

How To: Marine Electrical Seminar

Improving electrical systems on your boat.

Before we get started . . .

- Thank-You to BWC association for hosting this course
- Cell phones off please
- Take lots of notes / drawings
- Ask questions
- All slides will be provided to you online

Plan for the day . . .

- 10:00 am Start
- 11:15 am Break
- 12:30 -1:00 pm Lunch Break
- 2:30 pm Break
- 4:45 pm Done for the Day!

Agenda

- Storage of energy
- Power generation
- Power sharing
- Monitoring
- Power distribution
- Galvanic protection
- Safety

About Jeff Cote

- Owner/operator of Pacific Yacht Systems
- Systems Design Engineer, University of Waterloo
- NMEA & ABYC certifications
- Published monthly columns
 - Tech Talk in Pacific Yachting Magazine
 - HotWire in Northwest Yachting Magazine
- Sailboat moored on the Sunshine Coast, BC
- Favorite BC cruising grounds are Barkley Sound and the Broughton Archipelago

About Pacific Yacht Systems Inc.

- Specialize in marine electrical and electronics
- Servicing the lower mainland, Sunshine Coast and Vancouver Island
- Worldwide electrical design / consultation
- 2019
 - Worked on over 1000 boats
 - Designed / consulted on over 200 electrical projects
- www.pysystems.ca for videos, product info, articles



Safety First!

- **Electricity can burn or kill you**
- **Faulty electrical work can cause fires**
- Work within your competence level
- Follow industry standards / regulations
- Hire professionals when needed

Do It Right!

How To:

Marine Electrical Seminar

Overview

- Storage of energy
 - Battery
- Power Generation
 - Charger, inverter, alternator & regulator, solar, fuel cell, AC & DC generator
- Power Sharing
 - Battery combiner, battery isolator

How To:

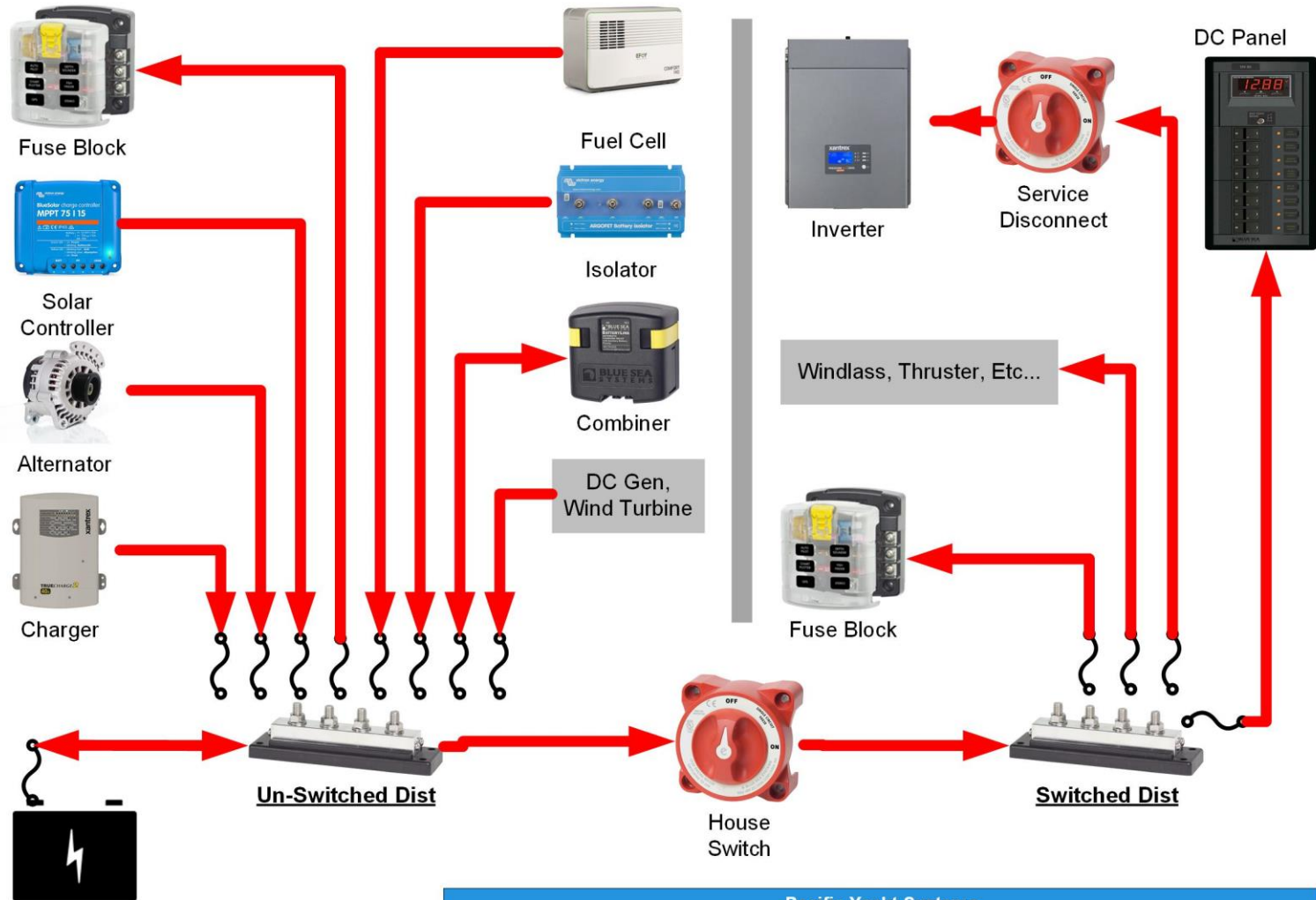
Marine Electrical Seminar

Overview

- Monitoring
 - Voltmeter, battery monitor
- Power Distribution
 - AC panel, DC panel
- Galvanic Protection
 - Galvanic isolator

DC Conceptual Overview

Conceptual Diagram – DC Overview



House Battery

Pacific Yacht Systems

Tech | Jeff Cote

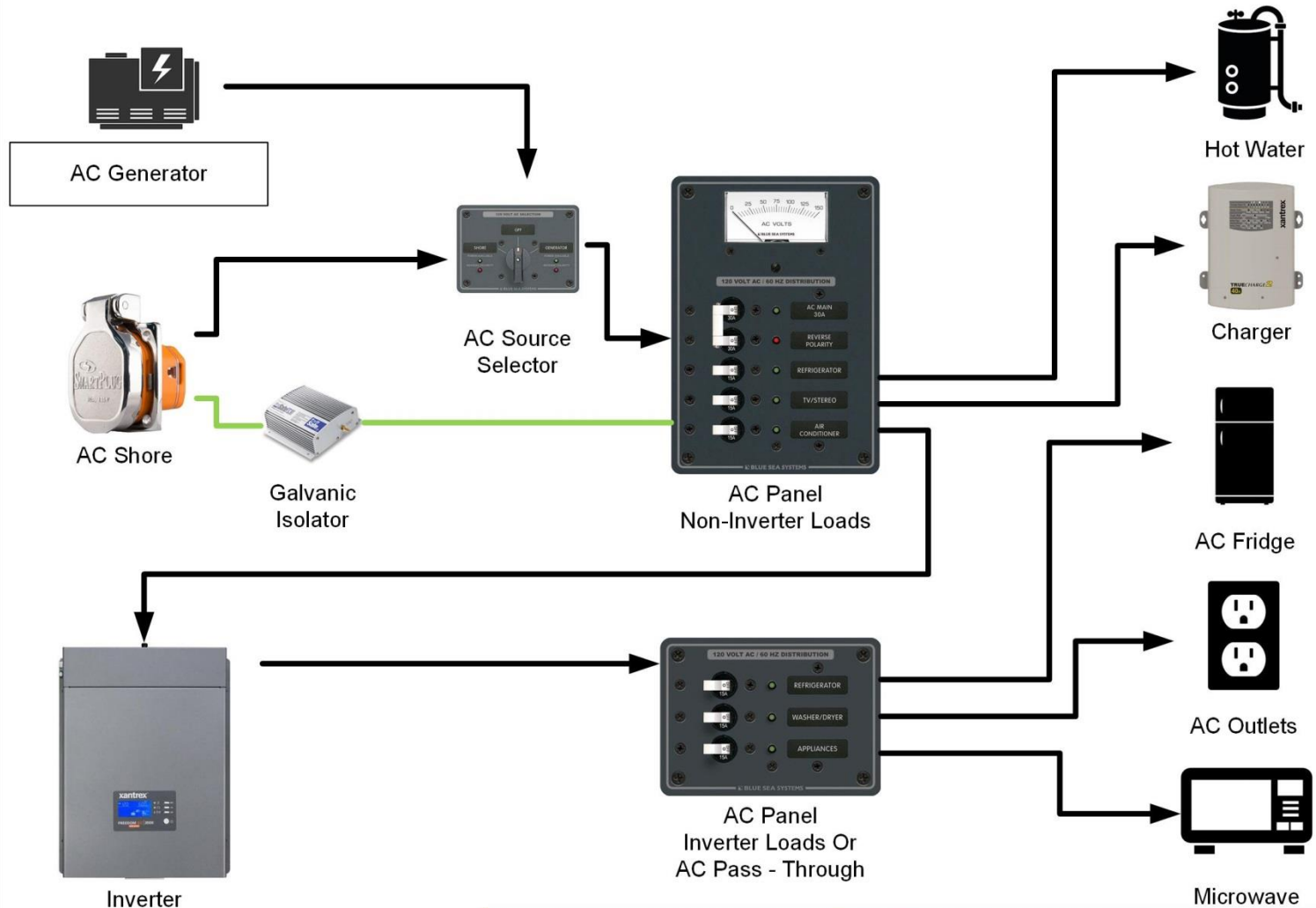
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AC Conceptual Diagram

Conceptual Diagram – AC Overview



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Energy Storage: Batteries

Marine Batteries



Engine Batteries (AKA cranking battery)

- Used to start the engine
 - E.g. thruster
- Designed to deliver high current for short period of time
- Should be immediately recharged by engine alternator
 - NOT designed to be left uncharged
 - NOT designed for deep discharge
- Capacity measured in Cranking Amps or Cold Cranking Amps

Example: 8D Engine
Flooded LA Battery

Notice: Fill Caps



Deep Cycle Batteries

- Used to supply power to devices on boat
- Designed for deep discharge over longer time
- Capacity measured in Amp Hours (AHr)



Lead Acid Battery Choices

Two Types

- Flooded Lead Acid (Starter, Deep-Cycle, or Hybrid)
- Sealed Valve Regulated Lead Acid
 - Gel
 - AGM (Absorbed Glass Mat)
 - Carbon Foam AGM (i.e. Firefly)

Flooded Lead Acid Batteries

- Flooded lead acid purchase cost (\$)
 - If properly maintained
- Liquid acid electrolyte
- Must use watertight battery box to contain any spilled battery acid
- Maintenance - top up with distilled water only
- Self-discharge of about 15% per month
- Practical available battery capacity about 35%
 - Bulk range: 85% to 50%
 - Example: 600 AHr battery capacity for 200 AHr useable capacity

L16 Flooded Lead Acid



Gel Batteries

- Gel purchase cost (\$\$)
- Electrolyte is in gel state
- Sealed Valve Regulated: limited gassing
- No maintenance required
- **CAUTION: Easy to overcharge with alternator and charger**
 - **Need specific gel charge profile**
- Self-discharge of about 2% per month
- Practical available battery capacity about 55%
 - Bulk range: 85% to 30%
 - Example: 400 AHr battery capacity for 200 AHr useable capacity

AGM Batteries

- AGM purchase cost (\$\$)
- Electrolyte is in Absorbed Glass Mat (AGM)
- Sealed Valve Regulated: Limited gassing
- No maintenance required
- Self-discharge of about 2% per month
- Practical available battery capacity about 55%
 - Bulk range: 85% to 30%
 - Example: 400 AHr battery capacity for 200 AHr useable capacity

AGM Battery



Firefly Oasis Batteries

- Carbon foam AGM purchase cost (\$\$\$)
- All benefits of AGM
 - Leak-proof, limited gassing, maintenance-free, faster recharge acceptance rate, limited self-discharge
- **Battery Life: 12 Times of Flooded**
 - **(FF 3600 cycles versus FLA 300 cycles at 50% DOD)**
- **No premature aging at partial state of discharge**
- 2 Sizes: Group 31 and L15+
- Practical available battery capacity about 65%
 - Bulk range: 85% to 20%
 - Example: 300 AHr battery capacity for 200 AHr useable capacity

Firefly Oasis Gr31 & L15+



Example: Firefly Oasis Group 31



Calculate Your Power Needs

- What is your daily power need?
 - Varies depending on the season, examples:
 - Lights are run earlier in winter
 - Heating in the shoulder and winter season
- Largest DC loads
 - Refrigeration is the largest draw: typically 50 – 125 Amp-Hour per day
 - Inverter powering AC loads
 - DC loads from running diesel heater (especially hydronic)

Typical Daily Battery Usage

Typical daily AHr budgets	AHr
Beneteau 33	85
Catalina 36	120
Suncruiser 38	225
Grand Banks 42	175
Ocean Alexander 48	375
Meridian 580	500

Sizing Battery Capacity

- Criteria to choose your battery bank
 - Daily Amp-Hour (AHr) budget
 - Estimated time between charging? How often do you charge your batteries?
 - Every ½ day
 - Every 2 days
- At a minimum, useable battery capacity needs to be
 - Daily AHr budget X Estimated time between charging
 - Example: 200 AHrs X 2 days = 400 AHrs of useable battery capacity

Recap:

Lead Acid Battery Capacity

BATTERY “FLOOR”

- To balance battery cost and life, you should never deplete your lead acid batteries below the following capacity:
 - Flooded: 50%
 - AGM/GEL: 30%
 - Firefly AGM 20%

BATTERY “CEILING”

- Due to lead acid battery chemistry, charging above 85% of capacity (absorption stage) is time-consuming

USEABLE BATTERY CAPACITY

- Therefore: while cruising effective useable battery capacity is:
 - Flooded: 35% (50% to 85%)
 - AGM/GEL: 55% (30% to 85%)
 - Firefly AGM 65% (20% to 85%)

AGM vs Firefly vs Flooded Lead Acid Summary

	AGM	Firefly AGM	Flooded
Initial Cost	\$\$	\$\$\$	\$
Battery Life	1.5X	4X	1X
Useable capacity	55%	65%	35%
Maintenance	None	None	Regular top-off
Self-discharge	2% per month	2% per month	15% per month
Purpose	Dual	Dual	Single
Sulfation	Yes	No	Yes

Sizing your Battery Bank

- Depending on your choice of lead acid battery, you will require the following:

Type	Useable battery capacity
Flooded	3 Times
AGM/Gel	2 Times
Firefly AGM	1.5 Times

- Examples, if you need 200 AHr of useable battery capacity, you will require:
 - Flooded: 600 AHr
 - AGM/GEL: 400 AHr
 - Firefly AGM: 300 AHr

Battery Sizes and Types

- Batteries come in all sizes
 - Group 24, Group 27, Group 31
 - 4D, 8D
 - Golf Carts
 - Slimline
 - L16
- All battery sizes come in different lead acid types:
 - Flooded , AGM, Firefly AGM, Gel
- Flooded batteries are built specifically for a purpose
 - Starter
 - Deep cycle
 - Dual purpose



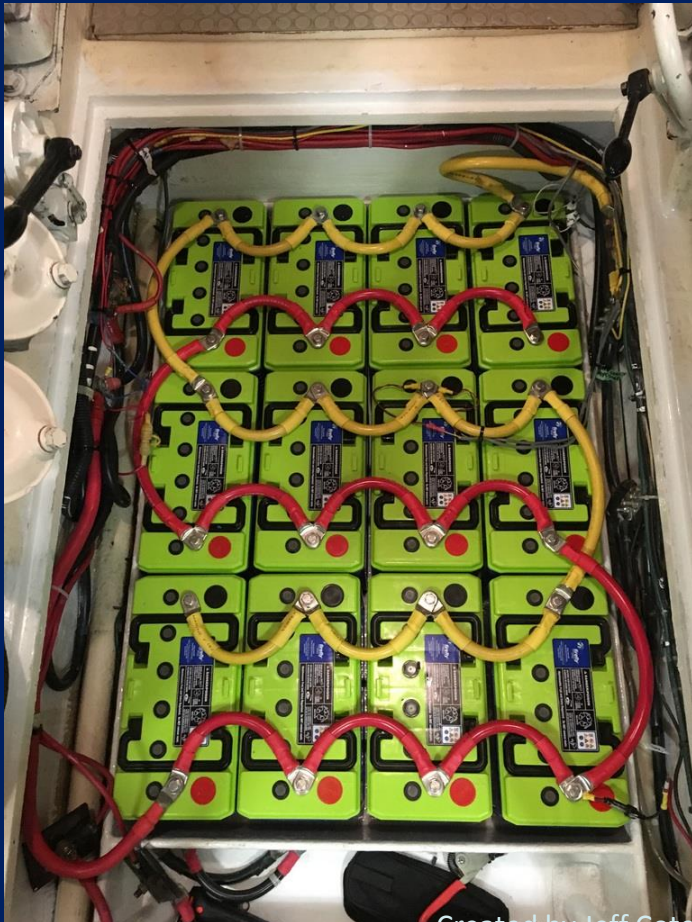
Ideal Charge Rate for Batteries

- Importance of sizing minimum charge rate to battery size
 - **Minimum: ~ 10% of capacity**
- Reduce your charging time by increasing your charge rate
 - **Maximum: ~ 25% of capacity (AGM/Gel: ~ 40%)**
 - How often to you want to run genset/engine per day?

