RV Solar

Typical RV Modifications For Off-Grid Living, Part 1

Jack Mayer, www.jackdanmayer.com

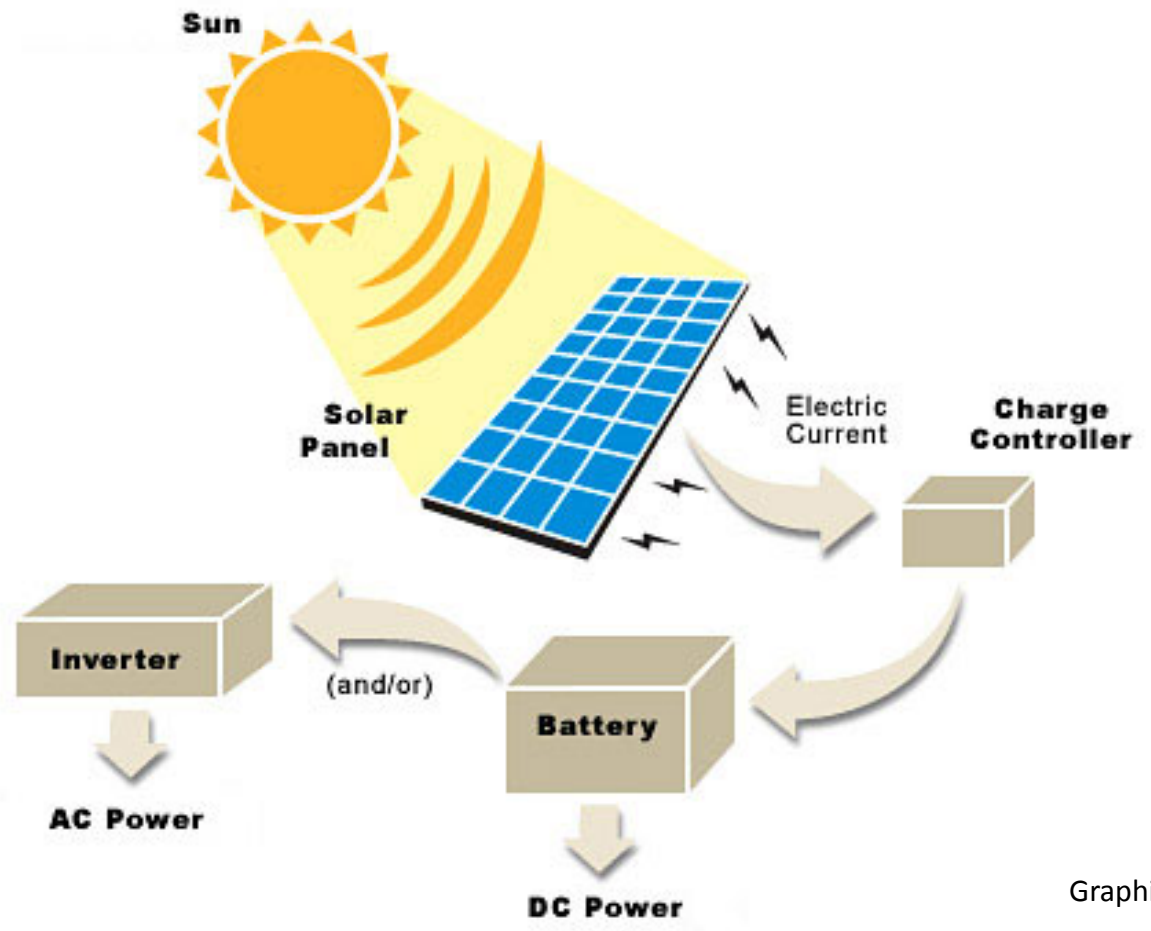
Contents

- Basic concepts
- Solar Panels
- Charge controllers
- Wiring techniques
- Design considerations and how it all fits together

Note: this is the first of two presentations. This focuses on Solar. The next covers the rest of the technology, wiring and design issues to complete the RV upgrade for boondocking.

RV Electrical System

Very Simplified View with Solar



Graphic: Jerry Winegard

The *DC* Side

- Charging Sources
  - Solar, Wind, Grid-based Charger, Alternator
- Battery Bank
  - Stores the Power for later consumption
  - The bigger the better (budget, space, weight)
- Loads
  - DC loads directly off battery (or converter)
  - AC loads require “inversion” from DC to AC (inverter) when off grid

