RV Electrical / Solar

Typical RV Modifications
For Off-Grid Living

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Contents

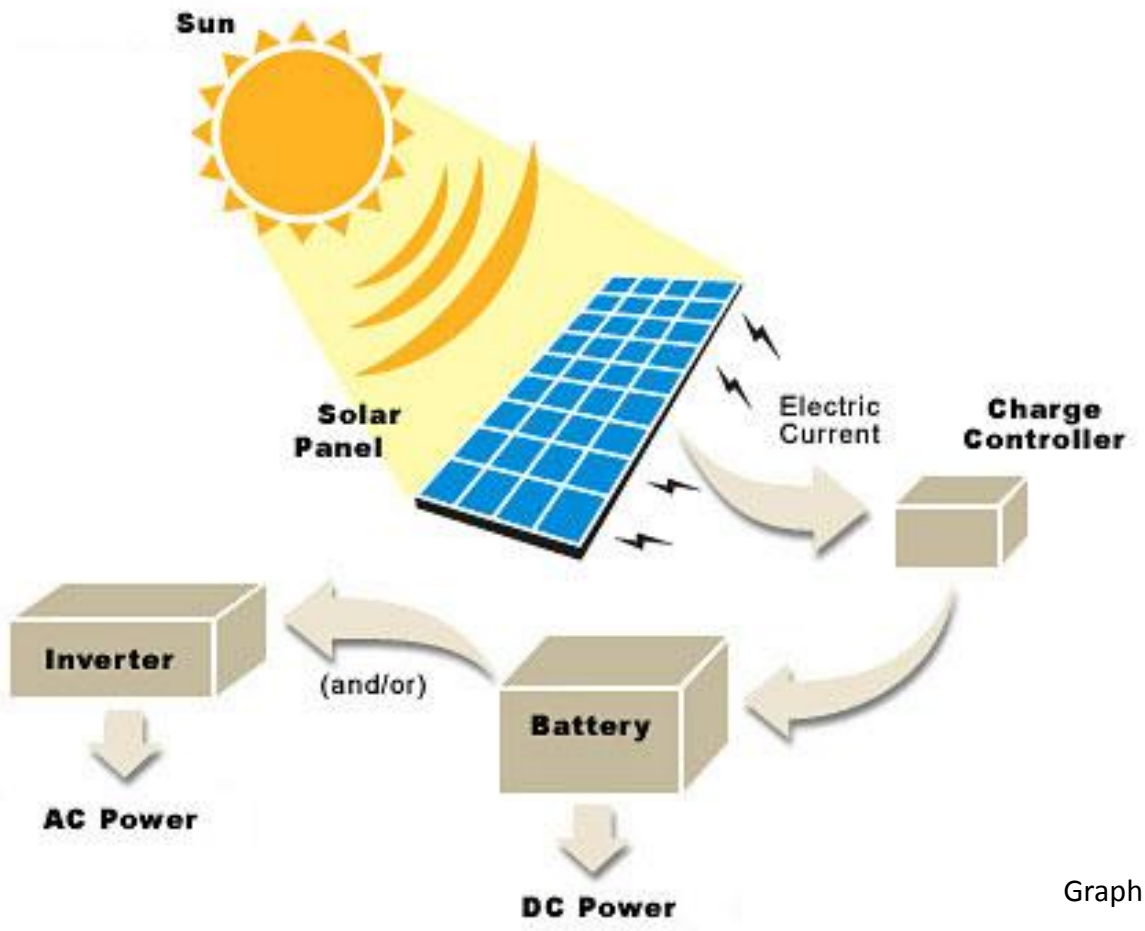
- Basic concepts
- Solar Panels
- Charge controllers
- Inverters
- Batteries
- Wiring techniques
- *The Golden Rules*
- Design considerations and how it all fits together
- Recommendations

