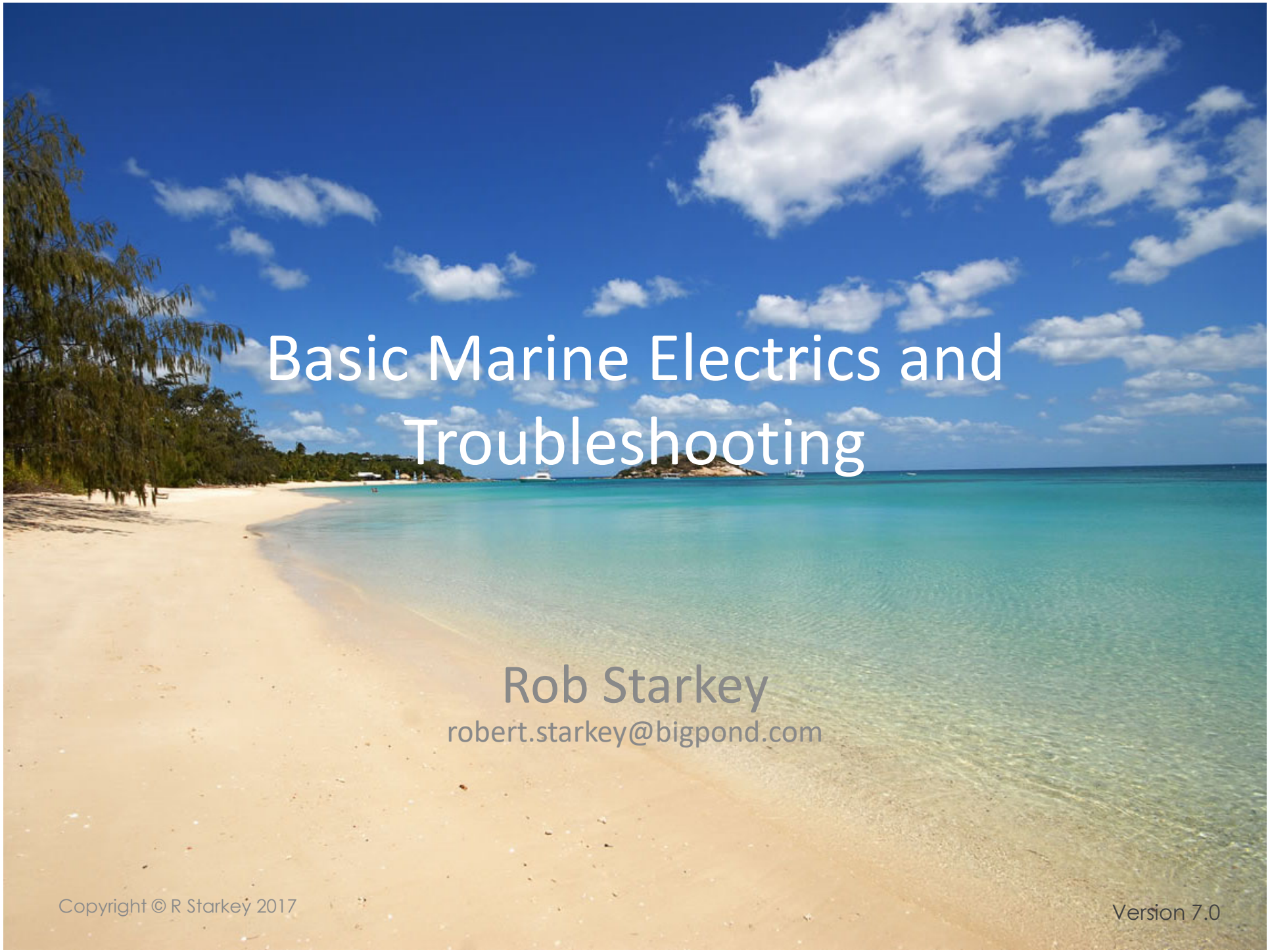

Basic Marine Electrics and Troubleshooting

Rob Starkey
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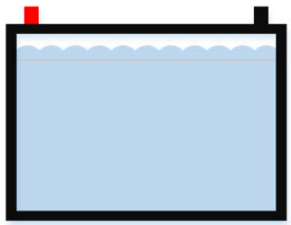
Version 7.0

Seminar Takeaways

- Voltage is the most important measurement
  - Voltage is Pressure, pressure produces output
- Must understand your system operational parameters
  - Operational; Usage, Capacity and Charge needs
  - Maintenance; System design
- Batteries do not store electricity

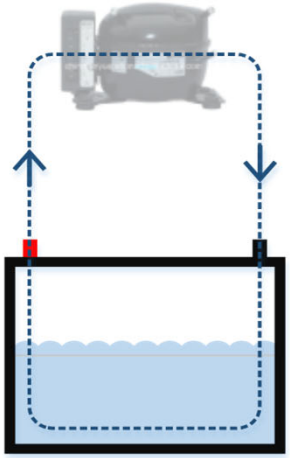
Introduction



Fully Charged

12.6V

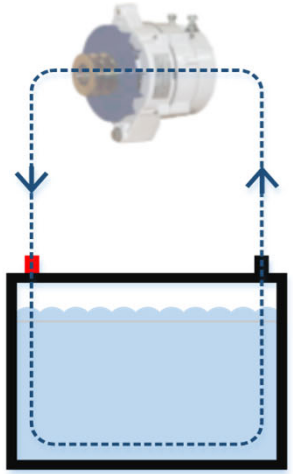
?Ah



Discharging

12.6V to 11.6V

? Amps for ? hours



Charging

13.0V to 14.3V

? Amps for ? Hours

Q1: What Battery size (Ah)?

Q2: When do we start charging?

Q3: Amps and hours required to re-charge?

A1: 3 times your daily consumption. (Note)

A2: 80% to 50% of Battery capacity. (Note)

A3: Amps = 20% to 30% Ah, 2to 3 hours

Note: Lead Acid not Lithium-Ion (A1: 1.4, A2 80% to 20%)

Agenda

- A few bootstrap terms to get started
- Managing expectations
- Battery fundamentals
- Charging batteries
- Introduction to marine 12 volt circuits
- Basic marine 12 volt systems
- Troubleshooting marine 12 volt systems
- Battery Management

First a few electrical terms

Voltage (V)	• The pressure of the circuit, without pressure there is no output!
Current (I)	• You increase voltage (pressure) to increase the current flowing measured in amps
Ampere-hours (Ah)	• The amount of current (amps) a battery will delivery and the time (hours) it delivers the current (Ah=current x Hrs)
Power (P)	• The work being done, measured in watt (Power = voltage x current)

First a few electrical terms

Battery	• A source of electrical energy
Starting battery	• The battery for starting or cranking engines (Cranking battery)
House battery	• The battery providing electrical loads when the engine is not running (Deep cycle battery)
Rate of discharge Rate of charge	• 20 amp charge for ½ hour increases your battery by 10 Ah
State of charge	• Indication of available battery capacity measured in percent (fully charged = 100%)

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Managing Expectations

2 What battery capacity do I require?

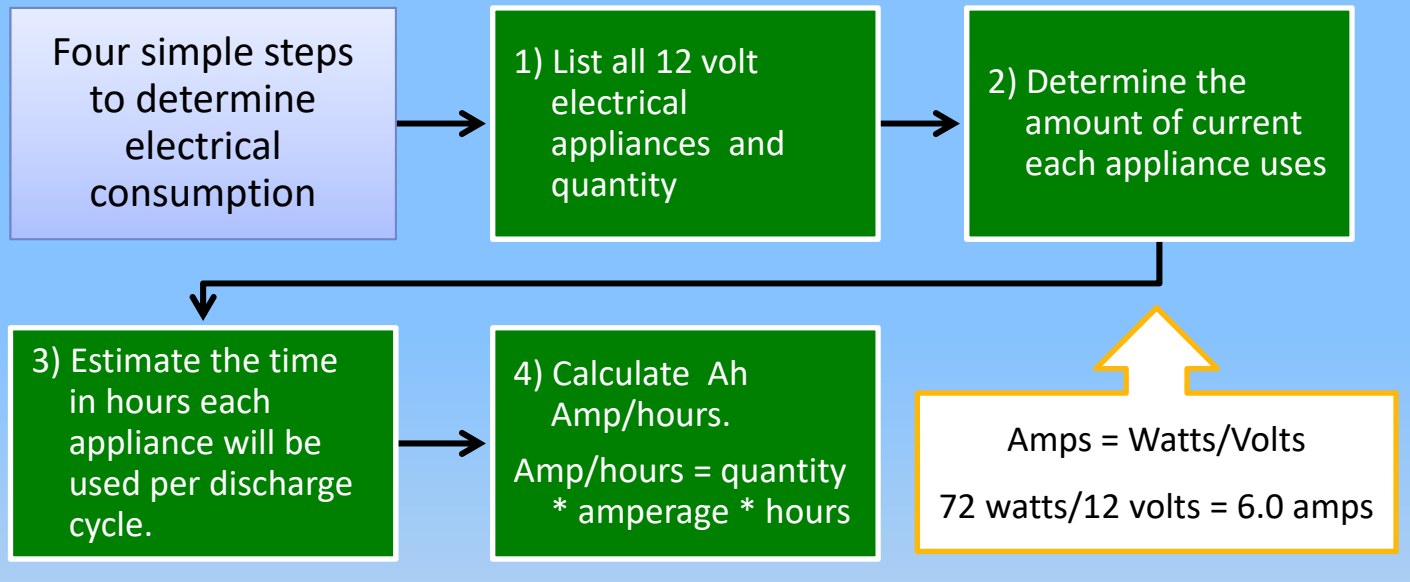
Discharge

Charge

1 How much electrical energy do I consume?

3 What charge current and charge time do I require?

1 Consumption per charge cycle



(1) Appliance	(1) Quantity	(2) Current (amps)	(3) Time Used (Hrs)	(4) Total (Ah)
Cabin lights	8	1.5 A	1.0 Hrs	**12 Ah**
VHF (receive)	1	0.3 A	24 Hrs	**7 Ah**
Fresh water pump	1	2.5 A	0.5 Hrs	**1 Ah**
Navigation lights	3	0.9 A	12.0 Hrs	**11 Ah**
Refrigerator	1	6.0A	24/3 Hrs	**48Ah**
		Total Amp-Hours (Ah) usage per discharge cycle		**79 Ah**

Typical appliance loads

12 Volt Appliance	Amps (typical)
Anchor Light	2.0
Anchor light (LED)	0.25
Anchor windlass	40 - 300
Autopilot standby (drive)	1 (30)
Bilge blower	2.5
Bilge pump	5.0
Cabin fan	0.2 - 1.0
Cabin lights (incandescent)	1.5 - 3.5
Cabin lights (halogen)	1.6 - 2.0
Cabin lights (LED)	0.3
Fluorescent light	0.7 - 1.8
Depth sounder	0.1 - 0.5
Fresh water pump	5.0

12 Volt Appliance	Amps (typical)
GPS	0.5 – 1.0
Log	0.1
Masthead (incandescent)	2.0
Radar	4.0 - 8.0
Refrigerator	5.0 - 8.0
Navigation lights	2.5
Spotlight	10.0
Deck lights	8.0
HF radio RX (TX)	2.0 (25 - 35)
VHF radio RX (TX)	1.0 (5.0 - 6.0)
Stereo HiFi	1.0
Instrument slave (each)	0.1
Instrument master	0.3 - 1.0

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Some battery facts

A battery does not store electrical energy, it converts chemical energy into electrical energy by electrochemical reaction

You shorten the specified life of your battery by undercharging and conversely by overcharging

Specified battery life is shorter when discharging below 50% of capacity

Batteries are inefficient, you need to replace 10% to 20% additional amp-hours to recharge your batteries

The voltage difference between a fully charged and fully discharged battery is approximately 1.0 volt (12.6 v to 11.6v).

