Electric Current

AC and DC Current

~**AC Current:** ☺Flow of electrons switches directions (US household wiring does this 60 times/second)
☺Typically wired as a "Hot" and "Neutral" wire
☺Efficiently operates at higher voltages; can readily be transmitted long distances
☹Must be used as it is created, cannot be stored
☹Typically more dangerous to work on
♦Not used for trolling motors/boats; only mentioned for comparison

⎓**DC Current:** ☺Flow of Electrons in one direction
☺Typically uses a Positive (+, Red) wire and Negative (-, Black) wire
☺Can be efficiently stored for later use in a battery
☺Relatively safe to work on
☹Not good for transmitting long distances

Measurements

Amp (A): Measure of current, or the number of electrons, traveling through the circuit.
1 Amp equals 6,241 quintillion electrons per second.

Volt (v): Electric Potential is measured in volts.
1 volt will do 1 watt worth of work at 1 amp of current.
If you think of electricity flowing like water volts are equivalent to water pressure

Watt (W): Watts measure power.
Amps X Volts = Watts; 1 horsepower is roughly 745 watts.

Ohm (Ω): Resistance is measured in Ohms.
As resistance increases power and voltage getting through a circuit decreases.
Energy lost due to increased resistance shows up as heat.

Hour (h): The measure of time you are familiar with.
Shows up on batteries as a measure of total capacity (Ah, which is Amps X Hours)
Shows up on your household electric bill (kwh, kilowatt hours)
Previous Measurements are instant, multiplying them by hours adds perspective

Since amps x volts = watts, and 745 watts equal on horsepower it is possible to find the horsepower of any electric motor. A 55-pound thrust motor is a 12v motor that draws up to 50 amps, so, 12v*50A=600w. 600w/745w is 0.805HP.

Thrust is a far more relevant measurement of how a trolling motor will function. Pounds of thrust are the pounds of force applied by the prop pushing against water. Thrust has **no** direct relationship to Horsepower.

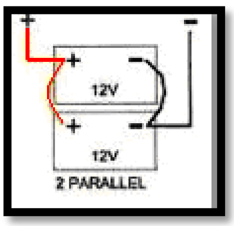
Electric Current (Continued)

Series vs Parallel:

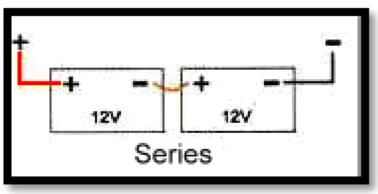
Parallel: In a parallel circuit there are separate paths for each item.
In parallel voltage is constant throughout the system, amperage/current is what changes

Series: In a series circuit items are linked on a single path end to end.
In series voltage varies, amperage is constant throughout the circuit.

Almost every practical wiring example whether household wiring or the accessories on a boat is parallel because most electric items are designed to operate at a specific voltage; the most common exception is batteries on a boat. Below are examples of batteries wired in series and parallel with a description of the results.



To wire in parallel, run Jumpers between the positive posts of each battery and between the negative posts of each battery (as shown to the left). Assuming these are 12-volt 105-amp hour batteries: Connecting a circuit to either positive post and either negative post will still find 12 volts, what has changed is that there are now roughly 210-amp hours in the system.



To rig batteries in series run a single jumper from the positive post of one battery to the negative post of the other. Again assuming 12 volt 105 amp hour batteries connecting a circuit to the free negative post and free positive post will find 24 volts. This system still has 105 amp hours.

Batteries

History:

Versions of devices that stored electrical energy do date back thousands of years. The lead acid battery as we know it was invented in 1859 by Gaston Planté (French physicist, lived 1834 to 1889). His early version was a spiral roll of two pure lead plates, seperated by a linen cloth, immersed in a glass jar of a sulfuric acid solution. This was the first rechargeable electric battery marketed for commercial use.

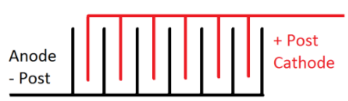
A video explaining much of the development of modern batteries can be seen at:

http://www.youtube.com/watch?v=rhIRD5YVNbs

Battery Types:

All batteries consist of three parts: Anode (- post), Cathode (+ post), and Electrolyte (acid, in the case of a lead/acid battery). In most Lead/Acid batteries the anode is composed of "sponge" lead, the cathode is lead dioxide, and the elecrolyte is a dilute solution of 33% sulfuric acid.

On cell of a lead acid battery consists of the anode and cathode arranged in a "sandwich" fashion with electrolyte bridging the space between. One cell producted between 1.5 and 2.2 volts; so a 12 volt battery consists of 6 cells connected in series. A diagram of a single cell may look like this:



Note: The anode and cathode are mechanically seperated, only connected through the electrolyte. If they touch directly this would result in a dead cell. A dead cell is best identified by a "load test".

Minn Kota recommends using a Group 27 or larger deep cycle marine battery power a motor. The three most common types of lead/acid batteries are: Flooded Lead/Acid, Absorbed Glass Matt (usually abreviated AGM), and Gel Cell batteries.

