ESP32 BMS Controller Assembly

for
Tesla Model S Battery Modules

http://evtv.me

INTRODUCTION

This document describes the installation and use of the EVTV ESP32 BMS Controller Assembly for the Tesla Model S Battery Module.

In 2012, Tesla Motors Inc. introduced the Tesla Model S, an 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 devices consisting of 7104 individual Panasonic 18650 format Lithium Nickel Cobalt Aluminum 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 and balancing 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/experimenter 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 management provided in the Tesla vehicle, these modules proved inherently unsafe and there were several spectacular 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. They would also feature CAN communications allowing them to be incorporated into other systems.

This document describes the fully assembled BMS Controller developed for the individual battery modules. As these modules are 225 Ah 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 energy storage for home solar installations.

In 2018 the microprocessor used to perform this controlling/monitoring function was upgraded to the Espressif ESP32 chip. The ESP32 featured faster (240 MHz) dual core operation and wireless WiFi and Bluetooth BLE capabilities.

Also in 2018, EVTV developed a 7-inch touch screen display with a Raspberry Pi 3B+ computer running the Raspian distribution of Linux. We have since upgraded to the new Raspberry Pi 4B. This unit still uses a 7" display but now supports use of an up to 4K external monitor. Specialized software was created to configure and display the operating parameters of the ESP32 controller and extend that on a global basis using Amazon's AWS IoT Core cloud service.

PHYSICAL DESCRIPTION

The ESP32 BMS Controller consists of a controller enclosure with connection cables for the battery, battery BMS boards, and the output loads. Included is a 7-inch touchscreen display kit further described in the EVTV Battery Display User Manual.

The controller and display communications rely on the availability of a Wireless access point – a home wireless hub/router.
The controller can operate from 1 to 20 Tesla Battery Modules configured for an output voltage between 18 and 50 volts.
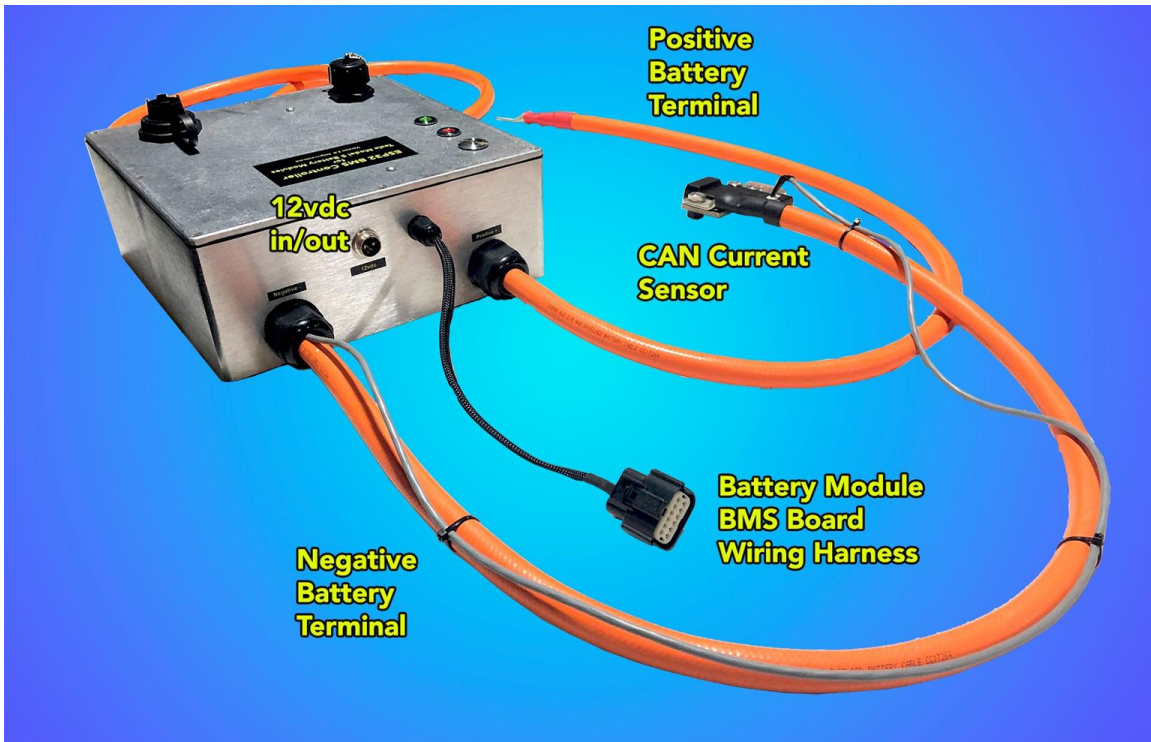It monitors each individual cell of all connected battery modules for voltage and the temperature of each output terminal of each module.

It has the ability to balance all cells in the battery pack of up to 20 modules per control box. Multiple control boxes can be used in parallel to support larger packs.

Additionally, it can measure the output current or charging current of up to 500 amps into and out of the pack. It calculates state of charge and total ampere-hours as well as power in watts.

It provides TWO contactors, one for each leg of the battery connection and makes provisions for precharging connected equipment.

Additionally, it provides wiring connections for the individual BMS subboards on each Tesla Battery module.

Convenient LED lights indicate the state of each contactor.

Switched ground outputs provide for CHARGE ENABLE and HEAT ENABLE outputs to control other equipment.

CAN communications is available, along with 12vdc power, from a CAT5 RJ-45 connector.

A 115,200 bps serial USB Port provides convenient access to the software operating the controller, allowing the operator to configure a number of variables controlling operation.

The main purpose of this device is actually to DISCONNECT the battery in the event ANY operating parameter set by the operator is exceeded.

In this way, it acts to safeguard home solar installations from battery failures that lead to fire or explosion.

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 in a corporate 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 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 problematic. Not only does the source of energy vary, but so does the amount of energy needed to power loads in the home. 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 meter power you PRODUCE and defray 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.
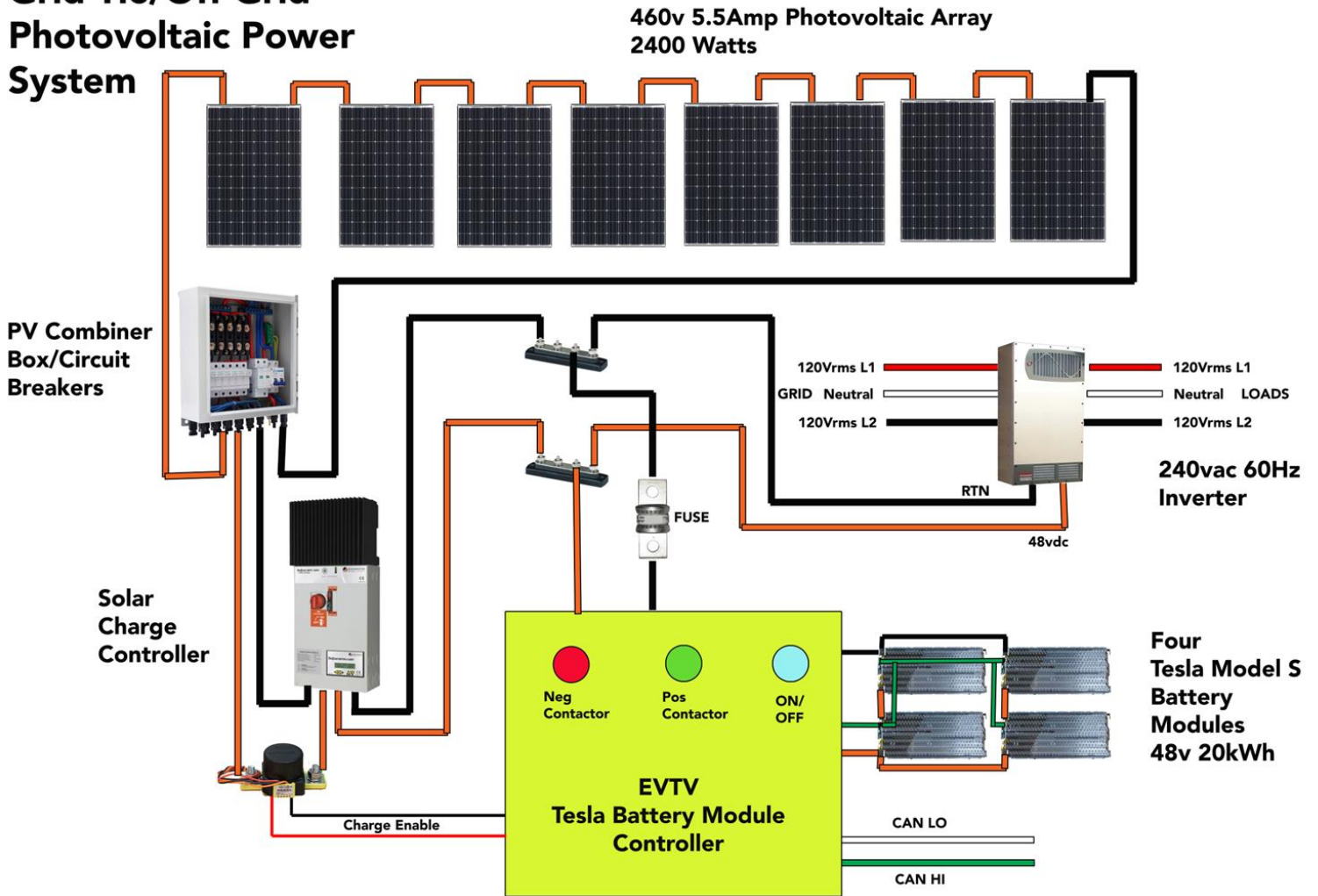
This poses a couple of corollary technical issues. First, the AC power we produce in our system must match the grid power exactly – not only in voltage but in phase and frequency.

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.

Representative Grid-Tie/Off Grid Photovoltaic Power System

460v 5.5Amp Photovoltaic Array 2400 Watts

PV Combiner Box/Circuit Breakers

120Vrms L1
GRID Neutral
120Vrms L2

120Vrms L1
Neutral   LOADS
120Vrms L2

240vac 60Hz Inverter

RTN

48vdc

Solar Charge Controller

FUSE

Neg Contactor

Pos Contactor

ON/OFF

Four Tesla Model S Battery Modules 48v 20kWh

EVTV Tesla Battery Module Controller

Charge Enable

CAN LO

CAN HI

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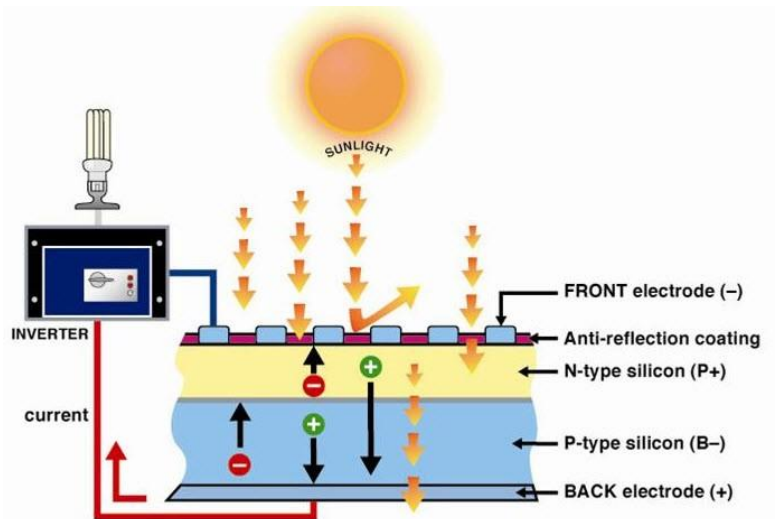
At that point, if we direct sunlight to the phosphorous surface, photons striking the phosphorous atoms will transfer energy to them, causing the promotion or "release" of the extra electron from the orbit of the atom and into free conduction.

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.

The voltage of these cells is precisely equal to the intrinsic electrostatic field set up by the P/N junction - typically 0.5 to 0.7 volts. A little sun causes this voltage, and infinitely more sun won't increase it.

More sunlight will cause an increase in available charge carriers and so it will support more current, but the voltage is basically static and produced in the presence of ANY photon activity incoming.

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. But as mentioned, this is also a function of the charge carriers. So more sunlight does mean more power – in this case by increasing the current at the cell 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 a load. At Zero load you have zero current, you will have maximum voltage. If you short 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 often see referenced. 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

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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.

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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 four basic "charge cycles:"

Bulk
Absorption
Float
Equalization

The bulk phase simply puts as much current into the battery as possible until it reaches a certain voltage..

The absorption phase then modulates the current to maintain that specific voltage until the current diminishes to some minor value.

The float phase allows the battery voltage to decrease to some usually slightly lower voltage, and then trickles power to the battery to maintain that voltage.

Equalization is kind of a special case where they intentionally overcharge the batteries to a higher voltage. In the case of Pb (lead) chemistry cells, this hits a certain voltage and beyond that simply causes electrolysis resulting in the release of hydrogen and oxygen gasses. But in this way, you can "equalize" the state of charge of all the cells to the same value..

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 (Volts root-mean-square).

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

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240vac for a heater, stove, or large air conditioner, 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.

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A MORE ADVANCED APPROACH

At EVTV we have developed a slightly less complex and a bit more advanced approach to home solar.

About 97% of the residential solar installations in the U.S. now use grid-interactive inverters to simply convert the photovoltaic output to standard 240 Vrms AC voltage with phases L1 and L2 180 degrees out of phase and a neutral. Connections between L1 or L2 to the neutral provide 120Vrms AC.

This is fed directly into the main loads panel. During the day, this photovoltaic output powers the loads in the home, and any power produced beyond the needs of the home actually feeds the public utility grid providing power as an output.

At night, of course, the photovoltaic array produces nothing and so all loads in the home must be powered by the public grid.

This rather uses the grid as an energy storage device, a role which it is extremely ill suited to perform.

Worse, in the event of loss of the public grid power, the photovoltaic solar installation is unable to produce ANY power at all – it must have a grid power waveform to "sync" to. And so weather events, floods, earthquakes, fires and the ever present danger of the zombie apocalypse leaves the homeowner totally without electrical power despite a significant investment in a quite advanced photovoltaic array on their own roof.

And so EVTV has taken an interest in solar energy storage using repurposed electric vehicle batteries from salvaged or damaged electric cars as a solar energy device.

Electric Vehicles offer extremely long warranties on the batteries – often eight years or more. This precludes really ANY automotive aftermarket for these batteries. Anyone with a battery problem usually gets a NEW battery from the manufacturer under warranty.

As a result, the salvaged batteries are often available in salvage for less than the manufacturers cost and often less than comparable lead acid batteries.

And the mission is to be able to easily retrofit existing grid-interactive systems for this energy storage.

This rather drastically modifies the concept and construction of residential energy production and storage and actually results in a much simpler system than the normal off grid battery solar installation. Consider the diagram below.

Here we see grid interactive microinverters collocated with the individual photovoltaic panels that provide 240vac directly to the main loads panel of the home.