Battery Bank Installation Tips

- Properly secure batteries from moving
- Wire battery positive and negative at opposite ends
- Battery bank in one location
- FLA batteries installed in leak proof container
- Protective boots on positive post terminals
- Keep battery load connections to a minimum
- Fuse all leads to battery (except starter)
- Install battery bank disconnect switch

Battery Install Firefly Examples



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Battery Install Secured & Contained



Side notes:

Battery Tips & Tricks #1

- Liquid in the bottom of your battery box is probably electrolyte, **NOT** water
 - Make sure battery box is leak proof
 - Why did it boil over?
 - Neutralize with baking soda



Side notes:

Battery Tips & Tricks #2

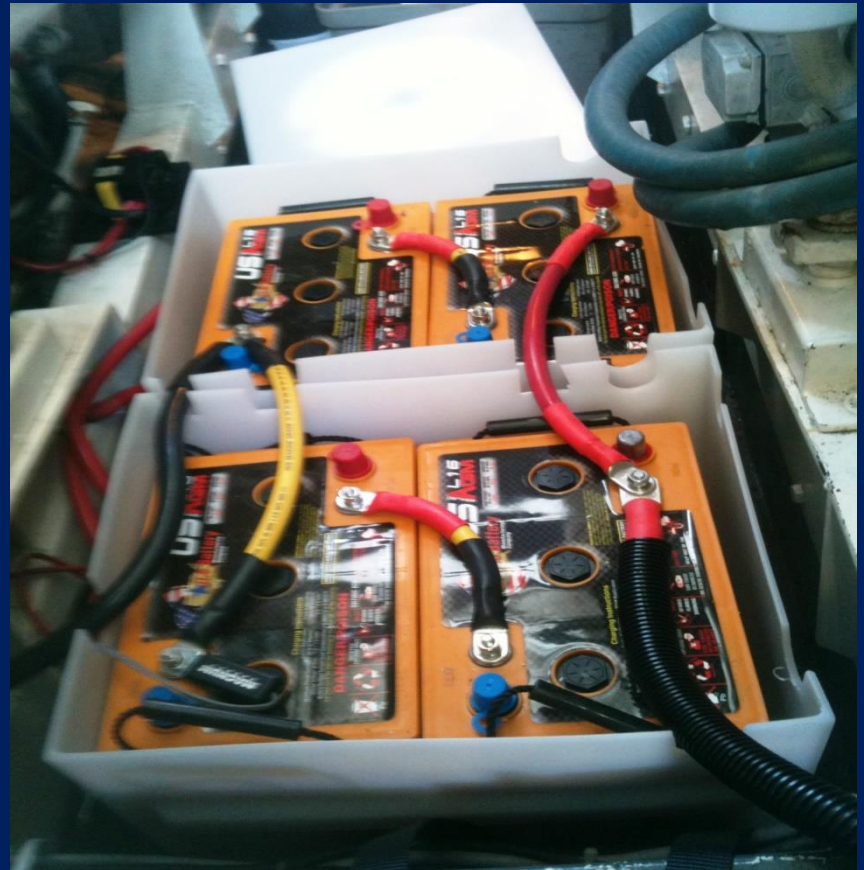
- Never expose your flooded lead acid battery plates to air
 - Once exposed, exposed battery is capacity lost



Side notes:

Battery Tips & Tricks #3

- Wire your batteries so they evenly discharge
 - Positive and negative at opposite ends



FAQs & Questions

- Can you mix and match different battery chemistries

Power Generation

Charger

Inverter

Alternator

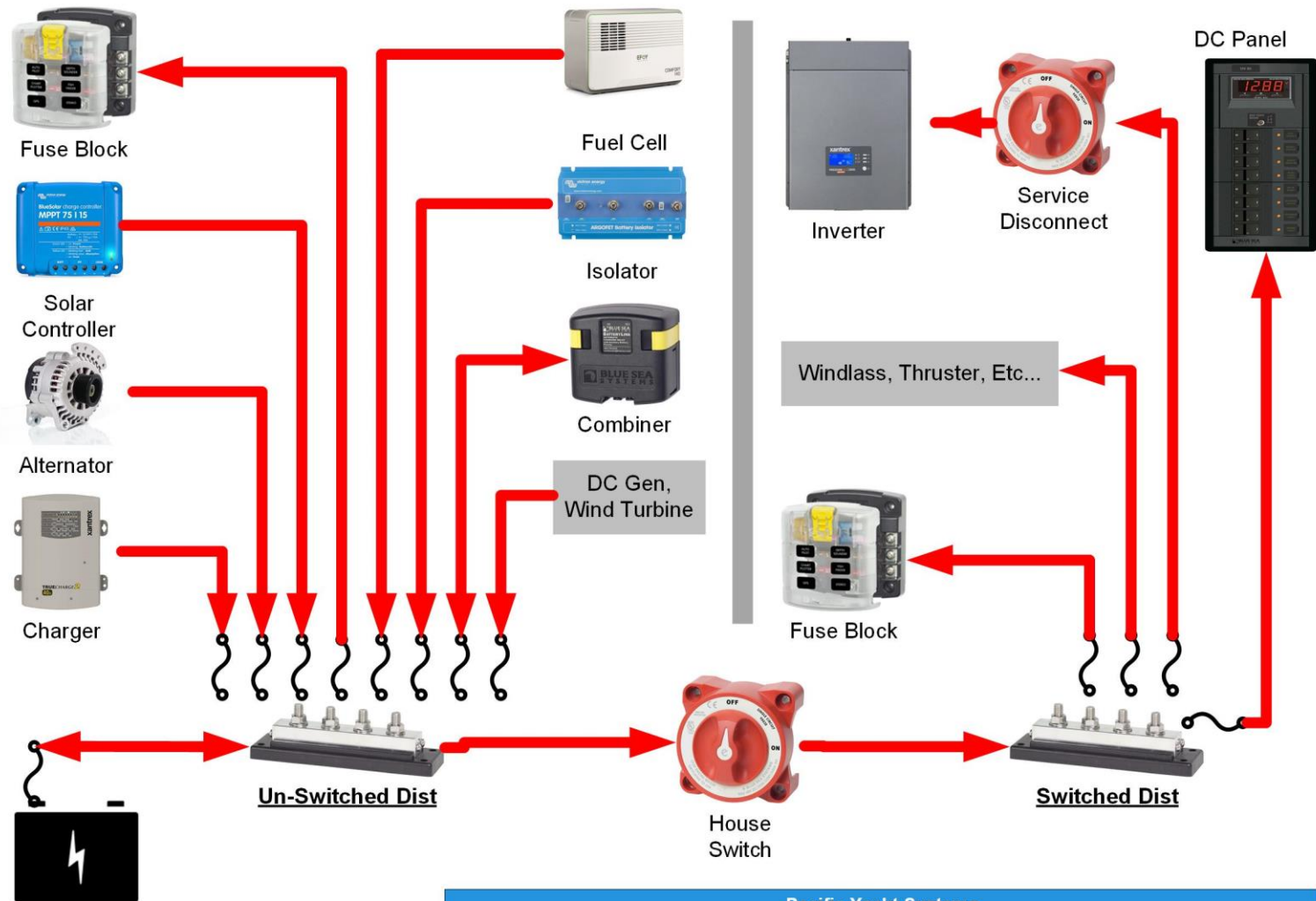
Solar

Fuel cell

AC & DC generator

DC Conceptual Overview

Conceptual Diagram – DC Overview



House Battery

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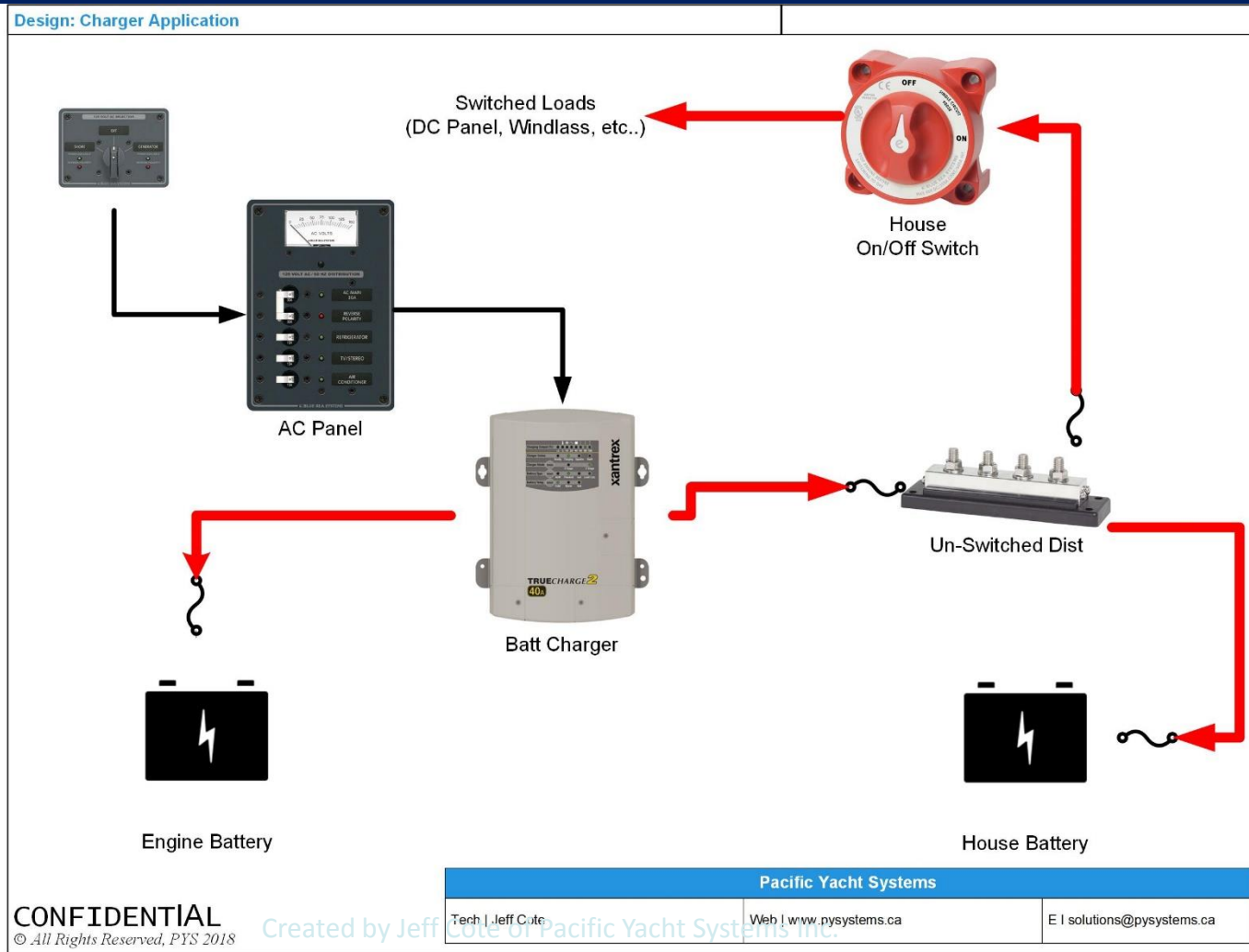
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Power Generation: Charger

AKA converter, smart battery charger

Charger Conceptual Diagram



Charger

- Charges batteries from AC source (shore or AC generator)
- **Reduce** the battery charge time
- Three-phase smart charge cycle:
 - bulk, absorption, float
- Correct rate of charge for extended battery life

Charger Purchasing Tips

- Three Phase
 - Bonus: Custom settings
- Battery type
- Temperature compensated
- Remote panel
- Marine model
- Popular models:
 - Xantrex TrueCharge 2 (10, 20, 30, 40, 50, 60 amps)
 - Victron Centaur



Charger Installation Tips

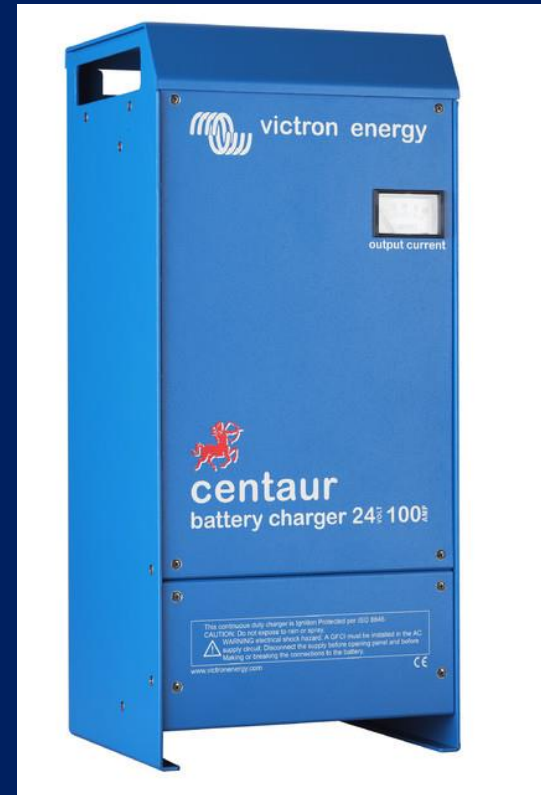
- Size charger at least 10% of house battery capacity
- Fuse leads at battery
- Connect directly to battery (NOT switched)
- AC breaker size to handle bulk mode
- Set correct battery type
- Temp sensor properly mounted



Charger

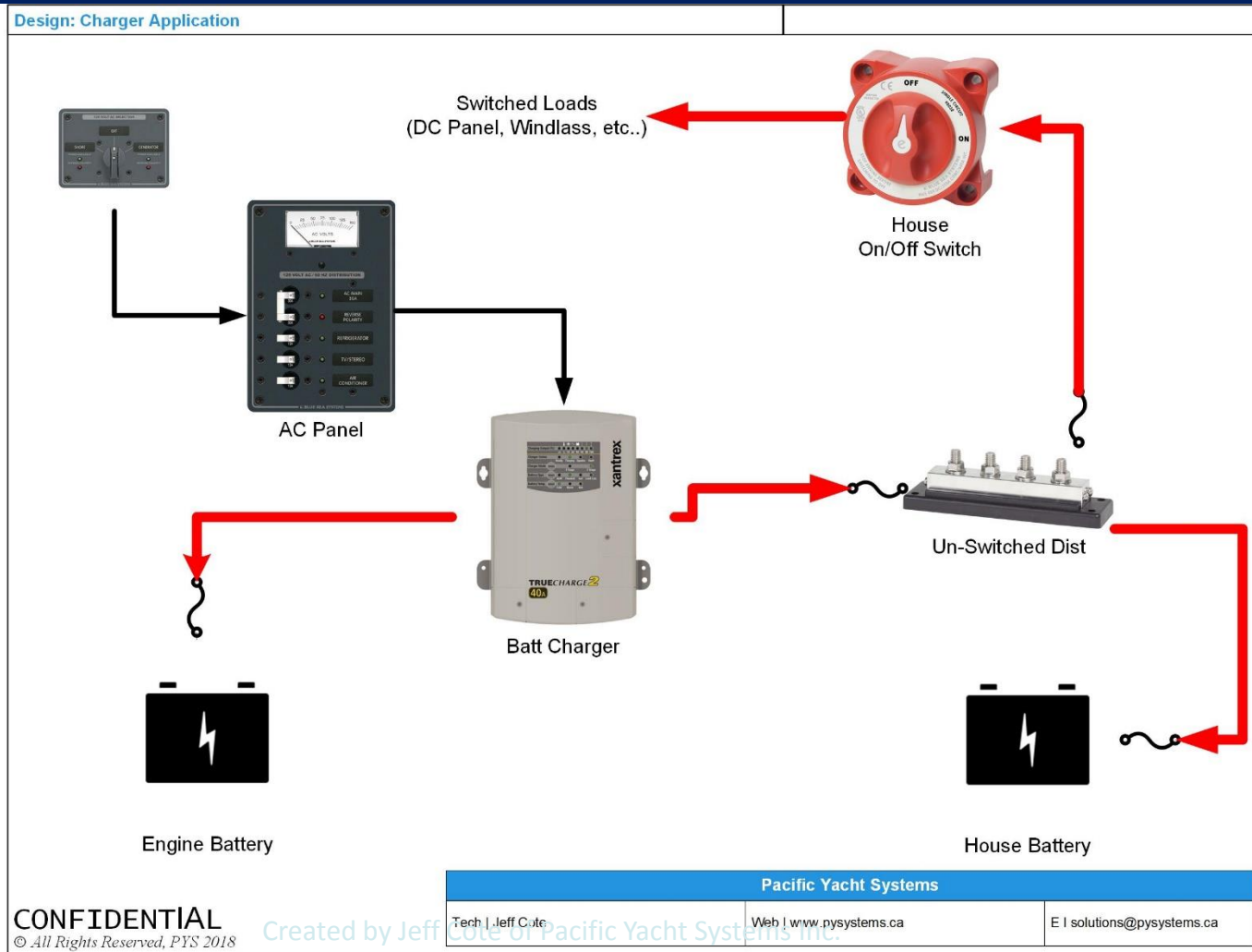
Application Multiple Units

- Reduce genset runtime by adding 2nd or 3rd charger in parallel
 - E.g. 1 hour morning and evening
- Charge at the ideal rate
- Min and Max Charge Rate
 - Flooded: 10% to 25%
 - AGM: 10% to 40%



Charger Recap

Conceptual Diagram

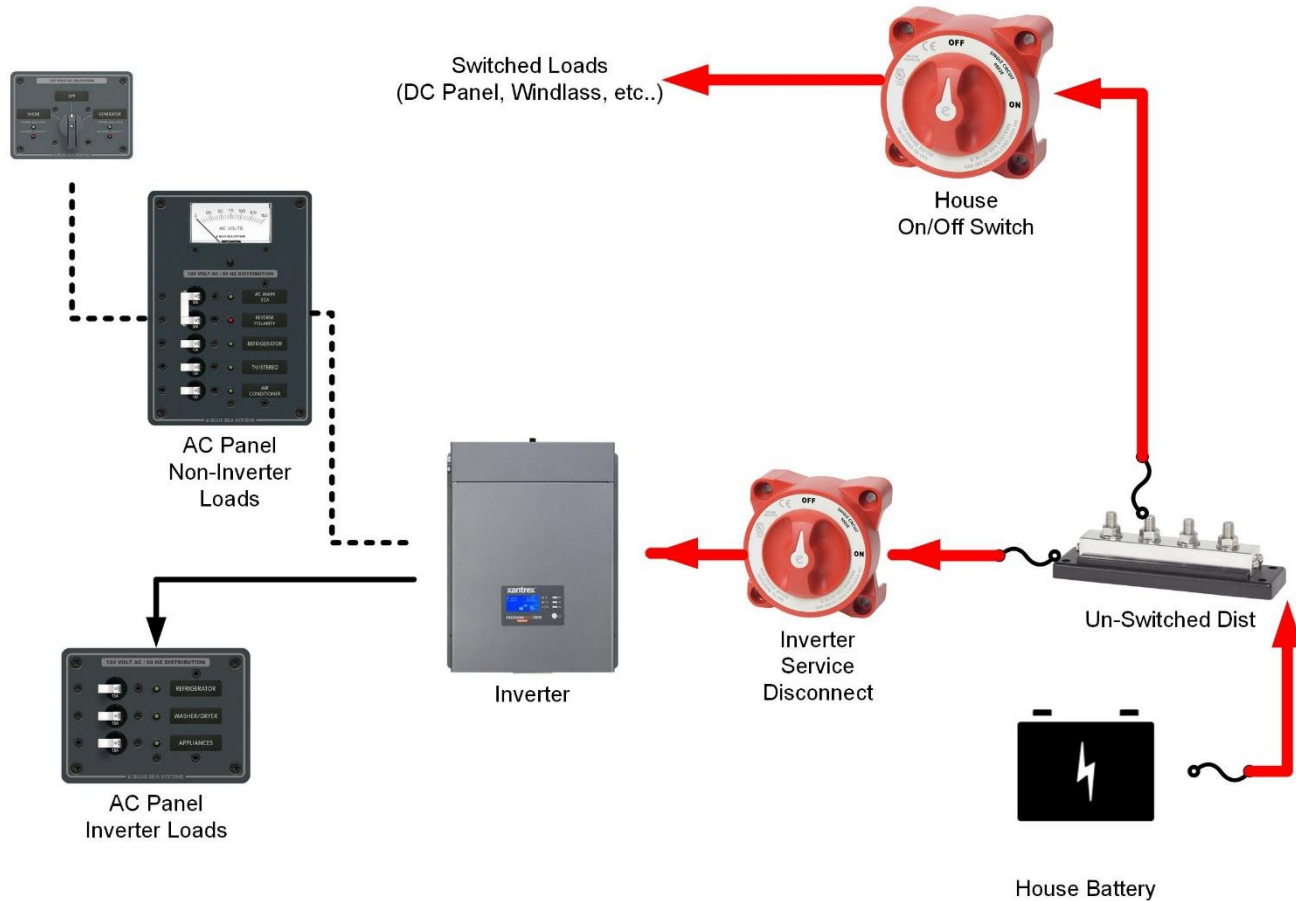


Power Generation: Inverter

& (Inverter/Charger)

