on TIP and CAN LO available on RING. Ordinary audio cables can easily carry the small currents involved in CAN communications.

CAN is a simple two-wire differential protocol using message IDs and eight byte data packets to convey operational information and commands usually in cars.

A big part of the information in CAN communications comes from the message ID. Each message on the CAN bus has a message ID and this ID determines in large part what the message is about and is to be used for. It basically defines message content by ID.

The standard IDs are 11bit numbers of the form 0x000 through 0x7FF. But the newer CAN 2.0 specification defines 29-bit message addresses along with backward compatibility for 11-bit addresses. At this point, almost all hardware available supports both message address formats, though 11bit applications still predominate.

The EVTV Controller for Tesla Model S battery modules features a new 29-bit CAN protocol specifically for the communication of battery storage system data for electric vehicles, residential solar energy storage systems, and large solar installation storage systems. We would propose this generalized CAN communication scheme for all battery systems and refer to it as the Battery Protocol for CAN.

ADDRESSING

The basic addressing scheme takes advantage of 29-bit CAN addressing to specify up to 14 batteries, 253 modules within each battery, and 253 cells within each module. It uses the hexadecimal values BA to indicate this is a battery related message. Numbering is 1 to n with 1 being the first module in the series.

It also supports a request/response format which is entirely optional. BMS designers may use broadcast on the response side for simplicity, but it also supports data requests. This is done with bit 29-27 of the message ID.

0BA = request in the Battery protocol.
1BA = response in the Battery Protocol

Subsequent bits define the specific battery, module, and cell in the following format:

1BAE FE FE

1 indicates response

BA indicates we are using the Battery protocol

E indicates battery number 15

FE indicates module 253

FE indicates cell 253.

FF EXCEPTION

Note that F is reserved to indicate ALL and this has different meanings in requests than it does in responses..

REQUESTS

A request for 0BA301FF would be requesting data for battery 3, module 1, ALL cells.

0BA7FF01 would request data from battery 7, ALL modules, cell 1.
0BA601FF would request data on battery 6, module 1, all cells.
OBAFFFFF = would request data from ALL batteries, ALL modules, ALL cell data.

In this way, you could conceivably have responders for each battery, each module, and/or each cell that would only respond to messages they can provide data for.

This would support multiple BMS modules scattered throughout the system, each responding to their known battery data. And the overall system master can request any data from any battery, module or cell in a flexible fashion.

RESPONSE

Responses are somewhat different. We use FF to indicate SUMMARY data which may be quite different.

1BA701FF. This is reporting summary data for module 1 of battery 7. 8 data bytes defined in the following format:

0x1BA701FF 81 8D 23 8C B8 4A 41 4F

Byte0/1 16-bit unsigned integer LSB/MSB indicating instantaneous voltage *100.

8D81 = 36225 / 100 = 362.25 volts

Byte2/3 16-bit signed integer LSB/MSB indicating instantaneous current *10. Negative values indicate discharge, positive values indicate charge.

8C23 &7FF = -C23=-3107/10 = -310.7 amperes discharge.

Byte 4 State of Charge in percent. Values 0-255 are divided by 255 to derive percent 0-100%

B8 = 184 / 255 = 72% SOC

Byte 5 Instantaneous average temperature of all sensors in Celsius with value 0 indicating -40C and 255 indicating 215C.

4A = 74 – 40 = 34 celsius

Byte 6 Temperature low recorded for session with value 0 indicating -40C and 255 indicating 215C.

41 = 63 – 40 = 23 celsius

Byte7 Temperature high recorded for session with value 0 indicating -40C and 255 indicating 215C.

4F = 79 – 40 = 39 celsius

Similarly 0x1BA7FFFF 81 8D 23 8C B8 4A FF FF

This response provides the same summary data for the entire BATTERY 7.

BATTERY ENUMERATION

Up to 15 batteries 0-E may be designated in a system. F is reserved for all. So in requests 0BAF is requesting summary data for the entire system. In responses, 1BAF is providing summary data for the entire system.

1BA4 = response, battery protocol, battery 4.