We have introduced/inserted a 12kw off-grid inverter between the public grid input and that main loads panel. And this inverter can choose between grid power and a controlled battery system as the source of power.
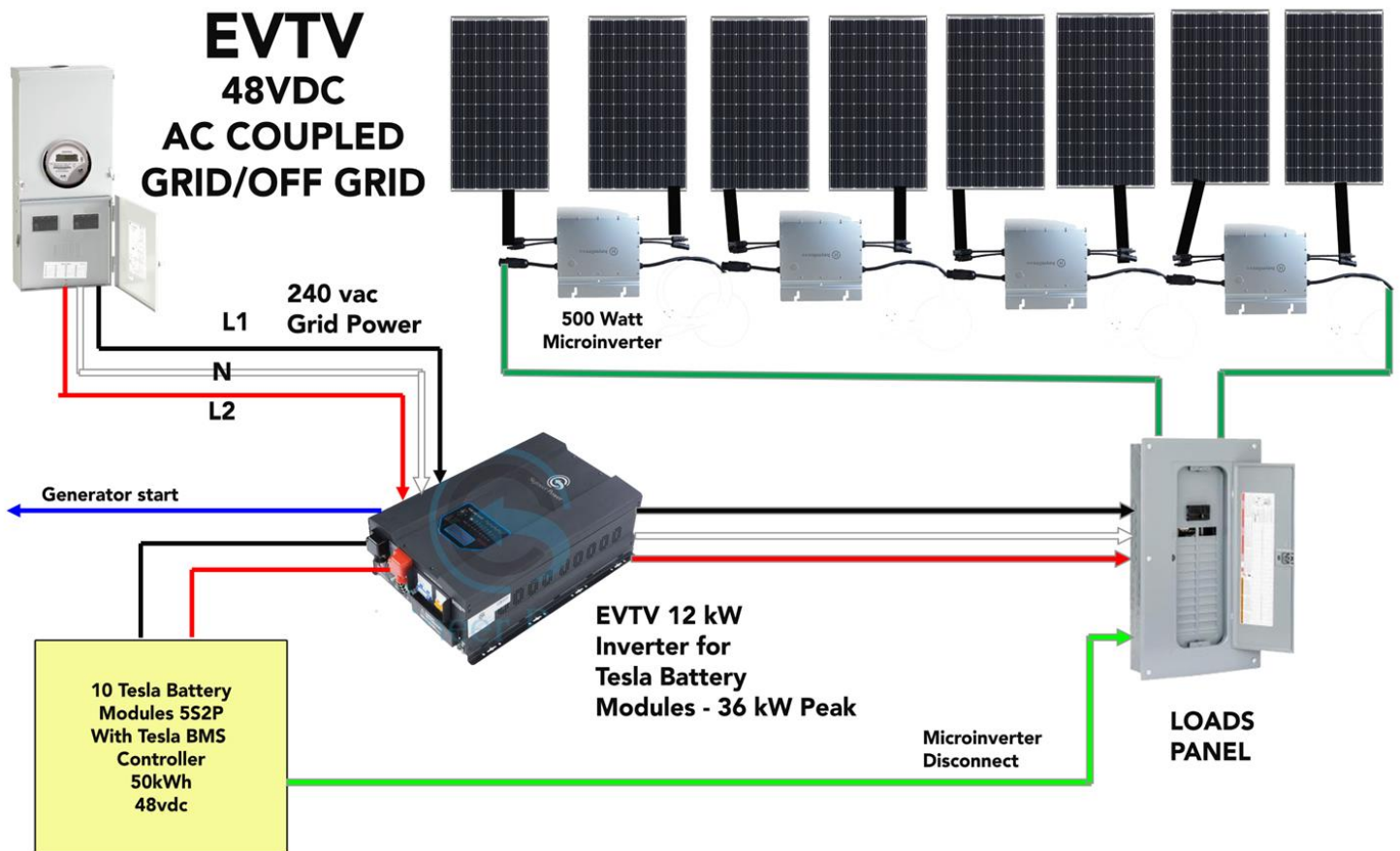

Key to this system is that the inverter can not only choose between grid and battery to power the system, but it can ALSO choose between grid and the grid-interactive inverters as a source to charge the batteries.

Instead of pushing excess power during the day to the grid, this system stores excess power from the photovoltaics back IN to the battery system.

And the only time it uses the grid is when energy from the sun is insufficient to recharge the batteries – due to weather or loads or seasonality. In that event, the public grid is tapped to recharge the batteries AND power the loads until the batteries have sufficient energy to resume the primary role of power supply.

And so rather than use batteries to back up the grid power, in this design, the grid provides occasional backup to a battery-centric solar power system. And we use Tesla Model S battery modules as the storage device.
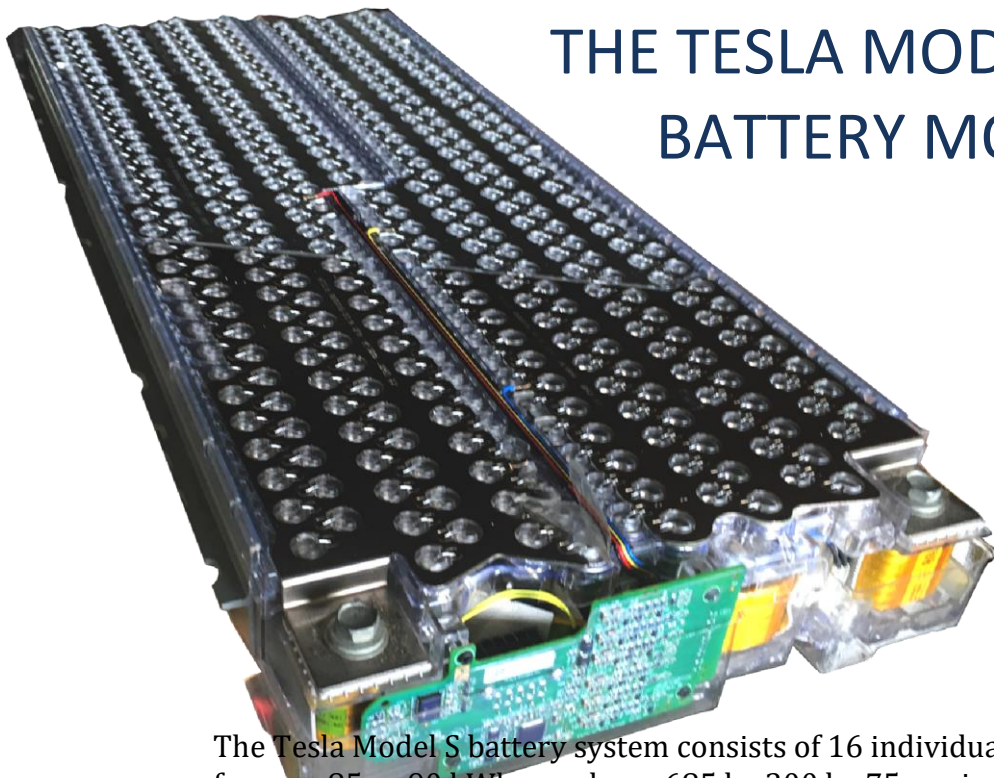
THE TESLA MODEL S BATTERY MODULE

The Tesla Model S battery system consists of 16 individual modules.   Each module from an 85 or 90 kWh   pack are 685 by 300 by 75mm 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 6S74P. The battery cells are most likely Panasonic NCR18650BE cells or close equivalent of nominally 3300 mAh capacity and 3.6vdc nominal voltage. These cells are of a nickel cobalt manganese aluminum oxide cathode and a graphite silicon anode.

For an 85kWh Tesla battery, this gives the module a 74 x 3.3Ah or 244 Ah capacity at the nominal voltage of 3.6v for a total power storage capacity of 5270 watt hours and a module nominal voltage of 21.6 volts. These modules are designed to produce up to 1150 amperes of current for brief periods. And so 16 modules provide 84320 Wh of storage.

The 60kWh Tesla battery uses 21 less cells per module at 53 cells for a total of 175 Ah or 3780Wh per module and 60480 Wh per pack.

The Tesla 100D model features a 100 kWh pack that simply packs in 516 cells per module with 86 18650 cells in each voltage segment.

The cathode chemistry of these cells is such that it 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 cylindrical cells 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.
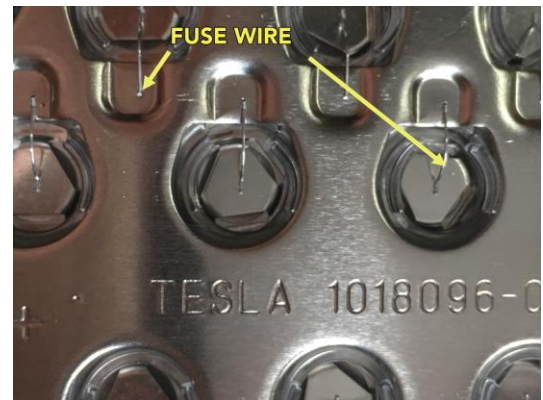

A series of flat fluid conduits winds between the rows of battery cells. These are connected to two pipe fittings on the end of the module. In the battery assembly these fittings are connected to clear tubing from one module to the next and to some external fittings to allow the circulation of fluid 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 the 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.
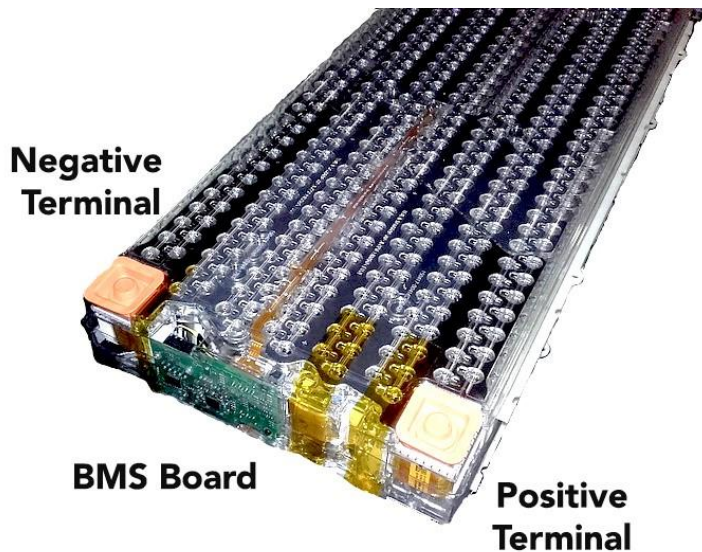
The modules are designed to be charged to a maximum voltage of 4.2 volts per cell for 25.2 volts per module and it is extremely important that this voltage never be exceeded.

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.

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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 or some other form of heating.

EVTV MONITOR/CONTROLLER

The EVTV ESP32 BMS Monitor/Controller is at attempt to design a replacement for the Tesla Battery System controller 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 Tesla Battery 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 during charging they can be brought down to the level of lower voltage cells and the cells balanced.
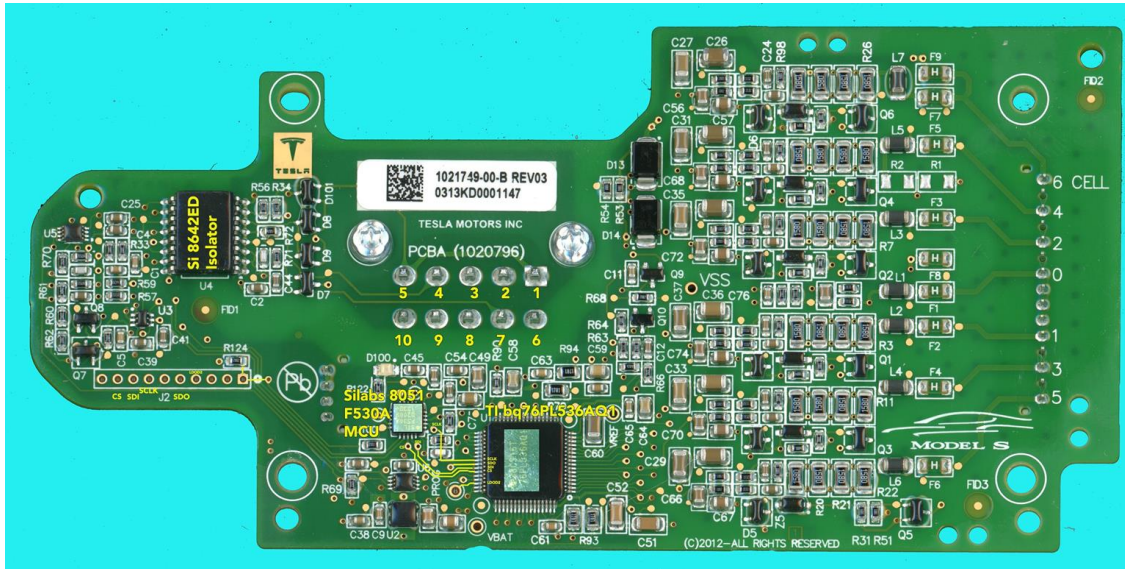
An important function of the battery system controller is to communicate battery state to other equipment in the vehicle over CAN bus.   Increasingly, Solar equipment is also adopting CAN communications, so the Tesla Battery Module Controller does support CAN communications.
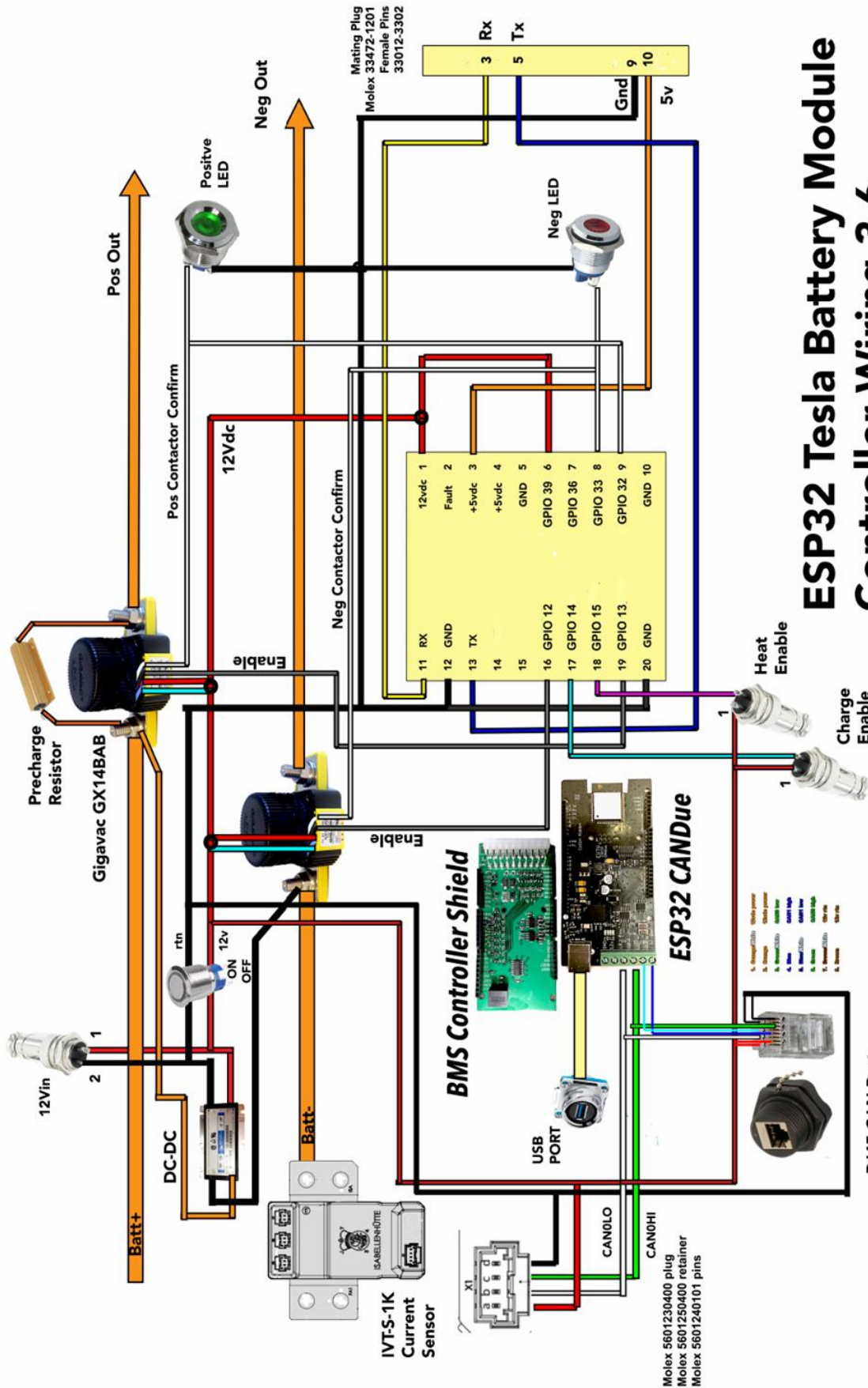
ESP32 Tesla Battery Module Controller Wiring 3.6

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 CHARGE ENABLE output that can drive an external contactor to control the charge process.