Inverter Conceptual Diagram

Design: Inverter Application



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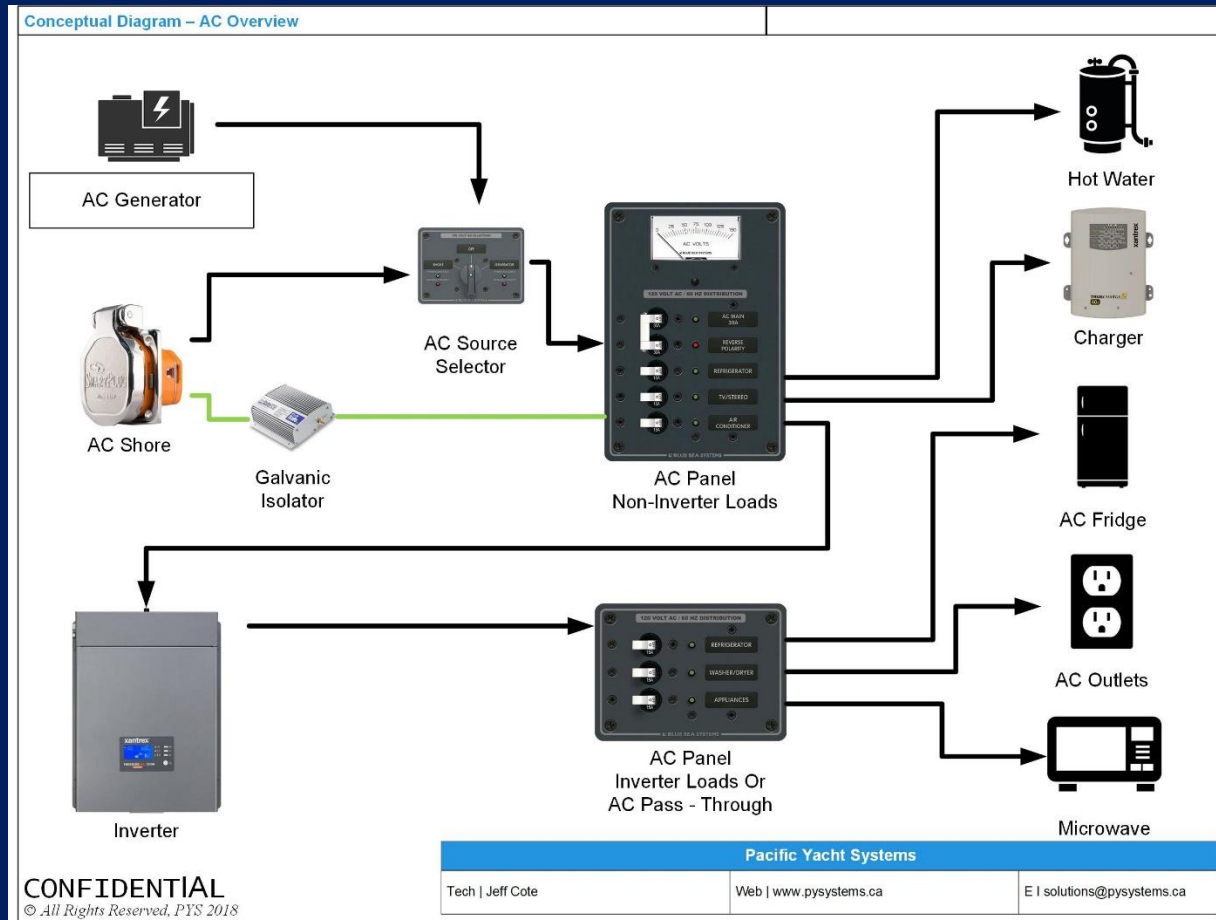
Inverter

- Run AC appliances without shore power or a generator
 - Microwave
 - AC outlets
 - TV



AC Overview

Conceptual Diagram



Inverter Purchasing Tips

- Marine models only
- True sinewave
- Low idle power draw
- High efficiency
 - DC to AC
- Remote controlled
- Popular Inverter
 - Xantrex X (1000, 2000, 3000 watts)
- Popular Inverter/Charger Models
 - Xantrex SW and XC
 - Victron Multiplus & Quattro



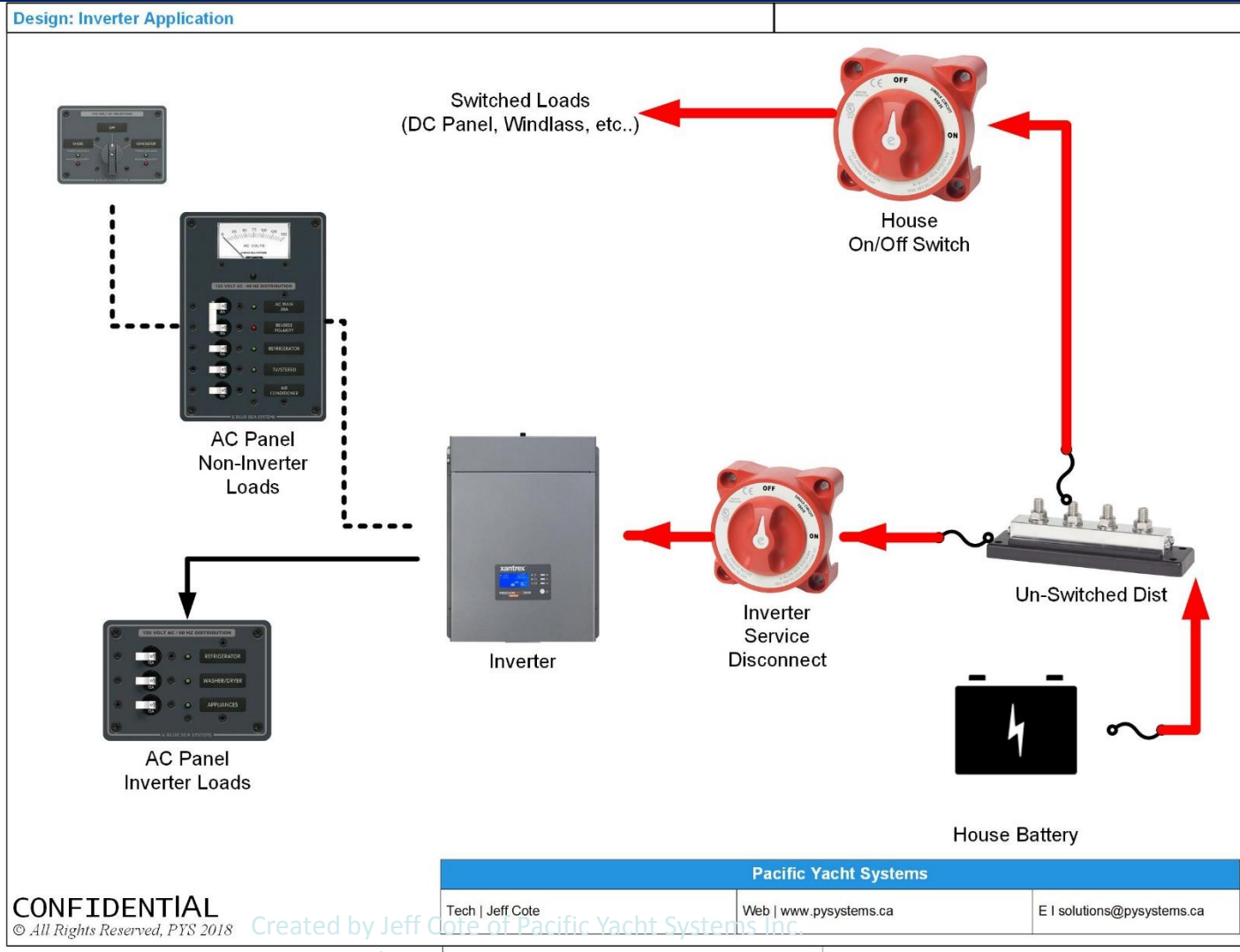
Inverter Installation Tips

- Class T fuse
- On/off master DC service disconnect
- Inverter-only neutral bus
- Chassis ground wire size
- DC wire size based on voltage drop and amps
- Location of inverter



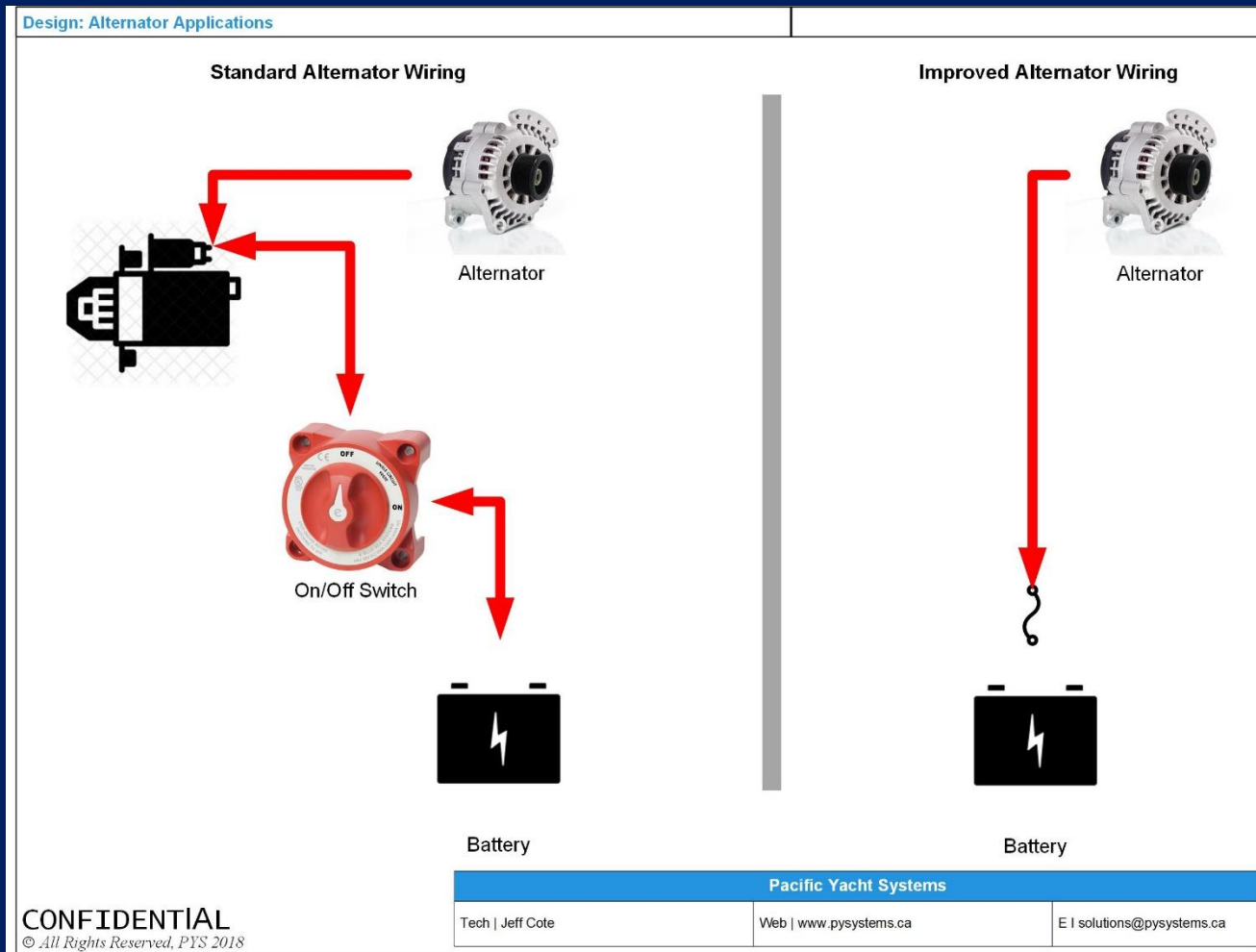
Inverter Recap

Conceptual Diagram



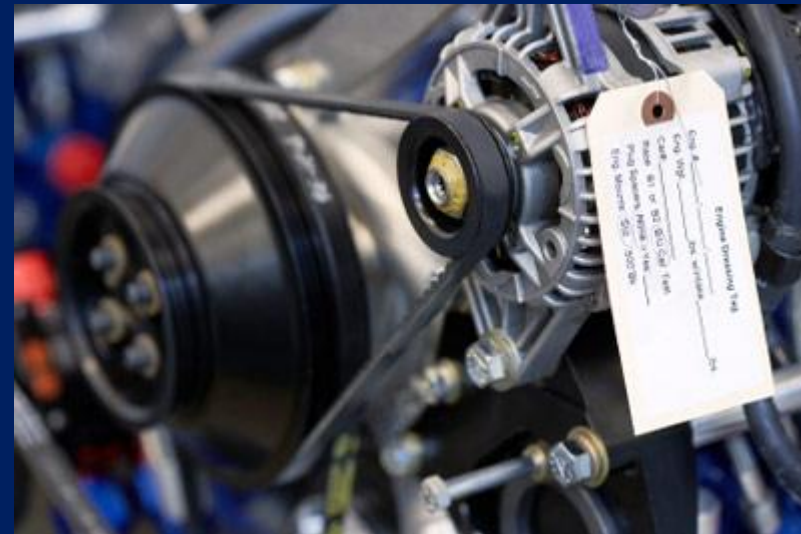
Power Generation: Alternators

Alternator Conceptual Diagram



Alternator

- Converting engine rotation to DC power
 - Note: AC shore or generator has nothing to do with alternator output
- Why maximize alternator output
 - No or reduced genset runtime
 - Typical little engine runtime (sailboat or fast power boat)



Alternator

Realistic Output

- Stock Alternator: 55 Amps with internal reg
- 55 amps is cold rated
 - after ½ hour of running: de-rate by ~ 15%
- Internal regulator limits output to about 2/3rd of output
- Realistic Output: 30 to 35 Amps at full RPM
- Consider loads (5A to 30A) while engine is running
- Effective Charge Rate =
(Alternator output) minus (loads while running)



Alternator Purchasing Tips

- Ignition Protected
- Variables for choosing a larger alternator output
 - V-Belt or Serpentine belt
 - Engine recommendations
 - Physical constraints
- Size for house battery bank
- Built for high output at lower RPM

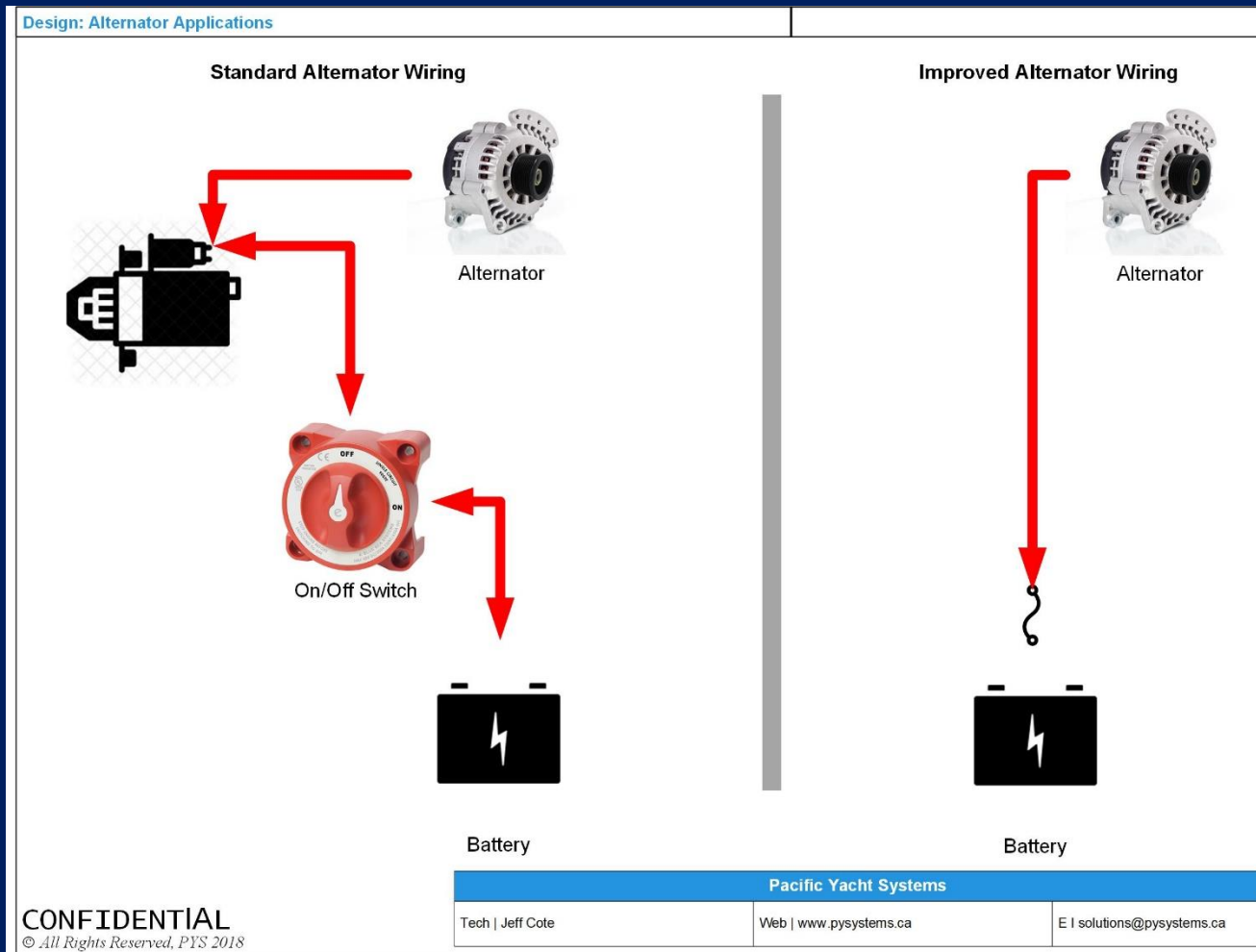
Alternator Installation Tips

- Alternator pos and neg wires can handle increased Amperage output
- Pulley alignment is critical
- Check belt tension