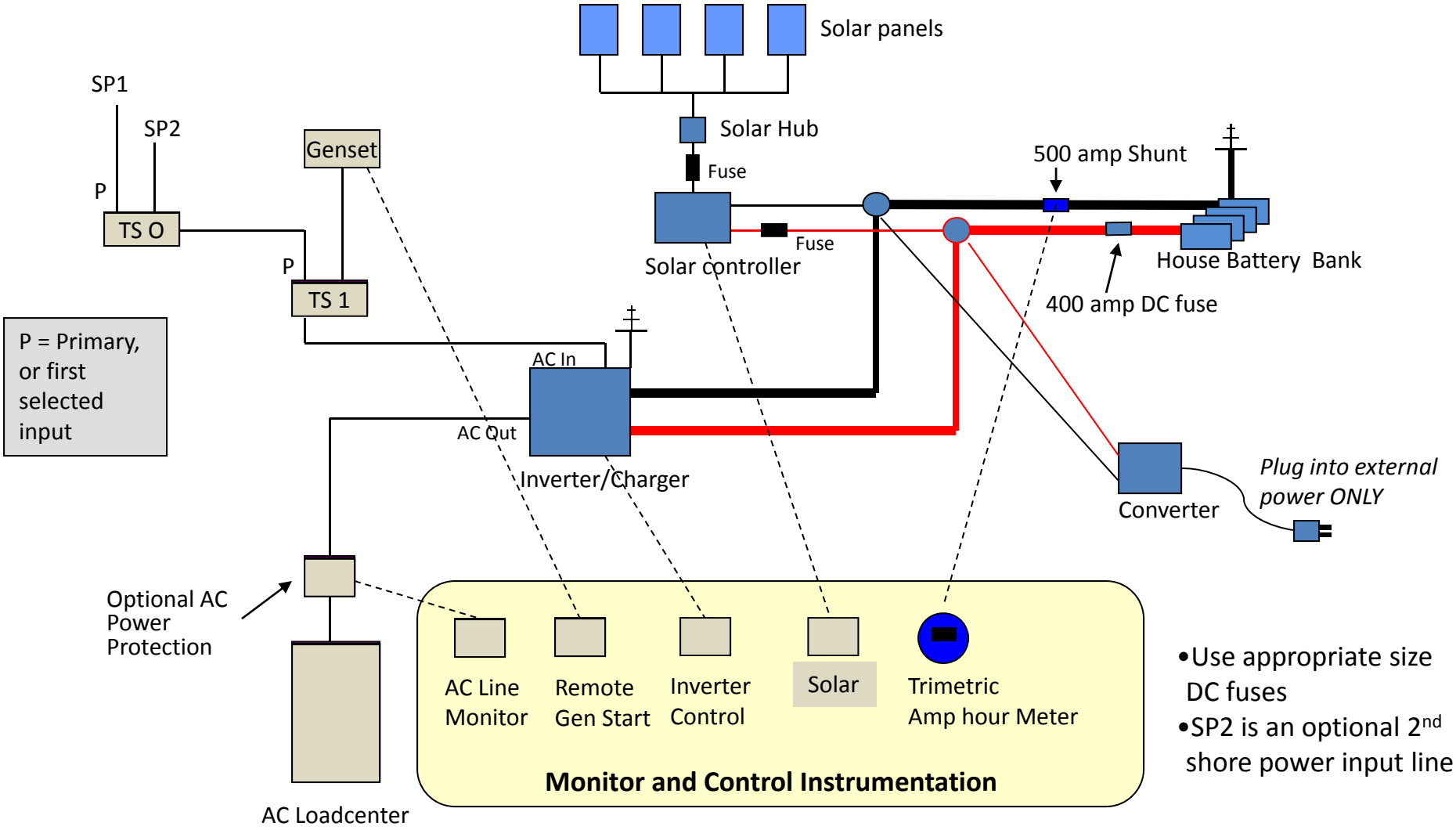
Electrical *Stuff*

- AmpHours is how much current is delivered over time
- Amps=Watts/Volts
- Watts=V*A (or VA); watts is same for AC or DC
- 120 volt appliance: watts/10 = DC amps
- 120 volt appliance: AC amps x 10 = DC amps
- Solar panels: Vmp (volts max power), Voc (Volts open circuit)

- If your TV uses 3 amps AC, 3x10=30 amps DC per hour
  - If you watch TV for 1.5 hours then you used 45 amps DC from your battery bank

RV Electrical System

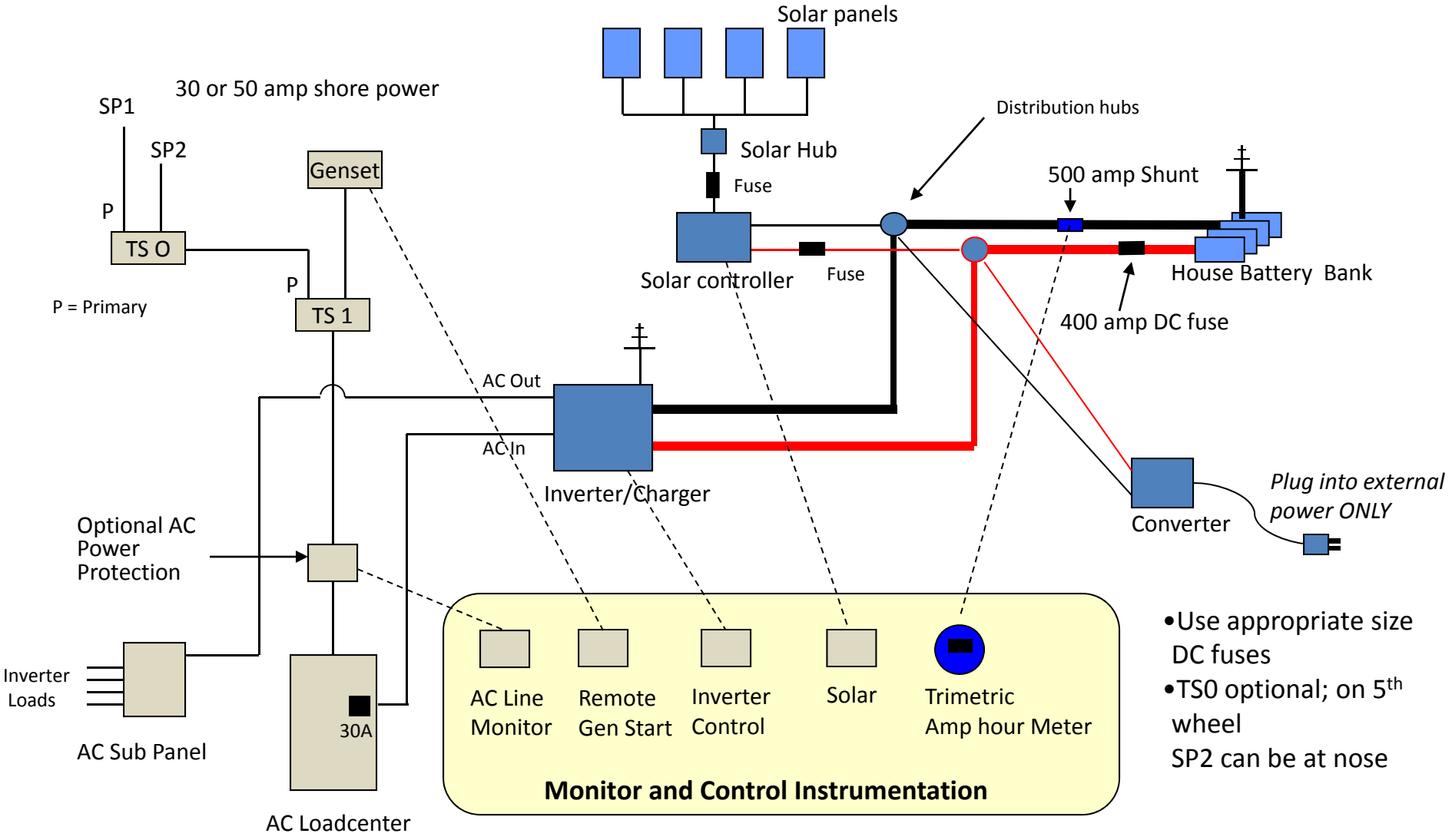
Inverter "Inline"