More battery facts

The greater the discharge rate, the less battery capacity available

- 100Ah battery discharging at 65A for 1 hour will exhaust battery providing **65Ah**
- 100Ah battery discharging at 5A for 20 hours will provide **100Ah**

A deeply discharged battery struggles supplying power to high amperage device, however may supply sufficient power to a low amperage device

- Open circuit voltage of **12.5 Volts**
  - Starter Motor 11.09 volts 231 amp 2562 watts
  - Light bulb 12.49 volts 1 amp 12.5 watts
- Open circuit voltage of **12.0 Volts**
  - Starter Motor 10.00 volts 200 amp 2000 watts (-22%)
  - Light bulb 11.90 volts 1 amp 11.9 watts (-5%)

More battery facts

When charging a battery, the charge voltage must be higher than the fully charged voltage, typically 13.8 to 14.0 volts

- Greater the voltage difference between charge device and battery, greater the charge current

A deeply discharged battery can absorb as much as 30% of its capacity, until it starts gassing (14.4 volts)

- 10% charge rate, reaches gassing voltage at 8 hours and will be 85% charged
- 40% charge rate, reaches gassing voltage at 1.3 hours and will be 55% charged

The most practical charging rate for a quick recharge is 20% to 30% of the battery capacity until it reaches the gassing voltage

More battery facts

A battery accepts more charge amps at 50% discharge than at 25% discharge

- Battery acceptance rate tapers to just a few amps as it approaches fully charged.
- A 100 Ah battery at 50% capacity, accepts 17 amps
- The same battery at 75% capacity, accepts 7 amps

The charge time from 50% to 80% is much shorter than the time it takes from 80% to fully charged

(Q2) What battery capacity

Discharging your battery below 50% will significantly shorten it's specified life expectancy

- 50% capacity should be your operational discharge limit

The charge rate of a battery decreases above 80% of charge

- For a 100Ah battery, 17A at 50% and 7A at 75%
- Both time and cost to charge double above 80%

Therefore the efficient capacity of a battery is 30% of its Ah capacity.

- For a 100 Ah battery you should only budget on 30 Ah discharge before recharging.

Battery capacity (Ah), needs to be at least three (3) times your usage between charges

Battery fundamentals

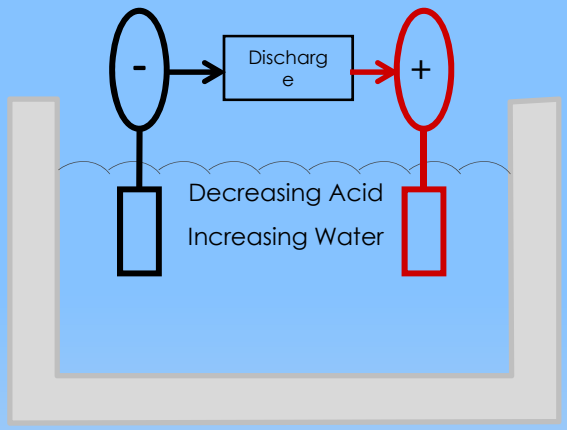
What type of battery is best suited for my type of sailing, what performance should I expect and what additional battery facts should I be aware of?

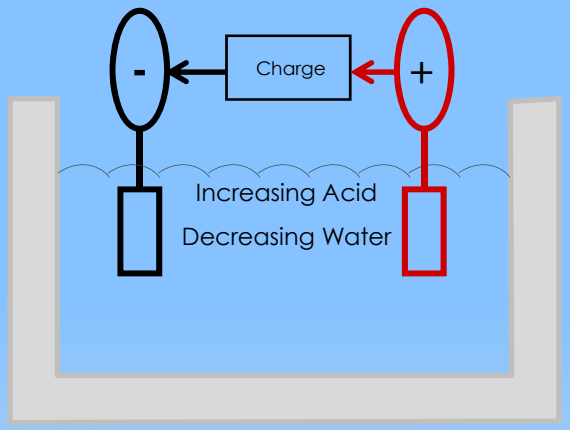
- The basic battery
- Battery types, (applications & construction)
- Understanding battery ratings
- Life expectancy
- Connecting batteries
- Battery maintenance

Galvanic series table (salt water)

Metals and alloys	Range in Volts	
Zinc	-0.98	-1.03
Aluminum Alloys	-0.76	-1.0
Cadmium	-0.70	-0.73
Mild Steel	-0.60	-0.71
Stainless Steel Type 410 (active)	-0.46	-0.58
Stainless Steel Type 316 (active)	-0.43	-0.54
Naval Brass	-0.30	-0.40
Copper	-0.30	-0.57
Lead Tin Solder	-0.28	-0.37
Admiralty Brass	-0.28	-0.36
Silicone Bronze	-0.26	-0.29
Stainless Steel Type 401 (passive)	-0.26	-0.35
Stainless Steel Type 316 (passive)	-0.00	-0.10

The basic battery





Decreasing Sponge Lead
Increasing Lead Sulfate

Decreasing Lead Oxide
Increasing Lead Sulfate

Increasing Sponge Lead
Decreasing Lead Sulfate

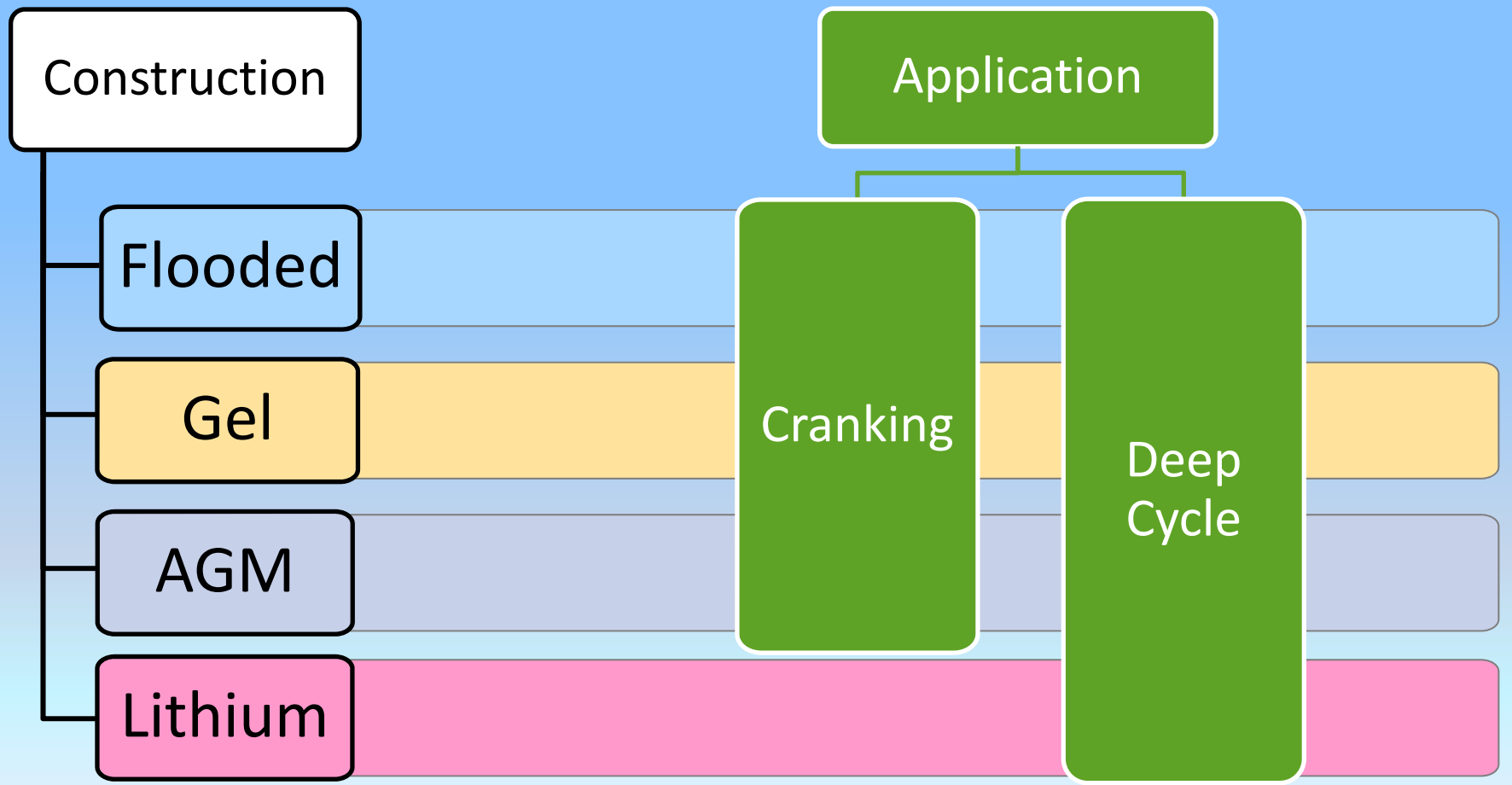
Increasing Lead Oxide
Decreasing Lead Sulfate

- A battery does not store electrical energy, it converts chemical energy into electrical energy by electrochemical reaction.
- For a lead acid battery, the fully charged voltage of each cell is 2.1 volts
- A 12 volt battery consists of 6 cells. The battery terminal voltage will be 12.6 volts (6 x 2.1) when fully charged

Note: Arrows show electron flow not current flow

Fully charged cell specific gravity 1.265 to 1.300 depending on temperature

Construction & Application



Flooded Batteries

The traditional battery construction consisting of lead and lead oxide plates immersed in a liquid electrolyte of sulfuric acid and water.

Often used as automotive starting batteries and some deep cycle batteries such as Golf Cart batteries

Require continuous maintenance to monitor and replenish evaporated water following loss of hydrogen and oxygen

Maintenance Free Batteries

A maintenance free version of the flooded cell, has hardened plates to reduce water loss during charging.

This plate hardening raises internal resistance preventing rapid charging, therefore lower acceptance rate

With the battery sealed, it is impossible to check electrolyte levels or measure specific gravity.

If subjected to excessive charging, the electrolyte will boil off causing premature failure

Gel Batteries

A sealed battery with a gel electrolyte rather than liquid as found in the flooded cell.

Because they are sealed their construction and chemistry is intended to significantly reduce gassing.

This battery must not be allowed to gas.

While they will accept high charging currents they are **very sensitive to high charging voltages**.

Gel batteries must not be charged above 14.1 volts or they will be destroyed. Normal flooded batteries charge at 14.4 volts.

Absorbed Glass Matt Batteries

Similar construction to gel, sealed, and can be installed on their side.

Some consist of soft thin rolled up plates (Optima) resulting in greatly improved resistance to vibration.

AGMs have very low internal resistance and can therefore accept very high charge rates, high acceptance rate.

Maintain a higher terminal voltage during discharge making them more suited for large inverters and sensitive electronics.

As they are not sensitive to charge voltages, standard constant rate charges can be used.

Understanding battery ratings
specific to application

Cranking

- CCA, Cold Cranking Amps
  - Is the maximum discharge a 12 volt battery can deliver for 30 seconds at 0°F
  - 525 CCA x 0.5 minutes = 262.5 amp-minutes divided by 60 minutes is 4.3 Ah
- CCP, Cold Cranking Power
  - Same as CCA
- MCA, Marine Cranking Amps
  - Same formula as CCA except rated at 32°F

Higher the CCA or MCA the better for cranking

Understanding battery ratings specific to application

Deep Cycle

- Reserve Capacity sometimes called Peak Capacity
  - Time a battery can supply 25 amps at 80°F to an end point of 10.5 volts
  - Reserve capacity of 160 minutes x 25 amps = 4000 amp minutes or 66.6 Ah
- Amp-hour rate (20 hour rate)
  - Amps required to drain a battery to 10.5 volts over a period of 20 hours at 80°F
  - A battery rated at 100Ah is capable of delivering 5 amps for 20 hours, or 10 amps at 10 hours

Life expectancy

it's all about cycles

When purchasing deep cycle batteries it is important to know the life expectancy in cycles

A battery completes one cycle when it is discharged and then fully charged

The number of cycles depends on the depth of discharge, rate of charge, the recharge method and quality of the battery

When purchasing deep cycle batteries, compare cost per specified cycle in addition to battery price

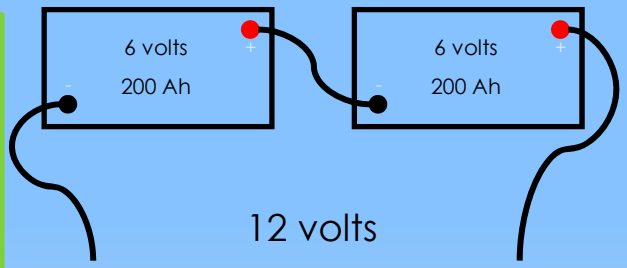
Battery Life Cycles (50%)	
Type	Cycles
Cranking	25 – 50
Flooded deep cycle	250 – 350
Gel	500
6 volt Golf cart	700
High quality AGM	900 - 1700

Actual AGM estimated cycle life
4,000 cycles @ 10% DOD
3,800 cycles @ 20% DOD
3,500 cycles @ 30% DOD
2,500 cycles @ 50% DOD 1,500 cycles @ 80% DOD

Connecting Batteries

Batteries in series

- Increase voltage by connecting batteries in series, connect positive of one to the negative of the other
- Two 6 volt 200 Ah batteries in series will yield one 12 volt 200 Ah battery configuration