Alternator Recap

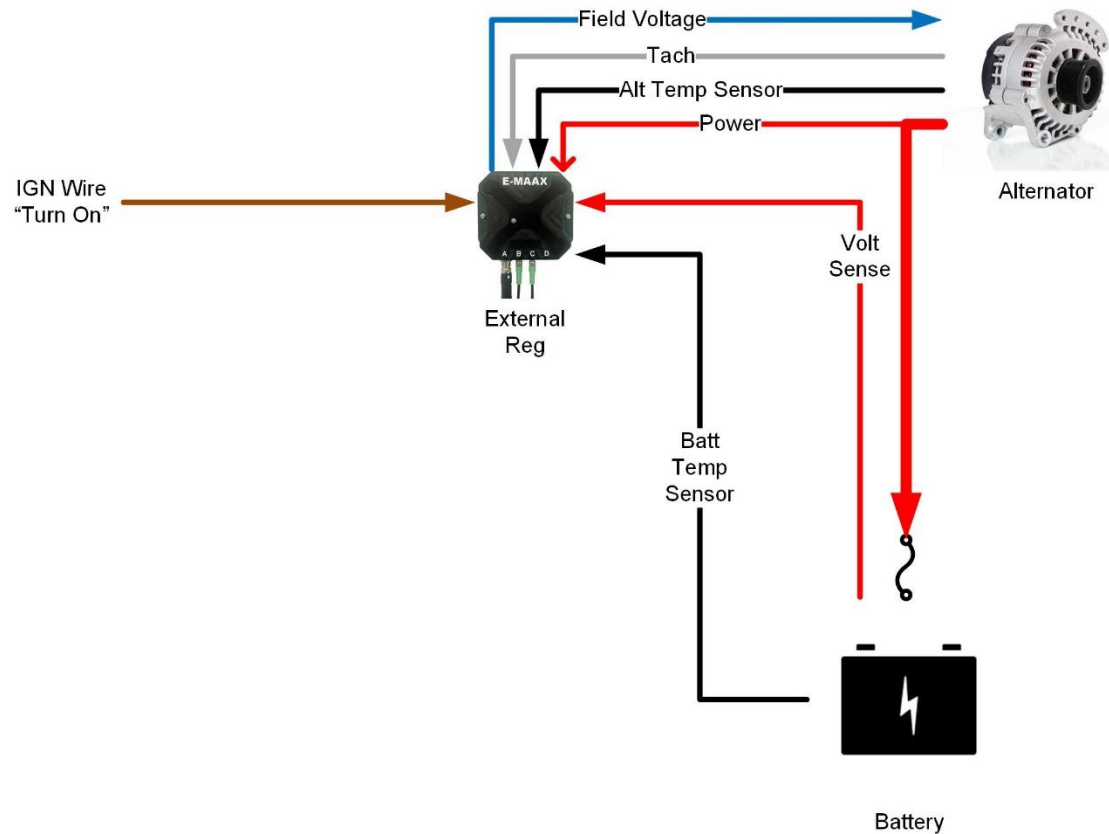
Conceptual Diagram



Power Generation: External Regulator

External Regulator Conceptual Diagram

Design: External Regulator Application



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External Regulator

- Converts alternator to smart 3 phase charge output
- Significantly increases alternator amperage output
- Properly charges different battery chemistries
- Temperature compensated charging



External Regulator Purchasing Tips

- Allows different battery types (FLA, AGM, Gel, etc...)
- Customizable charge profiles
- Remote battery temp and alternator temp sensors



External Regulator Installation Tips

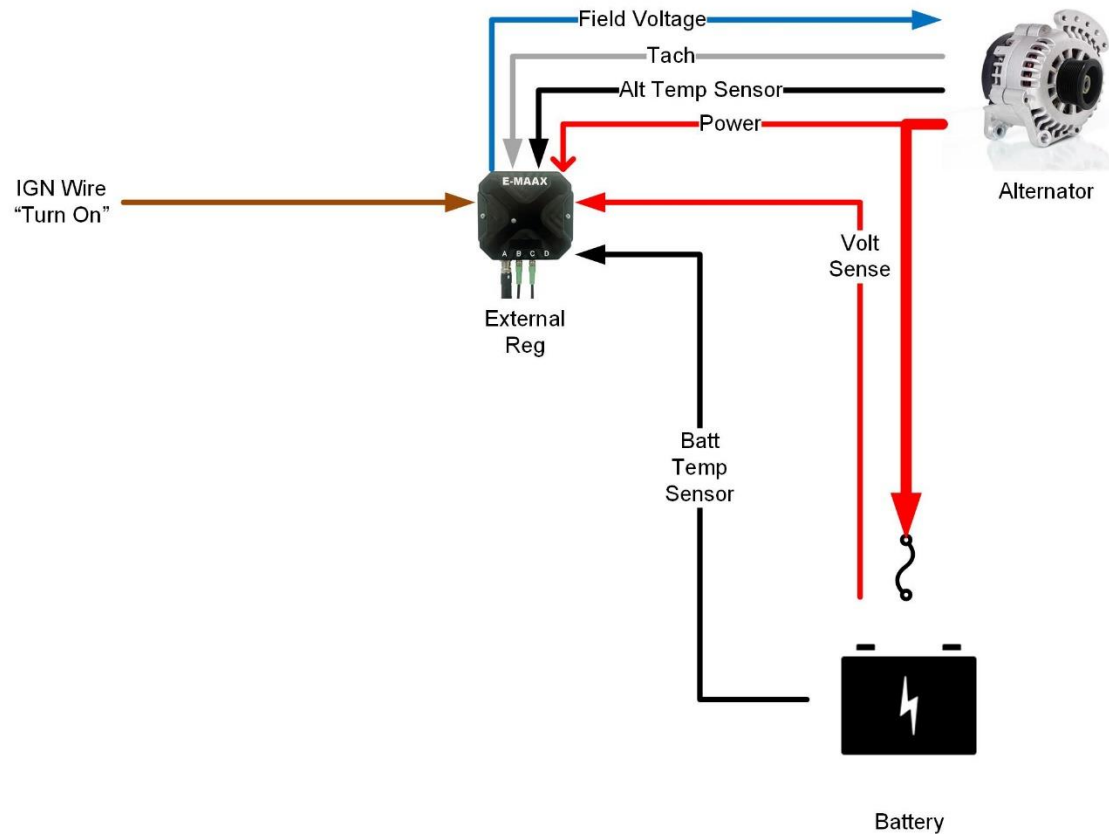
- Make sure alternator wire is sized properly
- Voltage sense leads needs to be at battery
- Fuse alternator lead at battery



External Regulator Recap

Conceptual Diagram

Design: External Regulator Application



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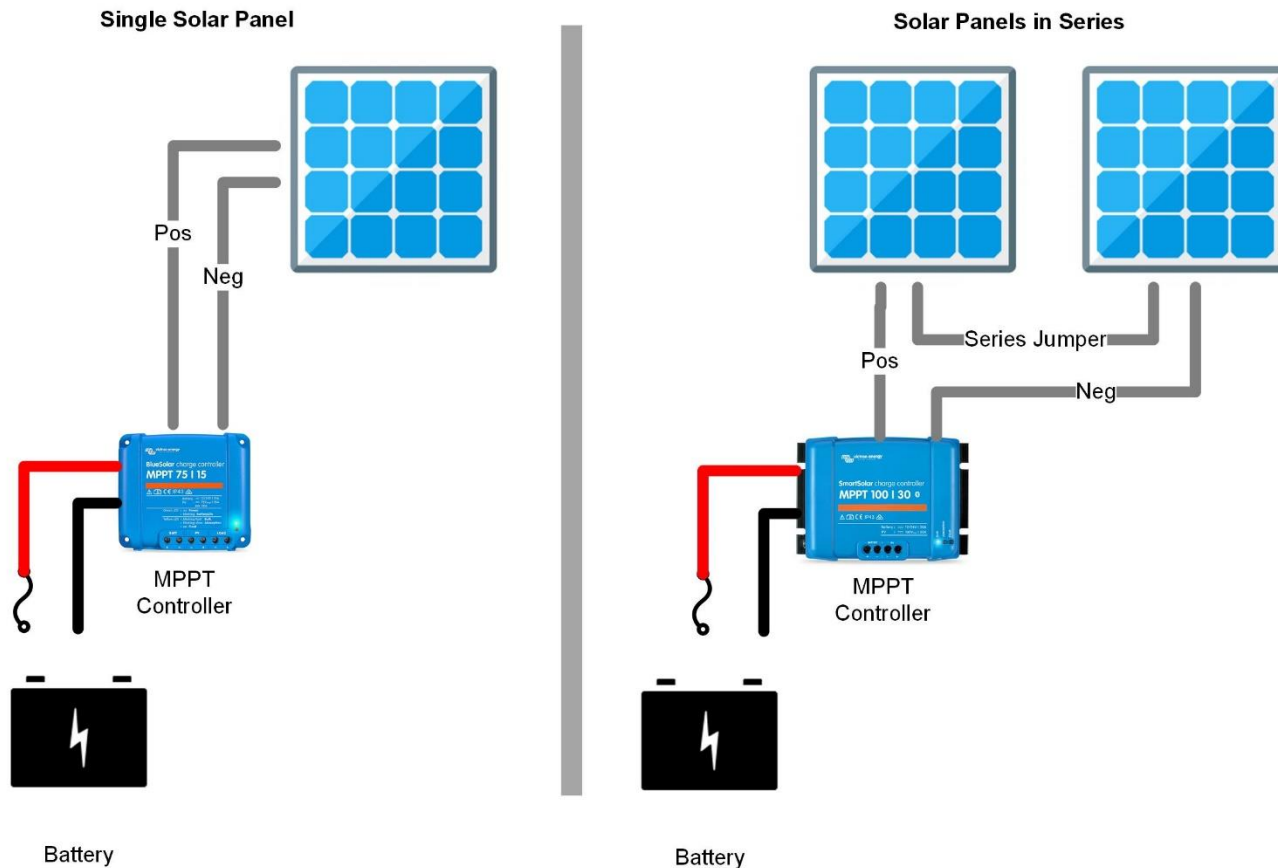
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Power Generation: Solar

Solar Conceptual Diagram

Design: Solar Array Applications



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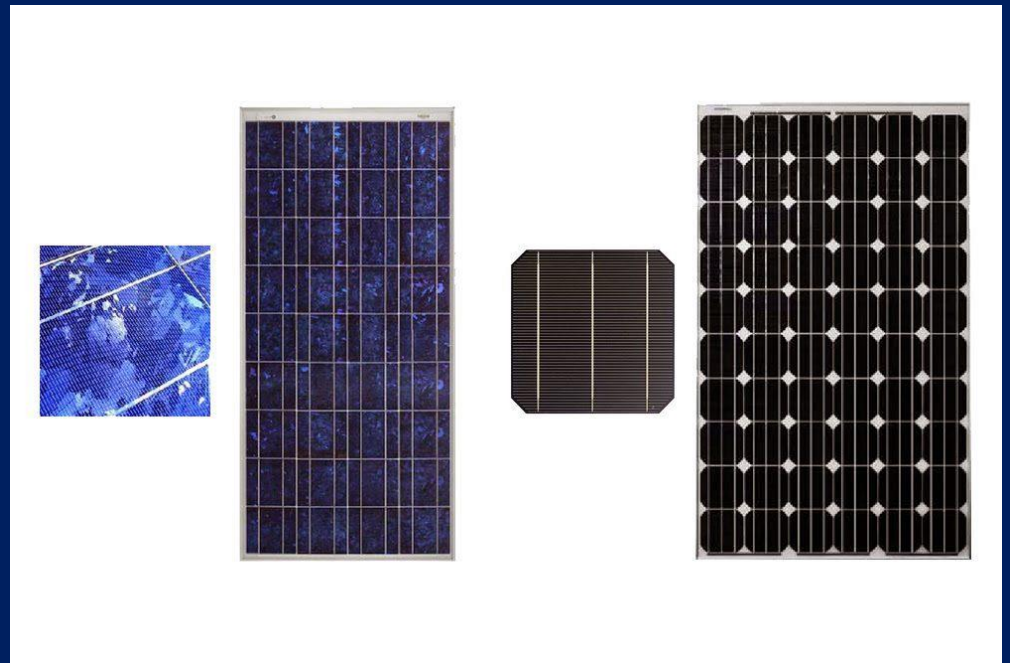
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Choice: Mono or Poly?

- Monocrystalline cells
 - Highest efficiency
- Polycrystalline cells
 - Best value



Solar – How Many Watts?

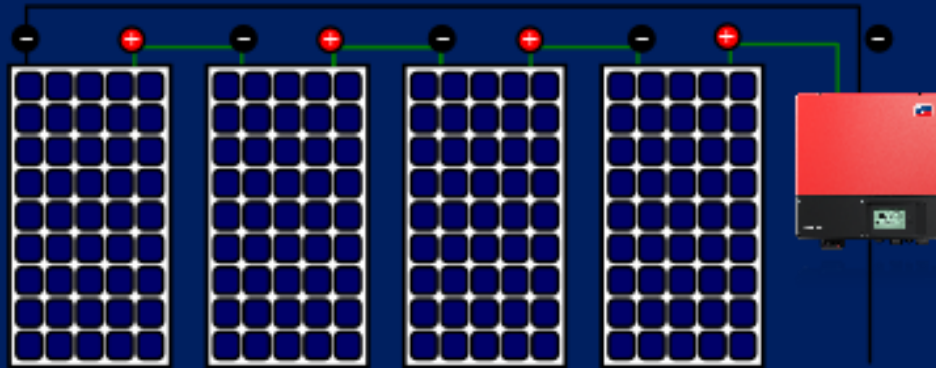
- Typical solar array goals:
 - Keep batteries top-off
 - Daily AHr demand
 - Refrigeration AHr demand
 - Extend your time at anchorage:
 - e.g. 3 days instead of 2 days

Sample - Quick Calculation

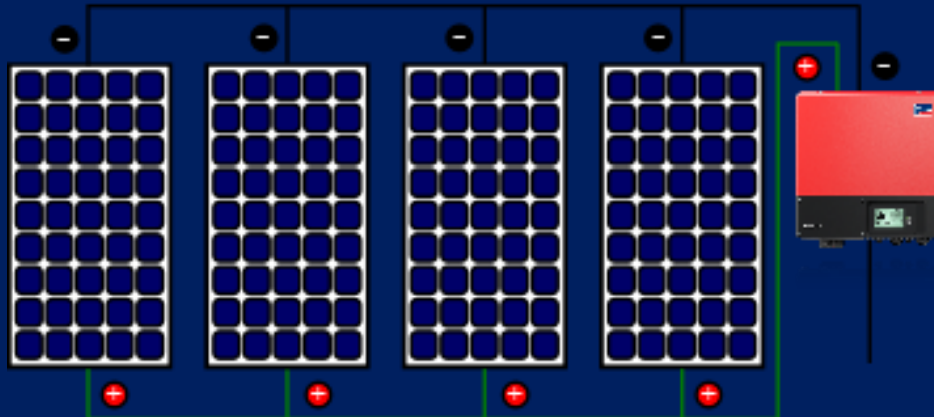
- Rule of thumb: 25% of wattage = daily Ah output
 - Watts X 25% or Watts / 4
 - E.g. A 100 Watt panel will produce 25 AHr
 - $100 \times 25\% = 25 \text{ Ah}$
- Optimistic: factor of 3 (i.e. 33 AHr)
- Conservative: factor of 5 (i.e. 20 AHr)

Solar Panel Series or Parallel

Wiring Solar Panels in a Series Circuit



Wiring Solar Panels in a Parallel Circuit



Solar Flexible Solar Panel Examples



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Solar System

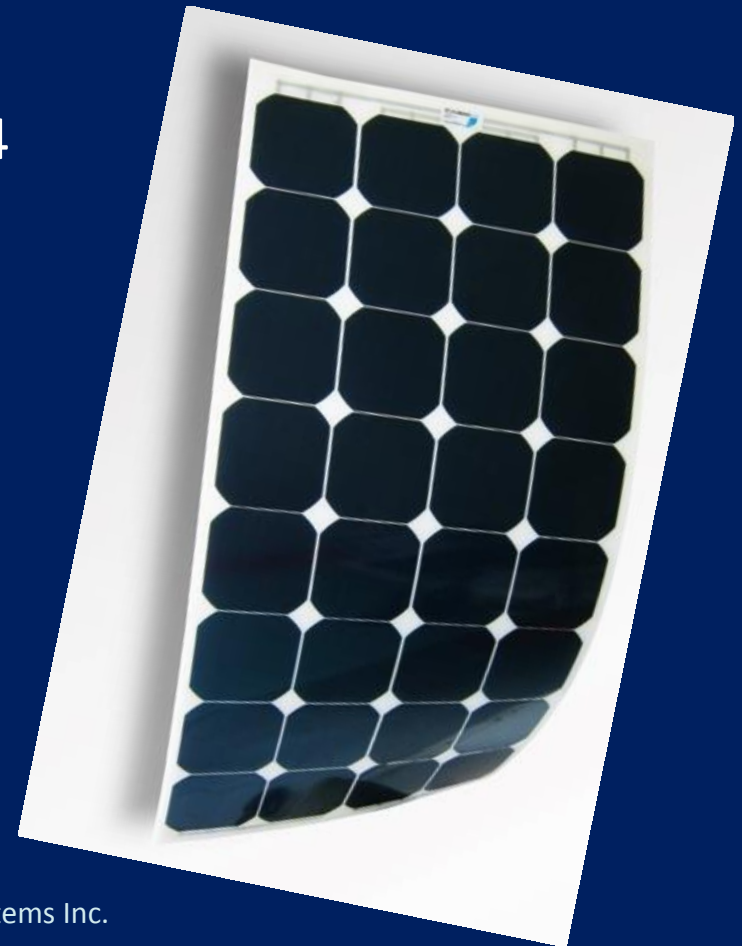
Rigid Panel Dimension Examples



Solar Panels

Purchasing Tips

- Daily output estimate:
 - Short-hand formula: wattage / 4
- Quality
- Shading “by-pass diodes”
- Mono vs Poly
- Popular flexible models
 - Gioco, Solara, Solbian
- Rigid models
 - Lots of selections



Controllers

PWM vs MPPT

- Definition
 - PWM (Pulse Width Modulation)
 - MPPT (Maximum Power Point Tracking)
- Differences
 - MPPT are more efficient (up to 30% more) then PWM
 - MPPT \$\$ vs PWN \$
 - MPPT allows for higher input Voltage
 - series wiring
 - Some MPPT models provide boost Voltage