- Use appropriate size DC fuses
- SP2 is an optional 2nd shore power input line

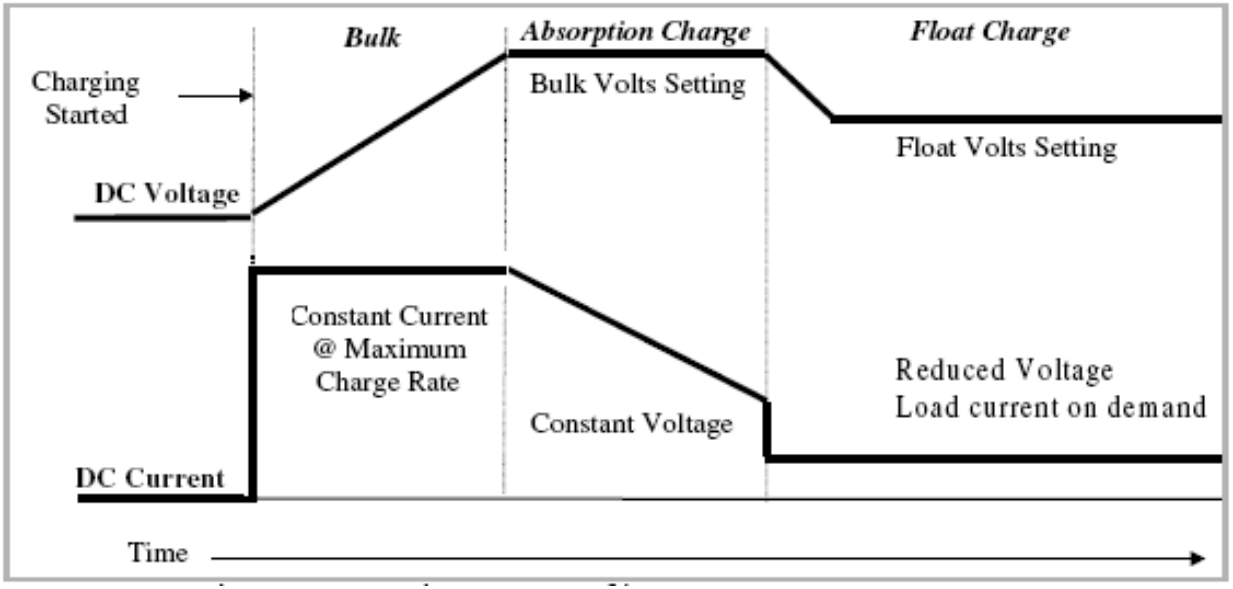
RV Electrical System

Inverter With Subpanel



- Use appropriate size DC fuses
- TS0 optional; on 5th wheel
  SP2 can be at nose

Three Stage Charging



- **Bulk**: Current supplied at constant (max) rate while voltage rises to setpoint; Often 14.2-14.6V; should be 14.8V for flooded cell
- **Absorption**: Voltage remains constant, while current is reduced as battery charges
- **Float**: After batteries reach charged state, voltage reduced and maintained. Usually 13.2-13.6V

Solar Modules

- Types
  - Amorphous
  - Poly-Crystalline
  - Mono-Crystalline
- Typical panel is 36 cells connected in series
  - Produces about .48 volts/cell = about 17 volts
  - Vmp varies by panel type and manufacturer
  - AMSolar produces 44-cell panels = about 21.5 Vmp
  - Higher voltage panels work better with MPPT controllers

Solar Modules

- Crystalline panels are more efficient than amorphous panels; they produce the same amount of power in about half the roof space
- Rated in watts, based on standard test conditions
- Crystalline panels cost more per watt, but are better suited for RV use (usually)
- Crystalline panels have 20-25 year warrantees.

Solar Modules

- Not very efficient; 12% - 16% energy capture
  - 1 meter of panel produces 130 – 150 watts
  - Crystalline panels are in the 16% area
- In the “real world” you get about 80% of the rated output (air pollution, sun angle, heat)

Solar Modules

Output Issues

- Heat – cells are rated at 77’F
- Available light – 1000 watts/square meter rating
  - Real world is more like 800-900 watts
  - Angle of the sun
- Shadows
- Wiring – MOST systems are under wired
- Figure on 5 hours of full sun when calculating output

Solar Modules
Output Example

- Kyocera KC130TM panel (with J-box, not MC)
  - 130 watts
  - 17.6 volts
  - 7.39 amps
  - About $450
- Assume 4 panels on a typical installation ($1800)
- 4x130 watts = 520 watts; 4x7.39 amps = 29.56 amps
- 29.5 amps x 5 hrs sun = 147 amp hours
- MPPT boost @ 10% = 147+15 = 162 amp hours
- 162 – 20% = 130 amp hours

Solar Modules
So, How Many Do You Need?