> The charge controller can monitor and control 1 to 20 Tesla Battery Modules (per controller). Multiple controllers can be used to support enormous battery banks of over 300 kiloWatt hours capacity.

> 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 225 ampere-hours for a backup capacity of 9.728 kWh. Naturally four of these modules would double that to a 19.440 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.

CONTROLLER

The heart of the Tesla Battery Module Controller is the controller electronics consisting of an EVTV ESP32 CANDue microprocessor board and a Tesla Module Controller shield.   The shield provides level shifting for the serial communications with the Tesla Battery Module BMS boards.

It also provides four switched ground MOSFET outputs capable of switching up to 2.5 amps of current at 12vdc. Typically you would use two of these to individually control a positive and negative high current high voltage contactor relay such as the Gigavac GX14.   But it provides two additional outputs to control external relays and devices or to signal other equipment.   Currently one output provides a CHARGE ENABLE signal while the other is a HEAT/COOL
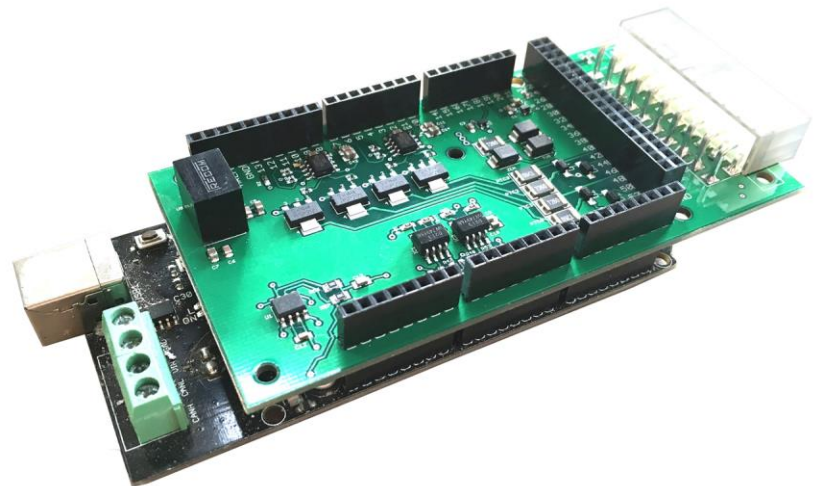
Enable output based on temperature.

It also provides a separate
12v to 5v voltage converter
to ensure sufficient 5v supply voltage for up to 20 Tesla Battery Modules.

The shield is connected to all this via a 20 pin Valu-Lok connector and harness.
Additionally, select lines go to the individual wiring harnesses we have available to
connect to different numbers of Tesla Model S battery modules up to a maximum of
20 modules. This series of harnesses uses a Molex 12 pin connector.

Four optically isolated inputs allow the shield to receive external 12v inputs. We
currently use two of those to detect contactor position through the Gigavac
GX14BAB auxiliary contacts and one to determine that 12v is actually available
externally.

The software that comes with this system is designed for the hardware connections
and layout of the provided diagram. This involves a number of accessory items.

CONTACTORS

The controller uses two GIGAVAC EPIC GX14BAB contactors. These are single-pole,
single-throw normally open high voltage high current relays capable of breaking
current flows of several thousand amperes of current and 800 volts. These are
hermetically 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 100 ohm 50 watt precharge resistor wired across the
terminals.

Both contactors are wired to switched grounds from the controller board. And 12v
is provided through the aux contacts to LED indicators. 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 a few amperes. 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 (HITEMP, LOTEMP), the controller will disengage both contactors, isolating the battery from any load and effectively disconnecting the battery.

Precharge resistor selection is important, but not terribly critical. It is important in that the input capacitors of inverters and the output capacitors of the MPPT charge controllers can cause a huge but brief surge in current through the contactors when first connected to the battery. This current spike can reach 10000-12000 amperes but only lasts for a few microseconds before tapering to quite manageable currents. But this is sufficient to arc weld the contacts of almost any high current relay contactor.

To prevent this, the precharge resistor allows current flow into the capacitors at a much decreased rate. An ampere or two of current for five or six seconds is usually sufficient to bring the voltage up in the capacitors sufficiently to limit this current spike. You don't actually have to REACH the system voltage, just preload the capacitors to some nominal level.

On a 16 module in series system you have a nominal voltage of about 350 volts and a 500 ohm resistor will allow about ¾ of an ampere. If you do this for a precharge period of 10 seconds or so, this will be sufficient.

For a 48volt system, perhaps a 50 ohm resistor will allow about an ampere and a 25 ohm resistor about 2 amperes. Typically five or six seconds of precharge then work.

And so selection of a precharge resistor is really a function of what voltage battery you are controlling.

The precharge resistor is simply connected to both power terminals of the POSITIVE contactor. In this way, when the NEGATIVE contactor closes the circuit is completed and a small current allowed to flow.

When the POSITIVE contactor closes six or eight seconds later, the resistor is effectively bypassed and the current flows directly through the positive contactor.

DC-DC CONVERTER

The system requires 12vdc to operate. Typically, an onboard DC-DC converter is connected across the battery side terminals of the two contactors. This DC-DC converter can convert the battery output voltages 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. The DC-DC converter used in this assembled unit has an input range of 18 to 50v and produces a 12v output.. If you need to power from a different sized battery, you will need to provide 12vdc and ground to the 12Vin connector.

ISAscale ICD-ACURRENT SENSOR

The Tesla Battery Modules BMS board provides detailed voltage and temperature information on the cells. But it does NOT provide any indication of current. The ESP32 Battery Controller needs to measure current to accurately count energy into and out of the battery.

We have found the **Isabellenhutte ISAscale IVT-S-1K** current sensor to be accurate and provides a CAN output describing current in amperes.

U3 U2 U1

Molex 5601230200 plug
Molex 5601250200 retainer
Molex 5601240101 pins

+

+

FA1

−

−

ISA

ISABELLENHÜTTE

X1

Molex 5601230400 plug
Molex 5601250400 retainer
Molex 5601240101 pins

X1

a b c d

a +12vdc
b CAN low
c CAN high
d 12v rtn
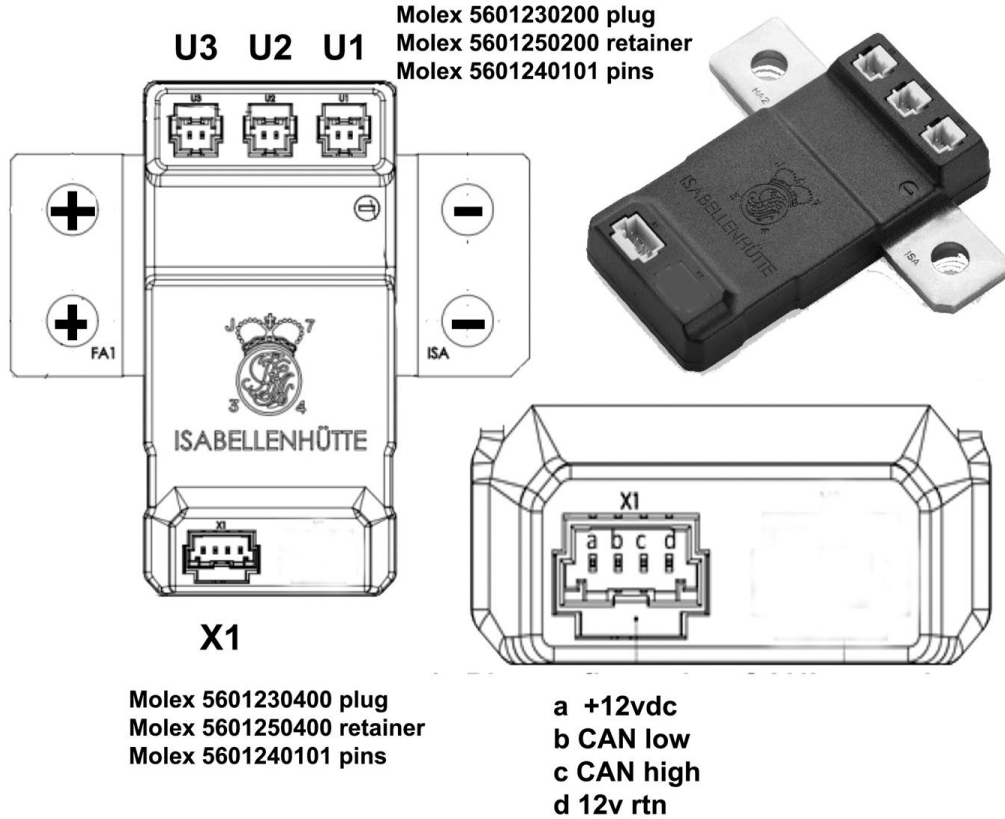
IVT-S-1K-U3-I-CAN1-12/24

This sensor is typically installed on the negative terminal of the battery itself. A six foot cable provides for connections to the X1 connector for power and CAN communications.

 ESP32 controller some distance from the current sensor and retain good accuracy. The IVT-S-1 reports currents of up to 500 amperes in either direction via CAN message to the controller electronics on CAN port 0 on the EVTV ESP32 CANDue microcontroller. Note that this current sensor is directional – the right side of the sensor should be connected to the negative terminal of the battery for proper data to the software provided in the ESP32 CANDue.

It is important to make a clean and tight connection on each end, using the full surface of the metal bar to prevent heating.

CHARGER ENABLE CONNECTION

A two pin output consists of our 12vdc supply on one pin and a switched ground MOSFET output on the other.. This is configured to have the ground supplied when charging is allowed and the ground pin is floated, breaking the circuit when charging should NOT be performed.. 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.

The CUTOFF and RESUME values should be selected such that hysteresis does not occur. Normally, if you charge to 4.15v for example, when you cut off the charging, the voltage of the battery will immediately fall back to a lower level. If your RESUME is above this level, the CHARGE ENABLE output will immediately energize the charge contactor. The voltage will rise and again CUTOFF will shut it off. This will continue to cycle indefinitely.

By setting the RESUME value somewhat lower, ie 3.90v, the charge controller will not resume charge output to the battery until the voltage falls to that lower level. You can adjust this to needs.

EVTV has also helped develop the Sigineer 15kw inverter. This inverter features an AC frequency input allowing you to shift between 60 and 62.5Hz very briefly.

If CUTOFF and RESUME are set to the SAME voltage value, when any cell reaches that value the CHARGENABLE output will turn on for approximately 500ms and then remain off for at least 2 minutes.

This frequency shift will cause ALL grid-interactive inverters such as the Solar Edge or Enphase inverters to CEASE providing power for a period of five minutes.

In this way, you can prevent overcharge by bumping the grid-tied inverters any time you reach your maximum charge voltage set in CUTOFF and effectively cycling them off for five minutes.

CAN CONNECTION

A second CAN connection is provided to communicate with inverters and other external equipment. We bring both CAN channels out using a panel mounted CAT6 RJ45 connector. Pin out is depicted.

EVTV CAN OVER CAT5
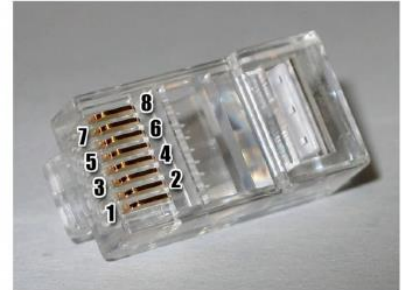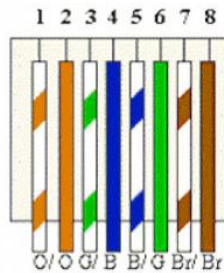
1. **Orange/White**   **12vdc power**
2. **Orange**   **12vdc power**
3. **Green/White**   **CAN0 low**
4. **Blue**   **CAN1 high**
5. **Blue/White**   **CAN1 low**
6. **Green**   **CAN0 high**
7. **Brown/White**   **12v rtn**
8. **Brown**   **12v rtn**

USB PORT

A standard USB mini-b printer port is provided on the end of the controller 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 will 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.

The display will be more pleasant to view if the terminal program also recognizes the FORM FEED ASCII command.

In normal operation, you would press the ON/OFF switch to initialize the system, then connect the USB cable to the port and select CONNECT on your terminal program.

Note that if you reverse this process, connecting to the port first, the USB cable will actually power the controller and it will go through the usual initialization and

precharge sequence. However, there will be no 12v supply to power the contactors. Then when you DO press ON/OFF, this will immediately close BOTH contactors and when connected to a capacitive input, cause a current spike and potentially arc weld the contactor contacts. This rather defeats the entire purpose of a precharge.

So when connecting to the USB port to view battery statistics or make configuration changes, always power up the system with the ON/OFF switch FIRST.

Further, understand that the process of forming and transmitting a large amount of battery status data out the USB port is a processor intensive task. It puts quite a load on our little microcontroller.

This is designed to allow you to CONFIGURE your battery and to perhaps TROUBLESHOOT problems. It was never designed to produce a continuous display output. So in theory, you would connect a laptop, configure your battery to the values you desire, and DISCONNECT the USB cable. Then restart your battery.

The reason we mention this is that there have been cases where the controller fails/reboots every couple of days it would appear. But in all cases, the USB port was in continuous operation. When we have them disconnect the USB port, the same controller will operate for weeks or months on end with no hiccups.

TESLA BATTERY MODULE CONTROLLER CONNECTIONS

The entire purpose of the controller is of course to interface with the Tesla Model S battery modules. This is accomplished with a series of cable harnesses.

The controller ships with a connecting plug and pins for the 20 pin edge connector on the shield. But we also have a prewired high quality harness that can minimize your work there with 24 inch wires already installed. This comes with a Molex connector you install to connect to the other wiring harnesses.
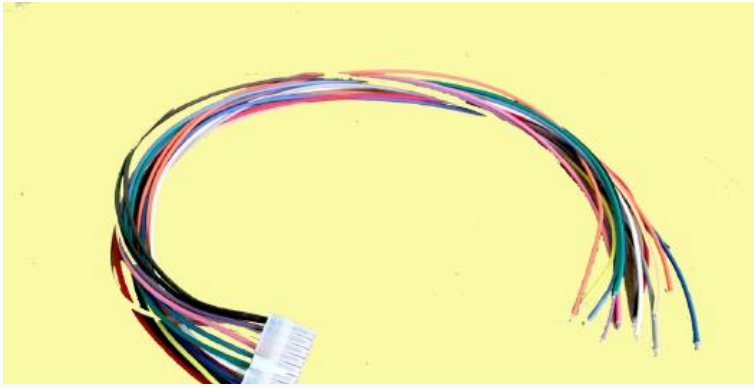
Diagrams below illustrate the wiring necessary to connect the Tesla Battery Module Controller to Tesla Battery Modules for control and monitoring. Note that two module, the four module, and the and four module extension cables are available from EVTV at http://store.evtv.me.