**MPPT
75 Volts
15 Amps**



Solar MPPT Purchasing Tips

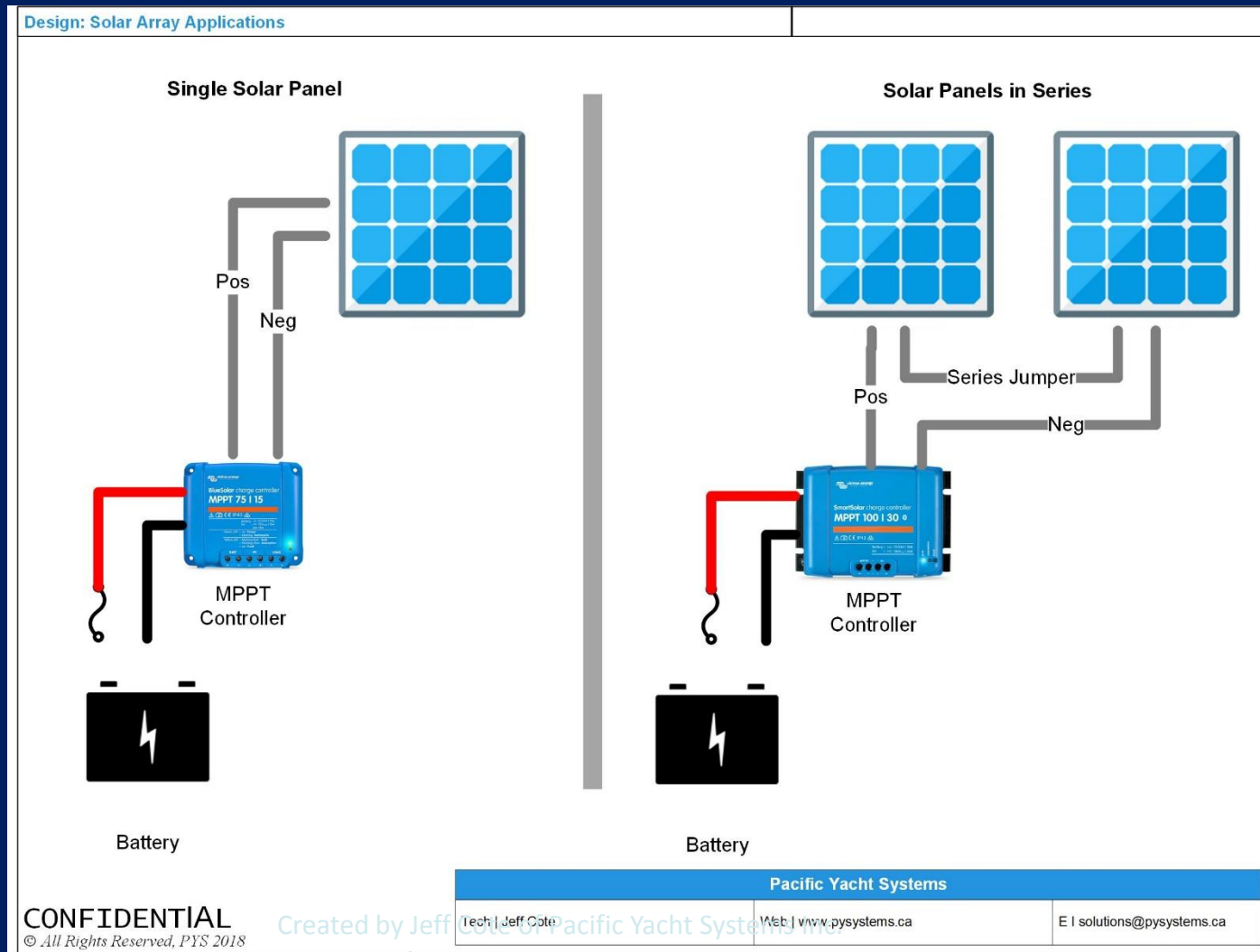
- Battery Voltage
- Maximum array Amperage
- Maximum array Voltage
- Battery chemistry
 - FLA, AGM, Lithium, custom

Solar MPPT Installation Tips

- Shade potential: consider one MPPT controller per panel
- Bring 10 gauge wire from panel to MPPT
- Config MPPT for the right battery type:
 - Flooded, AGM, Gel, etc...
- Fuse each panel and each individual load
 - Properly label all fuses and wire runs

Solar Recap

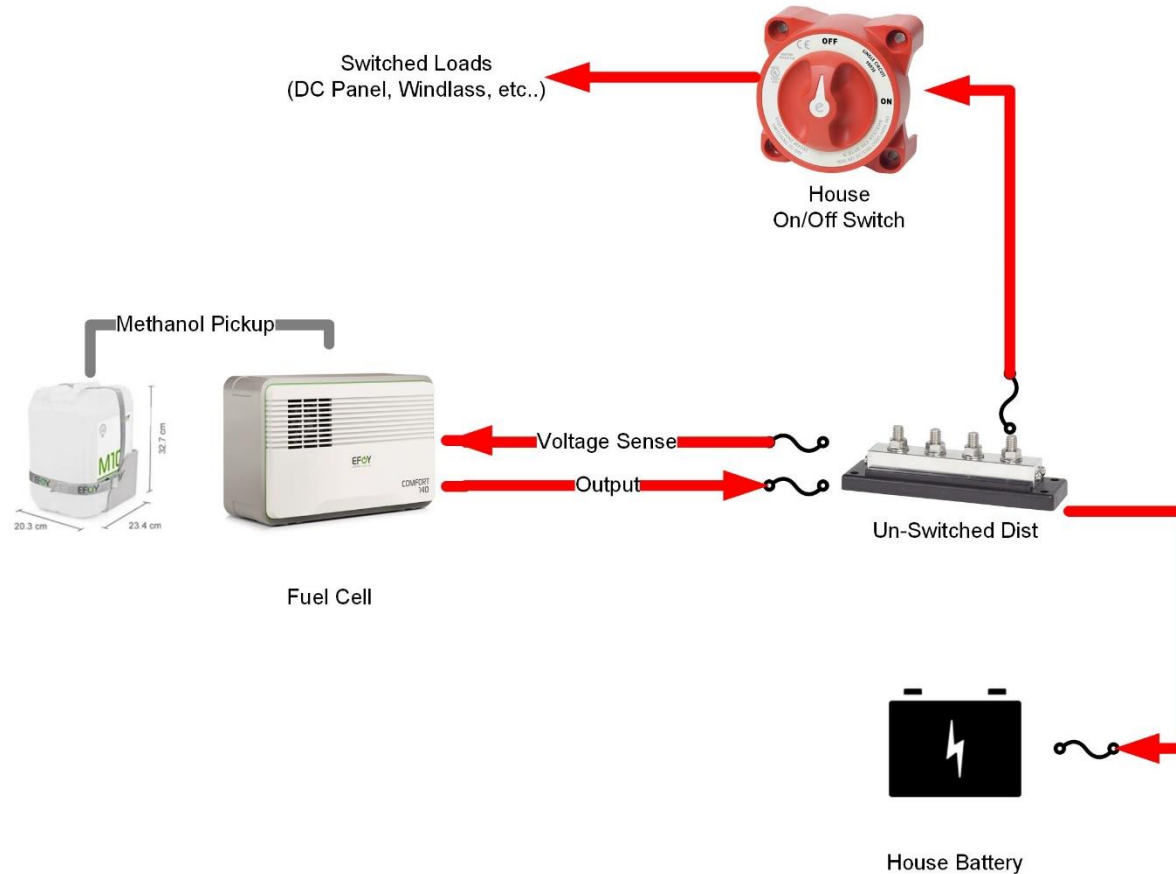
Conceptual Diagram



Power Generation: Methanol Fuel Cell

Methanol Fuel Cell Conceptual Diagram

Design: Charger Application



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Methanol Fuel Cell

- DC Charging with:
 - No noise
 - No vibration
 - No smoke
- Extends time at anchor
- Great for boats
 - Without or no need for AC genset
 - Limited battery bank
 - Limited alternator output



Methanol Fuel Cell Purchasing Tips

- Choose the right daily output:
 - 80, 140, 210
- Carry extra fuel onboard
- Popular model
 - EFOY



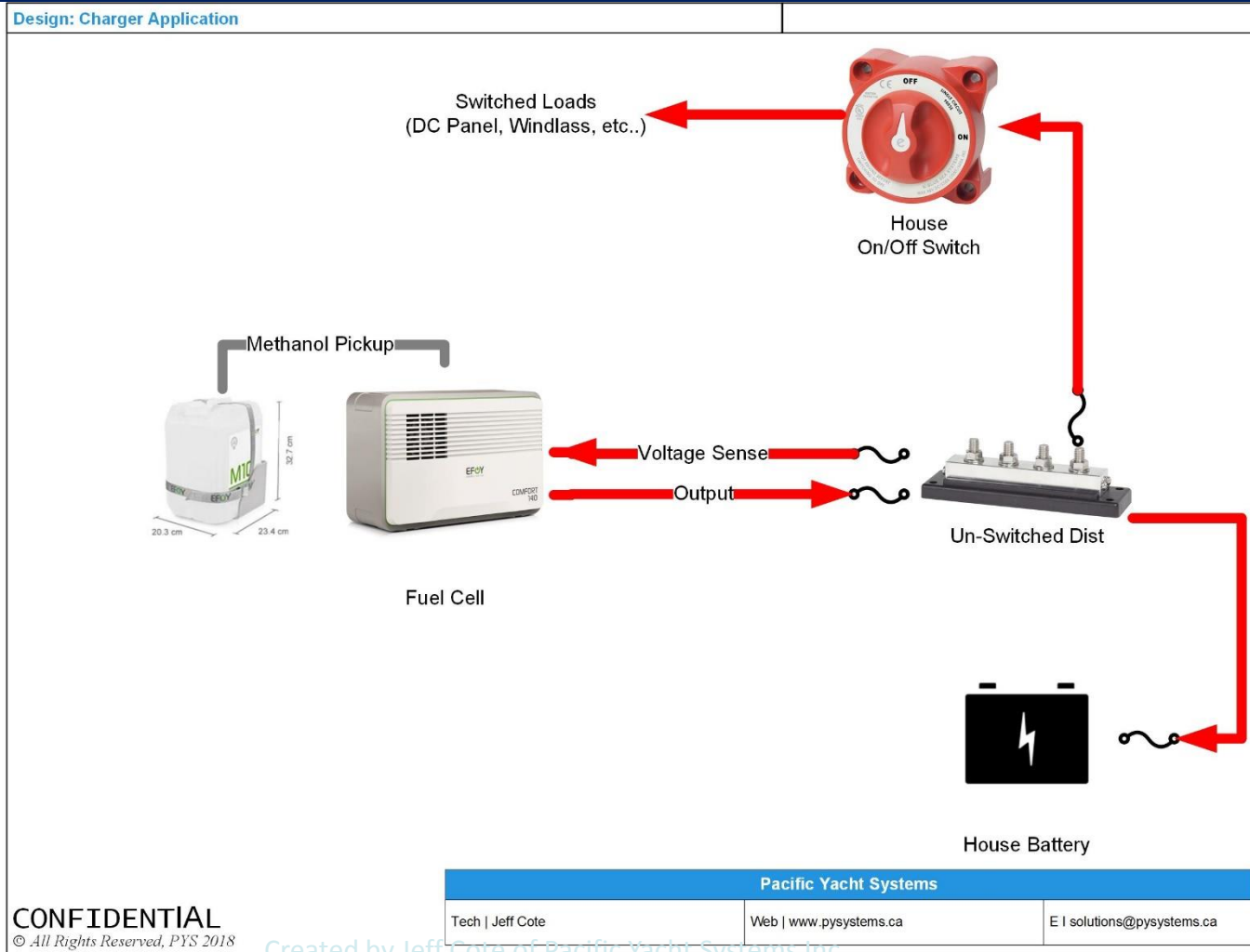
Methanol Fuel Cell Installation Tips

- Unit needs some ventilation
- Outputs distilled water
 - Water container or bilge?
- Fuel cartridge needs to be close and level to unit
- Choose right DC cable based on distance to battery



Methanol Fuel Cell Recap

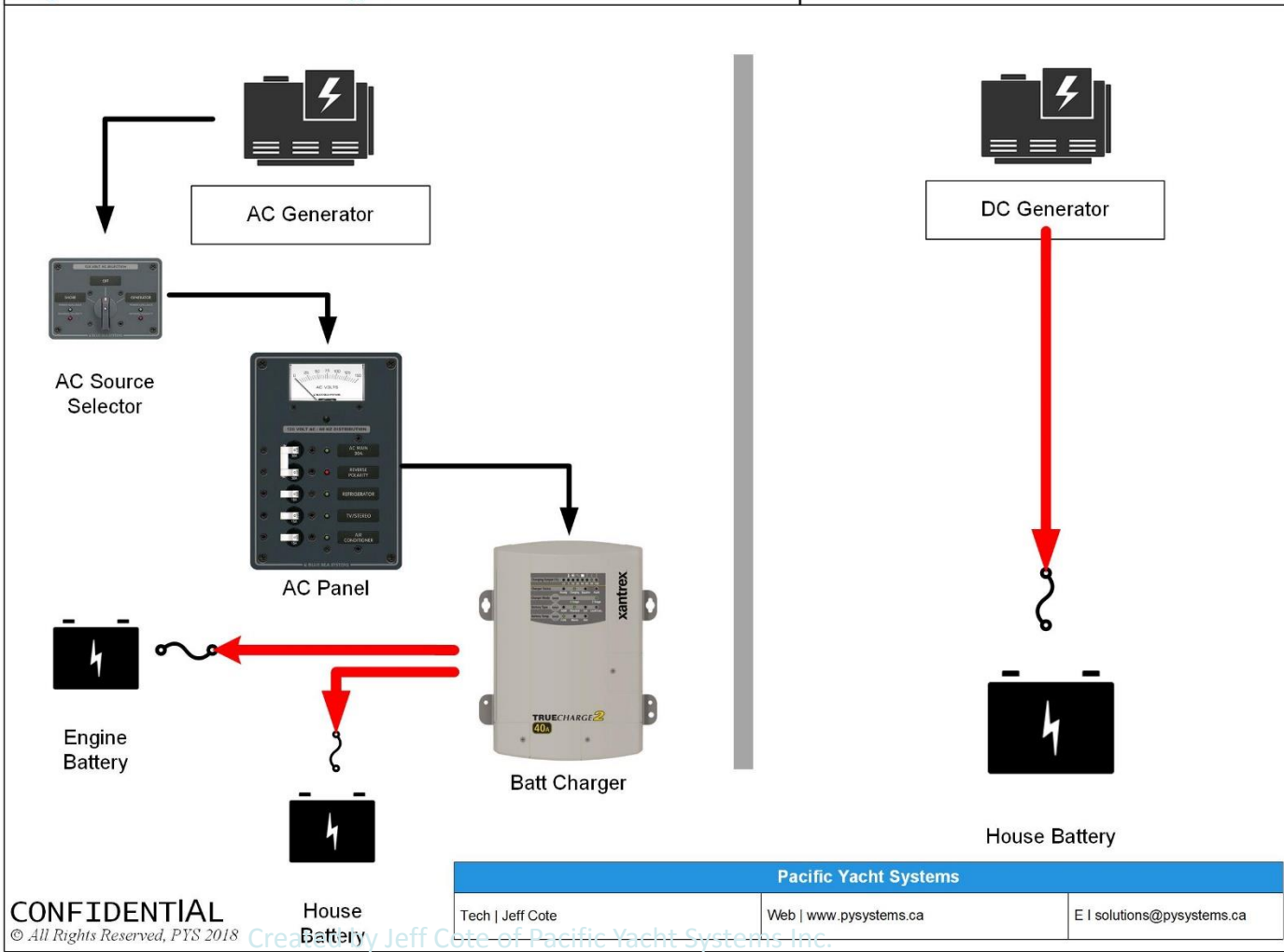
Conceptual Diagram



Power Generation: AC & DC Generators

AC Gen & DC Gen Conceptual Diagram

Design: AC Generator Vs DC Generator Applications



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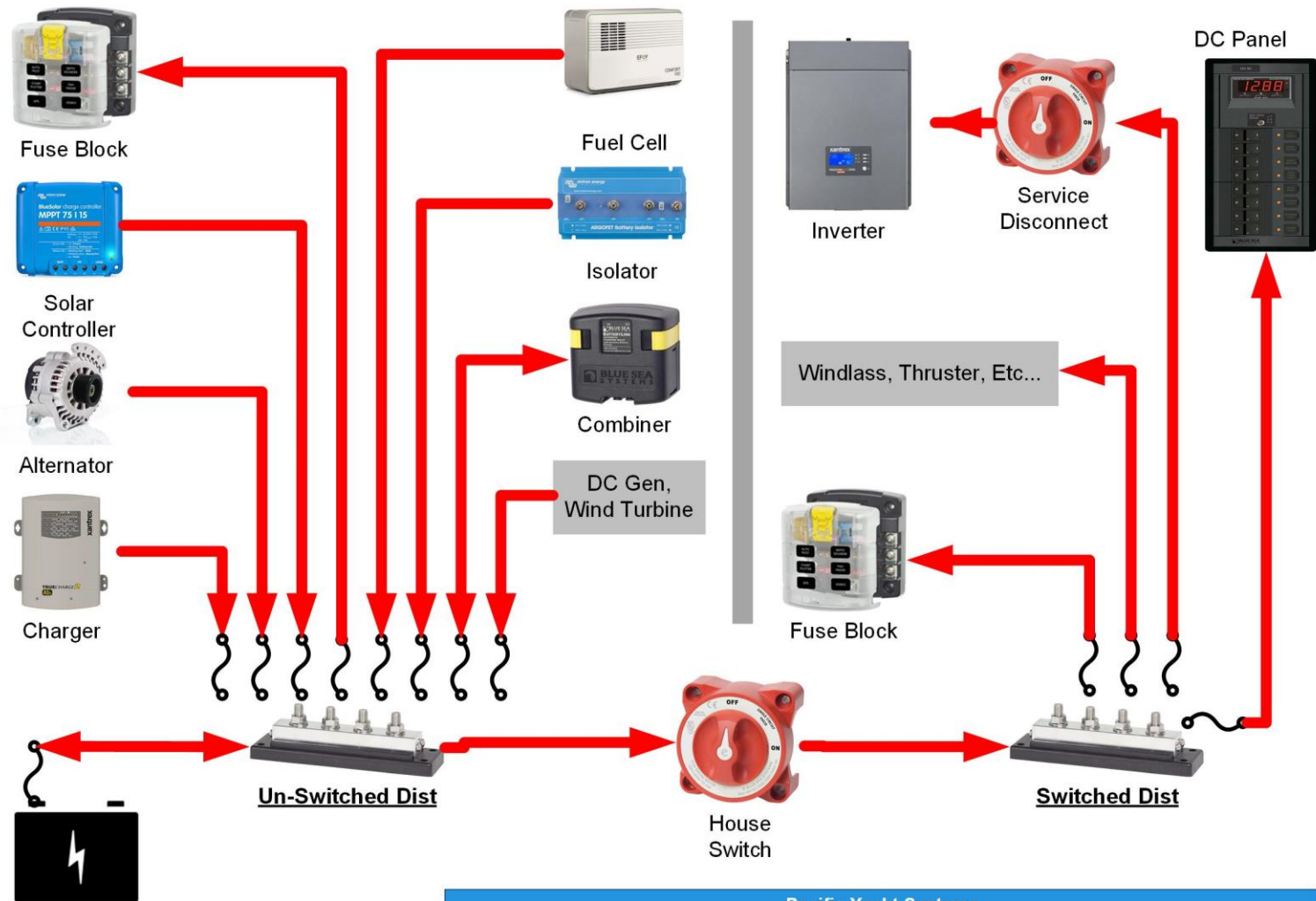
Power Sharing