Thursday afternoon – roundtable

Slides are downloadable from our website

RV Electrical System

Very Simplified View with Solar



Graphic: Jerry Winegard

The *DC* Side

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

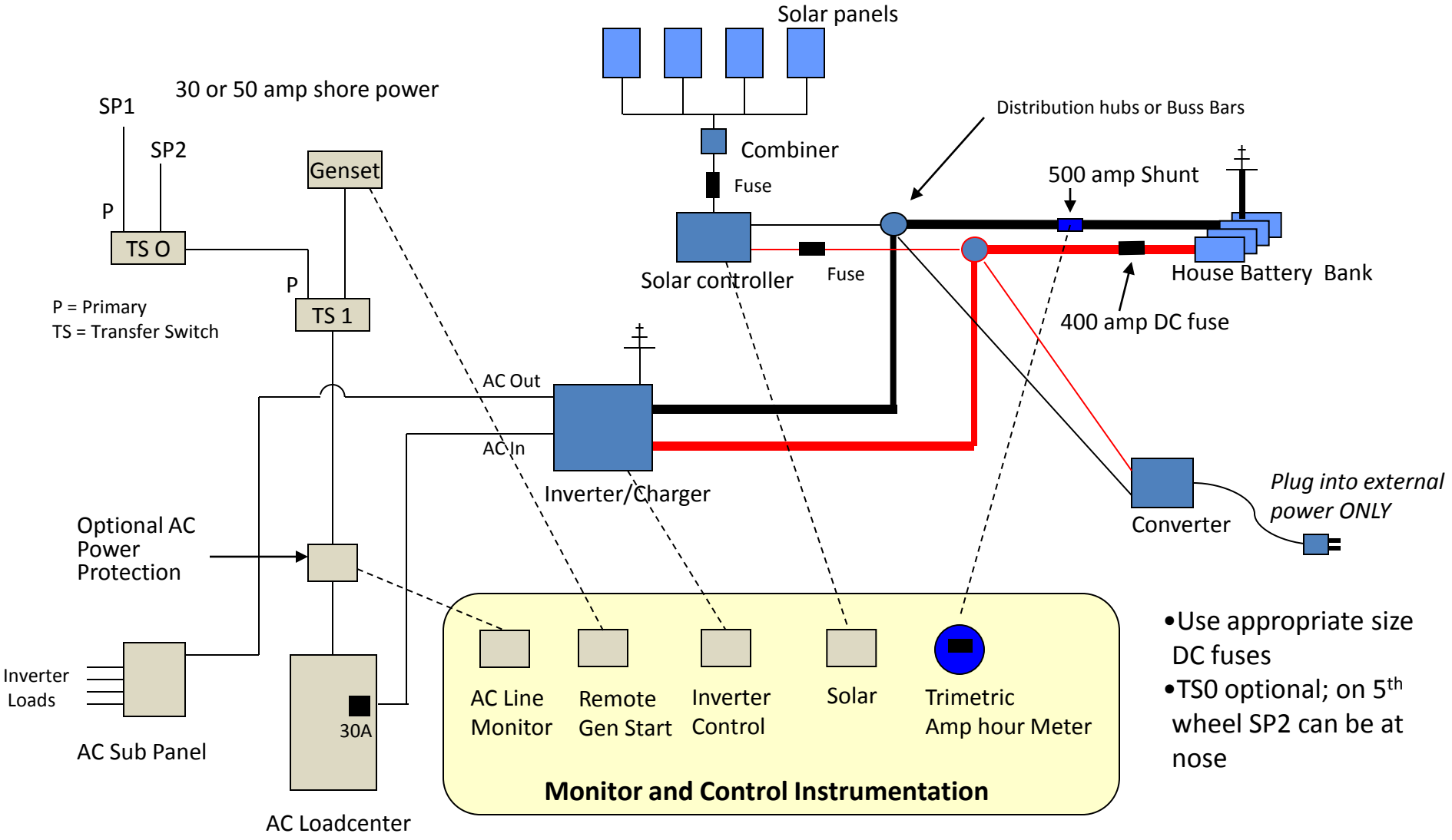
Electrical *Stuff*

- 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), Imp (Current max power)