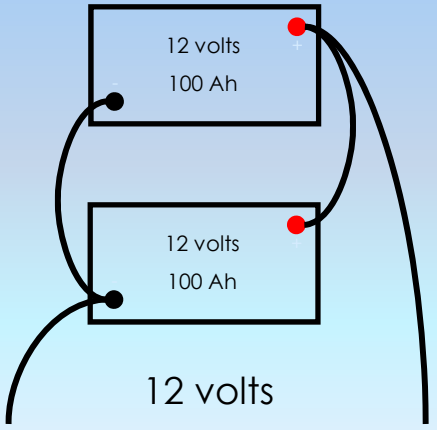


12 volts

200 Ah

Batteries in parallel

- Increase amp-hours (Ah) by connecting batteries in parallel, connect the positive terminals of two or more batteries and also the negative terminals of two or more batteries
- Two 12 volt 100 Ah batteries in parallel will yield one 12 volt 200 Ah battery configuration

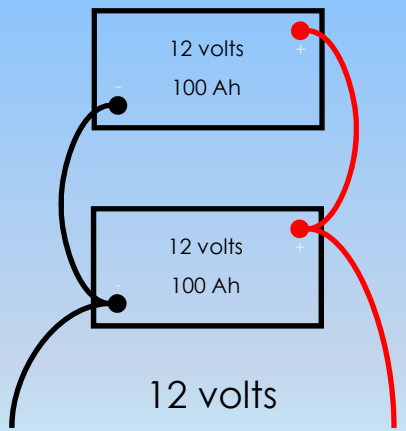


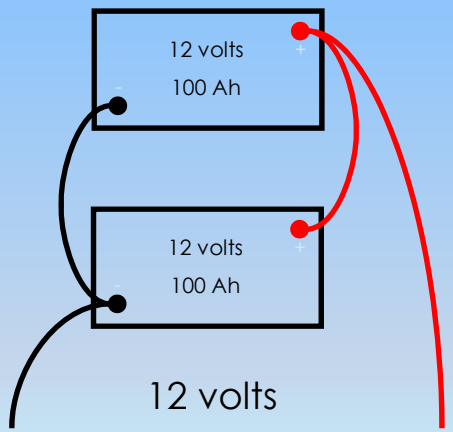
12 volts

200 Ah

Connecting batteries

1. Make sure the same current flows through each battery
   - Current will follow the path of least resistance
2. Do not combine old with new
3. Do not combine unlike chemistries





Battery maintenance

- Wet cell batteries must be periodically topped up with distilled water and specific gravity recorded
- Keep tops of batteries clean, especially the terminals
- Periodically remove battery connections clean the terminals and reconnect
- Always keep batteries at full charge when not in use
- Regularly monitor the battery voltage, especially during charge cycles on any form of sealed battery

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Charging batteries
the 3rd question

"Each morning I find my batteries are heavily discharged, they appear to have less and less charge available".

- "I thought I fixed the problem by adding batteries and yet a week later I find the batteries are in a discharged state again"

If we have matched our battery capacity with daily electrical requirements, Ah = 3 times daily usage, then we have a charge rate (amps and or time) issue.

(a) what charge device/s (b) what charge current and (c) how long?

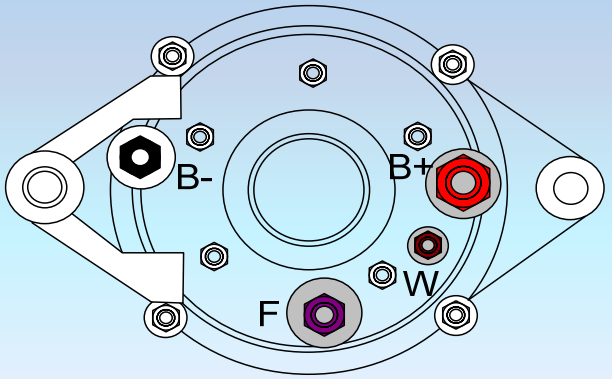
(a) Devices (b) Current (c) Time

- Alternators and their regulators
- 240 volt battery chargers
- Solar panels
- Wind generators

Alternators

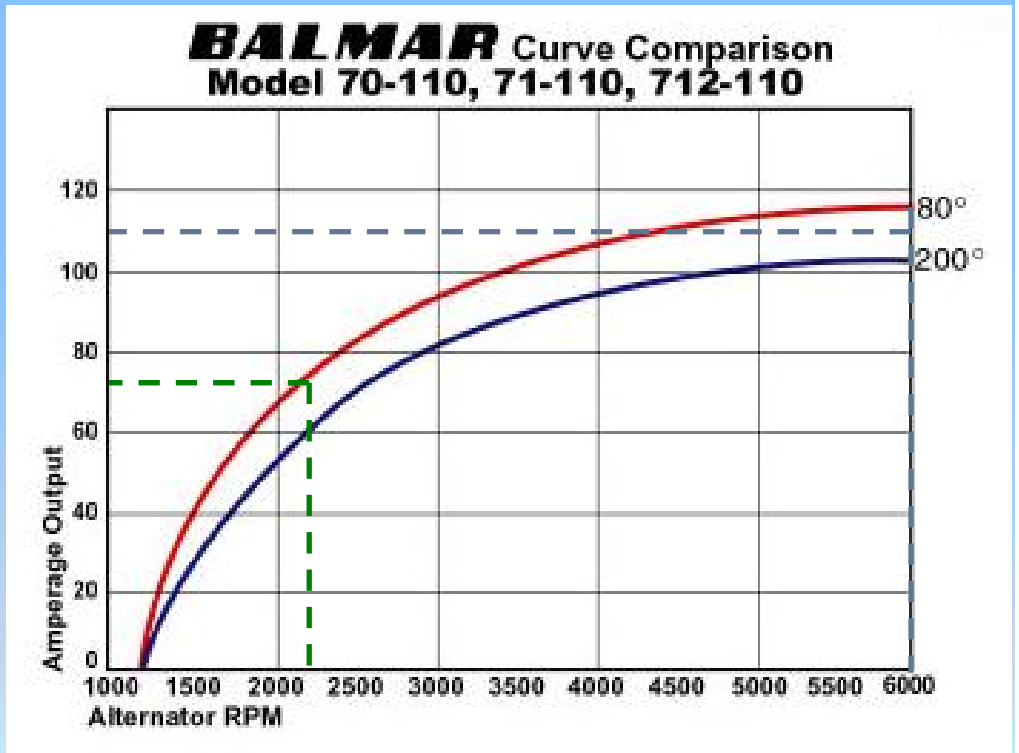
Alternators are an inexpensive and reliable method of charging batteries, mass produced, every car and truck has one, most boats have at least one sometimes two.

There are automotive and marine versions. Marine versions are continuously rated, sometimes fully enclosed, always with a negative power stud, so does not rely on the engine block for return current.

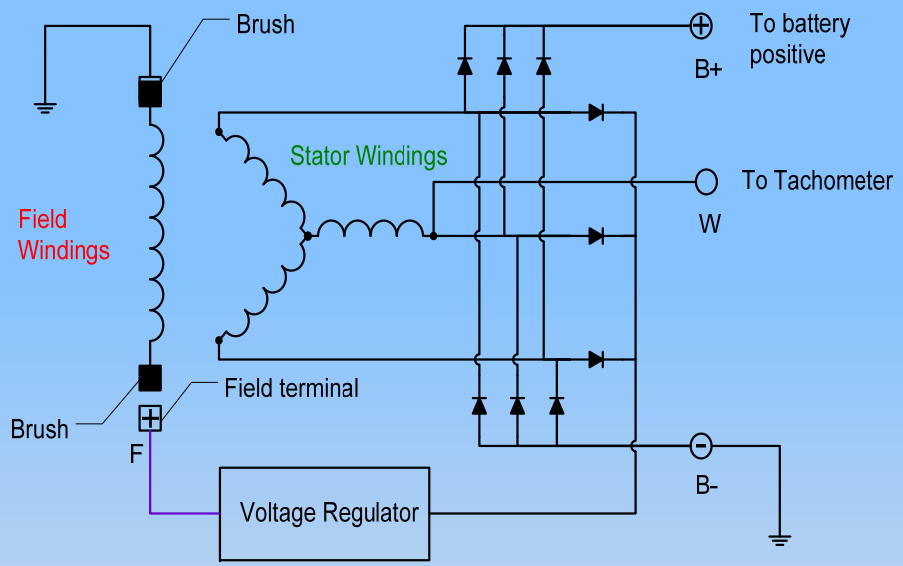


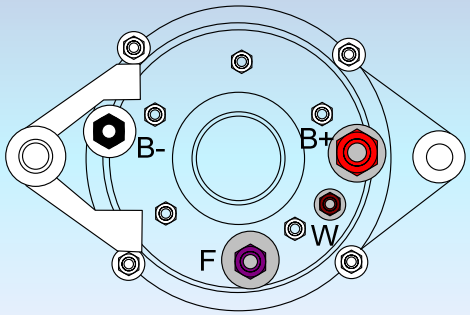
Alternator output

- Assume Balmar 110 Amp alternator with 1 to 3 pulley ratio
  - Alternator turns 3 revolutions for every 1 engine revolution
- At 800 rpm (engine) this alternator will provide 75 amps
- While at 2,000 rpm (engine) this alternator will provide the rated output of 110 amps



Alternators





- They work by passing a rotating field (field winding) over a stationary winding (stator windings).
- A variable current in the rotating field winding of approximately 1 amp will produce up to 100 amps in the stationary windings.
- The variable field current is controlled by the regulator, thereby controlling the alternator output voltage.
- The output from the stationary windings is alternating current, and is converted into direct current (DC) by a diode rectifier.

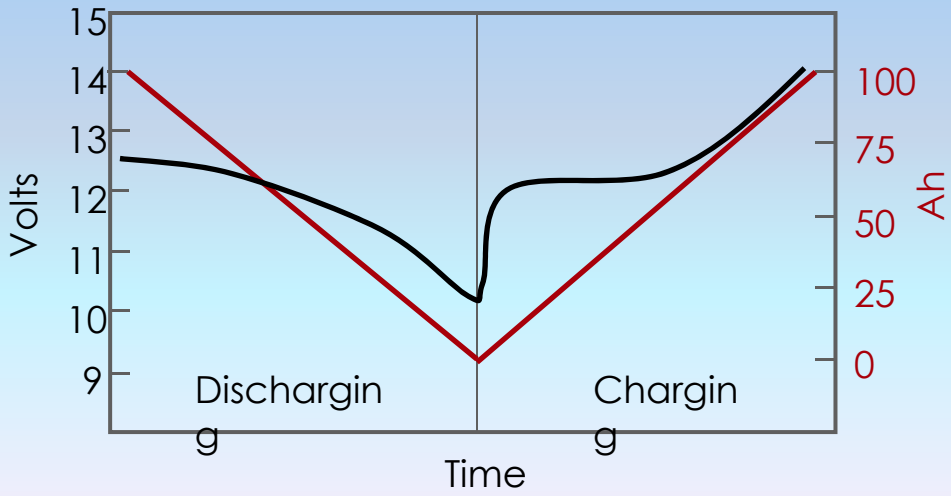
Constant voltage regulator

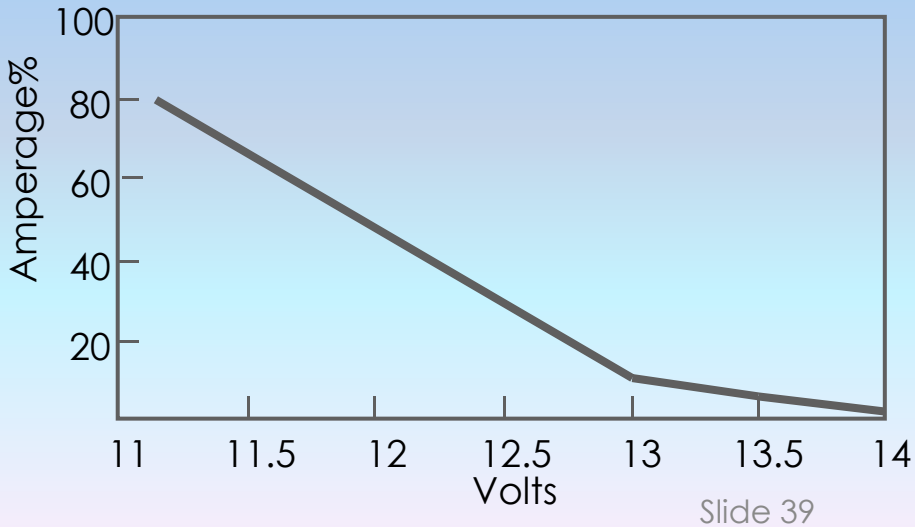
Automobile Regulators

- The alternator, not the battery provides energy to vehicle electrical system with engine running
- Designed to provide large current initially and reduce current as voltage increases
- Avoids overcharging, gassing of hydrogen and oxygen