Battery Combiners

Battery Isolators

DC Conceptual Overview

Conceptual Diagram – DC Overview



House Battery

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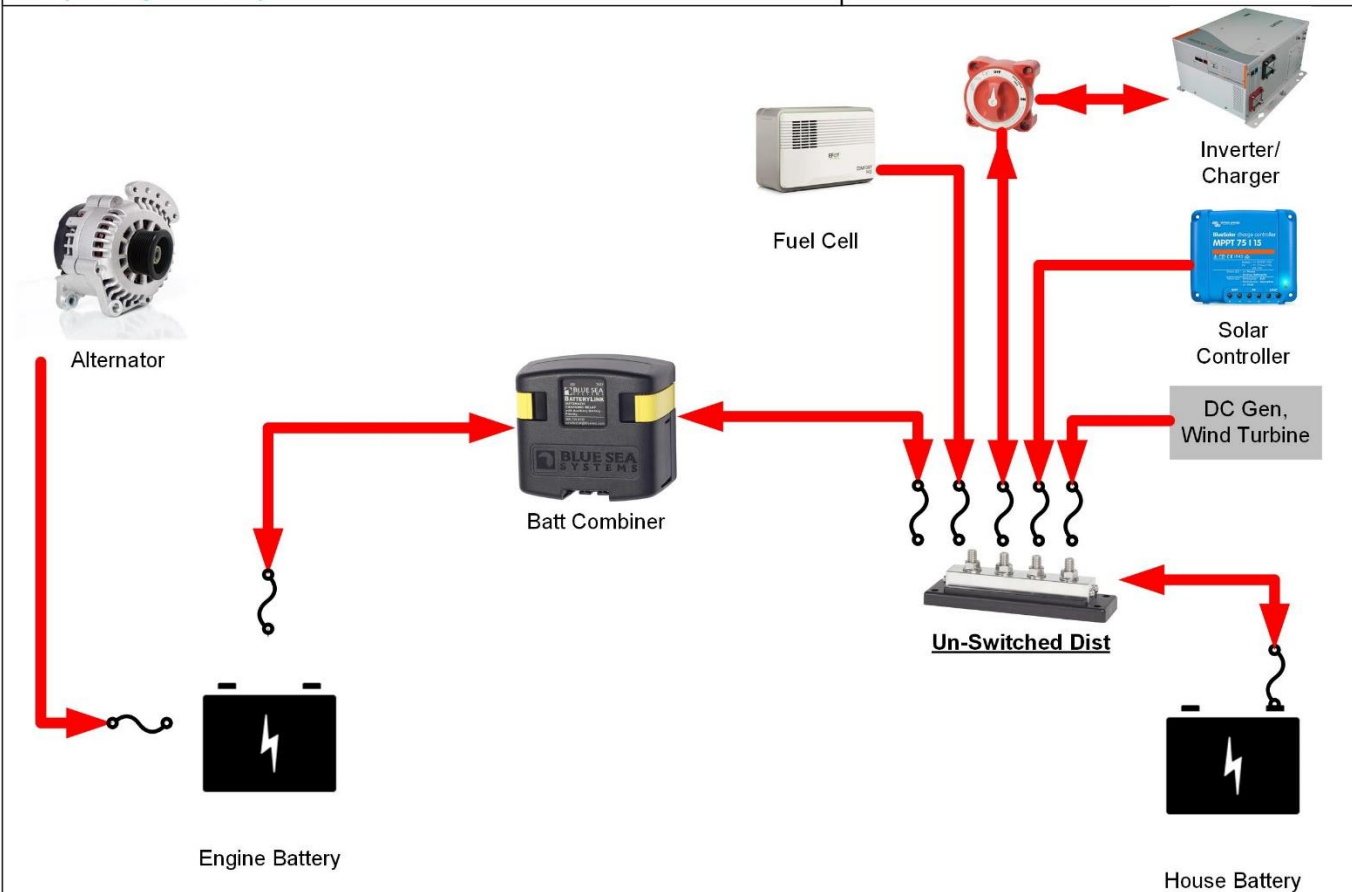
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Power Sharing: Battery Combiner

AKA ACR (Automatic Combiner Relay), VSR (Voltage Sense Relay),
Echocharge

Battery Combiner Conceptual Diagram

Conceptual Diagram – Battery Combiner



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Battery Combiners

- Batteries automatically in parallel (AKA combined) when charging voltage sensed (e.g. 13.3 VDC)
 - Automatically disconnected (e.g. 12.8 VDC)
- Replaces manually turning switch to all/both when charging



Battery Combiners

Purchasing Tips

- Amperage for application, e.g. 55, 120, 300, etc...
- Ability to activate manually
 - Local & remote
- Popular Models
 - Bluesea ACR
 - BEP VSR
 - Xantrex Echocharge (15Amps)



Battery Combiners Installation Tips

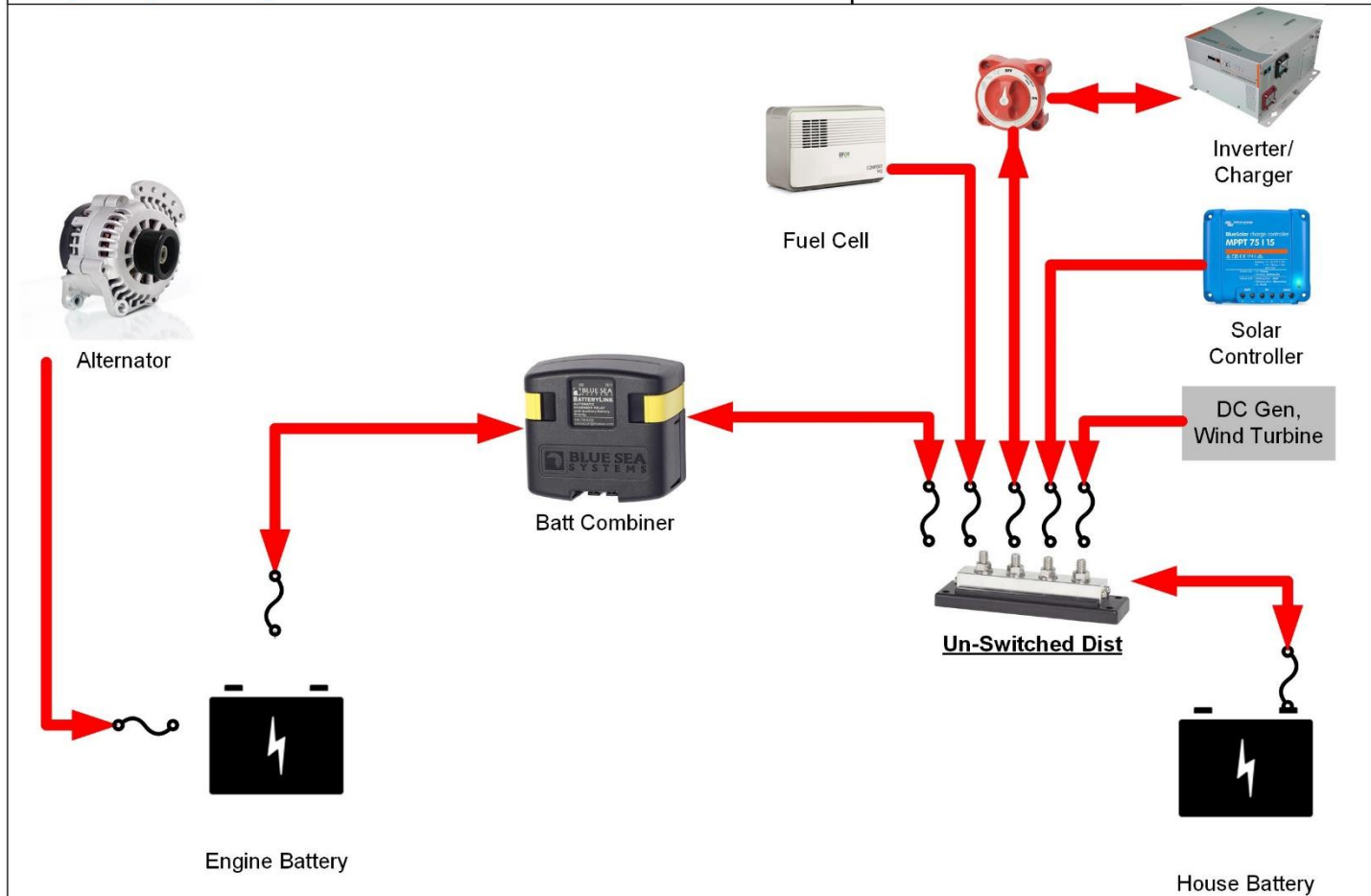
- Fuse for maximum amperage at each battery
- Connect at batteries (NOT after switch)
- Fuse ground sense connection
- Battery bank should be similar in size



Battery Combiner Recap

Conceptual Diagram

Conceptual Diagram – Battery Combiner



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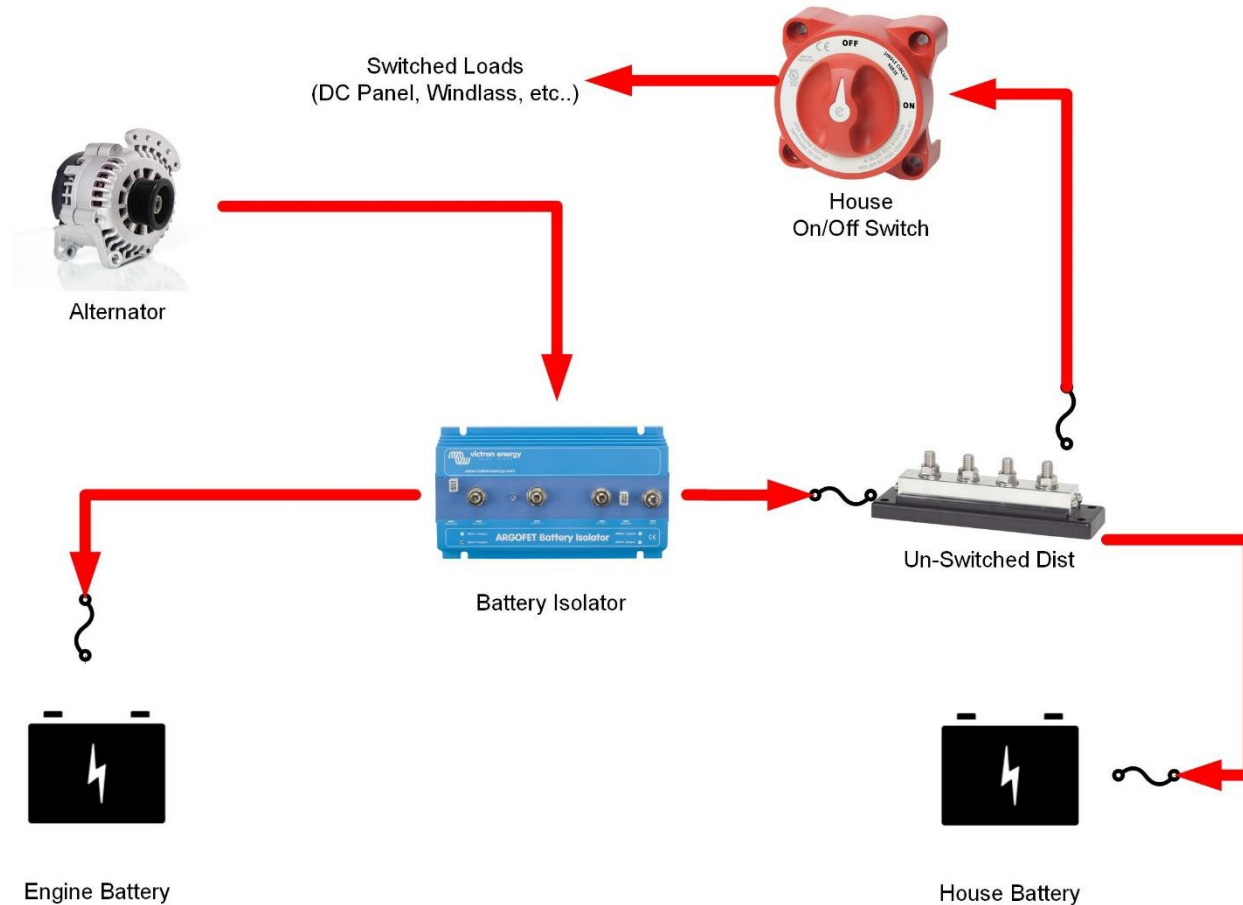
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Power Sharing: Battery Isolator

Aka FET Combiners

Battery Isolator Conceptual Diagram

Design: Battery Isolator Application



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Battery Isolator (FET)

- One alternator charging 2 or 3 battery banks simultaneously
- Replaces diode combiner
- No paralleling of batteries



Diode Combiner Example



Battery Isolator (FET)

Purchasing Tips

- High efficiency model (FET)
- Choose correct input amperage
- Prioritization of batteries
- Popular model:
 - Victron ArgoFET Battery Isolator



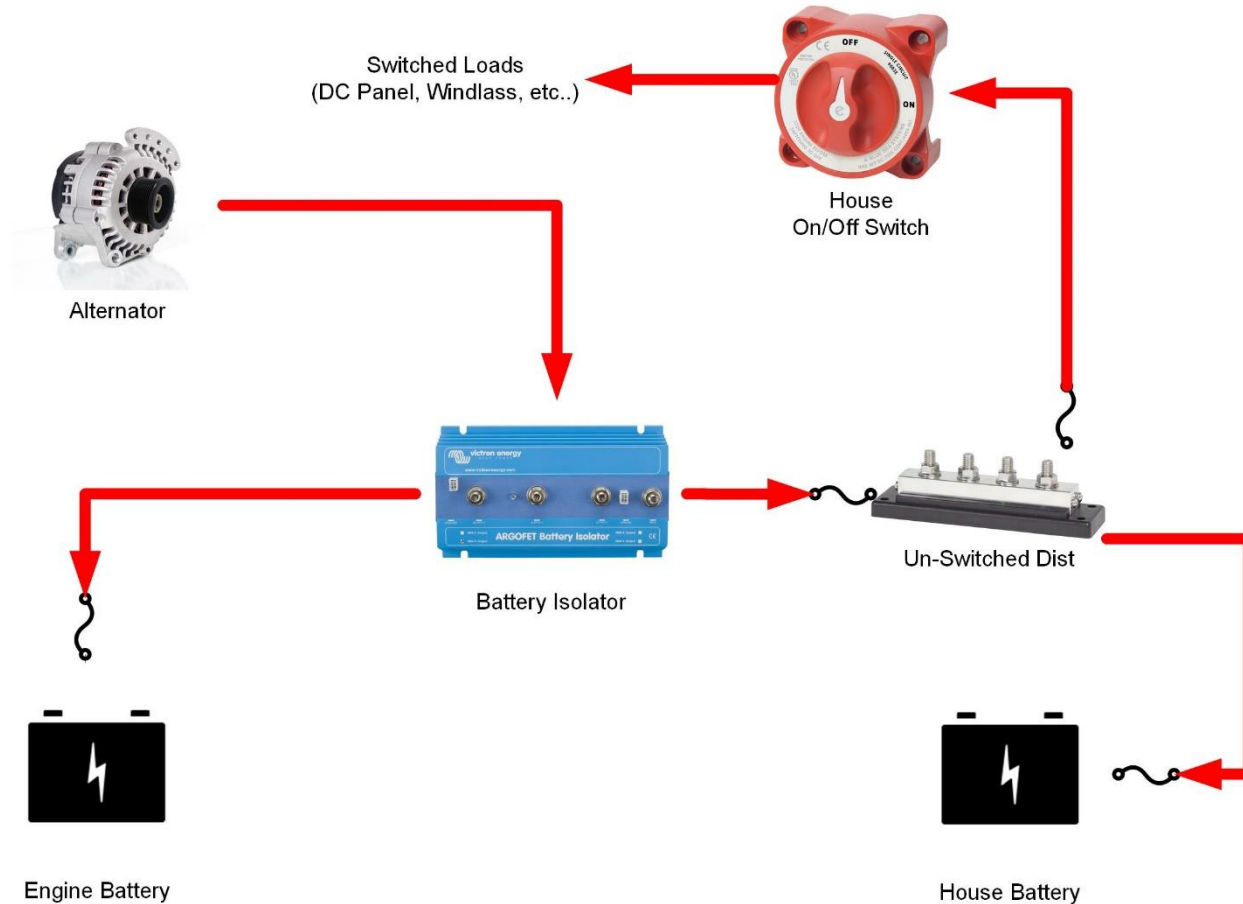
Battery Isolator (FET) Installation Tips

- Fuse alternator leads at batteries
 - Size to avoid nuisance tripping
- Size alternator cable to minimize voltage drop & alternator output amperage
 - E.g. 3% is good Voltage drop target

Battery Isolator Recap

Conceptual Diagram

Design: Battery Isolator Application



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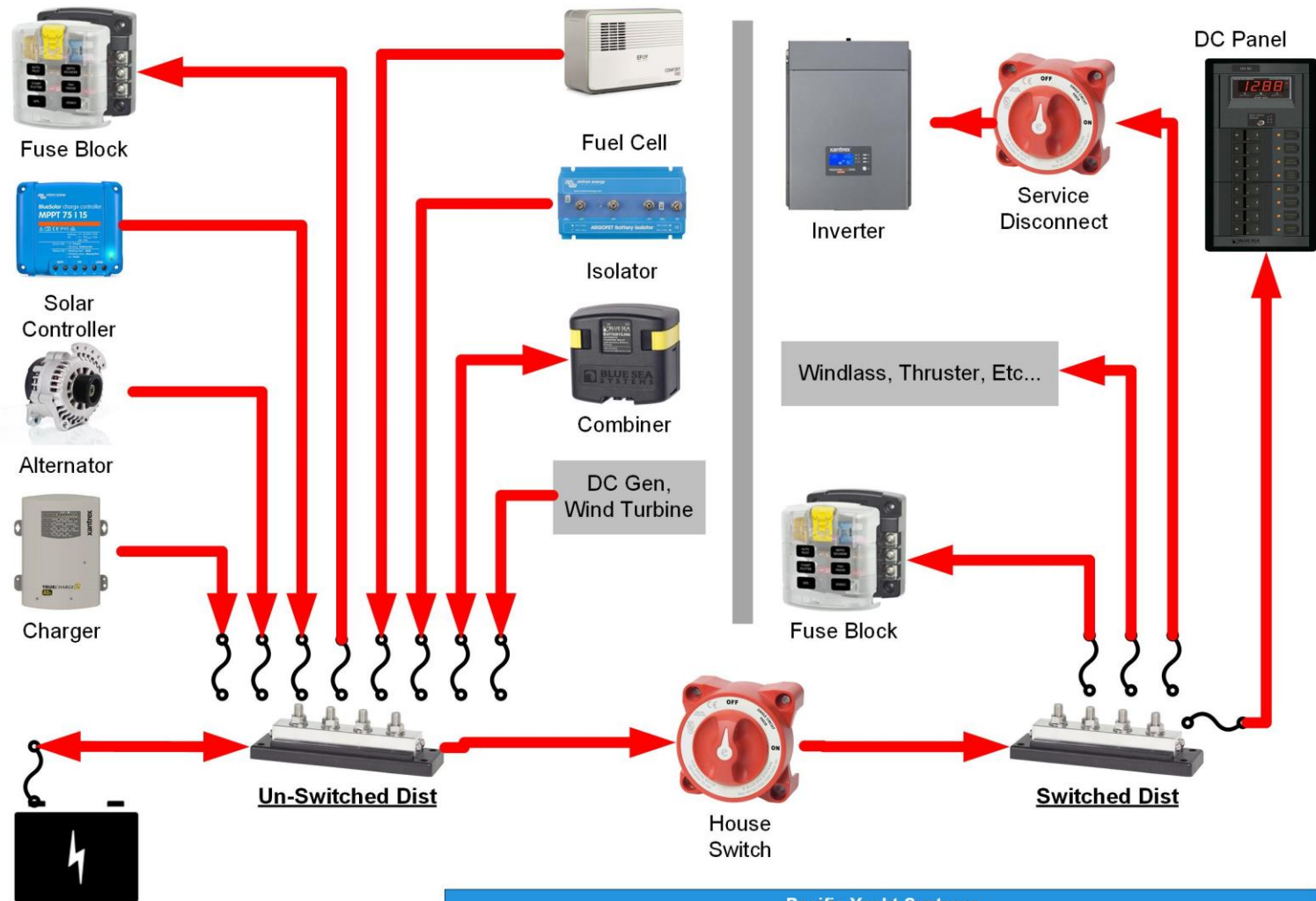
Monitoring