- 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

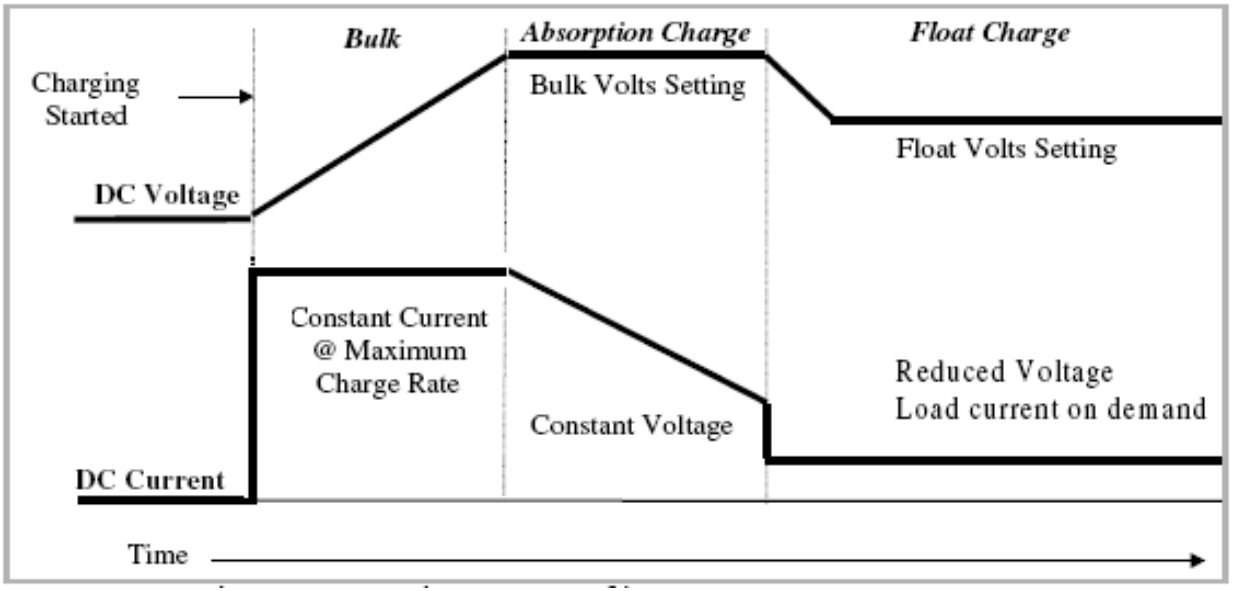
RV Electrical System

Inverter 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 absorption 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
  - “High power” panels have more cells, thus higher voltage.
  - “High power” panels are used with MPPT controllers

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 (STC)
- 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 KD135 DX panel
  - 135 watts
  - 17.7 volts
  - 7.63 amps
  - About $325
- Assume 4 panels on a typical installation ($1300)
- 4x135 watts = 540 watts; 4x7.63 amps = 30.52 amps
- 30.52 amps x 5 hrs sun = 153 amp hours
- MPPT boost @ 10% = 153+15 = 168 amp hours *theoretically*
- 168 – 20% = 135 amp hours, or less, in the real world

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 150+% 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 18 volts

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. Consider networked controllers
- Remote Temperature Sensor – required feature
- Input/output voltage
  - MPPT controllers take in high voltage (up to 150 volts) and output lower voltage (down to 12-volt, depending)
- Charge stage set points user configurable – esp. Bulk Stage
- Wire terminal input/output size (you *can* trim down wire size)

Solar Charge Controllers
Which One?