MODULE ENUMERATION

Up to 253 individual modules within a battery may be enumerated with F again reserved for all and 0 reserved for signaling. So modules are numbered 1 through 253. 0BA4FF is requesting data from all modules in battery 4 while 1BA4FF is providing summary data for battery 4.

CELL ENUMERATION

Up to 253 individual cells within a module may be enumerated with F again reserved for all and 0 for signaling. 0BA406FF is requesting data from all cells in battery 4, module 6 while 1BA406FF is providing summary data for battery 4 module 6.

And so you can see we can have a system size of 14*253*253 or 896,126 cells.

CELL RESPONSES

More detailed information is made available at the cell level. Consider the following information request:

0BA40602

This requests data from battery 4, module 6, cell 2. The Cell response would be of the form:

1BA40602 7E 01 A3 01 37 01 4A 00

Byte 0/1 16-bit unsigned integer LSB/MSB indicating instantaneous voltage *100.

017E = 382 / 100 = 3.82 volts

Byte 2/3 16-bit unsigned integer LSB/MSB indicating highest voltage this session *100.

01A3 = 419 / 100 = 4.19 volts high peak

Byte 4/5 16-bit unsigned integer LSB/MSB indicating lowest voltage this session *100.

0137 = 311 / 100 = 3.11 volts

Byte 6 Instantaneous temperature of nearest sensor in Celsius with value 0 indicating -40C and 255 indicating 215C.

4A = 74 – 40 = 34 celsius

Byte 7. Bit encoded fault data. Optional.

EXAMPLES

The hero in this battery protocol scheme is the module controller. This is a multicontroller managing one or more battery cells. If it is the only controller in the system, it would be battery 0 module 1.

If there are multiple controllers within the same battery, they would be numbered 1 through FE.

If there are multiple batteries, they would similarly be numbered 1 through E.

In this way, up to 14 batteries, each consisting of 1 to 253 modules, can be accommodated.

Similarly battery cells are numbered 1 to FE. Both 00 and FF are reserved.

0x0BA40600

As there is no battery cell 00, this reserved command requests that battery 4 module 6 provide its summary data.

Response 0x1BA406FF 81 8D 23 8C B8 4A 41 4F

0x0BA40602

This request specifically requests data on battery 4, module 6, battery 2. The response would look like

0x1BA40602 7E 01 A3 01 37 01 4A 00

0x0BA406FF

This is a request for battery 4 module 6 to report all cell voltages. If it monitors 6 cells, this would be the resulting output.

0x1BA406FF 81 8D 23 8C B8 4A 41 4F Module summary data
1BA40601 7E 01 A3 01 37 01 4A 00 Cell 1 data
1BA40602 7E 01 A3 01 37 01 4A 00 Cell 2 data
1BA40603 7E 01 A3 01 37 01 4A 00 Cell 3 data
1BA40604 7E 01 A3 01 37 01 4A 00 Cell 4 data
1BA40605 7E 01 A3 01 37 01 4A 00 Cell 5 data
1BA40606 7E 01 A3 01 37 01 4A 00 Cell 6 data

Note that the FF request for ALL produces the module summary data FF followed by each of the monitored cell voltage data 1 through 6.

The battery level works precisely the same way.

0x0BA40000

As there is no module 00, this reserved command requests that battery 4 provide its summary data.

Response 0x1BA4FFFF 81 8D 23 8C B8 4A 41 4F

0x0BA4FF00

This is a request for battery 4 to report all module summary data. If it monitors 6 modules, this would be the resulting output.

0x1BA4FFFF 81 8D 23 8C B8 4A 41 4F Battery summary data

0x1BA401FF 81 8D 23 8C B8 4A 41 4F Module 1 summary data

0x1BA402FF 81 8D 23 8C B8 4A 41 4F Module 2 summary data

0x1BA403FF 81 8D 23 8C B8 4A 41 4F Module 3 summary data

0x1BA404FF 81 8D 23 8C B8 4A 41 4F Module 4 summary data

0x1BA405FF 81 8D 23 8C B8 4A 41 4F Module 5 summary data

0x1BA406FF 81 8D 23 8C B8 4A 41 4F Module 6 summary data

0x0BA4FFFF

This is a request for battery 4 to report all module summary data AND all cell data. If it monitors 6 modules, this would be the resulting output.