- Must do an energy audit at start of design process
  - Kill-a-watt meter
  - Appliance Electrical-plate calculation
  - Actual use with battery monitor
  - Category guidelines
- Typical users
  - Low end: under 75-100 amp hours
  - Mid: 100-130 amp hours
  - Energy hog: over 150 amp hours (we know people who use over 800)
- Most Rvers are in the Mid category
  - 400 amp hours of battery
  - 4x130 watt panels
- Battery Storage Estimate
  - One “rule of thumb” is bank size in amps is ”about” as big as solar array size in watts.

Solar Charge Controllers

- Types
  - Shunt, or ON/OFF controllers; not really used anymore
  - PWM (pulse width modulation); rapidly “pulses” the power on/off holding battery voltage constant
  - MPPT (maximum power point tracking); extracts “extra" power from the solar array by using excess voltage to increase charge current

Solar Charge Controllers
MPPT Characteristics

- Uses base PWM technology
- Boosts charge by 10-30%
  - Typically closer to 10% in practice
  - May see 30% or more depending on the solar module and environmental conditions (high Vmp, altitude, cool weather, discharged battery, sky clear, etc.)
- Works best in cooler conditions with low battery SOC
- Panel Vmp (voltage output) is critical; >17Vmp
- There is no doubt that it works
- Costs 50-100+% more than most PWM controllers. Expect to spend *around* $500 on controller and remote panel

Solar Charge Controllers
When to Use MPPT

- Always
  - If money is no object
  - On a limited roof-space install
  - If you have high Vmp panels
  - All panels are within .5 volts Vmp (ideally, identical panels)
- Maybe
  - With Vmp lower than 17 volts
- Recommendation is to design for MPPT controllers unless you are on a very tight budget

Solar Charge Controllers
What to Look For

- MPPT unless on budget
- Remote mount near batteries
- Remote panel is interesting and useful, especially with MPPT
- Always buy bigger than you need – future expansion
- Remote Temperature Sensor – required feature
- Input/output voltage
  - Some take in high voltage (up to 150 volts) and output 12-volt
- Charge stage set points user configurable – esp. Bulk Stage
- Wire input/output size (you *can* trim down wire size)

Solar Charge Controllers
Which One?

- Blue Sky
  - **3024iL**, MPPT, 40A/12V, 30A/24V, IPN-ProRemote, chainable, cumulative amphours, $345
  - 2512iX/2512i, 25A/12V, use only iX (i has no temp sensor), ProRemote, chainable, cumulative amphours, best for small systems, $215
  - 6024HL, MPPT, 60A 36V/48V input to 12V/24V output, no cumulative amphour, use only if long distance runs – not typical on RVs,
  - Solar Boost 2000E, original model, 25A/12V, no remote location, limited features, do not use, $235
  - IPN-ProRemote, $200 w/shunt. Use instead of IPN-Remote (no cumulative amphours)

Solar Charge Controllers
Which One?

- AM Solar – custom Heliotrope
  - **HPV-30DR**, MPPT, 30A/12V, dual output, setpoints configurable, no cumulative amphours, remote panel shows “boost”, good for use with up to 6 AMSolar panels, $330, $160 (remote panel)
  - HPB-22B, MPPT, 22A/12V, OK for small systems, no remote panel or cumulative amphours, setpoints configurable, moderately priced, good for 4 AMSolar panels
- Combiner box (CB) – 4 input, no fuses, $50

Solar Charge Controllers
Which One?

- Outback FLEXMax – MPPT
  - **FLEXMax 60**, 60A, all output voltages, all input voltages up to 150V, user setpoints, RTS, etc. $550
  - Best, most flexible controller available
  - Mate remote instrumentation, inverter and solar control, Cat5 wiring, $270
  - FLEXNet DC provides complete DC monitoring, $340
  - Hub-4, communications interconnect manager, $175
- Combiner box – Flexware PV8
  - Circuit breakers (up to 8)
  - Must mount vertically or at most 3/12 pitch (15*)
  - $120
- Complete solution is very expensive ($1400+), but best available (+VFX2812M inverter, $2025)

Solar Charge Controllers
Which One?

- Xantrex (Trace) C-Series
  - C35/**C40**/C60 PWM, 12/24V output (48V on C60), RTS, CM-R Remote display, user setpoints
  - Best non-MPPT price/performance
  - C40, $135; CM-R50 remote, $105

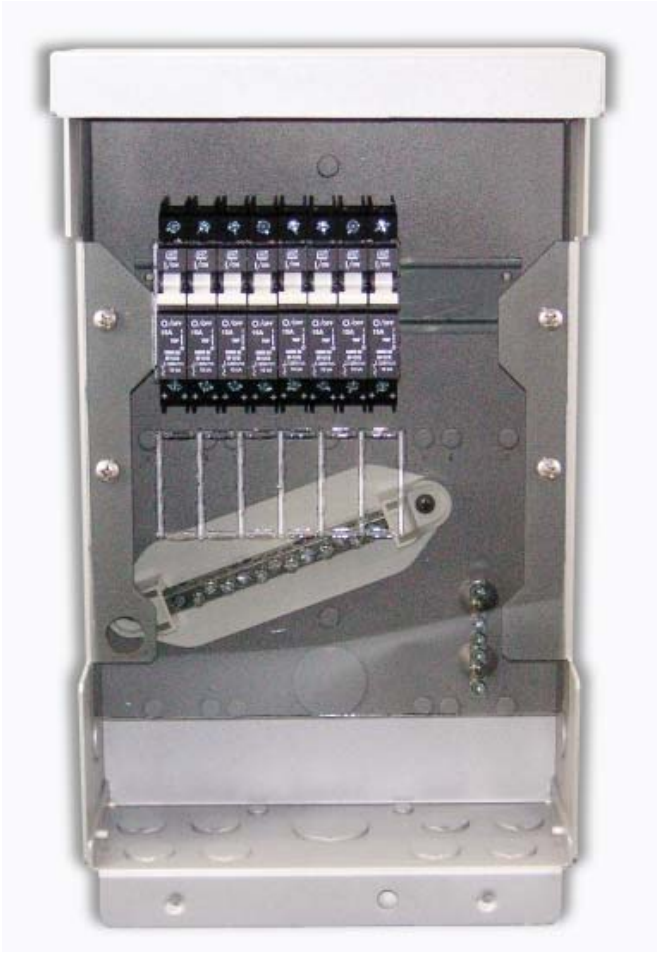
Solar Charge Controller/Panel
Design Considerations