Known as a constant voltage regulator

Great for cranking batteries, very bad for deep cycle batteries

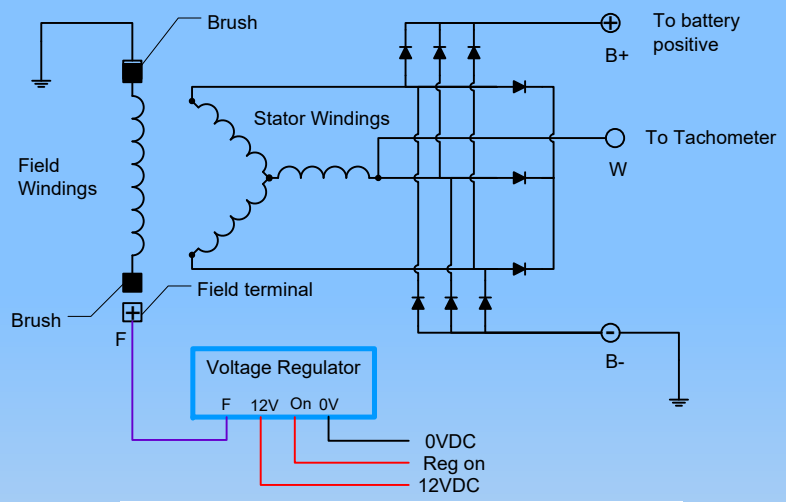




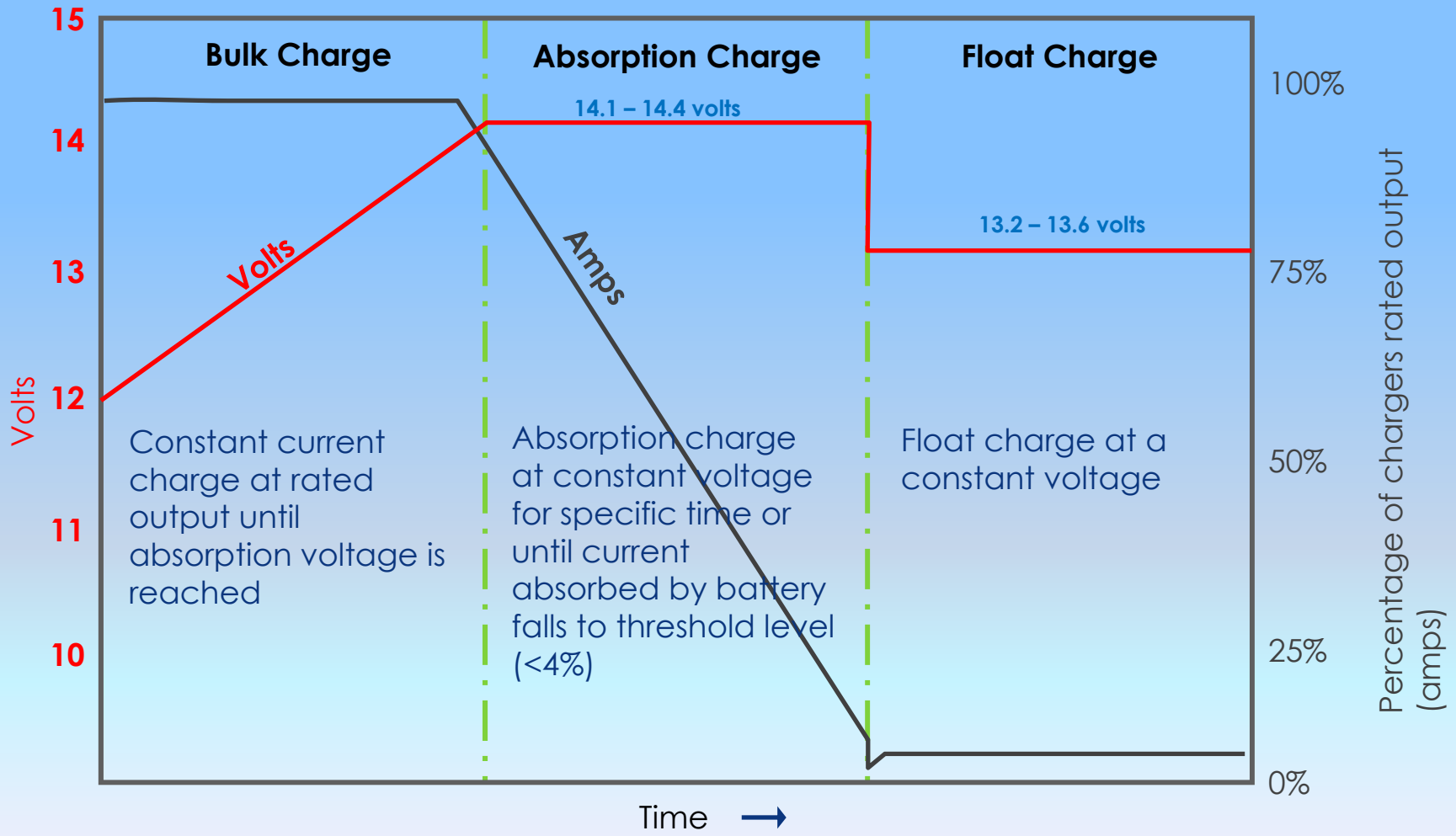
Alternator with smart regulator

Standard alternator with smart regulator makes a very efficient charge device

- Internal constant voltage regulator replaced with external smart regulator
- Provides bulk, absorption and float charge phases
- Constant current in bulk phase reduces charge time to less than 1/4 of constant voltage regulator



Multi stage regulator

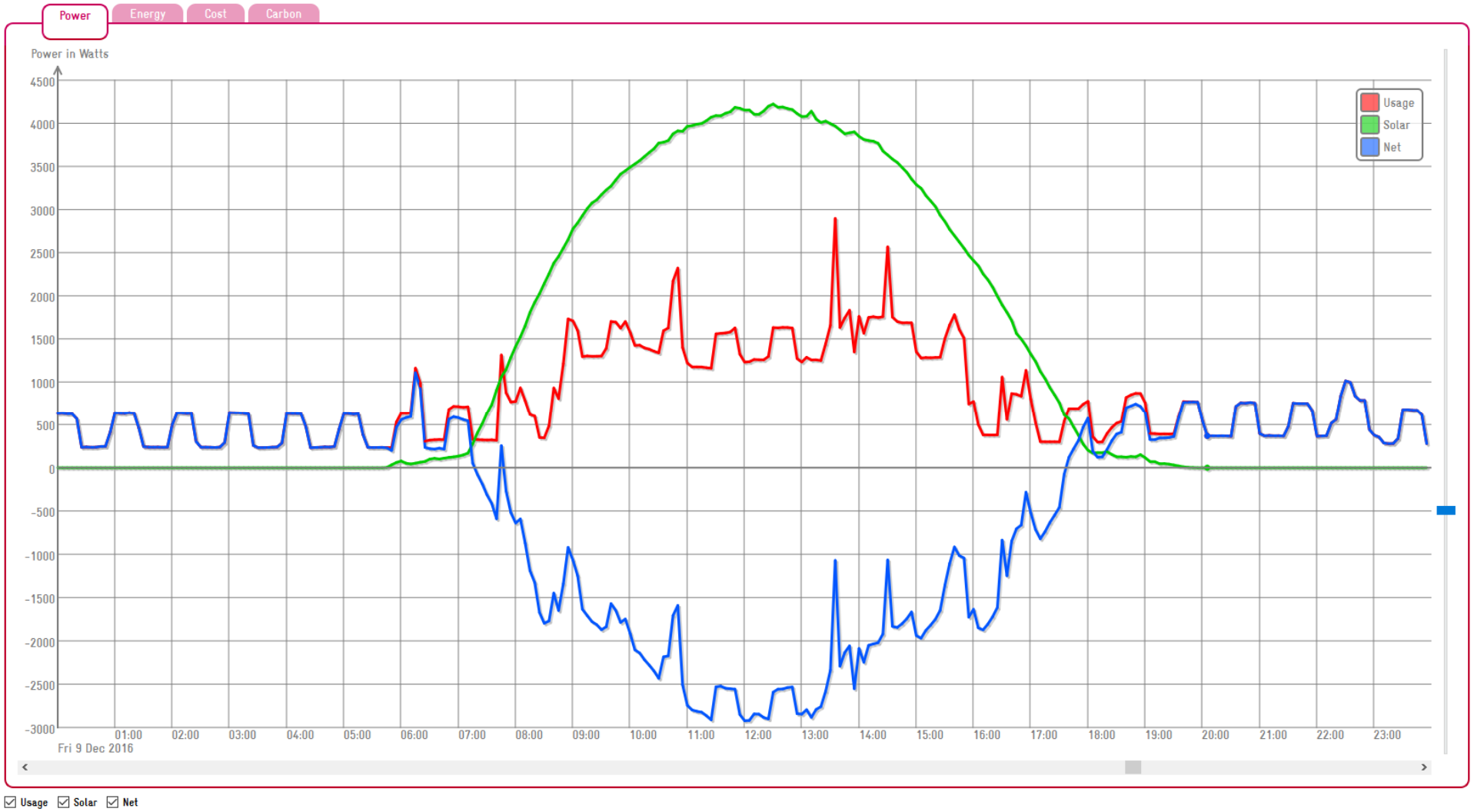


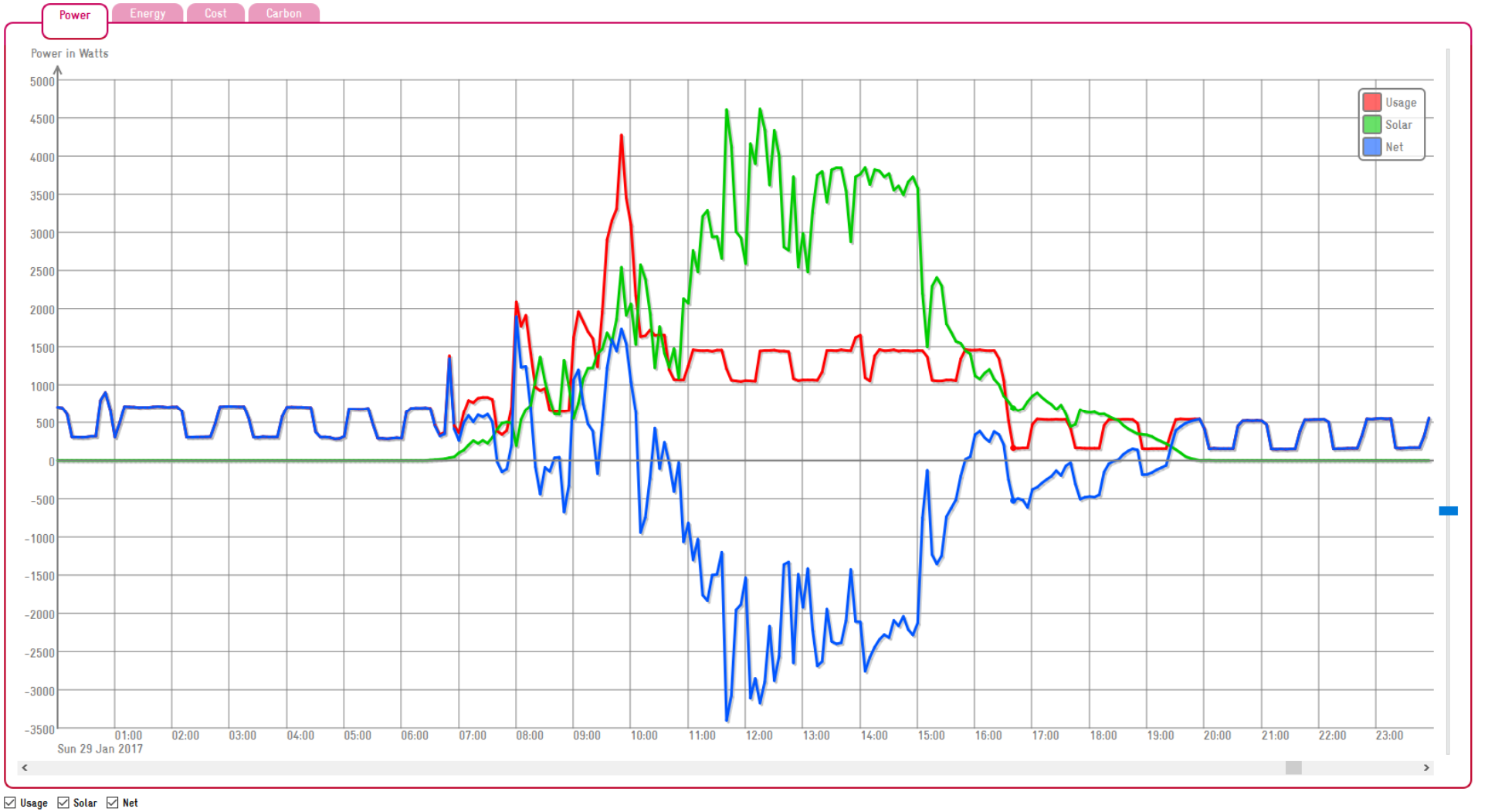
240 Volt AC battery chargers

- 240 Volt AC multi-stage battery chargers provide a constant charge current, 50 amp means 50 amps when in bulk charge phase
- Ideally suited for deep cycle batteries (flooded, gel and AGM)
- Suited for charging at marinas and where on board 240 volt AC generation is available
- Sometimes integrated with large inverters

Solar Panels

- Each cell generates about 0.45 to 0.5 volts so 32 cells are required to charge a 12 volt battery (14 to 16 volts)
- Solar panel must be at 90^{o} to the sun for maximum output, a shadow can reduce output as much as 60%
- Prime sunlight is 9:30 am through 3:00 pm, 6 hours per day
- At 3 to 7 amps an hour for 6 hours per day, typically 18 Ah to 42 Ah, so not a bulk charge device
- They are very good float charge devices preventing self discharge during unattended periods





Wind generators

- Dependent on wind strength, marginal in many areas, very good in trade wind areas (10knts - 1.6A, 29knts - 9.5 A)
- In consistent wind areas can produce up to 150Ah per day, so a viable charge option
- Selection should be based on output and noise level!