AC/DC Voltmeter

Battery monitor

DC Conceptual Overview

Conceptual Diagram – DC Overview



House Battery

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Monitoring: AC/DC Voltmeter

AC/DC Voltmeter

- Considerations:
 - DC Volts indication of capacity for at rest battery
 - Inspect at AC volts before turning “on” AC breaker
- Purchasing tips:
 - Consider OLED “low amp draw” display
- DC Voltmeter installation tips:
 - Connect to battery or panel?
 - Fuse battery sense connection



Voltmeter

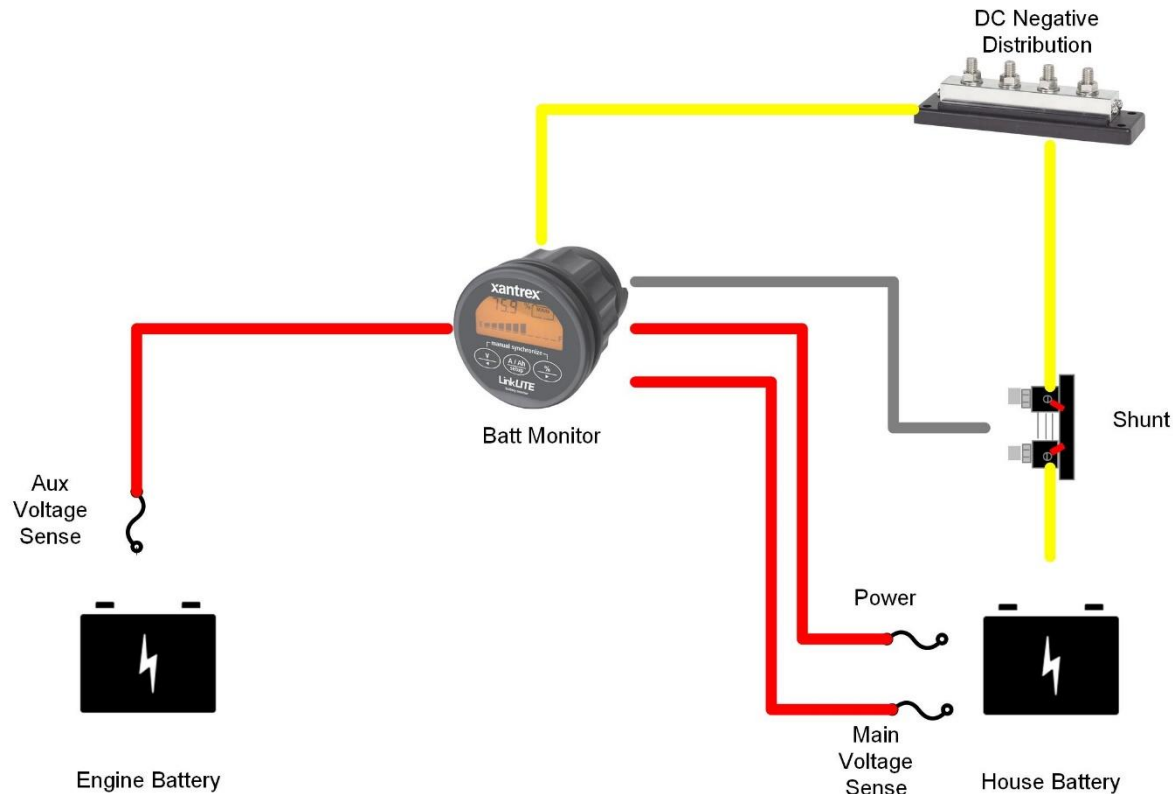
DC Analog & Digital



Monitoring: Battery Monitor

Battery Monitor Conceptual Diagram

Design: Battery Isolator Application



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Battery Monitor

- Fuel gauge for your batteries
- Monitoring for system health
 - State of charge
 - Usage patterns
- Information on your DC system
 - Voltage
 - Current
 - Amp hours



Battery Monitor Purchasing Tips

- Minimum 300 amp shunt
- Show battery capacity in percentage
- Popular models
 - Xantrex LinkLite/LinkPRO
 - Victron BMV 700 & 702
 - Bluesea M2 DC SoC Monitor



Battery Monitor Installation Tips

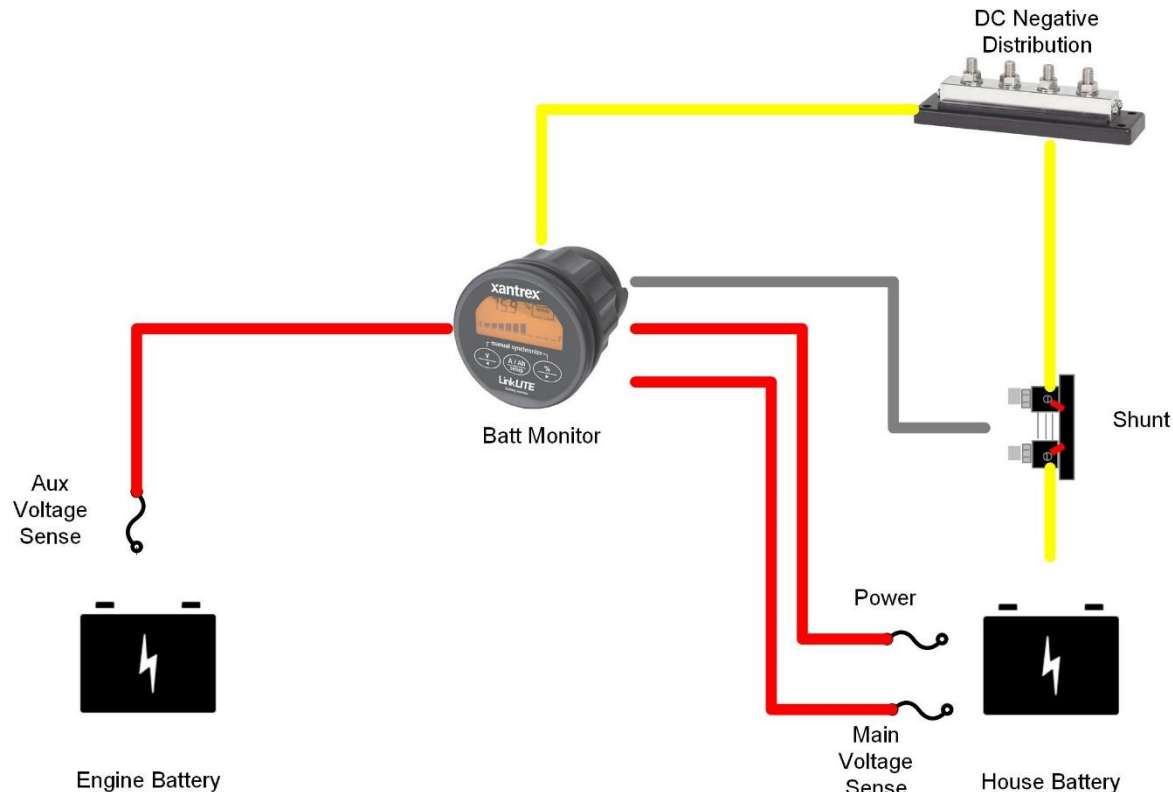
- Suited for deep-cycle batteries
- Shunt captures all current going in/out
- Voltage and battery monitor power directly connected at battery
- Configure battery amp-hours & type



Battery Monitor Recap

Conceptual Diagram

Design: Battery Isolator Application



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Power Distribution

AC Panel

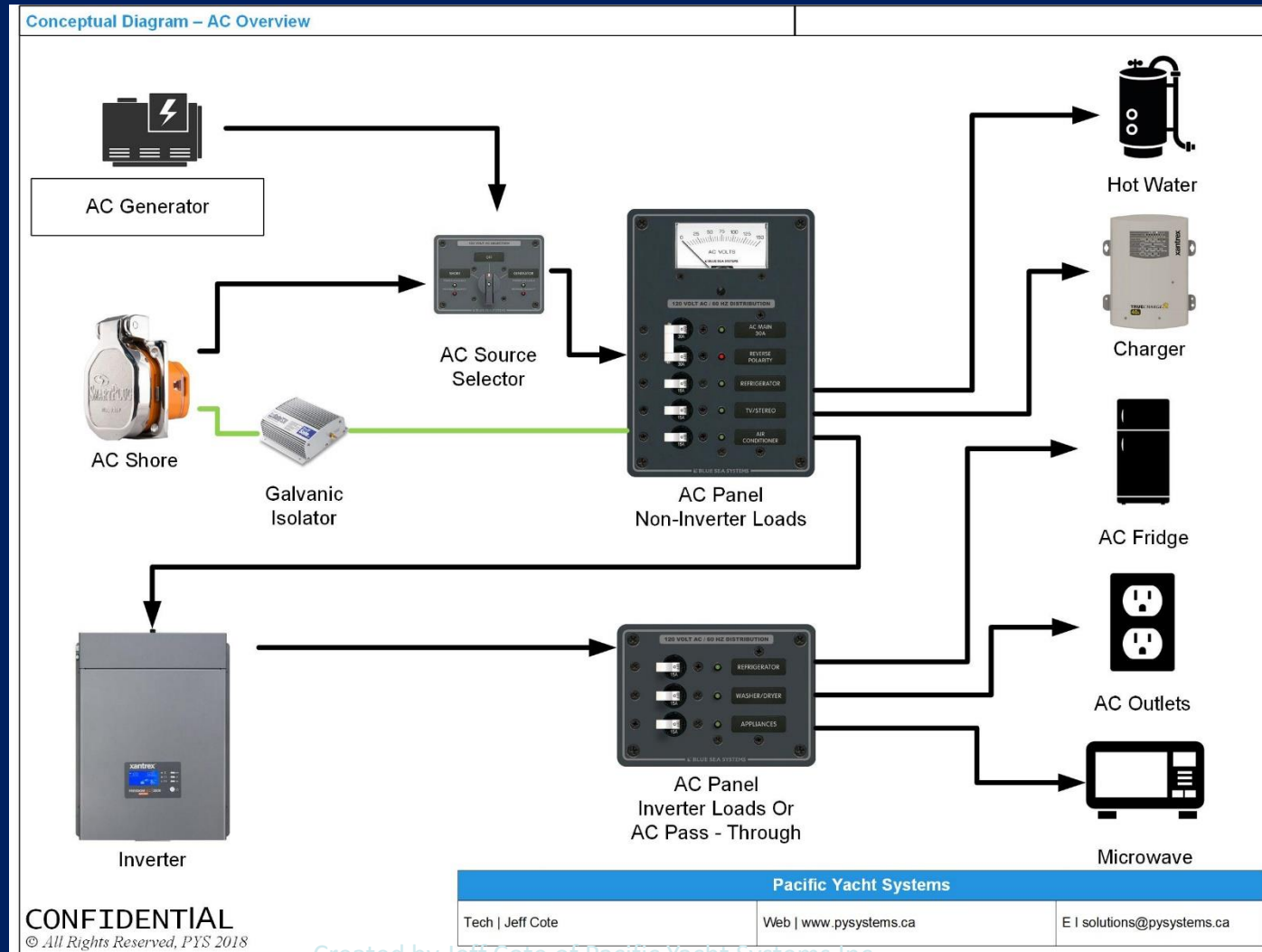
DC Panel

Power Distribution: AC Panel

Stray current protection

AC Panel

Conceptual Diagram



AC Panel

Purchasing Tips

- AC Voltmeter and Ammeter
- Double-pole input breaker for sources
- AC source selector
 - E.g. shore 1, shore 2, generator
- Reverse polarity light
- Protective AC back cover
- AC neutral and AC ground bus



AC Traditional Panel Example

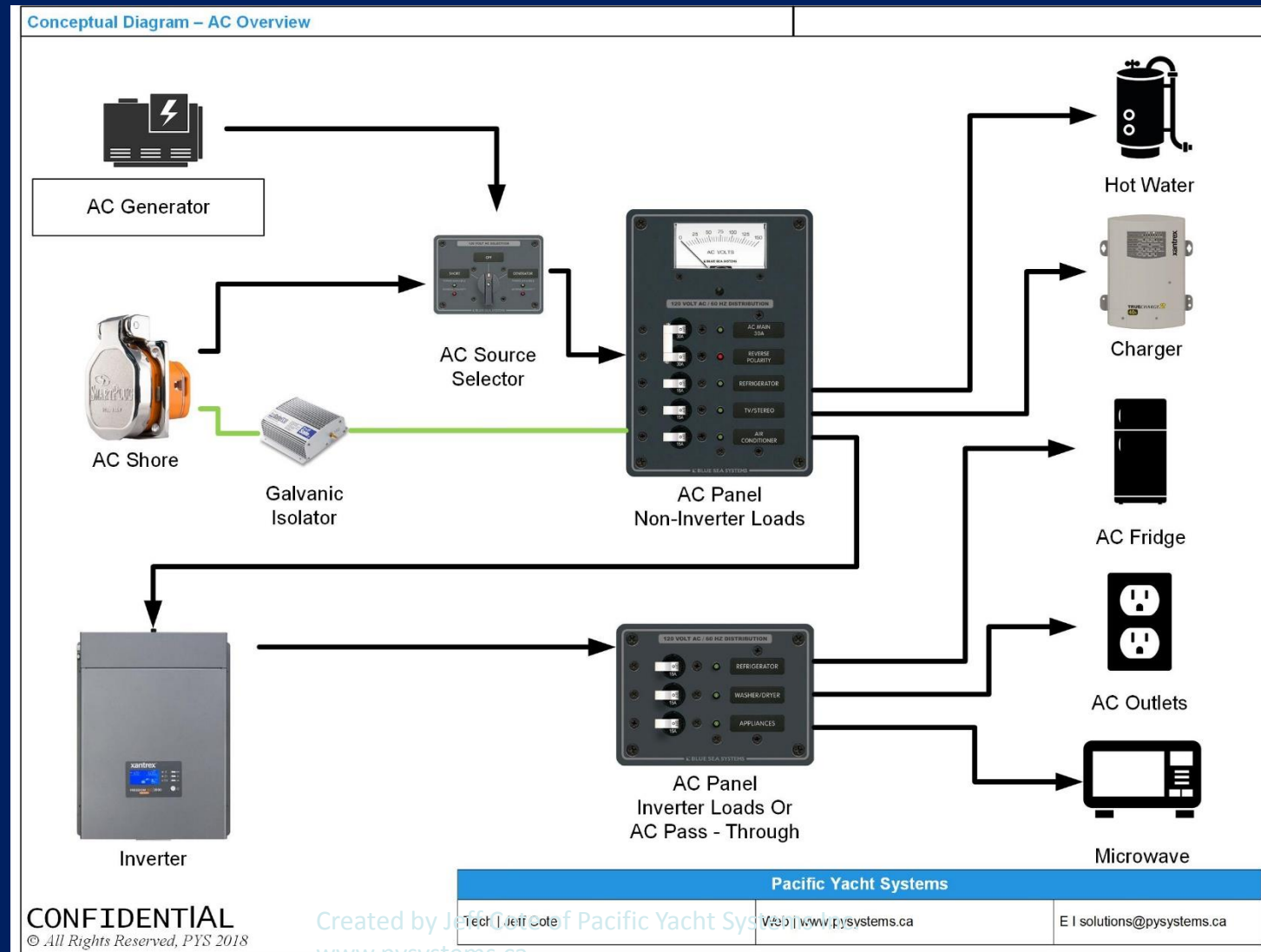


AC Panel Installation Tips

- SAFETY: Disconnect all AC sources
 - Shore, Generator, Inverter
- Label all AC cabling
- Size all AC breakers to AC loads
- Use ABYC AC color code
 - Hot (black), neutral (white), ground (green)
- Inverter integration consideration