- Morningstar TriStar
  - **My absolute favorite (2011)**
  - ***TriStar*** is PWM controller in 45 and 60 amps ($150, $195)
  - ***TriStar MPPT*** is available in 45 and 60 amps ($420, $500)
  - MPPT 60 has direct Cat5 wiring to router with PC application for data analysis
  - Remote panel has advanced functions
  - Use the MPPT 60 with panels with Vmp around 28 volts

10/17/2011 RV Electrical, 2011 Heavy Duty Truck Rally

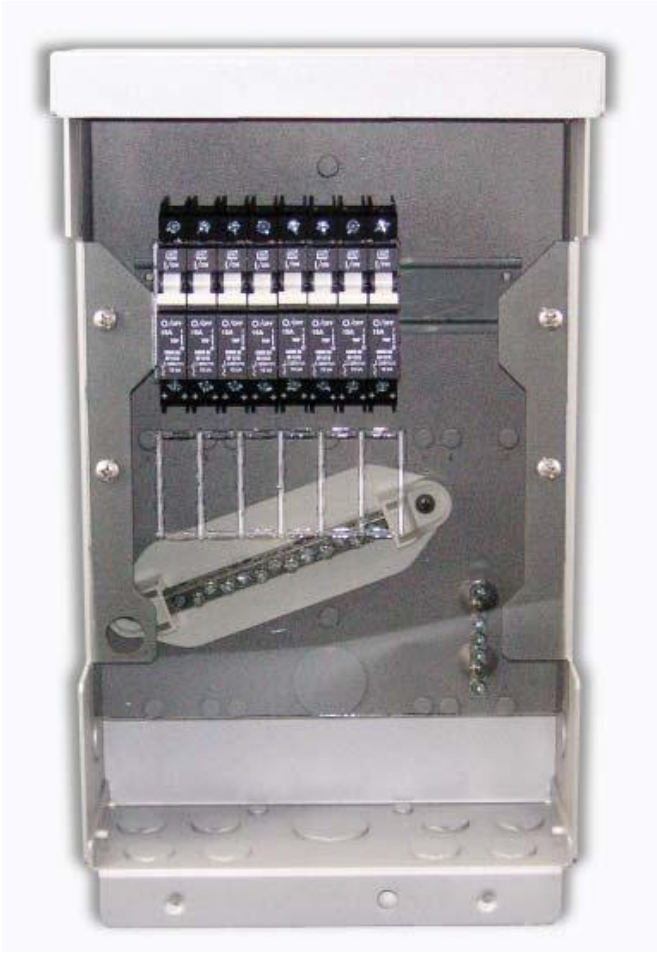
Solar Charge Controller/Panel
Design Considerations

- Best if all panels are the same, especially with MPPT
- Consider not tilting panels (use MPPT and more capacity to compensate)
- Panels MUST be located so they are never shaded – if space constrained, 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; high voltage panels are best
- Buy more controller capacity than needed; MPPT unless on budget
- Use a combiner box on the roof
- Use remote display

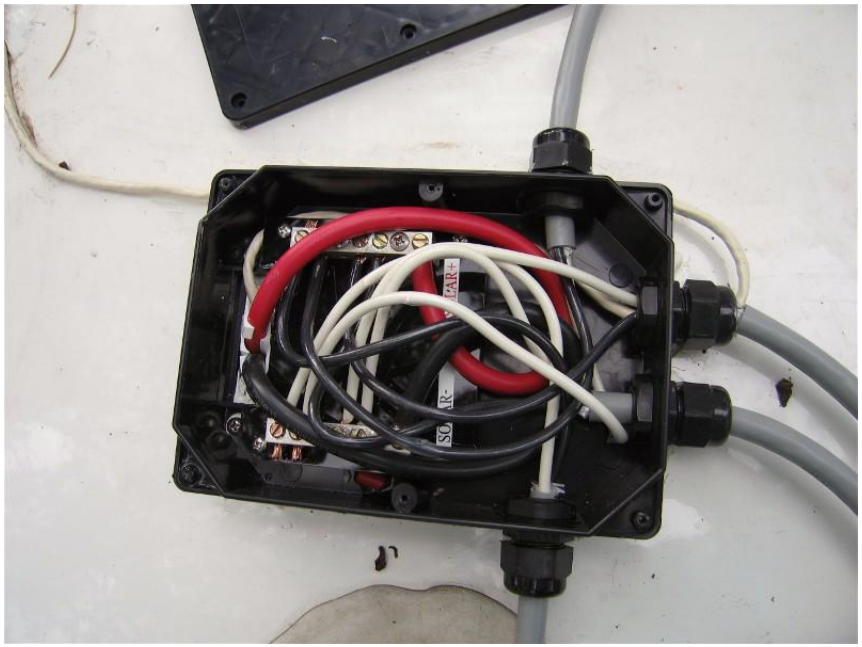
Solar Charge Controller/Panel
Installation Considerations