- Best if all panels are the same, especially with MPPT
- Consider not tilting panels (use MPPT and more capacity to compensate)
- Consider J-box panels instead of MC connectors (ease of installation/cost)
- Panels MUST be located so they are never shaded – look at AM Solar panels, which are narrower
- Use higher voltage panels if needed for distance
- If using MPPT ensure Vmp of at least 17V
- Buy more controller capacity than needed; MPPT unless on budget
- Use remote display

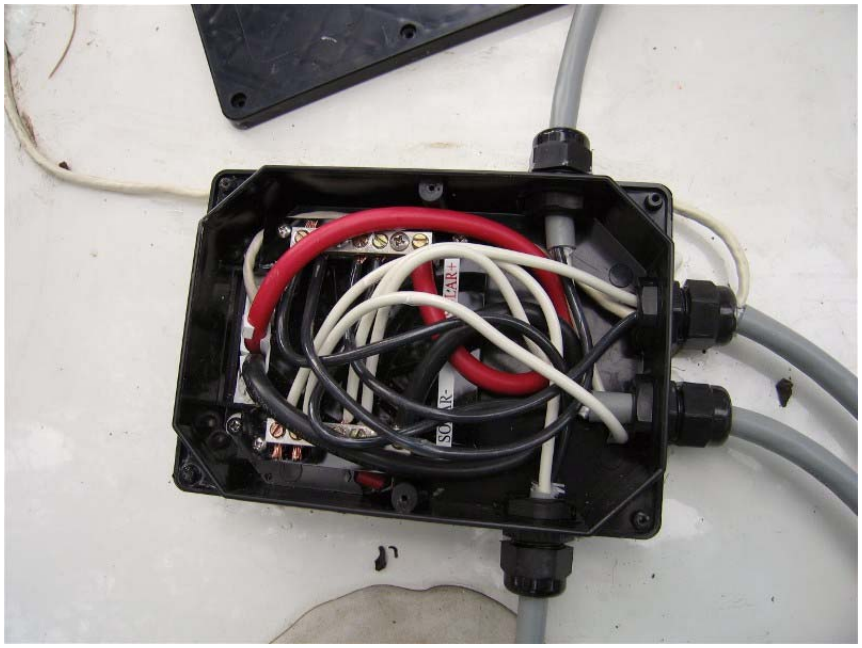
Solar Charge Controller/Panel
Installation Considerations

- AM Solar has best panel mounting system – worth the $60; or build own out of aluminum
- If roof is solid use VHB Tape or 3M Fast Cure 5200 Marine adhesive
- Stainless 1” #10 or #12 screws – only need 1 per location – embed in caulk puddle
- Attach wiring to roof with puddles of caulk; when dry overcoat puddle with more caulk
- Roof wiring – #10 tray cable homerun to combiner box
- Combiner-to-controller use #4 welding wire; protect exposed wire on roof from UV
- Consider fusing individual panel runs at combiner input (debugging is easier)
- Use vent to run wire to basement area
- Put controller as close to battery bank as possible
- Use 14.8V as bulk charge for flooded cell batteries
- Use A/C (air conditioner) disconnect box for fusing IN/OUT of controller

Combiner Box



Outback FLEXWave PV8 - $120



AM Solar CB Combiner - $50

Inverters, Batteries and Wiring

Typical RV Modifications For Off-Grid Living, Part 2

Jack Mayer, www.jackdanmayer.com

Contents

- System Overview
- Inverters
- Batteries
- Wiring techniques
- Design considerations and how it all fits together