0x1BA4FFFF 81 8D 23 8C B8 4A 41 4F Battery summary data

0x1BA401FF 81 8D 23 8C B8 4A 41 4F Module 1 summary data

1BA40101 7E 01 A3 01 37 01 4A 00 Cell 1 data
1BA40102 7E 01 A3 01 37 01 4A 00 Cell 2 data
1BA40103 7E 01 A3 01 37 01 4A 00 Cell 3 data
1BA40104 7E 01 A3 01 37 01 4A 00 Cell 4 data
1BA40105 7E 01 A3 01 37 01 4A 00 Cell 5 data
1BA40106 7E 01 A3 01 37 01 4A 00 Cell 6 data

0x1BA402FF 81 8D 23 8C B8 4A 41 4F Module 2 summary data

1BA40201 7E 01 A3 01 37 01 4A 00 Cell 1 data
1BA40202 7E 01 A3 01 37 01 4A 00 Cell 2 data
1BA40203 7E 01 A3 01 37 01 4A 00 Cell 3 data
1BA40204 7E 01 A3 01 37 01 4A 00 Cell 4 data
1BA40205 7E 01 A3 01 37 01 4A 00 Cell 5 data
1BA40206 7E 01 A3 01 37 01 4A 00 Cell 6 data

0x1BA403FF 81 8D 23 8C B8 4A 41 4F Module 3 summary data

1BA40301 7E 01 A3 01 37 01 4A 00 Cell 1 data
1BA40302 7E 01 A3 01 37 01 4A 00 Cell 2 data
1BA40303 7E 01 A3 01 37 01 4A 00 Cell 3 data
1BA40304 7E 01 A3 01 37 01 4A 00 Cell 4 data
1BA40305 7E 01 A3 01 37 01 4A 00 Cell 5 data
1BA40306 7E 01 A3 01 37 01 4A 00 Cell 6 data

0x1BA404FF 81 8D 23 8C B8 4A 41 4F Module 4 summary data

1BA40401 7E 01 A3 01 37 01 4A 00 Cell 1 data
1BA40402 7E 01 A3 01 37 01 4A 00 Cell 2 data
1BA40403 7E 01 A3 01 37 01 4A 00 Cell 3 data
1BA40404 7E 01 A3 01 37 01 4A 00 Cell 4 data
1BA40405 7E 01 A3 01 37 01 4A 00 Cell 5 data
1BA40406 7E 01 A3 01 37 01 4A 00 Cell 6 data

0x1BA405FF 81 8D 23 8C B8 4A 41 4F Module 5 summary data

1BA40501 7E 01 A3 01 37 01 4A 00 Cell 1 data
1BA40502 7E 01 A3 01 37 01 4A 00 Cell 2 data
1BA40503 7E 01 A3 01 37 01 4A 00 Cell 3 data
1BA40504 7E 01 A3 01 37 01 4A 00 Cell 4 data
1BA40505 7E 01 A3 01 37 01 4A 00 Cell 5 data
1BA40506 7E 01 A3 01 37 01 4A 00 Cell 6 data

0x1BA406FF 81 8D 23 8C B8 4A 41 4F Module 6 summary data

1BA40601 7E 01 A3 01 37 01 4A 00 Cell 1 data
1BA40602 7E 01 A3 01 37 01 4A 00 Cell 2 data
1BA40603 7E 01 A3 01 37 01 4A 00 Cell 3 data
1BA40604 7E 01 A3 01 37 01 4A 00 Cell 4 data
1BA40605 7E 01 A3 01 37 01 4A 00 Cell 5 data
1BA40606 7E 01 A3 01 37 01 4A 00 Cell 6 data

0x0BAFFFF

And of course the 0x0BAFFFFF command requests the entire system to report all batteries, modules, and cells in the same hierarchy.

A SIMPLER SYSTEM

Lets say we have one module and six cells.