- AM Solar has good 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 leg – 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; or Midnight Solar “Baby” breaker box

Combiner Box



Outback FLEXWave PV8 - $120



AM Solar CB Combiner - $50

Inverters, Batteries and Wiring

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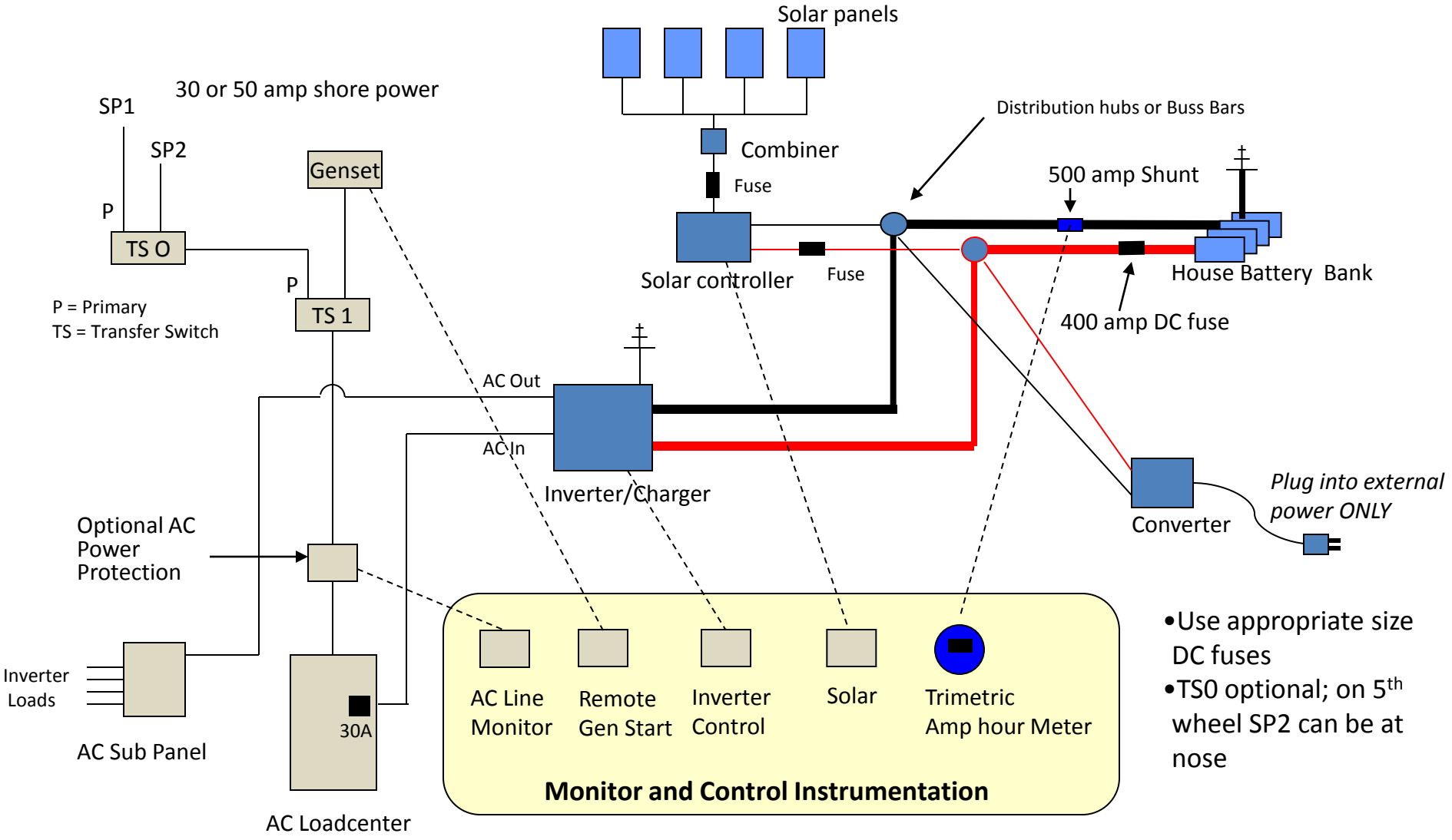
RV Electrical System