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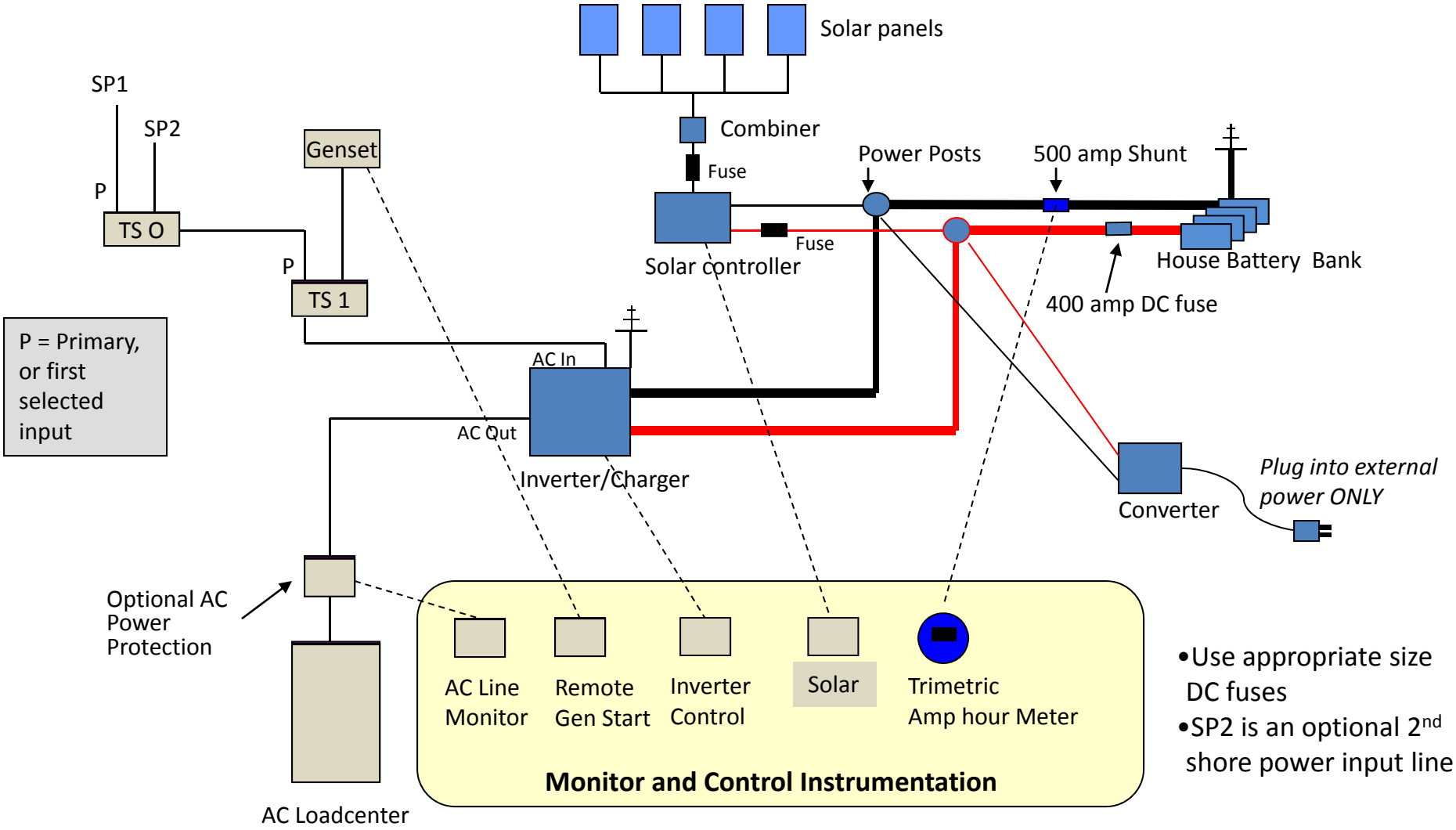
RV Electrical System

Inverter "Inline"



- Use appropriate size DC fuses
- SP2 is an optional 2nd shore power input line

Jack Mayer, 2005

Wiring

- Solar panels to combiner
  - #10 tray cable; individual “home runs”
- Combiner to battery bank (via solar controller)
  - #4 welding wire
- Control wires: instrumentation-to-sensors
  - Generally telephone cable or cat5
- DC cables between inverter and battery bank
  - 2/0 or 4/0 welding cable; treated lugs; adhesive heat shrink
- AC wiring between inverter and AC loadcenter
  - #6 conventional AC wire for 50A, #10 for 30A; use AC wiring techniques; tape wire nuts to wires (vibration)

Inverters

- Inverters are the “heart” of the system – most expensive single component ($1100-2500 for advanced inverter/charger)
- “Modified Sine Wave” vs. Sine Wave
  - About 5% of items will not run on MSW
  - Small, occasional-use systems might get by with MSW
  - Spend the extra money for a good Sine Wave inverter if setting up a whole-house system
- What to look for
  - Sine wave
  - Size – in RVs 2000 watts is almost always enough; charger output may be reason to go larger
  - Inverter/charger, or separate components – in RVs inverter/charger is preferred
  - Battery charge section – bigger is better if using AGM batteries, esp. if generator charging
  - Charger control – set points changeable, charger on/off, auto “back off”
  - Transfer section – 30A or 50A; does design place the inverter “inline” or in a subpanel
  - Instrumentation/control – unified control, battery monitor
  - Stacking – generally not a factor in RVs
  - AGS – automatic generator start; can even start larger portables