Q3 Charging your batteries?

There are three parts to the question;

- What charge current?
- What devices should I use?
- How long do I charge?

What charge current?

25% to 30% of your battery capacity plus your average usage in amps is the most efficient charge current

(can be increased with high acceptance rate batteries, AGM)

- Assume battery capacity 200Ah and average current drain 5 amps
- 30% of 200Ah = 60 amps plus average current of 5 amps = 65 amps
- You require a charge system of approximately 65 amp

What devices should I use?

The most efficient charge strategy is a multi stage charger combination of alternator and mains charger.

- Alternator/s (smart regulator)
- Gensets with 240 volt AC charger
- Wind and solar can be treated as incremental

How long do I charge?

If you discharge to 50% of battery capacity and recharge to 85%, you need to replace 35% of battery capacity plus inefficiencies (10%)

- 35% x 110% = 39% of battery Ah divided by charge current is the charge time
- Scenario above, charge time = (39% x 200Ah/60 amps) = 1.3 hour

Lithium-Ion Comparison

	Flooded	AGM	Lithium-Ion
Initial cost per capacity ($/kWh)	$131	$221	$530
Lifetime Cycles	200-500	300-1000	1000-4000
Cost per Life Cycle ($/kWh)	$0.66-$0.26	$0.74-$0.22	$0.53-$0.13
Specific Energy (Wh/kg)	30	40	150
Typical state of charge	50%	50%	80%
Charging	Smart 3 stage	Smart 3 stage	Constant Current/ Voltage

EVG POWER PAK RANGE – 12V LiFePO4 BATTERY PACKS

22/10/18

Lithium Iron Phosphate (LiFePO4) Battery Packs – Assembled in Australia with pride and quality you can see.

The EVG Series 12V battery packs have built in cell balancer/monitor modules. Recommended for use with the EV Power range of battery control units. Suitable for connection in series for higher voltages or parallel (through a BCU) to make higher capacities.

EVG12V40AH
$395 + GST
40 Ah
6.80 kg
197 x 127 x 190
Complete with BMS modules

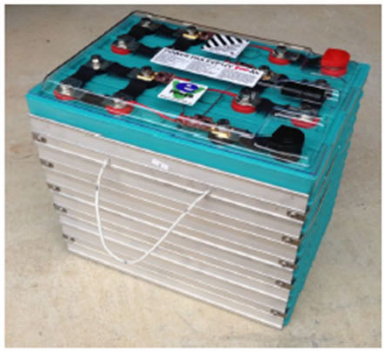
EVG12V60AH
$550 + GST
60 Ah
9.20 kg
273 x 128 x 192
Complete with BMS modules

EVG12V100AH
$790 + GST
100 Ah
12.60 kg
273 x 128 x 245
Complete with BMS modules

EVG12V160AH
$1,175 + GST
160 Ah
21.00 kg
280 x 290 x 190(h)
Complete with BMS modules and poly cover

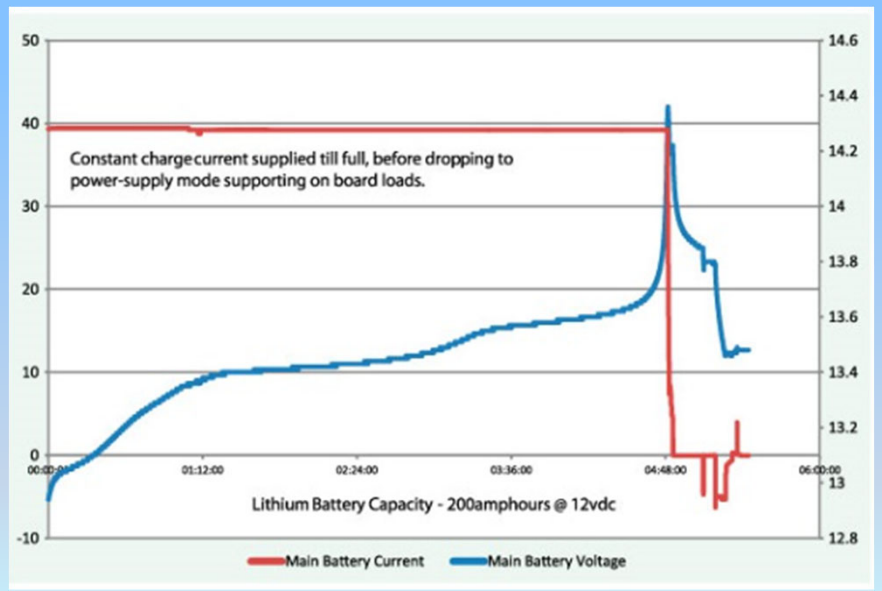
EVG12V200AH
$1,430 + GST
200 Ah
27.00 kg
285 x 290 x 250(h)
Complete with BMS modules and poly cover

EVG12V300AH
$2,100 + GST
12.8V
300Ah
3.84 kWhr
360 x 275 x 330 mm
46kg
Complete with BMS modules and poly cover

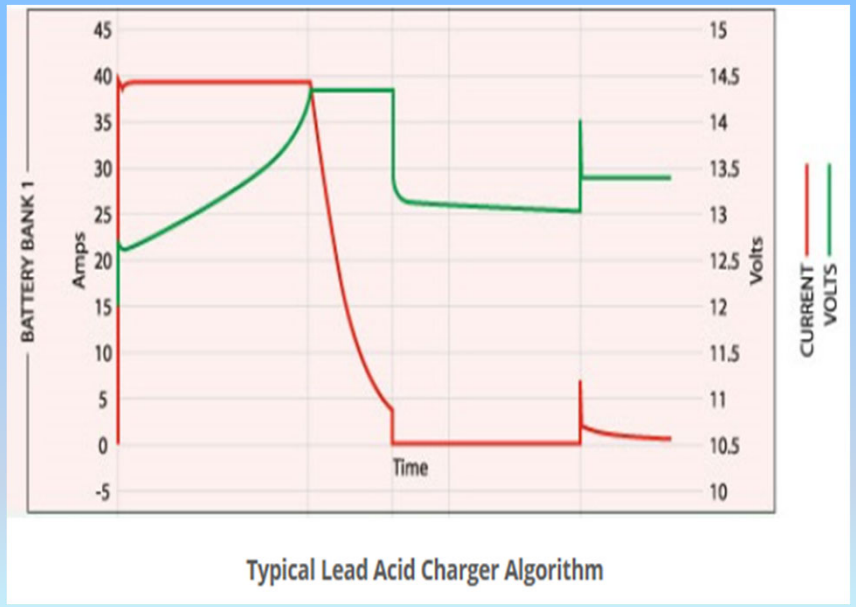


Lithium-Ion Comparison Charge Cycle

Lithium-Ion



Lead Acid



Lithium-Ion Summary

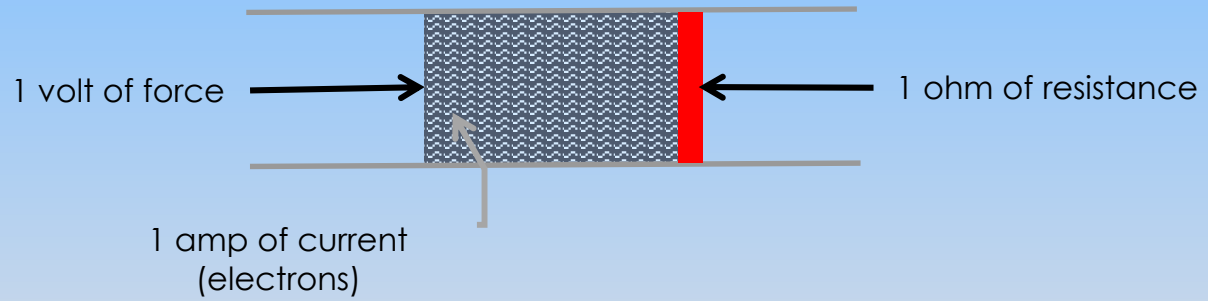
- Initial cost very high
- Cycle cost is best in class
- Weight very competitive, best in class
- Paralleling battery packs (issue)
- Unattended operation issue, fully charge and isolate (issue)
  - 24 Hour circuit operation (issue)
- Must not be overcharged
- Dangerous goods; Logistics companies place a Dangerous Goods Levey on transportation (issue)
- Installation requires expert system design (issue)
- Charge time (assuming 80% discharge) is longer (AGM 2 hr. Li-Ion 4 hr.) ??
- Bottom Line: must be a compelling Operational or System reason to install in Marine environment.
  - NOT early adoption.

Ohm's Law

- A mathematical relationship exists between the amount of voltage, current and resistance in an electrical circuit

  V (volts) = I (amperes) x R (ohms)

- It takes one volt of applied pressure to move one ampere of electrical current against one ohm of resistance



- Ohm's law can be written in several different forms:

  I = V/R R = V/I V = I x R

- **Power**, measured in watts is the **work** being done or the pressure times the current being passed

  Power = Voltage times Current, P = V x I (746 W = 1HP)

Diagnostic instruments

You can only see electricity in the form of lightning and sparks, feel it when shocked, so an instrument is required to troubleshoot electrical circuits.