Type E 20 AWG

Silver Plated Copper
19 Strands of 32 awg
.059" Diameter
600 Volts
PTFE Insulation
Temperature -60°C to 200°C
Length: 18 inches

Amp VAL-U-LOK
2-794954-0
1586315-1 Socket Terminals

RED	1	11		RX		YEL
GRY	2	12		GND		BLK
ORN	3	13		TX		BLU
ORN	4	14		CANL		WHT
YEL/BLK	5	15		CANH		GRN
RED/BLK	6	16	7	DOUT4		LTBLU
WHITE/BLK	7	17	6	DOUT3		PNK
RED/BLU	8	18	9	DOUT2		TAN
BLU/YEL	9	19	8	DOUT1		VIO
BRN	10	20		GND		BRN
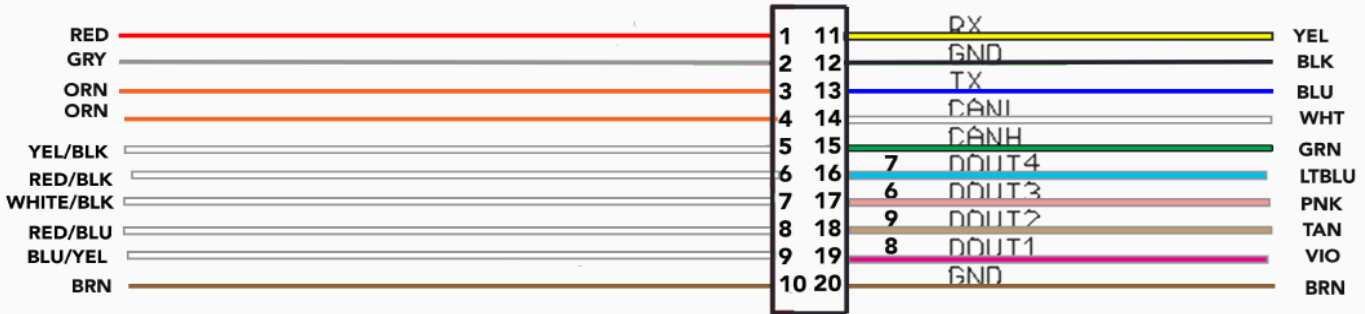
Tesla Battery Module Controller
Universal Wiring Harness

The two module harness allows use of two Tesla Battery modules for a 48v battery or a 1S2P 24volt battery.

The diagram below illustrates the daisy chain serial connection used to connect the module BMS boards.

GND

TX   5

Fault   1

TX

RX

Fault

10 9 8 7 6

5 4 3 2 1

10 9 8 7 6

5 4 3 2 1

RX

5V   10

GND   9

RX   3

5v

TX
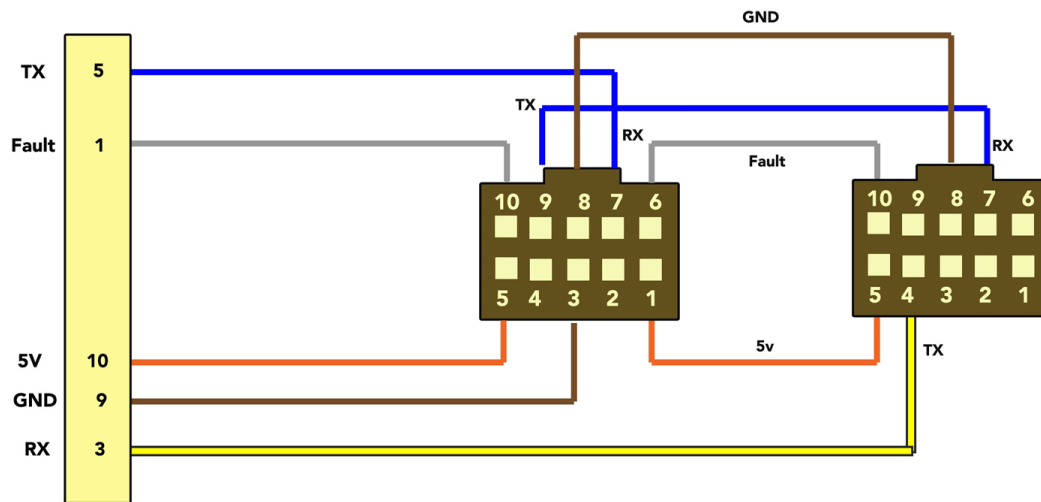
Tesla Battery Module
Two Module Harness

There is also a four port version of this harness allowing connection of up to four Tesla Model S modules.
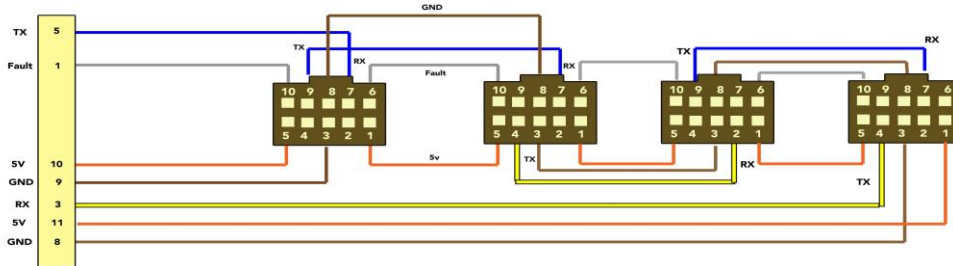
Tesla Battery Module
Four Module Harness
Max 62 Modules

For larger batteries of up to 20 modules, there is an extension cable featuring four port connections but with the proper Molex plug on EACH end of the harness. In this way, as many extension harnesses can be added as desired. But the final

extension harness MUST be terminated with either a two port harness or a four port harness. In this way, any even number of modules can be connected.
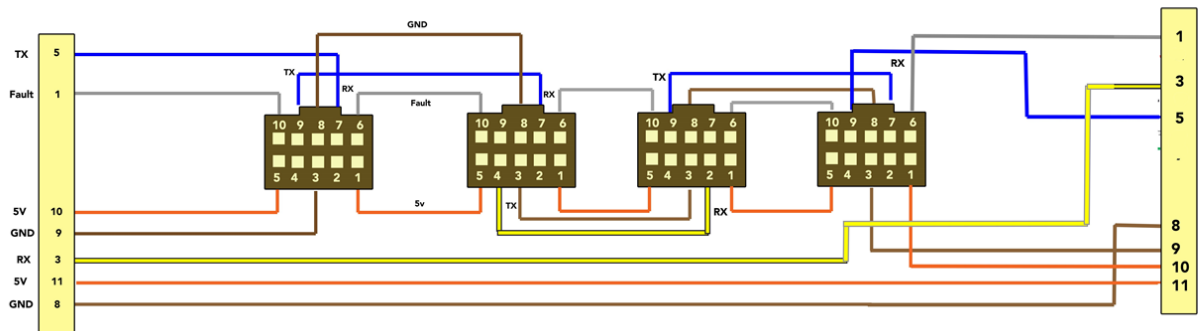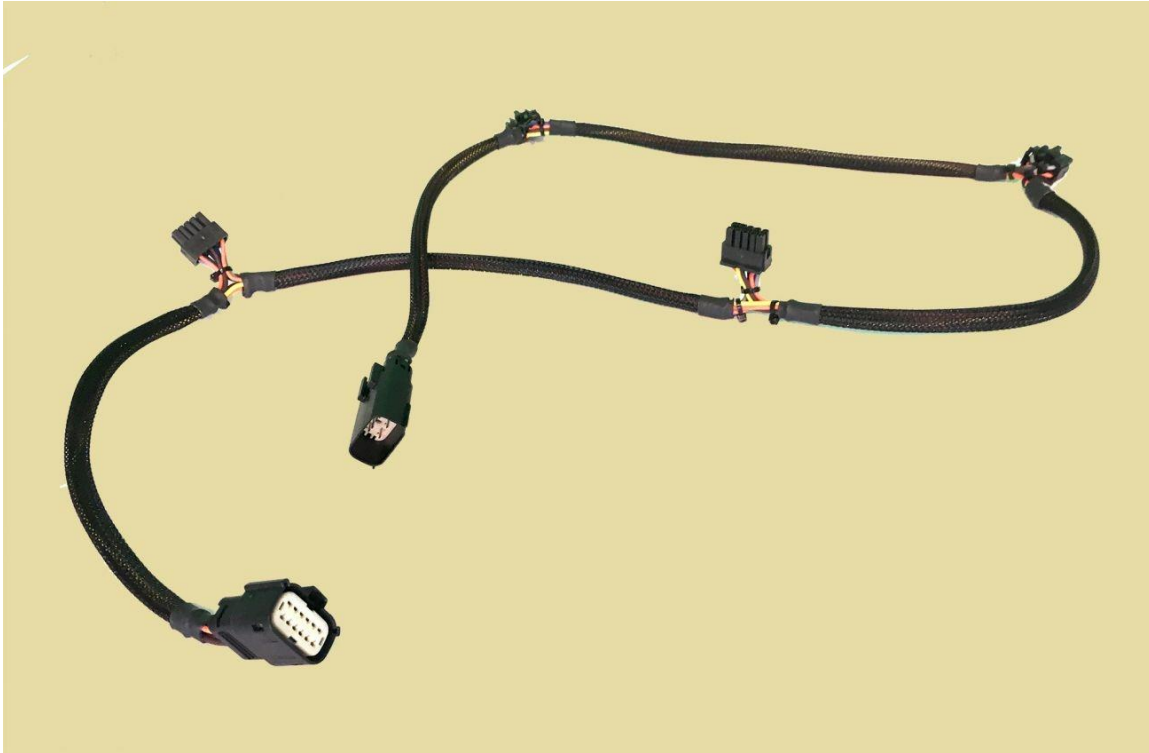
**Tesla Battery Module
Four Module Harness
Extension**

BATTERY TERMINAL CONNECTIONS

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The output of the battery modules should of course be connected to the contactors with heavy copper cable, typically 2/0 in diameter.

To interconnect the modules, our 70mm battery straps are the ideal length for two adjacent/side-byside modules and provide adequate current capacity.

In stacking modules, we have built copper stacking straps that are shaped into a U shape and can be bolted to the terminals of the modules when stacked.

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.

ESP32 BMS CONTROLLER OPERATION

The EVTV ESP32 BMS Controller for the Tesla Model S Battery Module is an entirely automatic system to connect a series of 1 to 20 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, current 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.

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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 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.

There are actually two screens available, the **MONITOR** screen and the **CONFIGURATION** screen. You can toggle between them by entering a question mark ? on the command line.

MONITOR SCREEN

The basic MONITOR screen is shown below:

```
========================================================================================================
**********  EVTV Tesla Battery Module Monitor Version ESP32-1.210  Wednesday, October 10, 2018  17:16:30   ******
========================================================================================================
******* WIFI STATUS..connected to local Access Point:EVTV as IP:192.168.1.117 signal strength:-63dBm ****
========================================================================================================
Module 1: 20.228V 29.3/28.9C Cell01:3.371V Cell02:3.375V Cell03:3.375V Cell04:3.376V Cell05:3.373V Cell06:3.373V
Module 2: 20.240V 29.3/28.8C Cell07:3.372V Cell08:3.376V Cell09:3.375V Cell10:3.376V Cell11:3.375V Cell12:3.374V
Module 3: 20.224V 29.3/28.7C Cell13:3.372V Cell14:3.375V Cell15:3.375V Cell16:3.376V Cell17:3.372V Cell18:3.373V
Module 4: 20.228V 29.1/28.8C Cell19:3.371V Cell20:3.375V Cell21:3.375V Cell22:3.375V Cell23:3.373V Cell24:3.373V
PACK STATUS:No Faults  Modules:4   Voltage:40.460v  Avg Cell:3.374v  Avg Temp:29.0C  SOC:99.99%
        CURRENT: -0.06A POWER: -2.6 Watts  AMPHOURS: -0.03 Ah   WATTHOURS: -1.2 Wh
        Max System Discharge Current: -0.07A Max System Charge Current: 0.00A
        Max Pack Voltage: 40.47vdc Min Pack Voltage: 40.44vdc
        Current High Cell Voltage: 3.376V Low Cell Voltage: 3.371V
Battery Lifetime Charging: 0.000 kWh   Discharging: -0.001 kWh


        Negative Contactor:OFF        Reported OFF
```

```
        Positive Contactor:OFF        Reported OFF
       Temperature Alarm:OFF          0
           Voltage Alarm:OFF          0
           Charge Enable:OFF          Heat Enable:OFF
            12v Reported OFF


Enter ? for Configuration Menu
```

It is refreshed with new data each second.

TITLE BAR

```
**********  EVTV Tesla Battery Module Monitor Version ESP32-1.210  Runtime: 00 Days 01:27:58  *************
```

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.

If and once you connect to a local Wireless Access Point hub/router, this title bar will change somewhat dramatically.

```
=========================================================================================================
**********  EVTV Tesla Battery Module Monitor Version ESP32-1.210  Wednesday, October 10, 2018  17:16:30   ******
=========================================================================================================
******* WIFI STATUS..connected to local Access Point:EVTV as IP:192.168.1.117 signal strength:-63dBm ****
```

In that event, the system will automatically retrieve a time mark from the National Institute of Science and Technology in Boulder Colorado using the NTP time protocol and display the local date and time according to the Time format string entered on the **CONFIGURATION** screen.

An additional line shows the Station Set Identifier (SSID) of the Access Point, the IP number assigned to the ESP32 controller, and the current WiFi signal strength in dBm.

INDIVIDUAL MODULE DISPLAY

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

```
Module 1: 20.228V 29.3/28.9C Cell01:3.371V Cell02:3.375V Cell03:3.375V Cell04:3.376V Cell05:3.373V Cell06:3.373V
Module 2: 20.240V 29.3/28.8C Cell07:3.372V Cell08:3.376V Cell09:3.375V Cell10:3.376V Cell11:3.375V Cell12:3.374V
Module 3: 20.224V 29.3/28.7C Cell13:3.372V Cell14:3.375V Cell15:3.375V Cell16:3.376V Cell17:3.372V Cell18:3.373V
Module 4: 20.228V 29.1/28.8C Cell19:3.371V Cell20:3.375V Cell21:3.375V Cell22:3.375V Cell23:3.373V Cell24:3.373V
```

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.

PACK SUMMARY

`PACK STATUS:No Faults  Modules:4   Voltage:40.460v  Avg Cell:3.374v  Avg Temp:29.0C  SOC:99.99%`

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.

Battery **Voltage** is the total voltage of all battery modules summed, divided by the number entered in **PARALLEL** on the **CONFIGURATION** screen 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 62 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.

SOC indicates your current state of charge in percent. It is calculated by comparing the current number of ampere-hours discharged to the configured capacity. So if you had a **CAPACITY** of 100 Ah and showed a current ampere hours of -10.00Ah, **SOC** would appear as 90%.

When **CHARGE ENABLE** output is on, you can charge the battery up to the **CUTOFF** voltage. When this is reached, the system automatically zeros the AH consumed and resets SOC to 100%

You can manually ZERO out the ampere hours measured at any time by entering the single character command "**Z**". This has the effect of zeroing **SOC** as well to 100%.