Inverter With Subpanel



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

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"
  - Does design place the inverter "inline" or in a subpanel
  - Instrumentation/control – unified control, battery monitor
  - AGS – automatic generator start; can even start larger portables
- **Magnum is my #1 choice**

Instrumentation
What Really Matters?

- *Cumulative amphours* into the battery bank (Magnum BMK, Trimetric, LinkPro, Blue Sky IPN ProRemote, etc)
- Instant amphour measure; power use *right now*
- Voltage
- AC line voltage/amps
- Control Functions: Inverter off/on, charger off/on, Genset off/on

Lots more monitor functions are typically available, but the above are critical

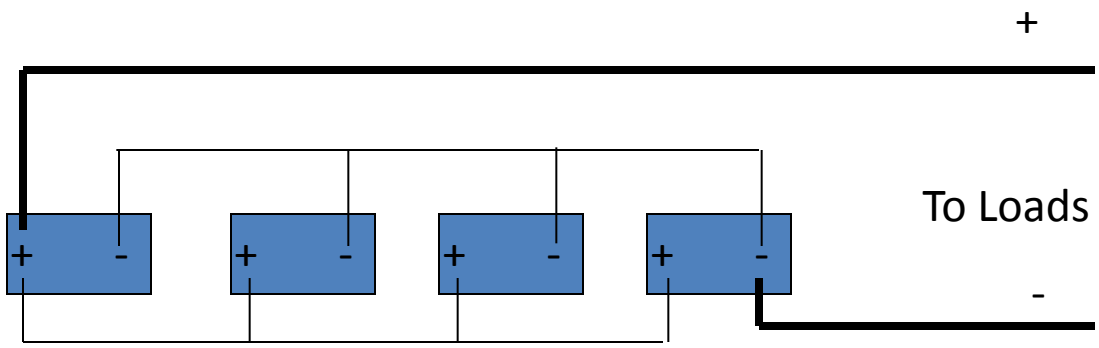
Battery Types

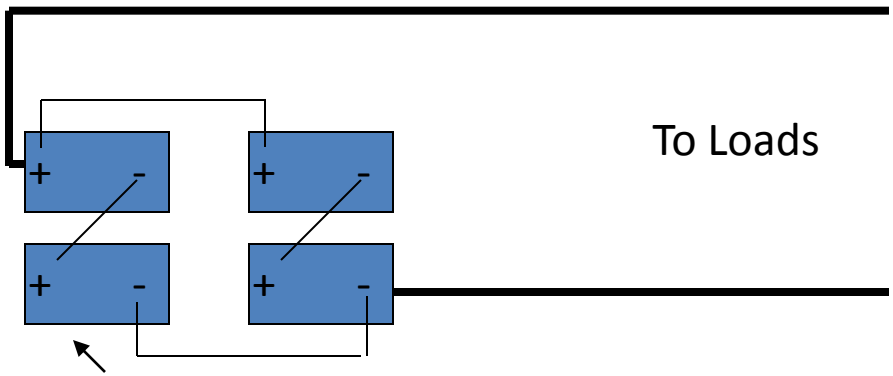
- RV batteries are Lead-acid (vs. Lithium, NiCd, etc)
  - Flooded-cell (wet cell)
  - Sealed Flooded (maintenance free)
  - Gel (sealed) - no longer used
  - AGM (sealed)
- Starting (SLI)
  - High starting current for short time
  - Thousands of low discharge cycles (10% discharge or less is typical)
  - 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

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.