- The multimeter is the most common instrument and is used to measure, amps, volts and ohms (AVO)
- Tong meters are excellent ammeters however only as a supplement to multimeters
- A test lamp can be used to measure voltage

Multimeter selection options

Volts Dc and

Volts AC

Resistance

Continuity

Voltage & continuity connections

Current Dc and

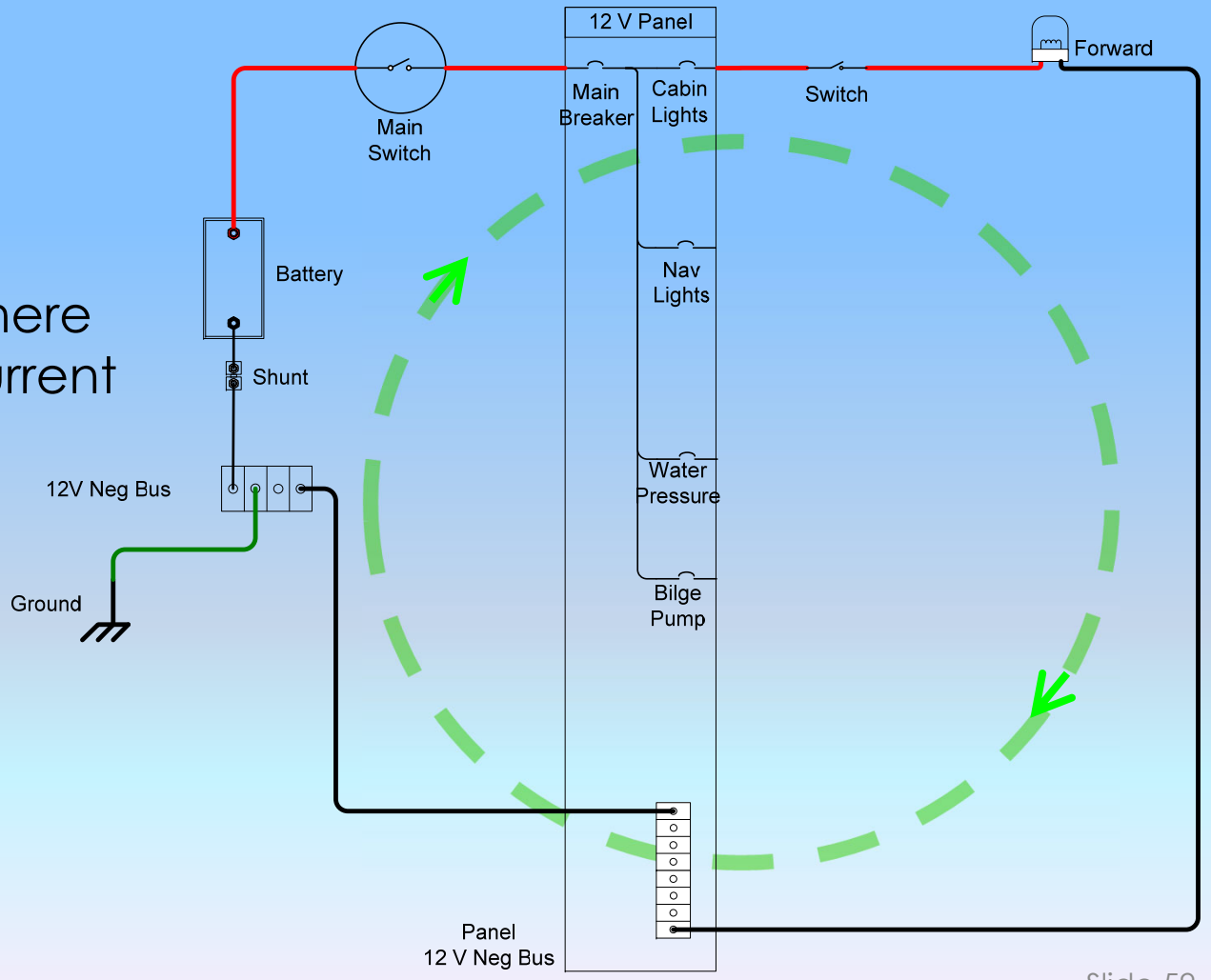
Current AC

Current connections

Basic marine electrical circuits

Series circuit

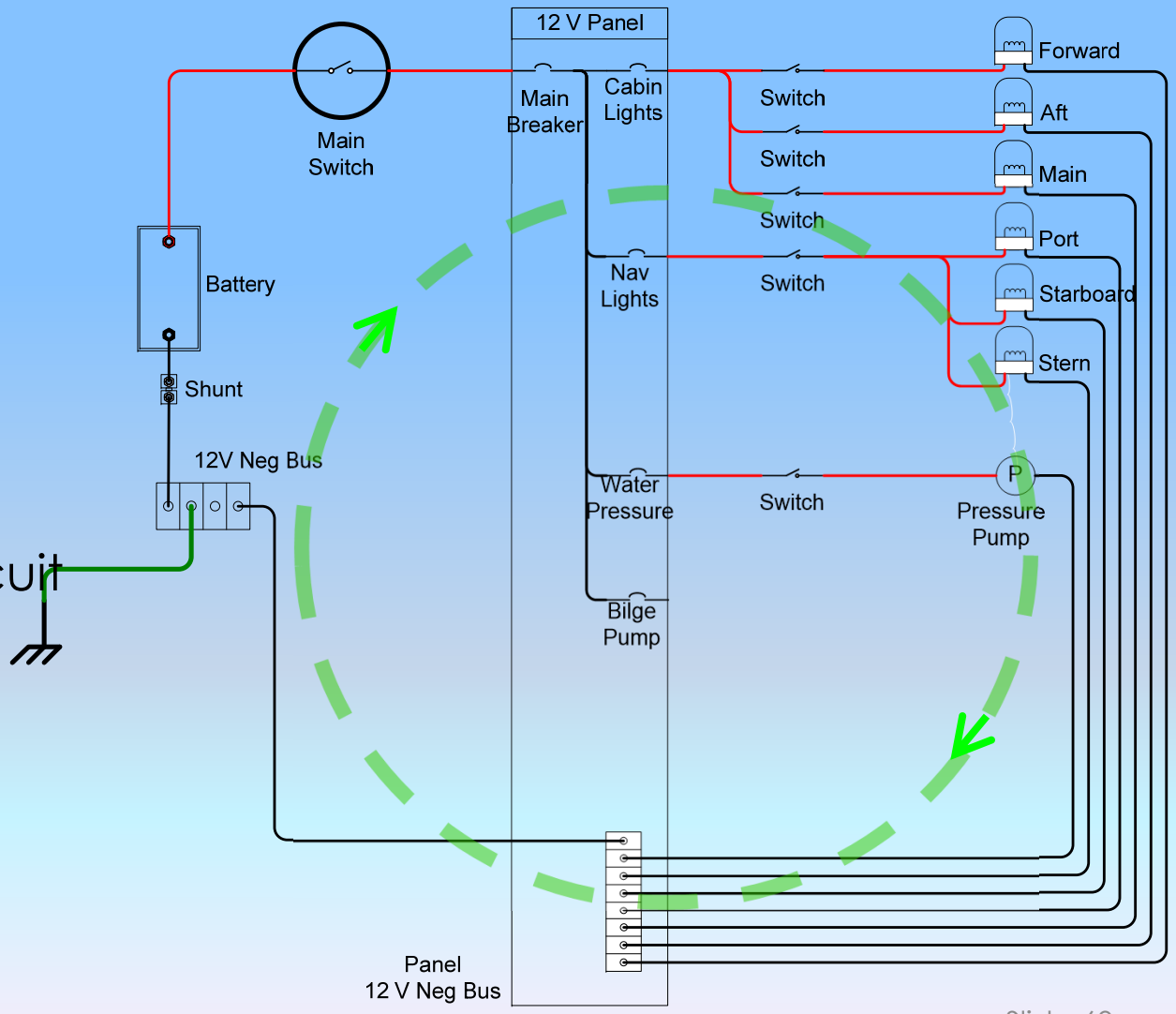
- Think of it as a circle
- A break anywhere will interrupt current flow



Basic marine electrical circuits

Parallel circuits

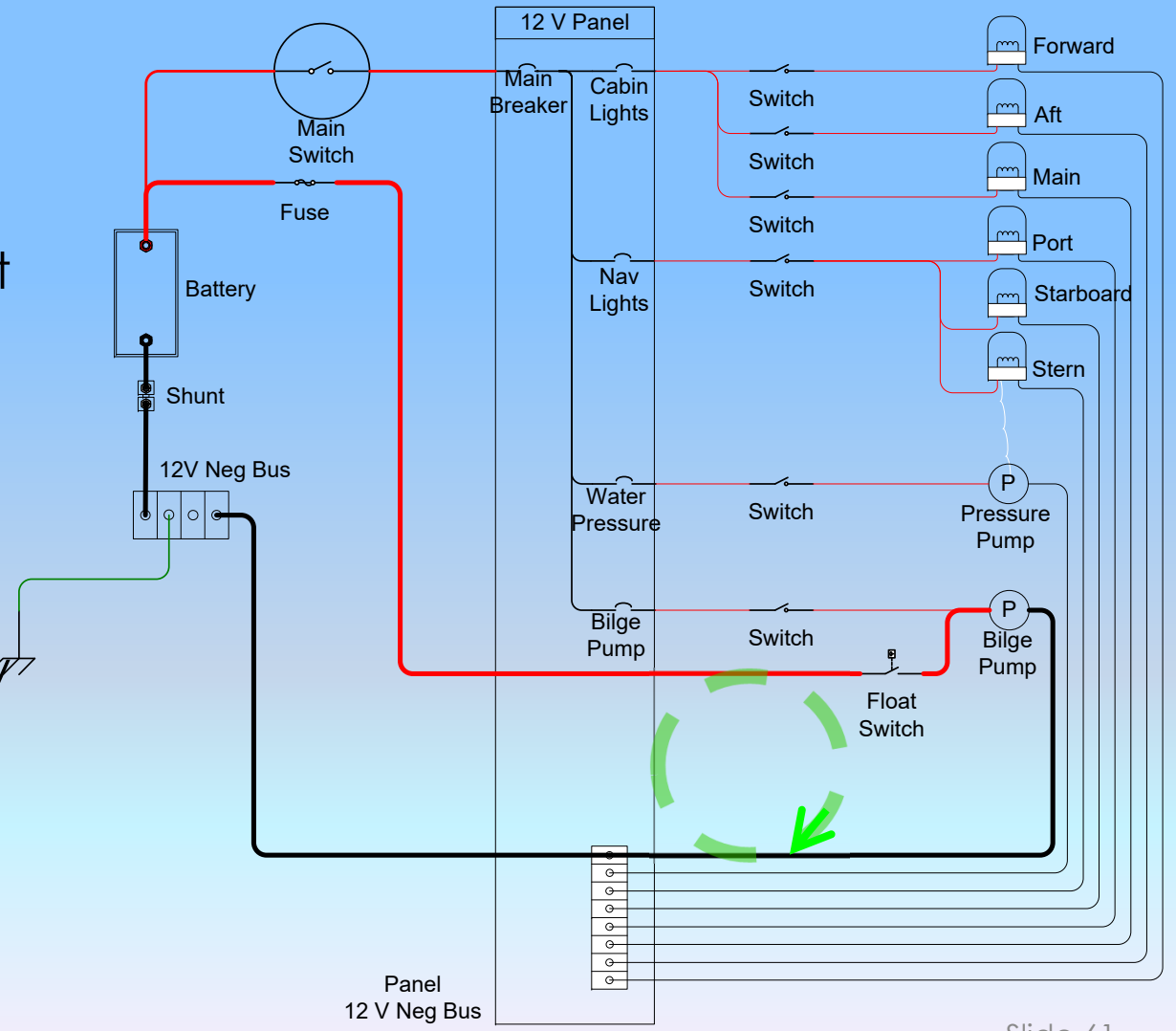
- A set of series circuits with common paths
- Makes for easier troubleshooting
- Think of each circuit as a circle



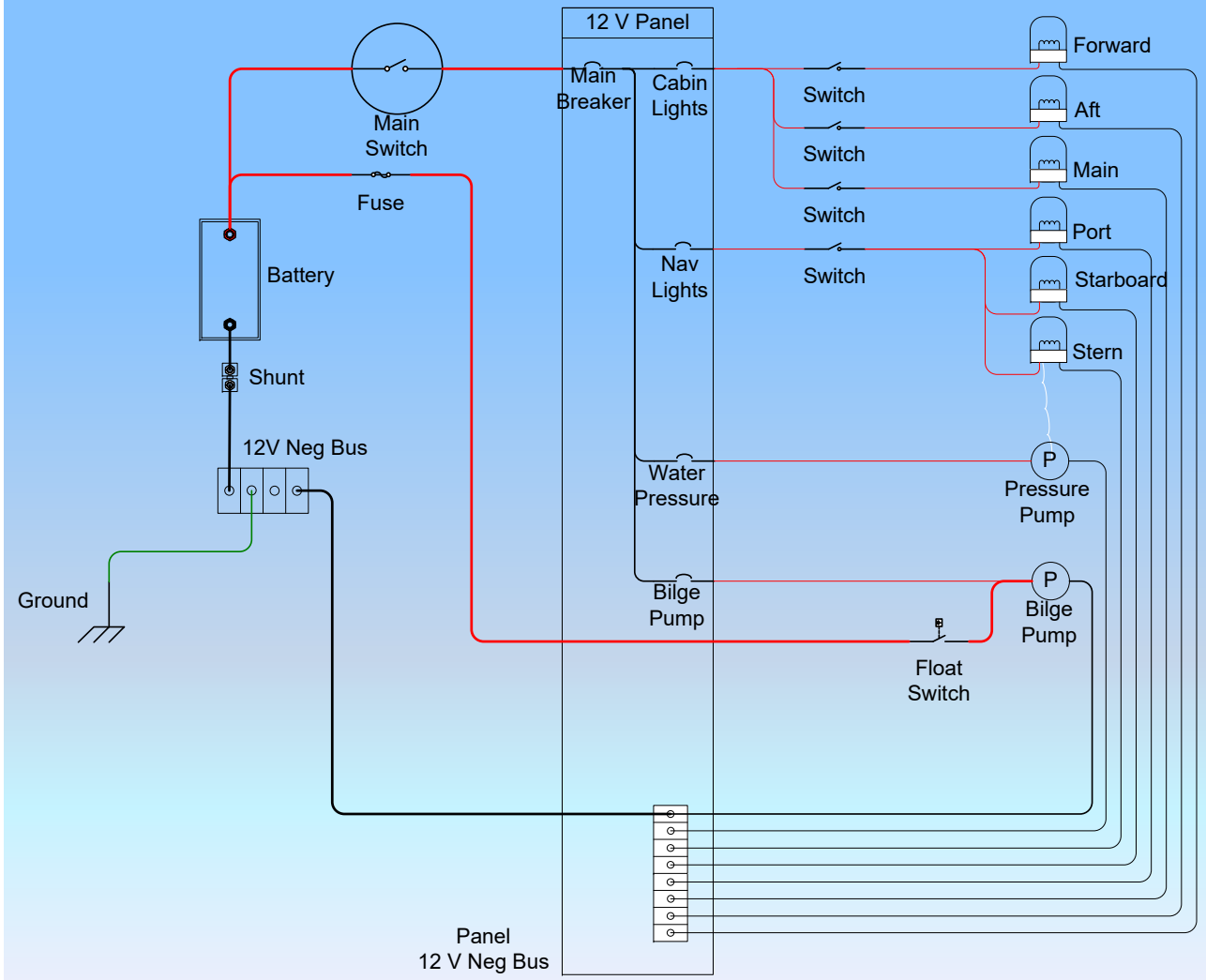
Basic marine electrical circuits

24 Hour Circuits

- Emergency and standby circuits that bypass the main switch
- Bilge pumps, appliances with stored parameters, shore based battery chargers, etc.
- Just another circle with different controls