0xBA10100
Request for battery 1 module 1 one summary data.

0xBA10103
Request for battery 1 module 1 cell 3 data.

OxBA101FF
Request for battery 1 module 1 summary data and all cell data.

EQUIPMENT SPECIFIC CAN SUPPORT

To enhance the usefulness of the EVTV Controller for Tesla Battery Modules, we will include support for equipment specific proprietary CAN messaging schemes as able and appropriate.

The typical home or light industrial Solar power system often features a mix of hardware from a variety of vendors. Increasingly, they too are adopting CAN as a communications protocol but of course each vendor uses a different CAN addressing scheme. Solar MPPT Charge Controllers and DC-AC Inverters each have an interest in interoperating with a storage battery.

SUNNY ISLAND 4548-US/6048-US

The Sunny Island Inverter requires an external BMS to use lithium batteries. It communicates via CAN through a provided CAN port using RJ-45 connector and CAT5 cabling.

You will have to fabricate an appropriate cable to connect to the EVTV Controller.

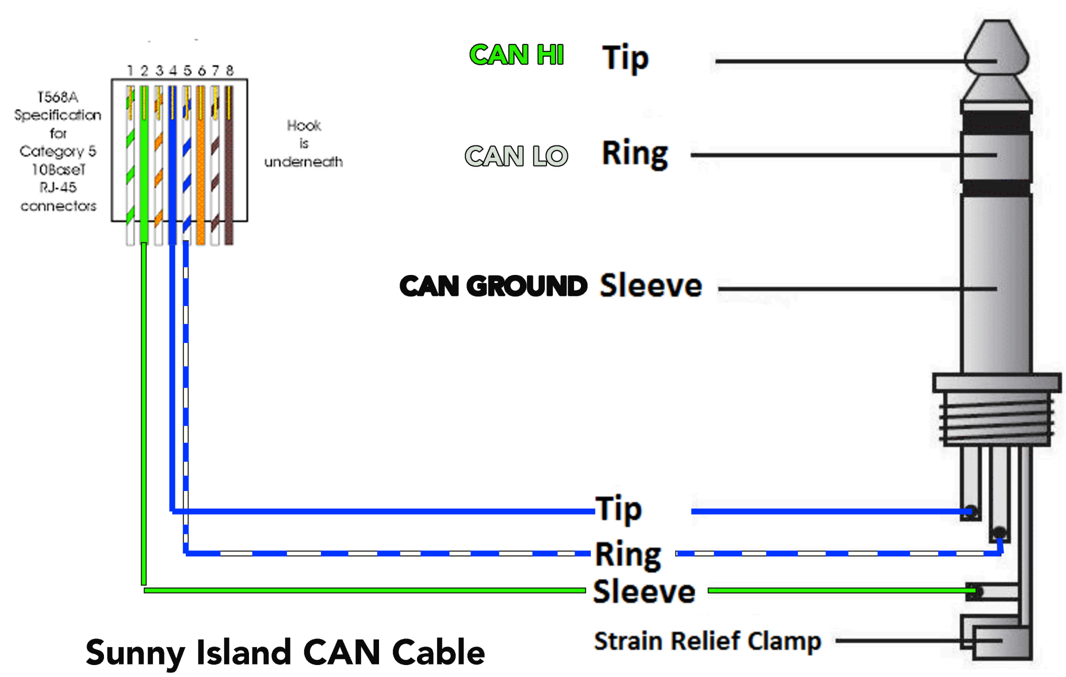
To do so, take any CAT5 cable with RJ45 plugs on each end.

Cutoff the connector from one end of the cable.

Connect to a 3.5mm male stereo plug.

RJ45 pin 4, blue to TIP for CAN HI.
RJ45 pin 5, blue and white to RING for CAN LO.
RJ45 pin 2, to Sleeve for CAN ground.

You can then plug this stereo plug into the CAN receptacle on the EVTV Controller, and the RJ-45 plug into the Sunny Island.