CURRENT/POWER

The next line provides the instantaneous state of current output in amperes. This updates frequently and continuously during operation.

`CURRENT: -0.06A POWER: -2.6 Watts  AMPHOURS: -0.03 Ah   WATTHOURS: -1.2 Wh`

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.

Ampere-hours is a running count of the number of AH withdrawn from the pack. Again negative shows discharge and this number will increase as you discharge energy from the pack. It will also decrease back toward zero as you CHARGE putting energy into the pack.

Similarly Watt Hours shows the cumulative Watt-hours consumed during this session.

SESSION MIN/MAX CURRENT AND VOLTAGE

```
Max System Discharge Current: -0.07A Max System Charge Current: 0.00A
Max Pack Voltage: 40.47vdc Min Pack Voltage: 40.44vdc
```

These two lines show the maximum and minimum values recorded for current and voltage THIS SESSION – that is, since the system was powered up. If you power cycle the controller, these values are reset to zero.

HIGH CELL /LOW CELL

Many of the limits configured for your battery are based on an upper voltage, a lower voltage, or a variance between individual cells. This line shows you the voltage of the HIGHEST voltage cell in the pack, and the current instantaneous voltage of the LOWEST voltage cell in the pack.

```
Current High Cell Voltage: 3.376V Low Cell Voltage: 3.371V
```

BATTERY LIFETIME RECORD

```
Battery Lifetime Charging: 0.000 kWh   Discharging: -0.001 kWh
```

This line is intended to provide a cumulative record of battery lifetime charging and discharging expressed in kiloWatt-hours. It is persistent between power cycles but usually reset during software upgrades.

CONTACTOR STATE

```
    Negative Contactor:ON          Reported ON     Positive
Contactor:ON          Reported ON
```

One of the most important functions of the ESP32 BMS 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 GX14 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 precharge resistor. While connected, this severely limits the amount of current through the system to about one ampere, 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.

The contactors are commanded by a switched ground output to the coils. But they also have some auxiliary contacts. 12vdc is provided to these contacts all the time. When the contactor closes, the aux contacts also close. The output of the aux contacts is actually what lights the LED.

This is also fed back to the controller as an input. In this way, we can tell if the contactor actually closed or opened.

And so you see CONTACTOR ON, but also REPORTED ON. This means we have sent the command to close the contactor and verified through the aux contacts that it did indeed close.

Why is this important? If you open a contactor carrying a high current, it is possible to draw an arc between the contacts and actually weld them together so they will not open at all. This is a potentially dangerous situation in that we have disconnected the battery pack, but one contactor didn't actually open.

And so in the event that CONTACTOR is OFF but REPORTED is ON, you will also see an advisory POSSIBLE WELDED CONTACTOR!!!....

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 0.3volts.

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

`Charge Enable:OFF          Heat Enable:OFF`

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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 leadacid "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.

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.

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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	4.2 x 12 = 50.4v	2.4 x 24 = 57.6v
Equalization		2.5 x 24 = 60.0v
Float		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. Your mission of course is to also try to ascertain WHY we reached this limit.

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 ESP32 BMS 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 ESP32 BMS Controller provides an external contactor signal via an external connector. This receptacle carries a 12v energize voltage on one pin and a return ground on pin 2. This can easily accommodate up to 4 amps to energize a contactor and the 200ma necessary in most cases to hold a contactor closed.

The 12vdc is ALWAYS present but the ground is a switched ground. It will be ground when the **CHARGE ENABLE** output is true, and floating when it is not. This switched ground/12vdc can be used to drive relays, optoisolators, or other circuitry as necessary to turn charging off and on.

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

And this **CHARGE ENABL**E 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. This de-energizes the external charging contactor and so stops the charge process.

And the **RESUME** variable is to prevent hysteresis. It establishes the voltage at which charging should **RESUME** as battery voltage falls 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 (100525v) 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 to the charge controller. We tie the coil connections of this contactor to the ESP32 BMS Controller CHARGE ENABLE receptacle. Now, whenever the voltage of the pack is less than the CUTOFF variable, the 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 CHARGE ENABLE output turns off and the contactor deenergizes, 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, and we can continue to operate the inverter with no loss of household power. Instead we 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.
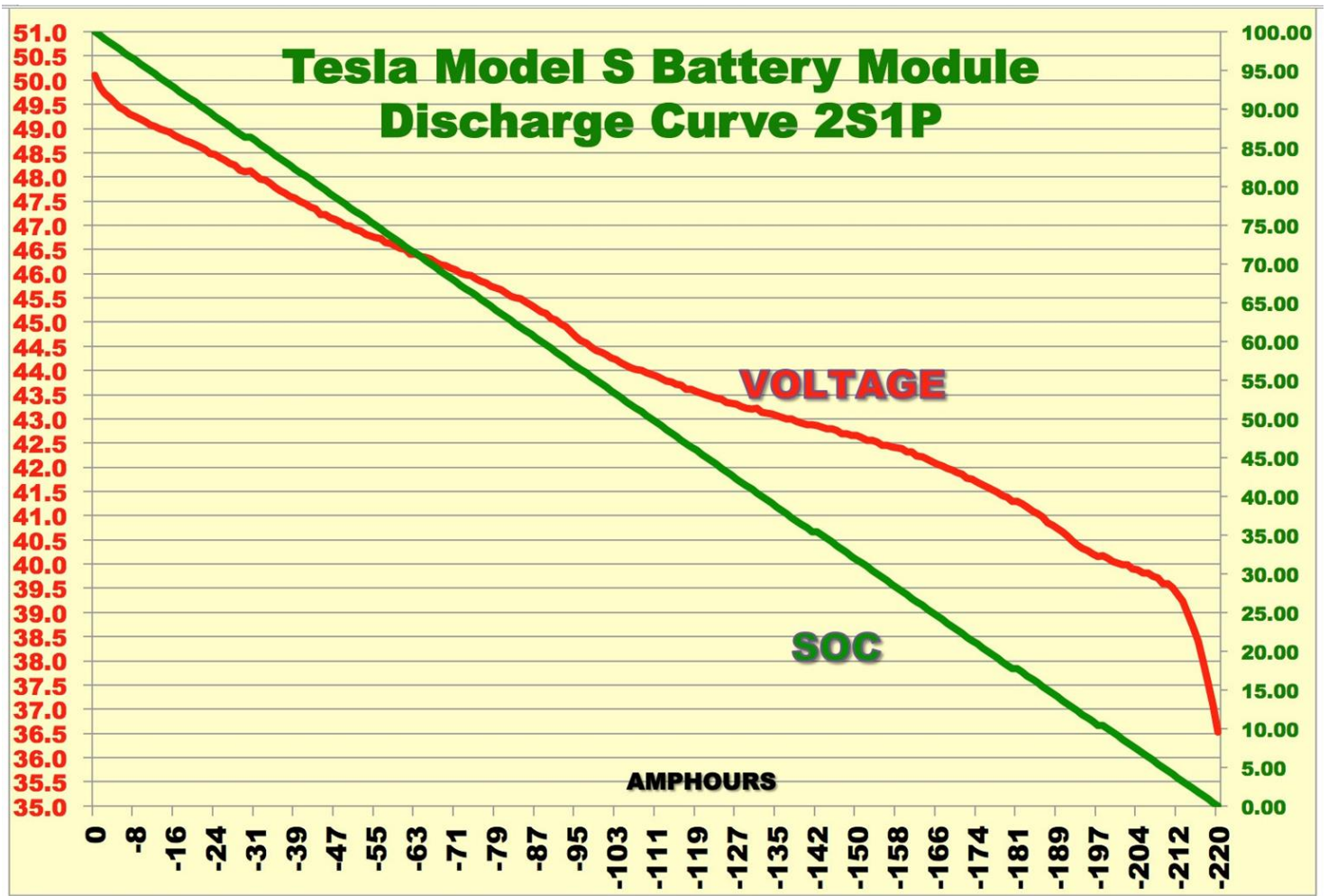
HEAT ENABLE

Heat Enable:OFF

In addition to the **CHARGENABLE** output, the system also provides a second switched ground output titled **HEAT ENABLE**. Again, a two-pin connector with 12vdc always available and a switched ground.

The Tesla batteries are normally both cooled and heated as necessary using a liquid coolant through a circuit that actually winds through each module and contacts each

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cell. It is not likely you will actually need to cool the pack during normal operation. But in high loads in a high ambient temperature environment it is possible.

More likely, the pack may be in an environment where winter temperatures venture below freezing. It is EXTREMELY IMPORTANT that you NOT charge lithium batteries below 32F or 0C – basically freezing. This causes lithium plating of the anodes and irreparable damage.

For this reason, a HITEMP limit and a LOTEMP limit are provided in the CONFIGURATION screen. If the pack exceeds the HITEMP limit, the contactors will be opened and the battery disconnected from the system.

If the temperature falls below the low temperature limit, the pack is again disconnected from the system by opening the contactors.

But if the pack temperature rises to HITEMP LIMIT minus 3 degrees Celsius, we first engage the HEAT ENABLE output. And if the temperature drops to 3 degrees ABOVE the LOTEMP limit, we also engage the HEAT ENABLE output.

This output can be used to turn on a pump and heater for example in cold weather. Or a pump and fan system to cool the pack if the temperature rises too high.

In this way, you can apply cooling or heating to the pack only as necessary.

Heating will continue until the temperature rises to 10C ABOVE the LOTEMP limit. Cooling output will continue until the temperature falls to 10C BELOW the HIGH TEMP limit.

CONFIGURATION SCREEN.

```
========================================================================================
************  CONFIGURATION MENU Version 1.21   Runtime: 00 Days 00:05:08  *************
========================================================================================
    c = Clear all Module Faults
S = Search/scan for Tesla Battery Modules
```

```
    u = Wifi UDP transmission OFF
    z = Resets State of Charge and AH Values to 100% Currently:99.98


  GENERAL SYSTEM


    SSID=EVTV     ---WiFi SSID
    PASSWORD=usatoday     ---WiFi Password
    TIMEZONE=CST6CDT,M3.2.0/2,M11.1.0/2     ---Time zone TZ string
    CLIENTID=601MorganOak-1    ---Amazon IoT Client ID
    CAN0SPEED=500000 Set CAN bus speed
 CAN1SPEED=250000 Set CAN bus speed
T - Toggle Tesla BMS Boards = New Version


  BATTERY LIMITS AND CONFIGURATION


    CAPACITY=  220    Battery pack capacity in ampere-hours
    AMPHOURS= -0.03    Battery pack ampere-hours used of 220 AH capacity.  Current SOC: 99.98%
    PARALLEL=   2    Number of series strings in parallel
 PRECHARGE=  8.5  Number of seconds in precharge delay
    HIVOLT=       4.20 High Cell Voltage limit
    LOVOLT=       3.00 Low Cell Voltage limit
    VARIANCE=     0.20 Maximum Allowable Difference Between Cell Voltages
    HITEMP=      55    High Temp limit C
    LOTEMP=       5    Low Temp limit C
    CUTOFF=       4.15 Charge Enable Output Cutoff Cell Voltage
    RESUME=       3.90 Charge Enable Output Resume Charging Cell Voltage
    SENSITIVITY= 128  Alarm sensitivity 1 (most sensitive) 254 (least sensitive)
    Enter ? to return to Main Display Screen
```

This screen allows you to enter various configuration values used by the system. Many 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 = 490.00

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

CAP=490

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

SINGLE CHARACTER COMMANDS

The following single character commands affect the operation of the device. To perform the function, simply enter the character on the command line and press ENTER. Note that these commands ARE case sensitive.

```
    c = Clear all Module Faults
    S = Search/scan for Tesla Battery Modules
u = Wifi UDP transmission OFF
    z = Resets State of Charge and AH Values to 100% Currently:99.98
```

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.

S - SEARCH SCAN FOR TESLA BATTERY MODULES

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. The S command scans for modules and assigns them each identification numbers for later reporting.

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

u – WIFI UDP TRANSMISSION ON/OFF

The ESP32 controller is capable of using an associated EVTV Battery Monitor Display to present system operational data. The link between the ESP32 board and the display is normally by User Datagram Protocol transmission over the Wireless network. The "u" command toggles UDP transmission on and off. If you do not use the Battery Display, you can toggle this to OFF and save some CPU time, energy, and frequency spectrum.

If you later set to ON it will also reinitialize the WiFi connection procedure to the local Wireless hub/router.

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 a lower case "z" really zeros the ampere-hour value, effectively also restoring state of charge to 100%.

GENERAL SYSTEM CONFIGURATION

SSID=EVTV

PASSWORD=usatoday

The ESP32 BMS Controller is a major upgrade to the EVTV battery controller lineup, most notably because it has WiFi communication functions. This means you can connect to your local WiFi wireless hub/router and thence to the world.

Normally to do this you need to specify the Station Set Identifier (SSID) and password for your local wireless router.

These two values can be up to 32 characters and contain any combination of upper and lower case characters, numerals, and punctuation.

If UDP is on, the ESP32 BMS Controller will attempt to connect to your wireless hub approximately 100 seconds after power-up. It will check this connection every 100 seconds thereafter, reconnecting as necessary.

TIMEZONE=CST6CDT,M3.2.0/2,M11.1.0/2

When the ESP32 BMS Controller first connects to a wireless hub, the first thing it does is attempt to connect to the NTP time server to get a National Institute of Science and Technology (NIST) time mark. This is a highly accurate time clock accessible over the Internet.

Unfortunately, time stands still for no man and worse, it is a bit hard to relate international time mark standards to local time.

The **TIMEZONE** variable allows you to specify your system timezone using the standard POSIX **TZ** variable format used by most unix-like computer systems.

The simplest form of this is something like **UTC+6** which works perfectly well to set your system to 6 hours lagging behind Universal Coordinated Time.

In our example, we are specifying that we are in the Central Standard Time zone

(**CST**) of the United States, **6** hours from UTC, and that we DO observe Central Daylight Savings time (**CDT**). We then go on to specify that we change to CDT in the third month, **M3**, the second occurrence **.2** of day **.0** (Sunday) at two AM in the morning **(/2**). Similarly we change back to CST in month 11 (November M11) on the first Sunday of the month at 2:00AM.

Who thinks this stuff up? Actually the TZ DATABASE is maintained by Paul Eggert. https://web.cs.ucla.edu/~eggert/tz/theory.html. More on the TZ database: https://en.wikipedia.org/wiki/Tz_database.

CAN0SPEED = 500000   CAN0=500

CAN speed sets the data rate for the CAN bus. Speeds must be between 33,000 bits per second and 1,000,000 bits per second. There are two CAN channels, CAN0 and CAN1. **CAN1SPEED = 250000**   is identical for CAN1

LIMITS AND CONFIGURATION

CAPACITY= 410.00 - Battery pack capacity in ampere-hours

This command allows you to enter the capacity of the entire battery pack in amperehours. 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.

AMPHOURS= 192 - Battery pack ampere-hours used

The "z" command described earlier allows you to zero your amphours used and reset your state of charge to 100%.

This command allows you to set some other value as the ampere hours used for test purposes or to restore a specific state of charge after a software update. Simply record your amphours, update your software, and then enter that recorded value into AMPHOURS and you will be right where you were in SOC.

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.

For a 16 module 48v system, you would then have 8 strings of 2 modules. By entering 8 here, we can do the math for you.