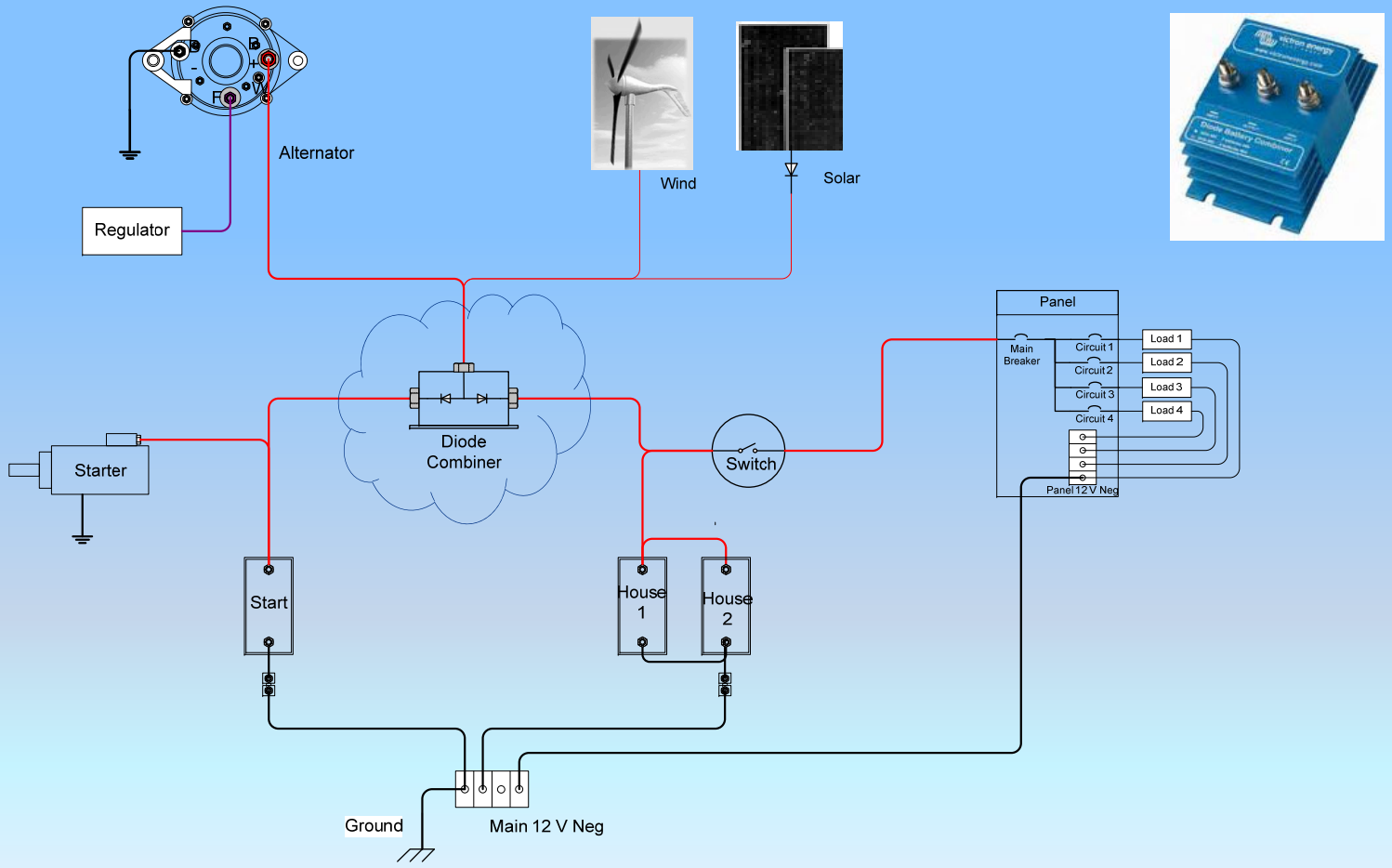
House circuit detail



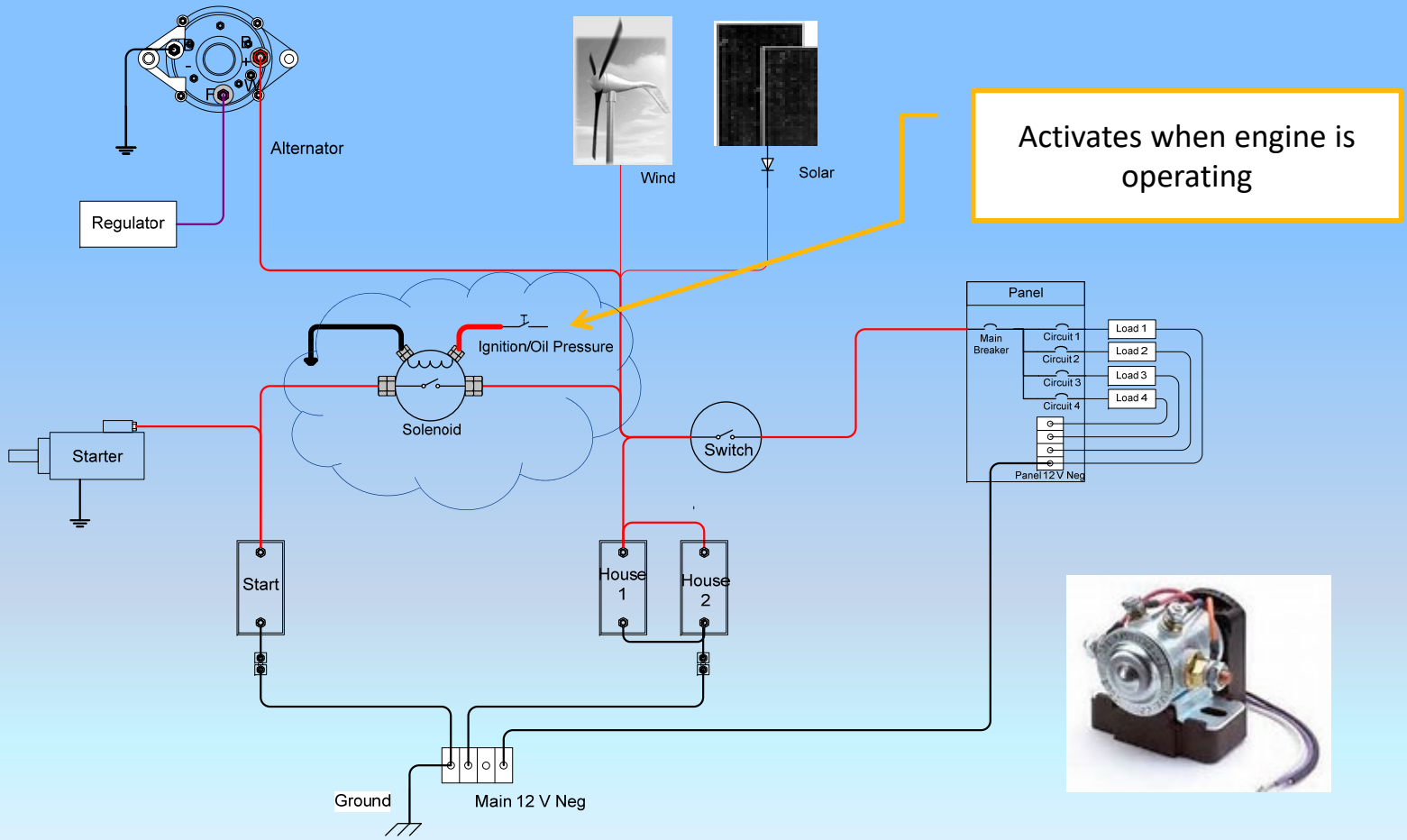
Agenda

- A few bootstrap terms to get started
- Managing expectations
- Battery fundamentals
- Charging batteries
- Introduction to marine 12 volt circuits
- **Basic marine 12 volt systems**
- Troubleshooting marine 12 volt systems
- Battery Management

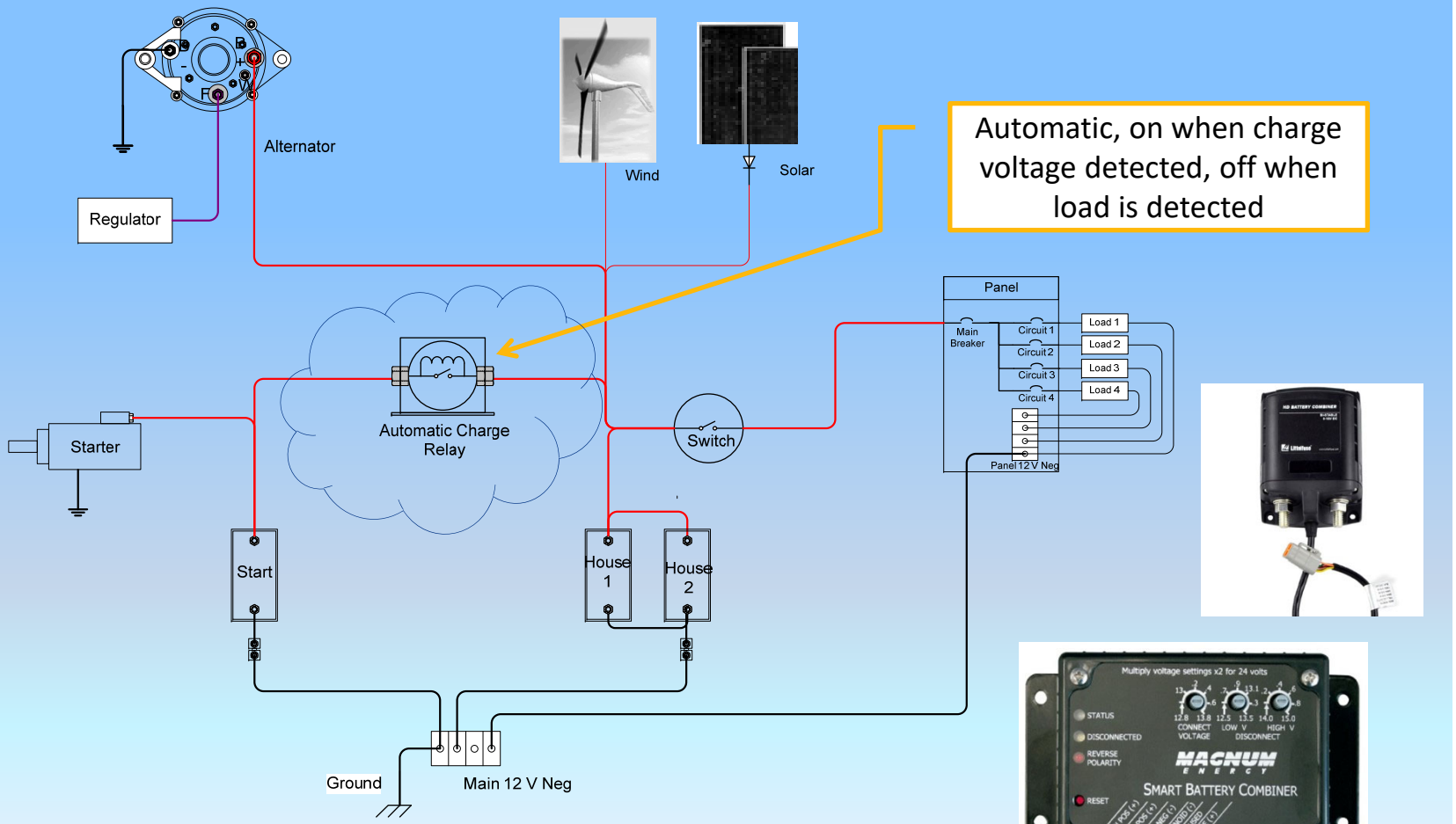
Battery combiner (diode)