Inverters
For the Truck

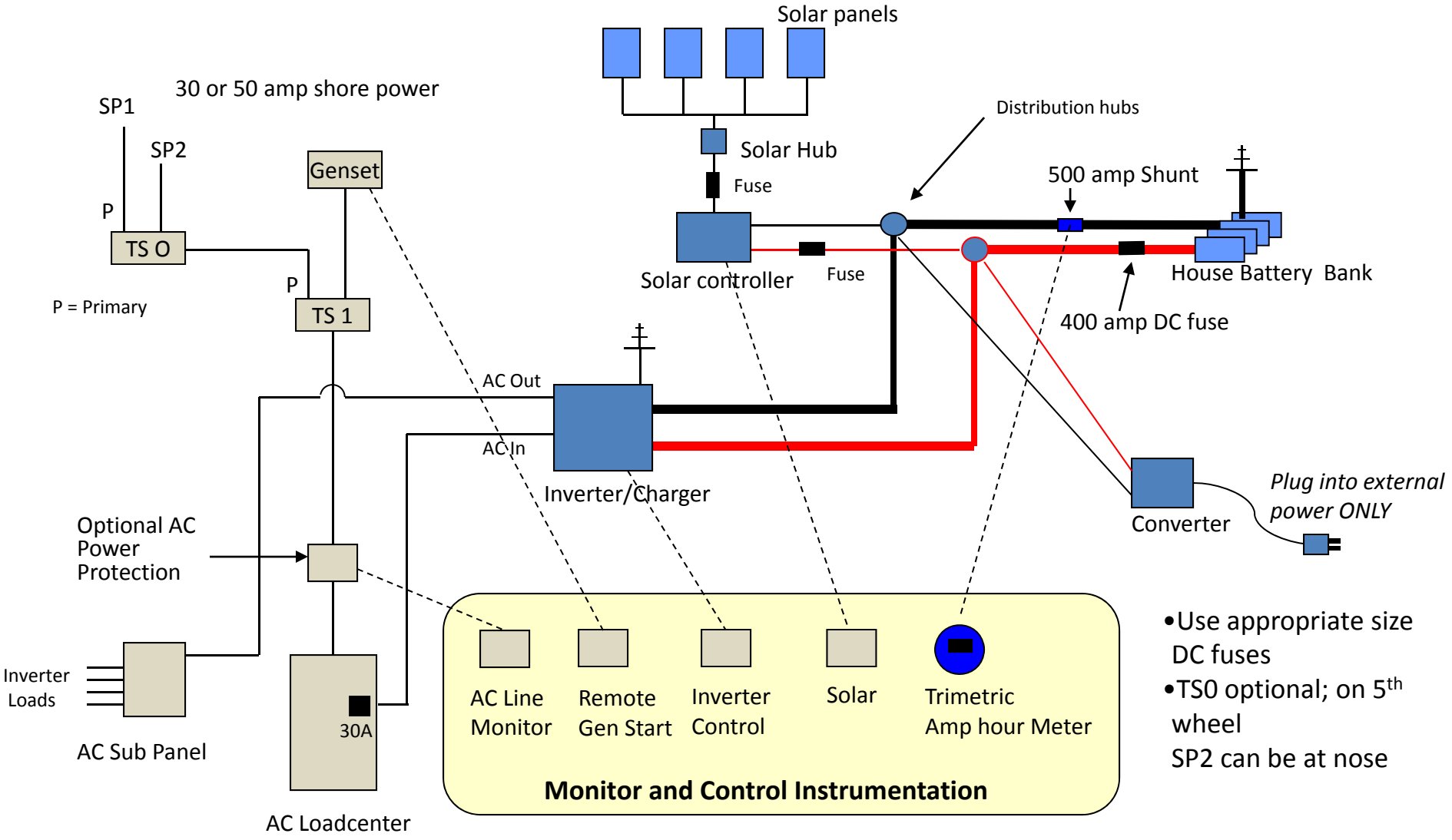
- First: evaluate use; long term camping, overnight, charger? Simple “point of use” or wired in?
- Generally need less than 2000 watts, and MSW is usually OK
- Want a remote switch – wire a reminder light or you will forget the inverter is on!
- I like the Xantrex Xpower line; reliable and cheap
- In inverter/chargers I like the Tripp Lite series, or a Xantrex (Heart) Freedom 458. But, there are others.
- If you buy a $150 Sam’s Club “big inverter” (eg. 3000 watts) expect issues. You get what you pay for…..

Interfacing to the AC Loadcenter

- 30A or 50A electrical service drives the decision
- 30A – easy inline implementation
  - All inverters work inline with 30A (insert in shore power line anywhere)
- 50A – Several design choices, but not all inverters work
  - Inline if inverter has 50A transfer switch – Xantrex RS3000, RV Series
  - Subpanel – all inverters work; can use 30A inverter
  - "Split panel"; inverter inline with *one* leg of power; must rebalance the box loads
- **Only 2 "good" choices with a 50A system**
  - Inverter w/50A transfer switch
  - Subpanel

RV Electrical System

Inverter With Subpanel



- Use appropriate size DC fuses
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Instrumentation

- Cumulative amphours into the battery bank (Link, Blue Sky IPN ProRemote, Trimetric, etc)
- Instant amphour measure; power use *right now*
- Voltage
- AC line voltage/amps
- Control Functions: Inverter off/on, charger off/on, Genset on/off
- Lots more monitor functions are typically available, but the above are critical

Battery Types

- RV batteries are Lead-acid (vs. Lithium, NiCd, etc)
  - Flooded-cell (wet cell)
  - Sealed Flooded (maintenance free)
  - Gel (sealed)
  - AGM (sealed)
- Starting (SLI)
  - High starting current for short time
  - Thousands of low discharge cycles (10% discharge or less is typical)
  - Only capable of 30-50 deep cycles (50-80%)
- "Deep Cycle" (golf cart, L-16, etc.)
  - Thicker and heavier plates allow deeper discharge levels
  - Designed for "lots" of 50% or more discharges
  - Weigh much more than starting batteries