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.   The circuit is completed through a precharge resistor across the terminals of the positive contactor. This will limit current to less than 2 amperes until the input capacitors of the device we are powering can charge to the output voltage. After a period of delay defined by PRECHARGE in seconds, it engages the positive contactor, connecting the battery directly to the system and bypassing this precharge resistor.

HIVOLT= 4.30 - 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= 2.90 - 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 disengaged, 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 disengaged, 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.

CUTOFF= 4.15 - Charge Enable Output Charging Cutoff Cell Voltage

That said, Cutoff, on the other hand, does not impact contactors at all. It simply establishes the cell voltage at which we wish to discontinue charging. This value is used with CAN commands to inverters and chargers, but it is also a limit for the CHARGE ENABLE output.   This output is a switched ground that can be used to control an external contactor or circuit effecting a separate charger or charge controller.   In any cell hits the cutoff voltage, that output is disabled and so the switched ground is removed.

RESUME= 3.90 - Charge Enable Output Resume Charging Cell Voltage

Resume would be a lower voltage than cutoff that re-enables the CHARGE ENABLE output. And so we charge until reaching CUTOFF and then stop until the voltage falls to RESUME.

There is a special mode of the ESP32 controller. It uses the CHARGENABLE output to switch the Singineer controller output frequency from 60Hz to 62.5 Hz for a very brief period (250 milliseconds).

You can set this mode to occur when the battery voltage reaches CUTOFF by setting RESUME equal to the CUTOFF voltage. This would never be used for normal chargenable operation.

SENSITIVITY= 20 - Alarm sensitivity 1 (most sensitive) 254 (least sensitive)

Most of the voltage and temperature limits trigger the contactors to de-energize and disconnect the battery pack from the system. Restarting generally involves some manual operator intervention so that the system can be checked for faults and voltages and either repaired or simply reconnected to check further.

These limits are by design a bit touchy. If ANY indication of an individual cell voltage, for example, exceeds HIVOLT, the limit trips and disconnects the pack.

Unfortunately, solar power systems can be noisy environments. For example, when an inverter goes from inverting to disconnect it dramatically reduces the drain on the pack and can result in a voltage pulse that makes the cell voltages appear to increase but typically for just a few milliseconds. The cell then immediately returns

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to its normal voltage. This COULD trip the limit, even though the real cell voltage is well within the limits.

As a result, the system actually works by counting the number of voltage alarms and when it reaches the defined count, actually trips the contactors. This defined count is termed sensitivity. A sensitivity of 1 is the most sensitive and will trip with even 1 incursion. Max sensitivity is 255. When 255 incursions have been counted, the contactors are de-energized.

In practice, voltages are read several times per second. If your cell voltage really does increase beyond the limit, it will trip the alarm several times per second. And so whatever the sensitivity, after just a few seconds it really will de-energize the contactors. But spurious reads or errors reading the cell voltage or voltage spikes on the output will not cause a "false alarm".

ADDITIONAL SECRET COMMANDS

There are a number of undocumented "secret" commands for the ESP32 BMS Controller. Well, that's not precisely true as we are documenting them here and they are not precisely secret either.

But they are rarely used, often uninteresting maintenance or development items and don't bear listing on the CONFIGURATION screen.

1 Negative Contactor
Entering a 1 toggles the negative contactor directly. If OFF sets ON and if ON sets OFF.

2 Positive Contactor
Entering a 2 toggles the POSITIVE contactor directly. If OFF sets ON and if ON sets OFF.

4 Charge Enable
Entering a 4 toggles the CHARGE ENABLE output. If OFF sets ON and if ON sets OFF.
5 Heat Enable
Entering a 5 toggles the HEAT ENABLE output. If OFF sets ON and if ON sets OFF. d

DEBUG COMMAND

Entering a lower case "d" causes an immediate jump to a debug mode where the normal screen display disappears and all CAN and UUDP CAN frames are listed instead, in the order they occur, and with a detailed time mark. Enter "d" again to return to your normally scheduled programming.

D DEBUG2 COMMAND

Entering upper case "D" simply selects a second debug mode listing mostly MQTT topic publish messages and some ICDA CAN traffic from the Isabllenhutter current sensor. Again, "D" to return to the MONITOR screen.

t or T serial data rate

 Toggles between two close values on the second serial port data rate to the Model S Battery Module BMS sub boards. One works better for original and the other for newer type BMS boards.

X or x Initializes WIFI

Turns on WIFI and attempt to connect to the SSID using PASSWORD configured. If successful, attempts to fetch a time.

Z ZERO

Clears life time charge and discharge counters

mqtt=500

Sets the transmission interval for MQTT topic publication in milliseconds.

NOTES ON USABLE CAPACITY

While the theoretical capacity of the Tesla Model S battery modules is impressive, use in a solar application does not always render the maximum theoretical capacity of the cells.

In theory, the modules of an 85kWh Tesla Model S battery pack are a NOMINAL 21.6 volts per cell. This NOMINAL voltage is the theoretical average voltage of the module from fully charged 25.2v or 4.2v per cell, to fully discharged. Fully discharged is usually defined as 2.50 vdc but this is necessarily vague. It is important to not OVER discharge the cells. Further, the decline in voltage curve as the cell discharges through about 3.00 v becomes so steep, that the difference in total energy between 3.00 volts and 2.50 volts is relatively trivial.

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The usable ampere-hour capacity is thought to be about 225-235 ampere-hours per module in a Tesla Model S 85kWh pack. This value actually varies somewhat even coming out of the battery assembly process.

Total capacity in kiloWatt Hours is a function of nominal voltage (21.6) times ampere-hours storage (235) for a theoretical 5076 wattHours or 5.076 kWh. And so you see that six of these are theoretically 30,456 wH or a little over 30 kWh.

As described elsewhere, the equipment found in the typical solar installation is designed for lead-based chemical batteries, not lithium based ionic batteries. And so the voltages are typically quite different with a "48v" battery operating from about 42 to as much as 56 volts. Lead chemistry cells are usually restricted to a total discharge of about 50% and discharging them below 50% SOC dramatically shortens their life span.

Lithium cells can safely be discharged to 20% or even below without serious shortening of battery life. And this is an advantage. But the mismatch in voltages to the typical system means that it can be very difficult to discharge your batteries below about 36v in a 48v system and to do that you usually have to resort to very specific modifications to the default configuration of your typical inverter.

36v would be about 3.00vdc in our typical Tesla Model S battery module setup with two modules in series. These modules would CHARGE to 50.4 vdc and in theory be good down to 30vdc fully discharged.

So in almost all solar applications for 48vdc equipment, these batteries will never be fully discharged.

That is NOT ALL BAD. The quickest way to damage your battery is over discharge or overcharge. And while the controller is designed to prevent just that, the inherent lower limits of most solar equipment precludes the possibility of over discharge. And that is just plain good medicine for these modules.

But it means you will not likely actually get to use 30kWh of your 30kWh pack. Most solar veterans are quite accustomed to this. They usually don't get to use HALF of the capacity of their lead chemical batteries.

Our percentage state of charge calculations are based on the CAPACITY in amp hours entered in the configuration screen of the controller. But you can get a much more accurate display of your USABLE or PRACTICAL capacity using the following procedure.

- Fully charge your modules to 50.4vdc.

- Zero your ampere hours and state of charge display by entering "Z" on the command line.

- Discharge your pack until the inverter reaches its low battery cutoff point and quits making AC power.

- Note the discharged ampere-hours recorded on the monitor screen. You can see that there is both an ampere-hours display and a more permanent DEMONSTRATED CAPACITY value. This is the largest number of amphours ever discharged from the pack.

- Revise CAPACITY to the actual observed value in ampere-hours at inverter cutoff.

We really don't use state of charge for any important calculations in the battery monitor software. It is mostly for your information anyway. All limits are based on individual cell voltages and actual current flows.

The AMPERE-HOURS display on the monitor screen is actually quite useful. Negative values are discharge Ah and positive values are charge currents. And so the actual numeric value will go up and down as the battery charges and discharges. IT is zeroed manually by entering Z at a fully charged state.

It is important to reset this occasionally. It doesn't have to be done every time the battery reaches full charge. But it should be done every few months. This is because there is a basic inefficiency inherent in the cells in that if you take 10Ah out of the cells by discharging, it will take very slightly MORE amp hours put back in to get you to the same point. This inefficiency is a function of heat loss in the cell as it charges and cell aging. And indeed, this inefficiency increases with time as the battery ages. To maintain a true SOC indication, it is good medicine to simply ZERO the reading every month or so at the point where the battery is at full charge.

Further, using the CHARGENABLE output, or in the worst case your HIVOLT cutoff, you can define what fully charged really means. By specification, this would be 4.2vdc and so 50.4vdc for the 48v pack. But there is no law requiring full charge and indeed you can prolong the life of your cells by intentionally undercharging them. If you decide that charging to 49.5vdc suits your needs better, then ZEROing at that level and setting your CUTOFF value when using charge enable to that value establishes that as 100% SOC. Indeed you could set 48.0vdc as fully charged just as easily and only charge to 4.00v per cell.

It is also quite common to be able to set the CC/CV voltage or charge voltage for your battery in your MPPT Charge Controller or inverter.

So by strategically using the Z function to ZERO your readings, and entering the new amp-hour value in CAPACITY, you can improve your SOC indication to what is really

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going on between the FULLY CHARGED state, as defined by YOU, and the actual low battery cutoff point of your inverter.

You can check this periodically every six months or so, and actually see that you are not reaching 0% before the inverter cuts out as the batteries age and the capacity diminishes. But in this way, you can see by how much capacity you are losing over a given period of time. Your DEMONSTRATED CAPACITY will remain the same. But your actual ampere-hour display of Ah at low battery cutoff will gradually become less than this.

The display also shows total kWh charged and total kWh discharged over time. This is regardless of how many cycles the battery undergoes. It simply sums ALL charge currents and ALL discharge currents over time. Comparing these values to your change in ampere-hour capacity will help you calculate the useful life of the modules over time.

This sounds like a great deal of daily trouble to go to for a battery. Actually it is not. It is some background information on how you can develop safe and effective strategies for knowing your battery SOC and life. But it is most likely something you would play with every MONTH OR SO for 10 minutes.

And none of it is particularly critical to battery operation. CAPACITY and SOC are almost entirely informational. Limits and safeties are based on actual cell voltages and temperatures.

SOFTWARE UPDATES

The software to operate the controller is of course preloaded in non-volatile RAM memory on the controller ESP32 chip itself. And so it is available between power cycles. Your configuration parameters are likewise held in NVRAM to persist between power cycles.

One of the long held traditions in software development is to feature some code instructions that perform functions quite differently from what the programmer originally intended. These clever "features" are sometimes inaccurately termed "bugs".

Additionally, we can't really see where we want to go until we reach an altitude offered by where we've come. And so with each additional feature in software, we see additional targets of opportunity of cool things it COULD do with just a few additional lines of code.

Users often provide input regarding "bugs" that only appear in rare edge cases or at particular times. And whatever the software does, they have insights into what it might also be used to do.

And so software is often updated. With microcontrollers, this poses a significant challenge as the means to update the software are limited by the hardware.

The Espressif ESP32 fortunately has a feature allowing it to hold programs in two different memory segments and either segment can be selected as the "boot" segment that is used on power up.

It also supports wireless communications using standard Internet protocols.

EVTV is hosted on Amazon's Amazon Web Services cloud.

We've combined all of this to provide Over The Air updates much after the fashion of the Tesla vehicle. We post the latest software to the cloud any time we make a change.

You can easily "fetch" this new updated software image over the Internet wirelessly into your unused memory segment, and then designate that as the "boot" segment. As the original software is still held in the other segment, you can also "revert" to the earlier software.

To update your software at any time, simply enter the following command:

UPDATE=1

The system will automatically check to see if a wireless connection is available, locate the AWS server, and download the new image over the wireless connection. It will also display the progress of this process and automatically reboot the controller once it has completed the download.

To revert to the previous version, enter **REVERT=1 .**

TOUCH SCREEN DISPLAY

ESP32 BMS Controller Assembly   Version 2.25   August 2022

The design and concept is to have a battery that protects itself AUTOMATICALLY from every extreme of overcharge, overdischarge, temperature and the potential for a single cell failure to initiate a failure. The entire point is you don't have to be there at all and if it does its job, there's nothing to see.

You can easily perform the initial configuration and make minor adjustments in the first few days of operation using any laptop with the simplest ASCII terminal program. Thereafter, it should just run. If there is an anomaly, simply reset and restart with the ON/OFF switch and that will generally take care of the matter.

In the event you actually DO have a problem, the included software will let you quickly determine the nature of the fault.

However, we do offer a unique Display System providing very detailed information on the battery and even allowing configuration of most of the important items of battery operation on an easy to use 7-inch touch-screen display.

The EVTV Battery Monitor Display normally works over WiFi to communicate with the ESP32 controller.

For more information on this display, refer to the EVTV Battery Monitor Display User Guide.

CAN COMMUNICATIONS

The ESP32 puts out a series of CAN messages on CAN1 and has the ability to transmit them over WiFi UDP packets as well. And so it is entirely plausible for you to develop your own display, logging, and analysis system simply by receiving these messages.

The EVTV Battery Display was designed specifically for use with the ESP32 version of the EVTV Battery Module Controller which in turn is specific to providing an interface to the Tesla Model S Battery Modules.

And that is the only use supported by EVTV formally.

That said, we are here providing the communications interface for the device. Batteries are batteries are batteries. And all battery management applications have most of the same features in common. ALL batteries have a state of charge, an input or output current level, a voltage level, power levels, and most provide access to individual cell voltage levels.

And so in theory, this display could be interfaced to almost any battery management system.

Essentially, the EVTV Battery Display uses the Controller Area Network (CAN) protocol 2.0A with 11 bit message identifiers. We originally configured it to use a third party CAN hat for the Raspberry Pi to receive CAN frames through the usual twisted pair CAN wired interface and indeed it can still be configured to do just that and it will work identically in all respects.

The development of the UDP WiFi interface was driven by a desire to separate the display physically from the physical battery assembly. In this way, you could have the display in the kitchen for example, while the battery itself was in an outbuilding or garage in a solar storage application. Similarly you could dash mount the display and have the battery itself elsewhere on a car or boat with no need to run hard wiring between them.

If using hardwired CAN bus connections, any device can produce the necessary CAN message and it will be received and displayed by the program. The configuration screens make no real sense or have application in other environments, but the displays can all be used quite successfully.

UDP COMMUNICATIONS

In the case of the WiFi interface, things get a little less standard and a wee bit more complicated. The Battery Display monitors for incoming UDP packets on port 6500. Any it receives will be interpreted as CAN frames.

The problem of course is there is no standard for UDP encapsulation of CAN.

In the case of WiFi interface, we simply encapsulated the raw CAN data structure we use in our own CAN libraries for the ESP32.
These are based on Collin Kidder's **esp32_can** library.
http://github.com/Collin80.

Much of this has no application of interest because it relies on our CAN libraries and we simply shuttle the entire structure peculiar to our libraries back and forth over UDP. This makes programming UDP, for us, just like programming CAN.

The basic EVTV CAN data structure is 24 bytes:

```
 BYTE 0-7       The 8 data bytes.
 BYTE 8-11    uint32_t Message ID    29 bit if IDEextended set, 11 bit otherwise
 BYTE 12-15   uint32_t   family ID - used internally to library
 BYTE 16-19   uint32_t timestamp recording when mailbox message was received.
 BYTE 20       uint8_t RTR -  Remote Transmission Request (1 = RTR, 0 = data frame)
 BYTE 21       uint8_t priority - only important for TX frames and not often then
 BYTE 22       uint8_t Identifier Extended flag 1 eq 29-bit 0 for 11 bit
 BYTE 23       uint8_t length -  number of data bytes
```

And so any UDP transmission with a raw data packet of 24 bytes on port 6500 will be received and interpreted if it is a CAN message ID of interest.