Battery combiner (solenoid)



Battery combiner (ACR)



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Troubleshooting Batteries

There are five ways to check the state of charge and or health of a battery

- In the case of wet cells, measure the specific gravity of the electrolyte
- Open-circuit voltage test
- Perform a load test to determine if battery is capable of delivering high currents
- Perform a capacity test to determine the actual Ah capacity of your battery
- Monitor Volts, Amps and Ahr with an amp-hour meter

Troubleshooting batteries

Specific gravity test

- Measure and record the specific gravity of each cell
- If cell readings vary by greater than 0.050 specific gravity or the lowest cell is less than 1.225, charge the battery
- Charge the battery until all cells are greater than 1.225 specific gravity. If this is not achieved in all cells the battery has one or more defective cells, change the battery

Approximate State of Charge (at 80°F, 26.7°C)				
Charged	1.225 Initial full charge	1.265 Initial full charge	1.280 Initial full charge	1.300 Initial full charge
100%	1.225	1.265	1.280	1.300
75%	1.185	1.225	1.240	1.255
50%	1.150	1.190	1.200	1.215
25%	1.115	1.155	1.170	1.180
Discharged	1.080	1.120	1.140	1.160

Troubleshooting batteries

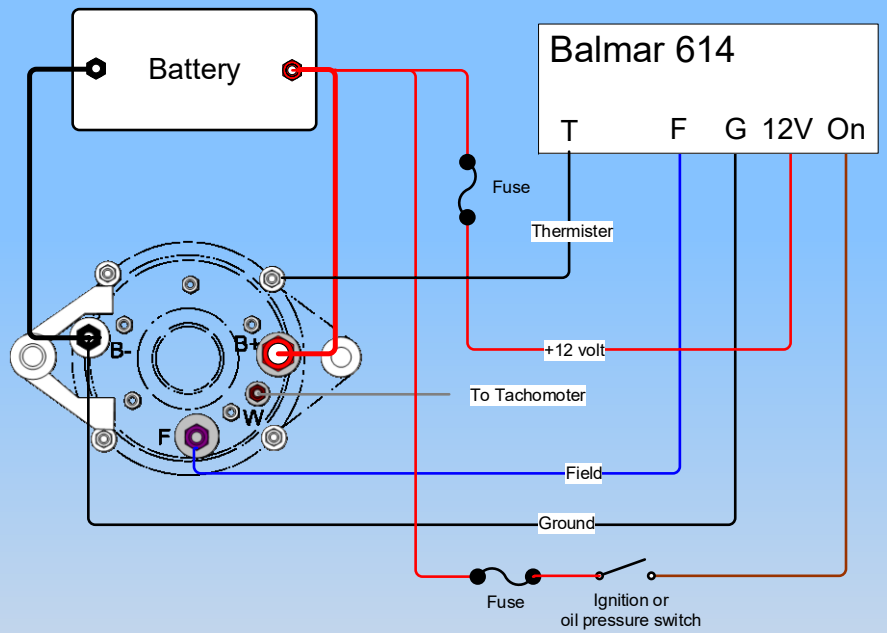
Open circuit voltage test

If battery has been on charge, apply a heavy load for 30 seconds, disconnect the battery, allow to sit for 15 to 30 minutes and measure the terminal voltage.

Open Circuit Voltage	Percent Charge
12.6 plus	100%
12.45 – 12.6	75 - 100%
12.24 – 12.45	50 – 75%
12.06 – 12.24	25 – 50%
11.7 – 12.06	0 – 25%
11.7 or less	0%

Troubleshooting alternators

1. Eliminate mechanical problems, loose belts etc.
2. With alternator spinning, voltage at battery should be > 12.6 volts
3. If battery voltage <=12.6, alternator not charging
4. Check, regulator +12v and “reg-on”, both should be 12 volt, if not correct
5. If regulator is turned on (4), disconnect field and connect 12 w lamp from alternator field to 12 volt
6. If alternator voltage increases to >12.6 volt, faulty regulator
7. If alternator voltage did not increase to >12.6 volt, fault alternator



Caution: Never disconnect alternator B+ or B- when alternator is spinning, this will destroy alternator internal diodes

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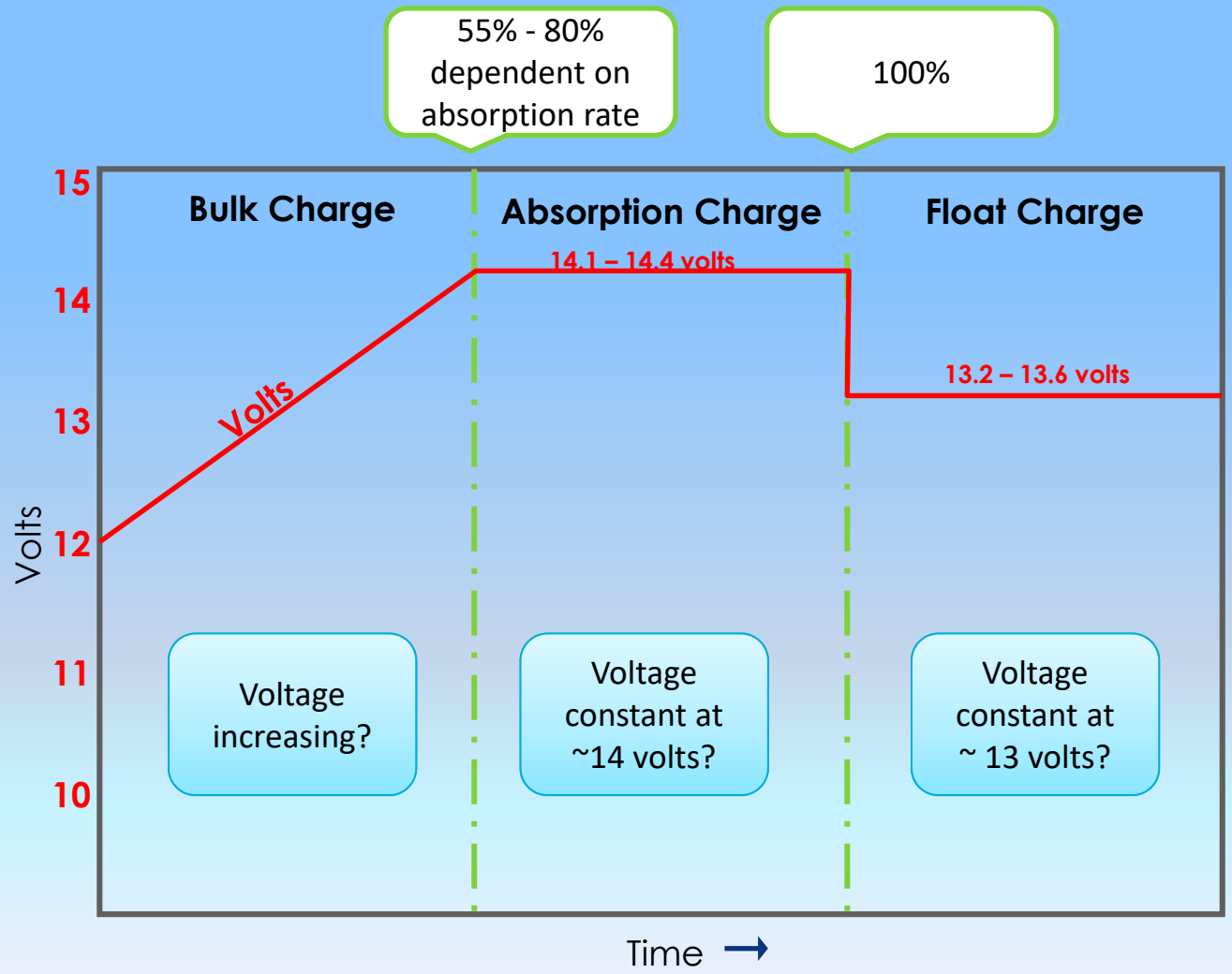
25%	1.115	1.155	1.170	1.180
Discharged	1.080	1.120	1.140	1.160

Open circuit voltage test

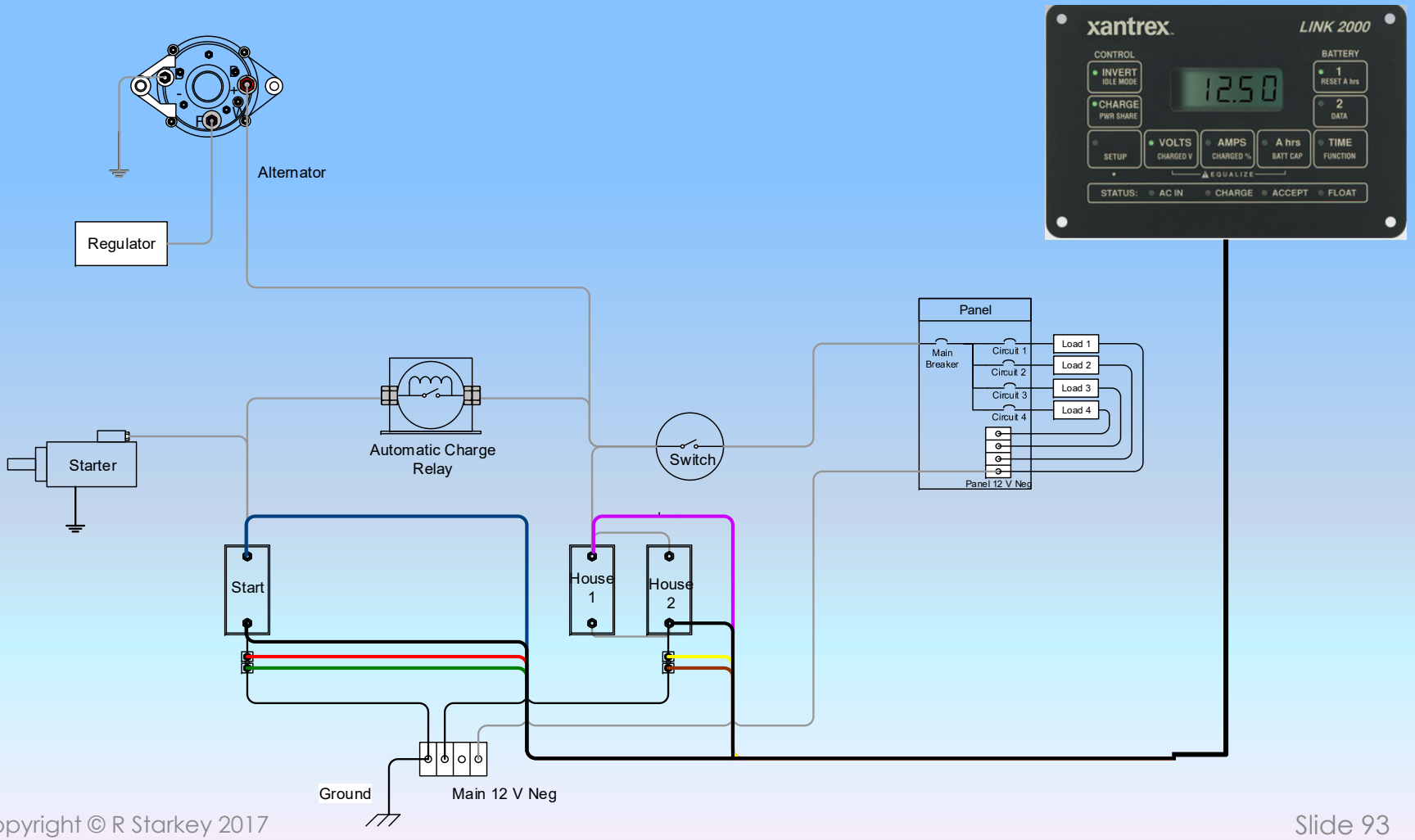
Open Circuit voltage	Percent charge
12.6 plus	100%
12.45 – 12.6	75% – 100%
12.24 – 12.45	50% - 75%
12.06 – 12.24	25% - 50%
11.7 – 12.06	0 – 25%
11.7 or less	0%

Apply moderate load for 15 minutes, disconnect battery, allow to sit for 15 minutes and measure terminal voltage

Monitoring charge cycle



Amp-hour battery management



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