Sunny Island reports certain voltages and states via CAN message ID 305 and 306. The EVTV Controller does not actually need or benefit from these, but it does use them to detect that a Sunny Island is connected and to reply with the following messages required by Sunny Island.

MESSAGE ID 351

Message 351 is the voltage and current limits message to the Sunny Island inverter.

BYTE 0/1 is a 16=bit Least Signifcant Byte /Most Significant Byte (LSB/MSB) integer
Containing the battery charge voltage x 100. This sets the voltage at which charging stops and is derived from the **CUTOFF** variable in the EVTV Controller.

BYTE 2/3 is a 16-bit signed integer LSB/MSB representing the charge current limit in positive amperes x 10. There really isn't a limit to battery charge current that would make sense to a Sunny Island. Tesla Superchargers can charge at 120kW or 300 amps and so we set this to 3000 representing 300amps.

BYTE 4/5 is a 16-bit signed integer LSB/MSB representing the the discharge current limit in negative Iamperes x 10. In the Tesla vehicle, these battery modules can produce 1155 amps for brief periods. So we set this again to an arbitrary value of -3000 indicating -300 amps. At 48 v that represents 14.4 kW which is over twice what the Sunny Island 6048 can produce anyway.

BYTE 6/7 is a 16-bit unsigned integer LSB/MSB representing the discharge voltage cutoff * 100. We set this to 1200 x **LOVOLT** value set for cutoff in the EVTV Controller, and add a small value so that the Sunny Island would normally cutoff at a very small value above that.

MESSAGE ID 355

Message 355 provides the Sunny Island with battery State of Charge information.

BYTE 0/1 comprise a 16-bit unsigned integer LSB/MSB containing our EVTV Controller SOC (0.00 to 100.00%). As this is a float value we round it to the nearest percent.

BYTE 2/3 comprise a 16-bit unsigned integer LSB/MSB containing battery state of health. We don't actually have a "health" value in the EVTV controller so we set this to 100 indicating we enjoy disease free batteries.

BYTE 3/4 comprise a 16-bit unsigned integer LSB/MSB containing our EVTV Controller SOC (0 to 100%)*100. In this HiResSOC case instead of rounding with multiply the float value by 100 to carry resolution to 2 decimal places in the 16-bit integer..

MESSAGE ID 356

Message 356 provides the Sunny Island with current voltage, current and temperature.

BYTE 0/1 comprise a 16-bit unsigned integer LSB/MSB containing current battery pack voltage x 100 to retain two decimal places of resolution.

BYTE 2/3 comprise a 16-bit signed integer LSB/MSB containing current amperes x 10 to retain one decimal point resolution. Positive values indicate charging and negative values indicate discharging.

BYTE 4/5 comprise a 16-bit signed integer LSB/MSB containing the average terminal temperature of all modules in the pack x 10 to retain one decimal point resolution.

MESSAGE ID 35A

Message 35A provides the Sunny Island with an 8-byte, 64-bit array containing alarms and alerts that can be displayed on the Sunny Island panel. Alarms will usually cause the Sunny Island to go to standby when SET and to resume when CLEARED and use 2 bits to signal this.

Alerts are simply displayed on the Sunny Island panel.

The EVTV Controller currently only uses five alarms of this array. This allows the Sunny Island to go to standby as the EVTV Controller disengages the contactors.

EVTV	BYTE	BITS	SUNNY ISLAND	
HIVOLT	0	2/3	External Alarm 2	XW02 DcHiVolt
LOVOLT	0	4/5	External Alarm 3	XW03 DcLoVolt
HITEMP	0	6/7	External Alarm 4	XW04 DcHiTmp
LOTEMP	1	0/1	External Alarm 5	XW05 DcLoTmp
VARIANCE	3	0/1	External Alarm 13	XW13 CellBal

In this way, in the event the system quits and the battery has disconnected from the system, you can observe the Sunny Island display to find out it was the battery that disconnected, and some indication of what limit was exceeded causing the disconnect without hooking a laptop up to the EVTV Controller. You would inevitably want to follow up using a laptop on the EVTV Controller to figure out what happened, but it would allow you to get a first indication from the Sunny Island panel.