The ESP32 controller actually broadcasts these packets on the IP broadcast address (.255) on port 6500. In this way they go to ALL devices connected to the Access Point and so the controller doesn't need to know the IP number of the Battery Display or even if a Battery Display exists. The user can simply configure the Battery Controller to send UDP or not.

And so the Battery Display simply monitors its' own IP number for ANYTHING coming in on port 6500. If a message ID of interest appears in bytes 8-11 of the packet, it processes the packet.

So don't be daunted by the structure. You don't need to put ANYTHING in most of the bytes in it. The data goes in the first eight bytes. The message ID, always 11bit, follows in Bytes 8-11, and the number of data bytes actually used goes in the last byte 23. Set all the others to zero. They have to be there. But the Battery Display doesn't actually process them.

And so, you can display anything you want on the Battery Display by connecting to the AP and sending 24 byte UDP packets to port 6500 on the broadcast IP address (.255).

CAN MESSAGE IDS

Whether transmitted by actual CAN differential wire pair or by UDP packet, the CAN message definitions are identical. You will note some odd usage here and unexplained gaps in the bytes used.

We used a display interface from Andromeda Interfaces termed the EVIC. We developed software to use this with our Tesla Model S Drive units. When we started employing salvaged Tesla Battery Modules for solar energy storage, we reverse engineered the Tesla BMS communications protocol and developed a "controller" that would communicate with the Tesla BMS and control access to the batteries via contactors. It might be nice to add a display.

Andromeda offered other versions of the EVIC with interfaces or "skins" for the HPEVS AC motor and Ewert Systems ORION Battery Management System. The Orion version used the touch screen and the HPEVS did not and so Andromeda would send us the Orion version. We were replacing the software anyway for the Tesla Drive Units.

So we simply plugged in the EVIC and sent it CAN messages to drive the Orion display.. As the systems were different, we found many data pieces in the messages simply didn't apply to our system.

Andromeda Interfaces is dropping the EVIC product line. Ergo the development of the Raspberry Pi based EVTV Battery Display. The CAN messages are simply legacy remnants. But they serve well enough.

You can do similarly. By sending these messages to the EVTV Battery Display, either by CAN or by UDP Wireless packet, you can easily display most crucial battery data. And the EVTV Battery Display performs logging functions that are quite useful as well.

MESSAGE ID 0x150

Length-8 bytes

Byte 0/1

Pack Current. LSB/MSB 16-bit signed integer containing pack current. Positive values are read as charging and negative values are read as battery discharge currents.

Byte 2/3

Pack Voltage. LSB/MSB 16-bit unsigned integer representing total pack voltage x 10. Multiply your reading by 10 to preserve on digit of decimal accuracy. Example: 48.76 volts sent as 487.

Byte 4/5

Pack Ampere-Hours. LSB/MSB signed integer representing ampere-hours used from pack x 10. Almost always a negative value. X 10 to preserve one digit of decimal fractional value. Example: 114.56 amperes discharged from pack – send as -1145.

Byte 6

Maximum Battery Temperature in whole degrees Celsius. 8-bit unsigned byte representing highest cell terminal temperature currently.

Byte 7

Minimum Battery Temperature in whole degrees Celsius. 8-bit unsigned integer representing lowest cell terminal temperature currently.

MESSAGE ID 0x650

Length-1 byte

Byte 0

SOC. 8-bit integer representing SOC*2. Take SOC, double it, and round it to a hole value. Example: 77.75% x 2 = 155.5. Round to 155. On display we will divide by 2 to get 77.5. In this way, ½ digit accuracy in 8-bits.

MESSAGE ID 0x651

Length-6 bytes

Byte 0/1

Low Cell Voltage. LSB/MSB 16-bit unsigned integer representing the lowest individual cell voltage in the pack *1000. Example: lowest cell = 3.214v x 1000 = 3214.

Byte 2/3

High Cell Voltage. LSB/MSB 16-bit unsigned integer representing the highest individual cell voltage in the pack *1000. Example: highest cell = 3.274v x 1000 = 3274.

Byte 4/5

Average Cell Voltage. LSB/MSB 16-bit unsigned integer representing the average if all cell voltages in the pack *1000. Example: average cell = 3.262v x 1000 = 3262.

MESSAGE ID 0x652

Length-8 bytes

Byte 4/5

High Voltage Cutoff. LSB/MSB 16-bit unsigned integer representing the highest individual cell voltage allowed before the battery system shuts down to prevent overcharge *10. Example: High Voltage Cutoff cell = 4.20v x 10 = 42. Displayed as the high voltage tick on the voltage dial.

Byte 6/7

Low Voltage Cutoff. LSB/MSB 16-bit unsigned integer representing the lowest individual cell voltage allowed before the battery system shuts down to prevent overdischarge *10. Example: Low Voltage Cutoff cell = 3.25v x 10 = 32. Displayed as low voltage tick on voltage dial.

MESSAGE ID 0x653

Length-8 bytes

Byte 0/1

Number of attached microinverters. LSB/MSB 16-bit unsigned integer representing how many Enphase microinverters are installed and reporting.

Byte 2/3

The current number of watts being generated. LSB/MSB 16-bit unsigned integer representing how many watts all the microinverters are collectively generating.

Byte 4/5

KilowattHours generated today. LSB/MSB 16-bit unsigned integer representing kWh * 100. So, a value of 1000 = 10kWh generated today.

Byte 6/7

KilowattHours generated over last 7 days. LSB/MSB 16-bit unsigned integer representing kWh * 100. So, a value of 12340 = 123.40kWh this week.

MESSAGE ID 0x654

Length-8 bytes

Byte 0

This is used as a bitfield to specify the I/O status of the system.

Bit 0 = Negative contactor commanded state (0 = open, 1 = closed)

Bit 1 = Positive contactor commanded state (0 = open, 1 = closed)

Bit 2 = Charge enable state (0 = No charge enable 1 = Charge Enable)

Bit 3 = Heat enable state (0 = No heat enable 1 = Heat Enabled)

Bit 4 = Negative contactor confirmation (1 = Contactor is open 0 = Contactor is closed)

Bit 5 = Positive contactor confirmation (1 = Contactor is open 1 = Contactor is closed)

Bit 6 = +12V detected (1 = Just USB power, 0 = Board is powered via 12V and not just USB)

Byte 1

The fault status of the system. The upper bit (bit 7) is set to indicate that currently there is a voltage related fault. Bit 6 is set to indicate that a temperature related fault is occurring. Bits 0-5 are a more detailed reason of the last fault registered. Currently these fault reasons are:

0 – No fault

1 – A cell has gone under the lowest allowable voltage

2 – A cell has gone over the highest allowable voltage

3 – A module is registering colder than allowed

4 – A module is registering hotter than allowed

5 – Either the highest and lowest cell voltages are too far apart or two or more modules are too far apart in voltage.

Bytes 2-7

Currently these bytes are all sent as zeros. They may be used in future firmware versions. If so, this space will be updated to show the new functionality.

MESSAGE ID 0x68F
Length-8 bytes

Byte 0
Sequence Number. 8-bit unsigned integer. Message 0x68F provides individual cell voltage data for the entire battery pack. As a pack can vary from six cells to hundreds, it does this by sending a sequence of ordered 0x68F messages with six individual cell voltages in each message. As some messages may be dropped, this message provides both a sequence number and the number of six cell messages in total. In this way, we use the sequence number to retrieve the individual cell voltages in the correct order. This number will increment with each message until all cell voltages are sent, and then begin again at 0.

Byte 1
Total Modules. 8-bit unsigned integer indicating the total number of 6-cell messages in sequence. Derives from Tesla Model S modules which each have six cells.

Byte 2-7
 Cell voltage. 8-bit integer. Each byte contains the voltage of one cell-2.00v. The result should be multiplied by 100 to retain two digits of decimal fractional accuracy. Example: 3.475v = 3.475-2.00=1.47 * 100 = 147. The display adds 200 to that value =347 and divides by 100 for 3.47v.

Note that the EVTV Battery Display actually graphs the voltage levels of all cells in the battery pack. As the number of cells varies from pack to pack, how does this work?

We use the Byte 1 data from the 0x68F message to determine the number of graph bars necessary, and scale the bar width appropriately. There are display limits to this and so the maximum MODULES displayed is limited to 40 or 240 individual cells.

REVISIONS

This section provides additional notes on software changes and revisions:

VERSION 1.59 FREQUENCY SHIFT CHARGE ENABLE

Notable in this version is the provision for a frequency shift output on the CHARGE ENABLE output.

The EVTV concept of using AC coupling to charge batteries from grid-interactive or "grid-tied" inverters and microinverters proved popular and useful. This is primarily achieved with the use of the SIGINEER 15kW inverter.

It became necessary to handle the case where the batteries reached full charge OR the output of the solar array and grid tie inverters exceeded the maximum power of the inverter.

CUTOFF and RESUME are normally used to control the CHARGE ENABLE output. If the battery voltage falls below RESUME the charge enable output will be ON.   If the average cell voltage reaches CUTOFF the CHARGE ENABLE output goes OFF.

To activate the FREQUENCY SHIFT CONTROL function, set CUTOFF to the maximum average cell voltage you want to charge to. But set RESUME to the SAME voltage.
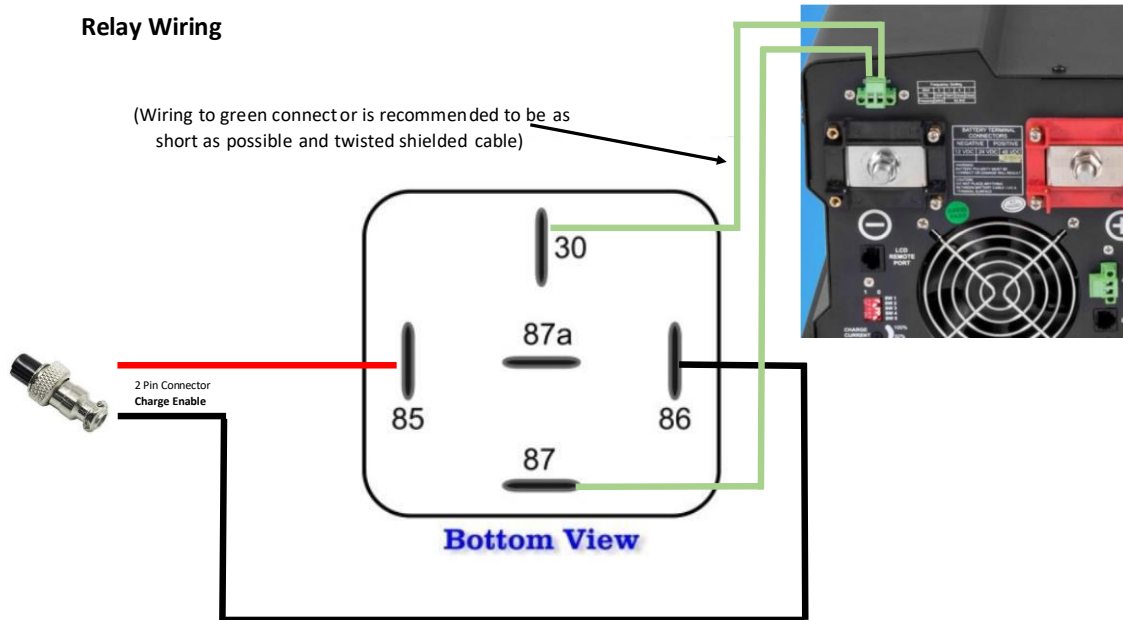
If RESUME=CUTOFF, the CHARGE ENABLE output will be off and would normally never come on. But in this special case, when you reach the cutoff voltage the CHARGE ENABLE output will be activated for 500ms or about ½ second.

We had SIGINEER add two contacts to their 15kW inverter for FREQUENCY SHIFT to switch from the normal 60Hz output to 62.5Hz.

The CHARGE ENABLE output is used to activate a normal Bosche Automotive 12v relay. The normally open contacts are connected to the Sigineer frequency shift contacts and the CHARGE ENABLE output closes the relay, shorting the two Sigineer contacts together for 500ms.

This causes a very brief shift in frequency from 60 Hz to 62.5Hz for about a half second. This will be unnoticeable by almost all electrical equipment. But grid tied inverters are required by UL1741 to perform a rapid shutdown in this event.

The result is this very brief frequency shift will shut off all grid-tied inverters – stopping the charge. These inverters have a five minute time out and will RESUME operation after that timeout period.

Relay Wiring

(Wiring to green connector is recommended to be as short as possible and twisted shielded cable)

In this way if your batteries get full or the solar array produces too much current for the system, the controller automatically shuts the grid-tied inverters off for five minutes. During this time power output of the inverter continues without interruption using power from the batteries, and thus diminishing their charge below the cutoff level.

After five minutes, the array resumes charging and will do so for 10 or 15 minutes until the battery again reaches a fully charged state and at this point the frequency shift/shutdown is repeated.

In a properly sized system, the batteries would then begin charging as the sun rises and reach fully charged state sometime in the late afternoon. At that point it would repeatedly charge and discharge in 5 minute increments in a kind of slow motion hysteresis designed to ensure the batteries are within a five minute period of fully charged as the sun goes down and the evening begins.

Note that the relationship between CUTOFF, RESUME and CHARGE ENABLE remains the same with the exception of this edge case. And the frequency shift function only occurs in the unusual setting of RESUME=CUTOFF.

Note also the use of an intermediate relay. We use this with the Sigineer 15kW inverter but have no idea what inverter might be used in any particular installation.

But ANY inverter capable of frequency shift can be used, with appropriate interface of this switched ground output to shift frequency or otherwise interrupt the grid tied inverters.

You could for example simply have all grid tied input to the house system controlled by a contactor and use this CHARGE ENABLE output with another relay to disconnect that contactor for 500ms. This will be long enough to disable the grid – tied inverters and send them into the same five minute timeout.

Note that you can toggle the 500ms CHARGE ENABLE output any time using the single character command "**f**" from the ASCII terminal console.

VERSION 1.61 AC LOAD DUMP OPERATION

Notable in this version is the provision for a grid control feature on the HEAT ENABLE output.

The HEAT ENABLE output was a brilliant concept to automatically control either heating or cooling equipment if the battery terminal temperatures approached the HITEMP or LOTEMP temperature shutoff values.

As it turns out it was a brilliant solution to something that is almost never a problem.

In solar applications the batteries are typically enclosed and in continuous operation. And so even fairly low ambient temperatures do not cause the batteries to be below freezing because of the internal activity of the batteries which generates some internal heat.

Additionally, these batteries are designed for high loads of 1100-1300 amps in a series application in a vehicle. In solar applications they are more arranged in parallel making even 300-400 amp loads less than 100 amps per module in practice. And the power load cycles of most installations are simply much much less than that – often requiring 10 to 20 amps per module on average.

And so we've never actually seen any of these batteries approach the 48C upper limit recommended by Tesla.

And so we are aware of a very few installations where the owner/designer has gone to somewhat elaborate measures to use this HEAT ENABLE output to control heating and cooling devices of some remarkable design. We've just never heard of any of that actually being used in anger.

And so our advice, don't spend to much time and money solving a problem until you actually HAVE a problem.