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 system for a 25-30% depth of discharge (DOD)
- **You WANT a battery monitor that uses cumulative amphours**

Wiring

- Solar panels to combiner
  - #10 tray cable; individual “home runs”
- Combiner to solar controller
  - #4 welding wire
  - Probably #2 between controller and batteries
- 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)

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/bussbar; 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

- **Inverter**: Magnum MS2812 ($1900)
- **Solar Controller**: MorningStar MPPT 60 with remote (TS-RM2) ($620)
- **Battery Bank**: 8 – LifeLine GPL-4C 6 volt AGM batteries (880 Ah rating) ($350 ea)
- **Solar**: 4 – Sun 200 watt panels ($268 ea)
- **Components**:
  - AM Solar Large combiner ($60)
  - MidNite Solar Magnum E-Panel ($600)
  - Wire, lugs, etc. ($300)

- **Total $6000**

Sample System
Economy

- Heart (Xantrex) 458 Modified Sine Wave Inverter 2000 watt/30 amp pass thru. With panel.
- Trace C40 charge controller. PWM controller, not an MPPT.
- Trimetric RV 2025Monitor. Has cumulative amp hours.
- 3 – Sun 185 watt Solar Panels. Best price/size/performance tradeoff. You can add one more panel with the C40 controller.
- 4 – Sam's Club 6 volt Golf Cart batteries (410 Ah rating).

The *Golden* Rules

- Solar Panels
  - Use high voltage panels (around 28 volts) on any but the smallest systems
  - Price panels on a per-watt basis. There is not much difference in panels.
  - Use serial/parallel connection to get higher voltage, when required. Panels must be matched.

The *Golden* Rules

- Wiring
  - Wire size is CRITICAL. It is the single-most common issue with installations. Use voltage/distance calculators. Then go heavier.
  - Manufacturers almost never provide adequate wiring
  - Wire for 2% loss or less
  - Use quality lugs, and properly attach them; use dielectric grease and adhesive heat shrink
  - Fuse before/after controller; catastrophe fuse at battery bank
  - Use combiner on roof; I prefer a Midnight Solar DIN breaker box
  - Use distribution buss bar(s) near battery to tie loads together.
  - Make sure the shunt has no loads between it and the battery.

The *Golden* Rules

- Solar Controller
  - Use an MPPT controller; high voltage; boost in the 10%+ range is realistic
  - Controller must allow adjustable voltage and charge times
  - Position close to the battery bank
  - Make SURE the wire size to the batteries is correct. It will be bigger than what comes from the roof in most cases.
  - Temperature compensation is NOT an option – use it.

The *Golden* Rules

- Batteries
  - Balance the system; have enough batteries for the amount of watts of panels you have
  - Rule of thumb: 1 amp of storage for each watt of solar panel. Generalization – this is not “exact”.
  - Flooded cell batteries charge at 14.8 volts NOT at 14.4/14.6 volts that you commonly see.
  - AGMs have advantages and are ALWAYS better, but cost much more.
  - Solar alone generally will NOT bring a bank up to “full” state of charge.
  - Use a battery monitor with cumulative amphours (like a Trimetric or LinkPro).
  - With flooded cell batteries check specific gravity at least every 6 months. Equalize if required.
  - A desulfator “may” be helpful. Reports vary in RV use.

The *Golden* Rules

- Inverter
  - Wiring is critical. Never less than 2/0 and usually 4/0
  - Short distance to the batteries
  - Catastrophe fuse
  - Remote display/control is important
  - Do not use too large an inverter for your needs. It is inefficient. Consider second small inverter for small loads.
  - Charge section is critical if using AGM batteries. You want a LARGE charger with AGMs. 125 amps +
  - On flooded cells properly set the charge amperage
  - Wire through a subpanel. Wired in-line is OK for a 30-amp RV, but a subpanel is preferred. Do not wire 50-amp in-line.
  - Temperature compensation is NOT an option – use it.
  - Build in provisions for removing inverter for service or upgrading your RV. AC wire length and junction box.

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/