AC Panel - Recap

Conceptual Diagram

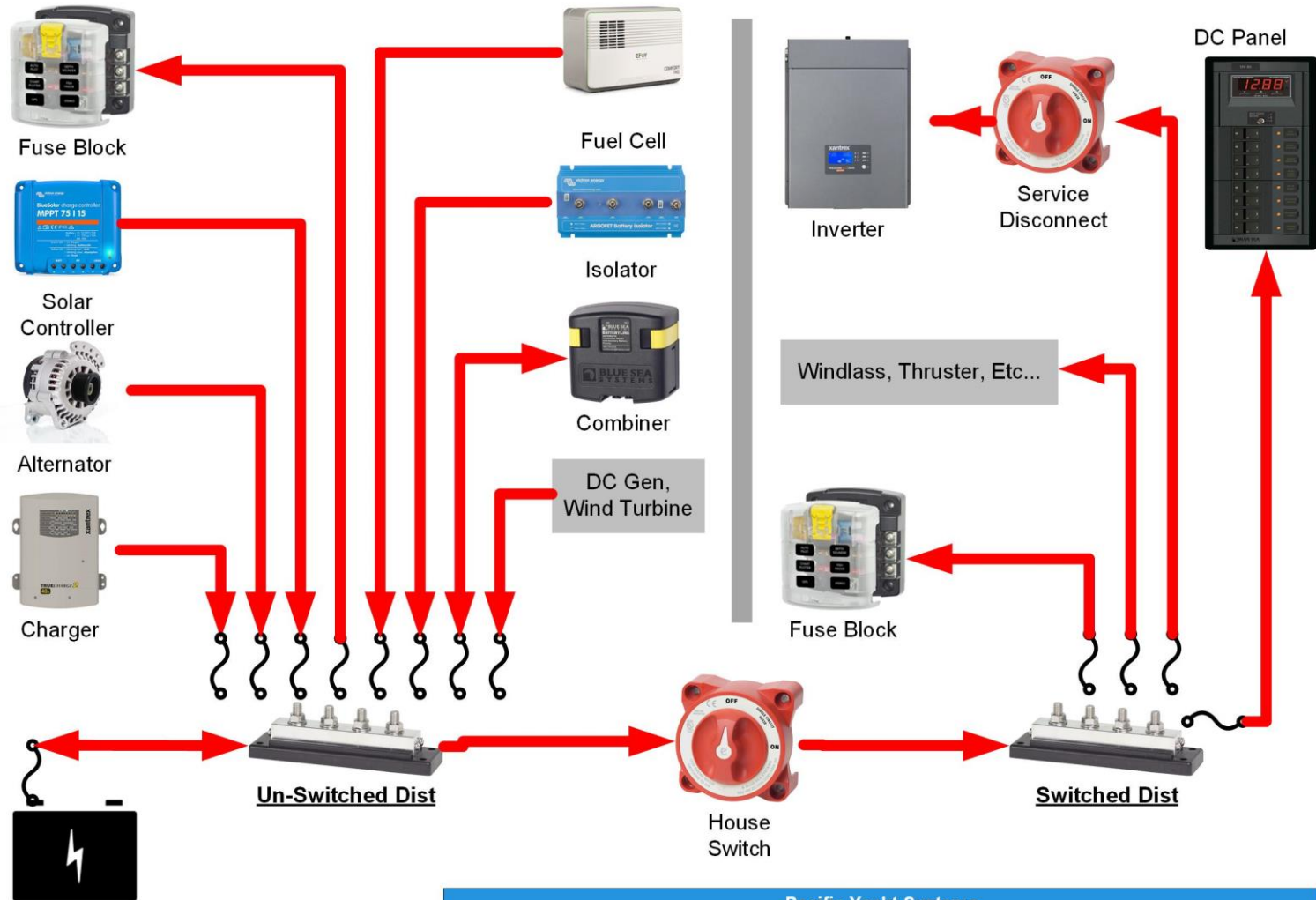


Power Distribution: DC Panel

Stray current protection

DC Conceptual Overview

Conceptual Diagram – DC Overview



House Battery

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DC Panel

Purchasing Tips

- Modular or traditional
- Anticipate growth
 - Room for spare breakers
- DC metering
- USB & 12VDC outlets



DC Panel

Installation Tips

- Appropriate DC feed wire
- Select correct circuit breaker size for each load
- Terminate loads on terminal strip
- Label all positive and negative wiring
- Wire panel voltmeter to battery or panel

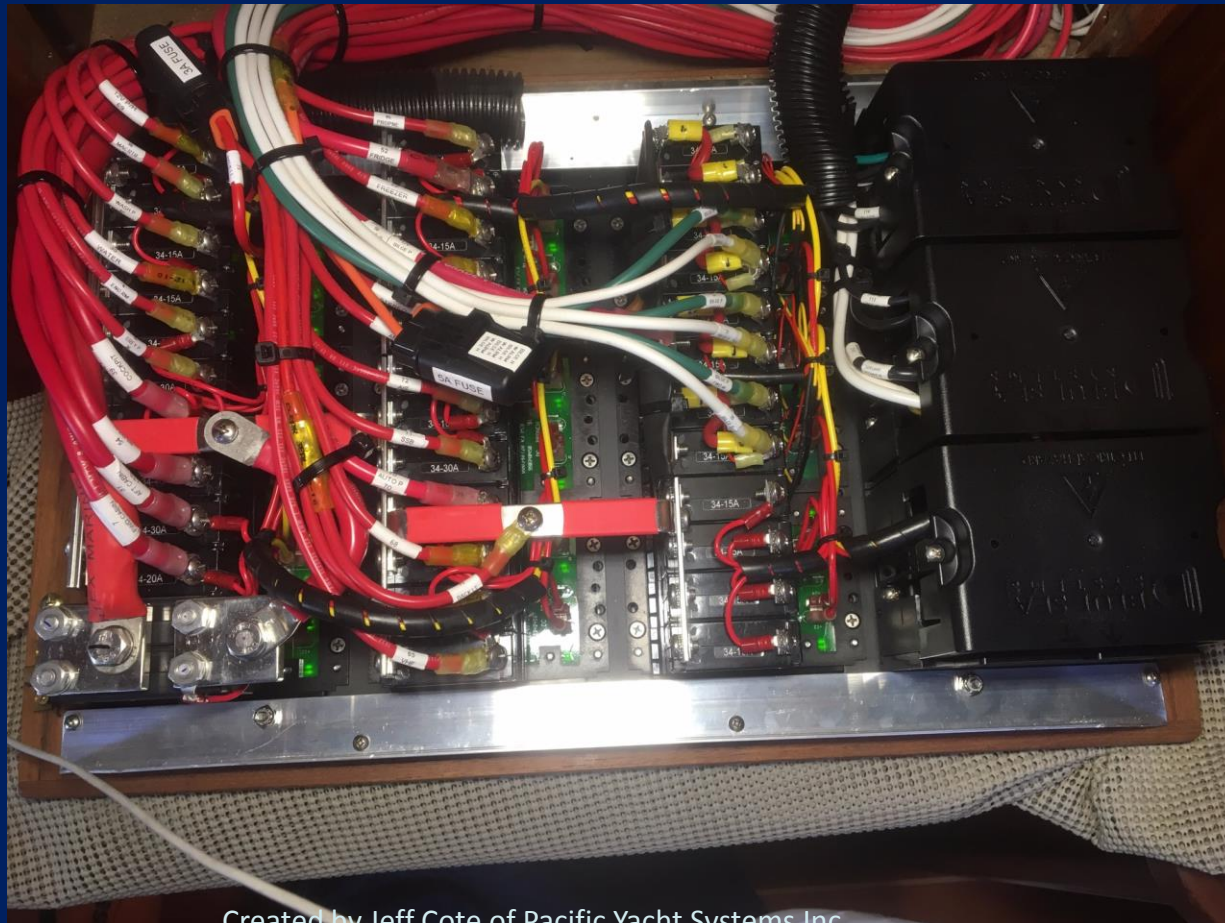


DC Panel Details

- Service loop (e.g. open panel)
- Drip loop
- Indicator lights on breakers
- Neatness
- Crimps (e.g. rings vs blade)
- Voltmeters
 - Digital vs analog
 - Voltage sense

AC/DC Panel

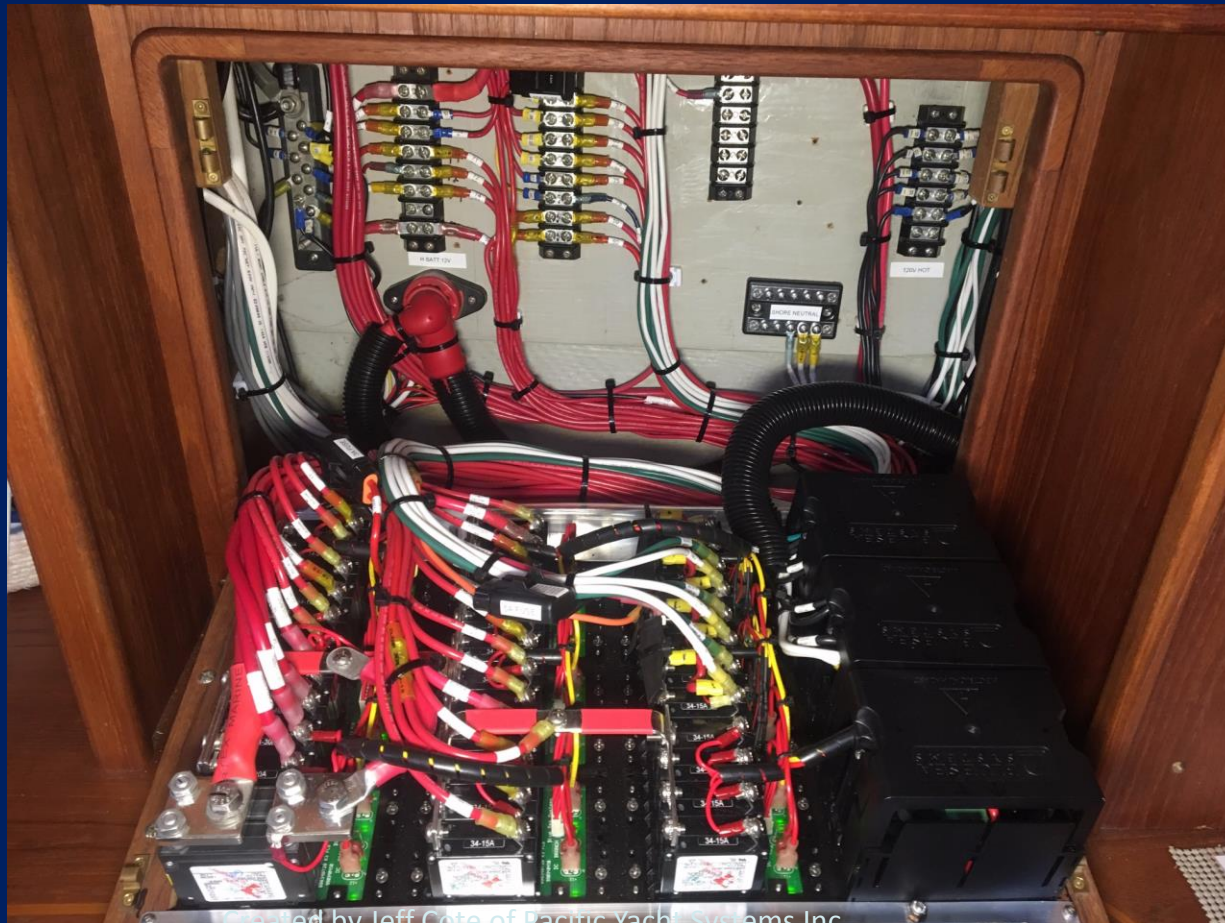
Neat & Labelled



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AC/DC Panel

Terminal Strip Interconnection Point



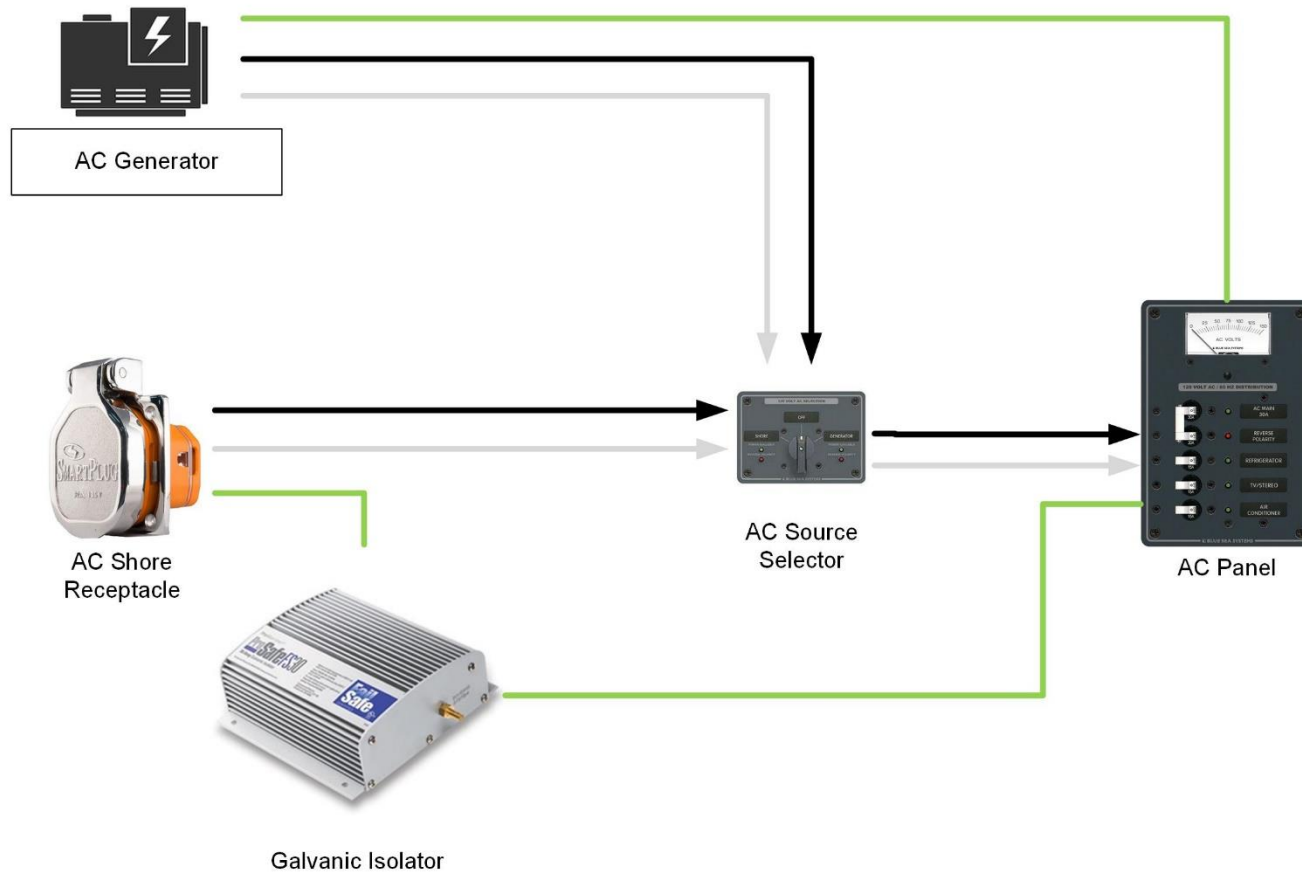
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Galvanic Protection: Galvanic Isolators

Stray current protection

Galvanic Isolator Conceptual Diagram

Conceptual Diagram: Galvanic Isolator Applications



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Galvanic Isolator

- Reduce stray low DC currents on shore power ground wire
 - Between AC and DC grounds
- Protect against destructive galvanic corrosion
- Reduce the likelihood of damage to underwater metals



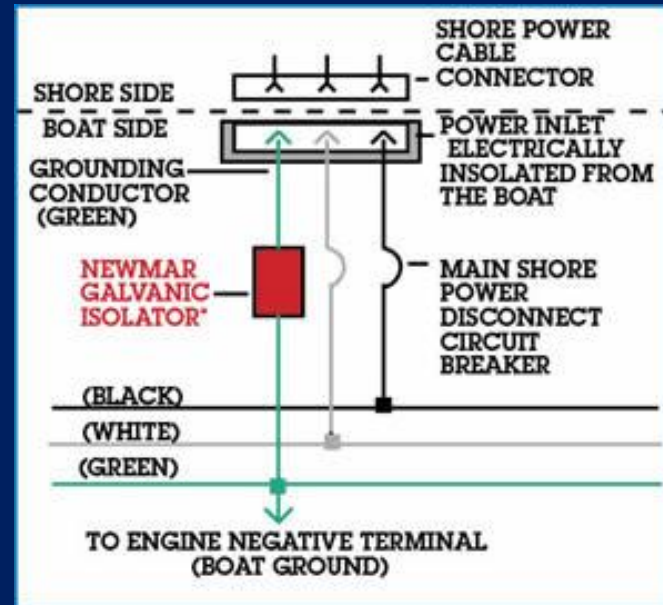
Galvanic Isolator Purchasing Tips

- Choose based on AC breaker size:
 - 30 or 50 amp
- Fail-safe models
- Popular models
 - Newmar GI-30 & GI-50
 - Promariner ProSafe 30, 50



Galvanic Isolator Installation Tips

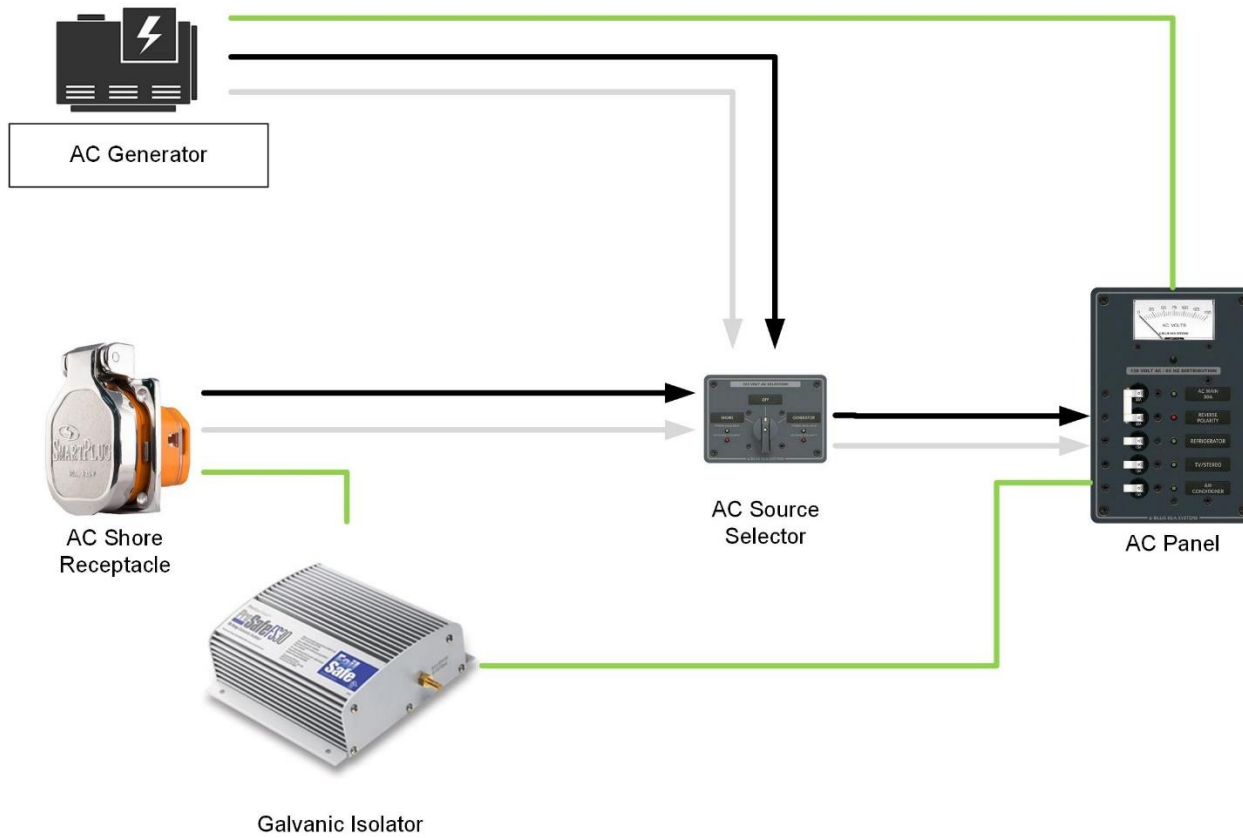
- Intercept AC grounding wire (green) as close to AC shore power
- Make sure no AC grounding wire bypasses GI unit



Galvanic Isolator Recap

Conceptual Diagram

Conceptual Diagram: Galvanic Isolator Applications



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