But we do have an edge case that bears some explaining and a solution. It was difficult to foresee the case where we have TOO MUCH SOLAR POWER.   That sounds like a marvelous problem to have, but actually it still has to be solved. And this is MUCH more common in actual operation than temperature issues.

The heart of this is the exceeding variance in irradiance across the year. Everyone is aware you get less sun in winter than in summer, but the scale of this is poorly perceived. At summer solstice, your solar array can produce as much as 450% the amount of power produced at winter solstice. And this varies with the distance from the equator.

And so if you design your system for barely minimal requirements during the winter months and short days, you will find it surprising to face being overrun by solar power by spring.

The Sigineer inverter is a hybrid. IT can be used for battery backup of normal grid operation or grid backup of normal battery operation. And increasingly, most inverters on the market use this HYBRID concept to maximize sales in a variety of situations.

In BATTERY PRIORITY mode, the inverter normally operates from the battery. If battery state of charge decreases to some set value, it switches to AC mode and uses either the grid or a generator to recharge the batteries while it passes that source THROUGH to the normal loads of the installation.

In GRID PRIORITY mode, it normally passes the AC source through to the load and maintains the battery at 100% charge. In the event of grid failure it of course switches to battery power.

We normally use the battery priority mode and only use grid or generator as necessary during prolonged periods of overcast.

We can use the frequency shift function introduced in version 1.59 to intermittently shut off the solar power production – preventing overcharge of the batteries.

This works up to a point. But we have a largish photovoltaic array specifically to find these edge cases. And by spring, we were producing so much solar power, that the batteries were fully charged by 9:30 AM. Worse, it was producing so much current that it readily exceeded the 15kW limit of the inverter causing the inverter to automatically fault and shut down. This had to be manually reset to resume power.

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And so in the best case, within a couple of minutes of the array coming up, the system frequency shifted to disable it. Five minutes later, it came up again and again had to be immediately shut down again. And so for the majority of the day our photovoltaic array produces nothing – baking in the sun quite uselessly.

The solution is to install a pair of contactors on L1 and L2 phases on the grid input to the inverter and control those contactors with the HEAT ENABLE output.

We put the inverter in the GRID PRIORITY mode or AC PRIORITY mode. But the contactors are off/open and so no grid is available and we operate from the batteries and photovoltaics as if we were on a grid outage battery backup scenario.

In the event the batteries reach maximum state of charge, or in the event that the solar arrange current is too large for the inverter, we set HEAT ENABLE to ON energizing the two contactors and applying the grid power to the inverter.

In the case of Sigineer 15kW, it detects the grid is "back up" and after a 15 second stabilization timeout, it switches to AC pass-through to the loads and shuts off the battery powered inverter.

At the same time we set HEAT ENABLE to ON, applying the grid, we also do the normal frequency shift to shut down the grid tied inverters. And so the grid comes up in a fairly controlled and stable fashion powering the house loads. Five minutes later the grid-tied inverters come back online and any excess power is fed through TO THE GRID, and so we use the AC grid as a power dump load for the solar photovoltaic array for the rest of the day.

We use the NTP time to turn HEAT ENABLE OFF at 7:00 PM local time – removing the grid for overnight operation from the batteries. We re-enable this function at 7:00 AM. Note this does not immediately cause the HEAT ENABLE to enable grid operation. It simply resets it so it COULD do so after the batteries fully recharge any time during the day AFTER 7:00 AM.

To use this feature, simply set the LOTEMP configuration to the same temperature as the HITEMP configuration value.

Note that if HITEMP and LOTEMP are set to DIFFERENT values, the HEAT ENABLE output operates normally as originally designed.

Also note that this operation does not require a net metering agreement with the grid provider. The grid will readily accept the excess power with a net metering meter installed or without.

With a net metering agreement, you will receive a credit from the utility company for the power you produce. But even without a net metering agreement, you can still use the AC grid as a dump load.

Also note the secret single character command "**g**" from the ASCII terminal console will toggle the heat enable output on and off for test purposes if HITEMP and LOTEMP are the same.

VERSION 2.00 TIME OF USE

Since the introduction of the EVTV Tesla Battery Module Controller the conflict between residential home solar owners and the utility grid operators has intensified.

In the summer of 2019, San Diego Gas and Electric Company has implemented a dramatic increase in the basic connection charge for electrical service to $40 per month. But more egregiously, they have introduced mandatory time of use charges for their entire customer base.

These actions are actually part of a California state law, SB327, that represents one of the most egregious examples of collusion between the utility grid operators and their regulators ever conceived.

These changes have become apparent at SG&E first because they have a relatively small customer base with a high level of residential solar – some 150,000 customers at this time. They also have more modern billing and accounting systems than some of the larger utilities.

But the much larger Pacific Gas and Electric and Southern California Edison are slated to implement this same scheme by years end.

The new SG&E rates are as follows:

EV-TOU-5

Plan	On-Peak	Super Off-Peak	Off-Peak
Time of Day	4:00 pm - 9:00 pm (Everyday)	Midnight – 6:00 am (Weekdays) / Midnight – 2:00 pm (Weekends & Holidays)	All other hours
Amount	53¢	9¢	29¢

Basic service fee: $16

But note that the Basic Service Fee has risen from $16 per month to $40.

And so this isn't the future, it is the already.

PG&E has extended the battle. Facing a $10 billion lawsuit from some wildfires they have already filed for BANKRUPTCY and while how that comes out is up in the air, they have just recently cut power to 800,000 customers (some 2.5 million people) for up to two weeks in case it MIGHT cause a fire from prevailing winds and dry conditions. This likely has nothing to do with the weather or fires and everything to do with the bankruptcy and regulation. It's a bit of a "here's what we CAN do to you if you challenge us".

And of course, many of those customers DO have grid tied solar energy systems. But they are learning that without the grid, those systems don't generate ANY power, day or night. With $70,000 invested in solar on the roof, they can't make enough power to charge their cell phones.

Our solution is battery based photovoltaic solar systems that only use the grid for backup purposes. And those using that, are largely unaffected. We term it "selfish solar".

But our customers have prevailed upon us to make some concessions to the "selfish" part so they can sell power to the grid during sunny periods and "time shift" power to the 4:00 PM to 9:00 PM period when their photovoltaic panels produce negligible power output.

We can do that. So in version 2.00 we have added a THIRD screen to our main screen/config screen pair. You can still navigate between the three by entering a **?** followed by a carriage return and/or line feed.

But you can now navigate between screens bidirectionally using the **<** or **,** (comma) and the **>** or **.** (period) keys.

For our Time of Use (TOU) screen to make any sense, you DO have to have a connection to your home WiFi Access Point (AP) and that AP does have to have some sort of connection to the Internet.   The controller gets time from the Network Time Protocol (NTP) server ultimately tied to the National Institute of Science and Technology (NIST) time standard in Boulder Colorado.

And you do have to have a POSIX time string specified in the CONFIG screen so that the time displayed is equal to your local time.

Finally, you have to set the HITEMP value on the CONFIG screen to 0 (zero). This value is generally used for temperature alarms triggering the HEAT ENABLE output to energize in an overtemperature condition. Overtemperature has proven to be a very rare event in most installations anyway. And for TOU switching, we are going to use the HEAT ENABLE output to control an external relay or contactors to connect AC to the system as an input.

This will work with any inverter that can be operated in UPS mode. We would normally connect the AC grid as an input to the inverter, where it would pass THROUGH the inverter to the loads. On the event of an AC power failure, the inverter automatically switches to battery output mode.

And so your external relay, using the HEAT ENABLE output, is used to simulate grid on and grid off conditions to the inverter.

```
=================================================================================================
**********  EVTV Tesla Battery Module Monitor Version ESP32-2.00  Wednesday, October 16, 2019  12:38:52   ******
=================================================================================================
******* WIFI STATUS..connected to local Access Point:riverhouse as IP:192.168.1.152 signal strength:-62dBm ****
=================================================================================================

    AC grid scheduler is ACTIVATED   AC grid input is currently switched ON

=================================================================================================

    AC grid time 00:  ON        AC grid time 12:   ON
    AC grid time 01:  ON        AC grid time 13:   ON
    AC grid time 02:  ON        AC grid time 14:   ON
    AC grid time 03:  ON        AC grid time 15:   ON
    AC grid time 04:  ON        AC grid time 16:   ON
    AC grid time 05:  ON        AC grid time 17:   ON
    AC grid time 06:  ON        AC grid time 18:   ON
    AC grid time 07:  ON        AC grid time 19:   ON
    AC grid time 08:  ON        AC grid time 20:   ON
    AC grid time 09:  ON        AC grid time 21:   ON
    AC grid time 10:  ON        AC grid time 22:   ON
    AC grid time 11:  ON        AC grid time 23:   ON


            Enter A to toggle grid scheduler activation.
            Enter GRIDON=4 to turn grid ON at 04:00 AM
            Enter GRIDOFF=16 to turn grid OFF at 04:00 PM
            Enter GRIDALL=OFF to turn grid OFF for all time slots
            Enter GRIDALL=ON to turn grid ON for all time slots
            Enter < or > to go to other menus...
```

In the case of our SIgineer inverter, this operation is controlled by a dip switch that allows us to run in AC PRIORITY mode or BATTERY PRIORITY mode. We usually run in BATTERY PRIORITY mode. But by setting this switch to AC PRIORITY mode, it acts as an Uninterruptible Power Supply that normally passes AC grid power through to the loads panel. Refer to the EVTV Sigineer 15kW Inverter User Manual for more information on that.

The first line of the TOU screen shows the software version and current local time.

The second line shows our WiFi connection status.

The third line is important.

AC grid scheduler is ACTIVATED   AC grid input is currently switched ON.

The scheduler can be toggled between **ACTIVATED** and **DEACTIVATED** by entering the **A** or **a** character.

The state of the **HEAT ENABLE** output is indicated by the AC grid input is currently switched **ON** or **OFF**.

Below this is a matrix of AC grid times. ON means the HEAT ENABLE output is energized and the grid AC is applied to the inverter. OFF then indicates the output is de-energized and the external grid relay is off with NO grid power applied to the inverter.

This matrix lists all 24 hours of the day as hour 0 (midnight) to 23 (11:00 PM). And switching occurs at the top of the hour.   So if you had times 0 through 5 set to ON and 6 through 23 set to OFF, the grid would be applied beginning at the stroke of midnight. It would switch OFF at the top of hour 6 or 6:00 AM

To turn ON a specific time:

GRIDON=5

This would change hour 5 to ON.

To turn OFF a specific time:

GRIDOFF=5

This would change hour 5 to OFF.

To turn ALL the times ON

GRIDALL=ON

To turn ALL the times OFF

v

In this way, you can fill out the grid to control the **HEAT ENABLE** output and thus the external relay to apply grid power or remove it from the inverter.

And so if you had this controller and a set of Tesla battery modules, with a SIgineer inverter and indeed almost any inverter, and NO SOLAR AT ALL, you could still time shift your grid use.

You would charge the batteries with GRIDON from 0 to 13 applying grid power from midnight to the top of the hour at 4:00 PM. You could then have GRIDOFF from 16 to 23 to operate solely from battery from 4:00 PM to 11:59PM. In this way, you would charge your batteries during off peak period and use the energy from the battery during the peak periods.

VERSION 2.06 Auto Reset Modules

This version adds the ability to optionally attempt to automatically reset communications to the Model S modules. There are two new configuration options.

`MODULEMODE=1`

Will cause the system to use the heat enable pin as a power pin for the modules. When in this mode, sever the ground connection to the modules and connect it to the heat enable output. The system will then toggle this output in order to "power cycle" the modules in case of communications trouble.

`COMMFAULTMODE`

Setting this to 1 will cause the power cycling above to be enabled. Setting this to 0 will instead cause a software reset which will open the contactors but leave the modules powered.

VERSION 2.14 Extension Mode

Testing with larger packs revealed that Model S modules are not meant to be used much over 20 per communications chain. This is far lower than the theoretical 62 possible given the hardware used. For maximum reliability we cannot recommend connecting more than 20 modules to each control box. We have developed this update to allow for a variety of extension possibilities. It is now possible to use either just our TeslaBMS boards or another full control system in conjunction with your primary system in order to extend to another 20 modules for each additional extension system.

`ACTEXT`

If this option is set to 1 then the current control board will act as an extension. Extensions can still use their contactors but will report to the "main" system as additional modules. This allows the use of one 7" display for multiple control systems.

`EXTNUM`

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If this system is acting as an extension then its extension number is set here. The default extension number is 0. This can be any number from 0 to 4.

EXPECTEDEXTS

If this control system is not an extension then it is considered a main unit. Main units can set how many extensions they should have connected. If this number is not matched by reality then an error is raised. In this way the system can be shut down if one or more extensions quit reporting.

This update also adds the ability to send logs to a remote host in order to aid us in helping you to diagnose your system. There are three new configuration settings for this:

UDPLOGGING

This takes one of three values. 0 means to not send any data remotely. 1 means to use the "REMOTELOGIP" address to send data over the internet to a remote host. It defaults to a server we have setup for this purpose. 2 means to send this same data to a network local Raspberry Pi computer. This will cause the system to send a local /24 broadcast of the log. A local machine can then capture this data to analyze it.

NAME

This puts a tag on the sent data to allow whomever is reading the log to determine which system data has come from. You should set a unique name here, perhaps your name.

REMOTELOGIP

If UDPLOGGING has been set to 1 then this option will allow you to set the IP address to send to. It defaults to our logging server.

VERSION 2.17 SOC Drift and Debugging

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State of charge drifting has been added to the system. The reason for this mode takes some explaining. The default behavior is to "integrate current." This means that we take readings from the current sensor along with the time span between readings to determine how many kilowatt-hours of power has been either used or returned to the pack. We then add or subtract this from the remaining kilowatts set for the battery to get to a state of charge percentage. This has a number of potential pitfalls. For one, if you have not 100% properly set the remaining kilowatts, either because the capacity is wrong or because the number of used amphours is wrong, then you will never have the proper state of charge. Secondly, unfortunately no one has invented a perfect current sensor. They all have some offset and scaling errors. These errors needn't be large. A ½% error will still accumulate over time which skews the state of charge. For this reason, we have added this new mode. This mode will pay attention to the actual average voltage of the cells in your packs. When the cell voltages are either close to the upper or lower limit the state of charge will be drifted toward a voltage based number instead of the amperage based system used in the middle. This will automatically correct inaccuracies and slight configuration mismatches.

SOCCOMP

If this is set to 0 then the system will retain the usual state of charge calculation where only current integration is used. If set to 1 then the new SOC drift code will run.

Additionally, more debugging information is now sent to the Raspberry Pi display unit. This can allow for checking the status of the contactors and the heat enable and charge enable outputs. This information also requires that the Raspberry Pi software be updated to the most recent version.

VERSION 2.18 Charge Termination

This update causes the system to force the "Charge Enable" pin to off before opening contactors upon an error/fault. Some chargers do not like still being on when the battery disappears. So, if you use the charge enable pin to enable your charger, it will now be turned off about 2 seconds before the contactors are opened. This should allow the charger sufficient time to deactivate.

VERSION 2.25 Additional Fault Checking

Better detection of cell voltage variance, additional debugging output which can be displayed by the Raspberry Pi program, added the ability to directly send MQTT from the board to a local MQTT broker. Fixes to ensure that faults are properly registered and that current is zero'd if no readings happen within a reasonable amount of time. Additional communications checks to ensure everything is running smoothly. WiFi improvements for greater reliability.