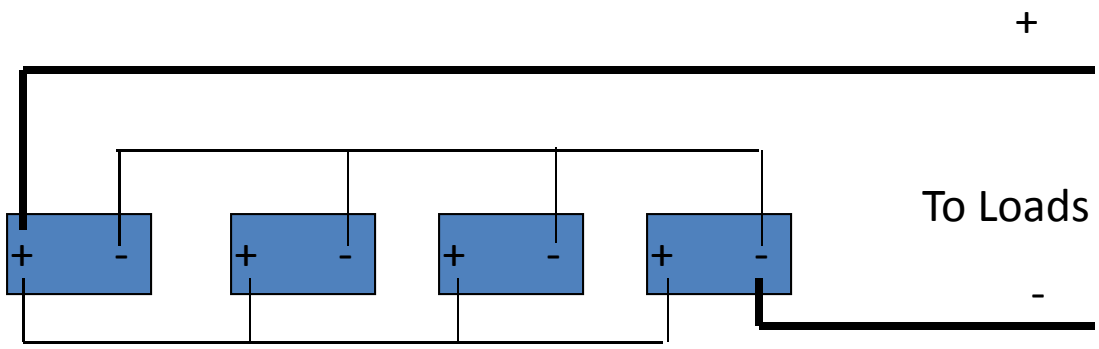
Battery Characteristics

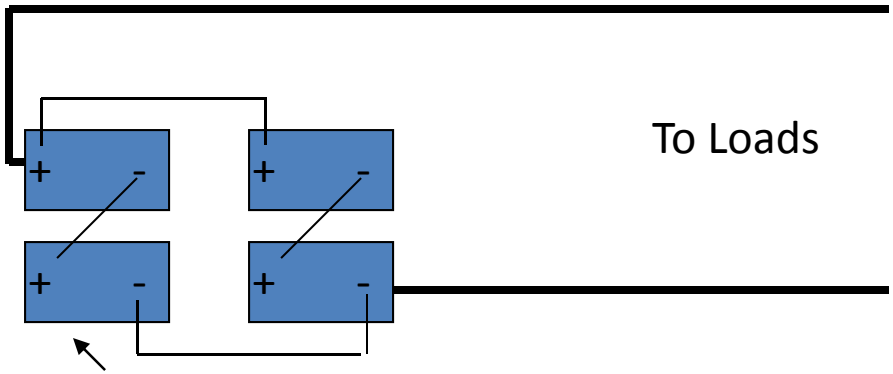
- Golf Cart
  - Last 3-5 years, sometimes as long as 8 years
  - Must be vented
  - Need to be monitored and “watered”
  - Charge at C/3 or C/4 (where C is the total Ah of the bank)
  - Cheap & readily available: $65-125
- AGM
  - Last 4-7 years
  - Resist vibration better than golf cart
  - Do not outgas – can be placed anywhere
  - Zero maintenance - no attention at all (other than terminals)
  - Can be charged faster and at higher rate (C*4, or more)
  - Cost far more: 2-4 times as much

Random Battery ***Stuff***

- Check flooded cells water level every month
- Charge only with solar when you can; easier on the batteries – no constant float
- Use proper size wires for interconnect; anti-oxidant, proper crimps, adhesive heat shrink
- Diagonal taps
- Catastrophe fuse – based on inverter size
- Equalize only if needed – AGMs not generally equalized
- No direct load attachments to battery; attach loads at power posts
- Always use temperature compensation for charging
- Design for a 25-30% depth of discharge (DOD)
- **You WANT a battery monitor that uses cumulative amphours**

Battery Connections





2- 6-volt in series = 12-volts; Amp hours remain the same

Parallel Hookup

- Voltage stays the same. Connect all + to each other, and all – to each other
- Amperage adds
- 4 – 12 volt 100 amp batteries would yield 400 amp hours at 12 volts
- Always take “load” wires from “opposite” sides to balance bank

Series/Parallel Hookup

- In series, voltage adds. Connect + to -
- Amp hours stay the same
- Two sets of batteries in series are then joined in parallel to double amp hours.
- 4x 6-volt 210 amp batteries yield 420 amp hours at 12 volts.

Wiring Techniques

- Coat wires with anti-oxidant before crimping
- Do not solder large lugs (arguable – my opinion); if you do, use Fusion lugs
- DO solder any brake controller connections, and you can solder any small wires
- With wire nuts, tape them to the wires after twisting on (vibration issues)
- Use adhesive heat shrink, color coded; use colored tape if no colored heat shrink
- Use welding wire for battery/inverter connections; never less than 2/0
- Power posts upstream of shunt for all load connections
- Always install a DC fuse center fed from power posts; convenience
- In trucks: always isolate interface to truck electrical with relays
- Use a ratchet crimper on small lugs – less than $30 at auto stores; on large lugs hammer crimper will work IF used correctly
- Always use a catastrophe fuse near battery
- Battery cables: build to length, but leave slack (batteries change)
- If adding a subpanel for inverter circuits make sure to keep neutral and ground wires separate – NO BONDING

Sample System
High End

- Outback VFX2812M sine wave inverter with subpanel
- Outback FlexMax60 PV charge controller (MPPT)
- Outback Mate Monitor
- FLEXNet DC provides complete DC monitoring
- Flexware PV8 combiner
- 6 Kyocera KC130 solar panels (with J-boxes) or other high Vmp panels of appropriate size
- 8 – LifeLine GPL-4C 6 volt AGM batteries (880 Ah rating)

Sample System

Economy System

- Heart (Xantrex) 458 Modified Sine Wave Inverter 2000 watt/30 amp pass thru.
- Trace C40 charge controller. PWM controller, not an MPPT.
- Link 1000 Monitor. Has cumulative amp hours.
- 3 - Kyocera KC-130 Solar Panels. Best price/size/performance tradeoff. You can add three more panels with the C40 controller.
- 4 – Sam's Club 6 volt Golf Cart batteries (410 Ah rating).

The Phased Approach
You Don't *Have* to Do It All At Once

- First: You MUST design and understand the entire system
- Batteries
  - Upgrade your bank, new battery box, interconnects, relocate, revise house wiring
  - AGM or flooded cell?
- Battery Monitor
  - Trimetric or equivalent
  - Installing shunt has implications on wire organization
- Charging
  - Generator, Alternator, converter upgrade
- Inverter/Charger
  - Could start with "point of use" small inverter
  - Later add whole-house inverter
  - AC electrical system modification/implications
- Solar/Wind
  - Tax credits encourage adding; no cap on amount – 30% CREDIT on panels, labor and wiring

Parts Sources

- Power Posts, Blue Sea distribution centers, other marine components: http://dogbytecomputer.com
- Lugs, adhesive heat shrink, hammer crimpers, DC fuses/breakers, Trimetric, Iota transfer switches, fuse blocks, distribution blocks, battery post connectors/extenders, Anderson connectors, misc. components: http://solarseller.com/
- Battery isolators/combiners, Solid state relays: http://www.hellroaring.com/