Flooded Lead Acid

- ☺ Anode and Cathode separated by "Paper"
- ☺ Electrolyte "bath" that the plates are submerged in
- ☺ Removable caps allow for maintenance of the electrolyte
- ☹ Require maintenance

AGM (Absorbed Glass Matt)

- ☺ Anode and Cathode separated by fiberglass matt that has electrolyte soaked into it (like a sponge)
- ☺ Maintenance free
- ☹ More expensive
- ☹ Some have lower than expected AH ratings

Gel Cell

- ☺ Electrolyte mixed with silica to immobilize it.
- ☺ Maintenance Free
- ☹ More expensive
- ☹ Hard to find (in large sizes)
- ☹ Special charging requirements (lower voltage)

Batteries (Continued)

Lead/Acid Battery Chemistry:

A charged battery has a dilute 33% mixture of Sulfuric Acid (H_2SO_4); the other 66% is water (H_2O). The plates are usaully Lead (Pb) (Anode side) and Lead Dioxide (PbO_2)(Cathode side). When a circuit is completed from between the Cathode and Anode electrons travel from the electrolyte into the anode then into the circuit; these electrons are made available through a chemical reaction between the electrolyte and the anode and cathode. This reaction is described:

H_2SO_4 + Pb – (2) electrons = $PBSO_4$ + H_2O and H_2SO_4 + PbO_2 – (2) electrons = $PBSO_4$ + H_2O

Note: The results of these reactions ($PBSO_4$ + H_2O) the Lead Sulfate ($PBSO_4$) is solid so as the battery discharges a greater portion of the electrolyte is water (H_2O). A 100% charged battery will not freeze until
-92° F; a 40% charged battery can freeze at +16° F because of the increased percentage of water.

The reaction for charging is described:

$PBSO_4$ + H_2O + (2) electrons = H_2SO_4 + Pb or $PBSO_4$ + H_2O + (2) electrons = H_2SO_4 + PbO_2

During these reactions some Hydrogen is lost as Hydrogen gas. **Note:** This is why during charging it is recommended to open the compartment the batteries are in because concentrated hydrogen gas can be explosive.

Some Lead Sufate ($PBSO_4$) will be permanently combined, this is why over time the capacity of a battery decreases. On a flooded lead/acid battery a specific gravity test done with a hydrometer will let you know what percentage of the electrolyte is still sulfuric acid and give an indication of how much life remains in the battery. Since Gel and AGM batteries are sealed this test in not possible.

Note: A fully charged new battery at 77-80° F should have a specific gravity of 1.265 or slightly higher. In any battery the difference in specific gravity between cells should not excede .05.

Lithium Battery Chemistry:

There are many different Lithium (Li) Battery Chemistries, the most common one for Marine Deep Cycle Batteries is Lithium Iron Phosphate ($LiFePO_4$).

The Chemical Reaction in a $LiFePO_4$ Battery Cell is:

$LiFePO_4$ = $FePO_4$ + Li – 1 electron

Li + C6 + 1 electron = LiC6

Where C6 is the Graphite Anode and the freed Li Atom are positive ions

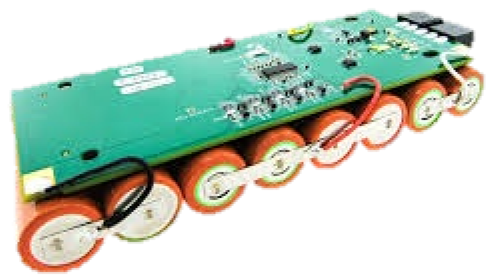
A Cell generates 3.0-3.3V, so most Lithium Iron Phosphate Marine Batteries are 4 Cells in Series to match the voltage of 6 Cell Lead/Acid Batteries.

Batteries (Continued)

Lithium Battery Design:

Lithium Battery Cells have the potential to have a runaway reaction and start on fire if they are used when damaged, too hot or too cold, so for safety they must incorporate a Battery Management System (BMS) in the circuit. The BMS shuts the inputs/outputs to the cells of if the BMS detects adverse conditions. The BMS monitors:

- Temperature
- Charge Rate
- Discharge Rate
- Cell Balance



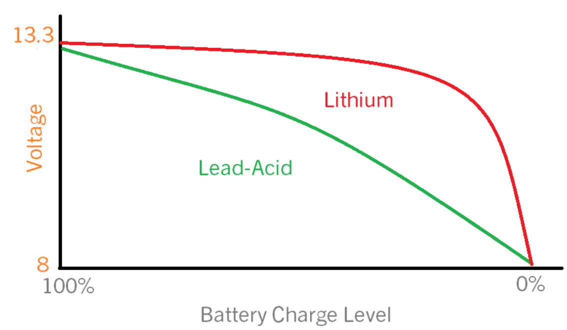
In "Drop In" batteries the BMS is inside the Battery case, integrated in the battery case. Electronics that use Lithium ion Batteries often have the BMS built into the electronic, some applications have an external BMS where the BMS is completely separate to the battery cells and the devices on the circuit.

When a BMS detects a Fault, it will disconnect the cells from the terminals; resetting a BMS after this is typically done by disconnecting everything from the terminals.

Using or charging a Lithium Battery effectively requires "negotiating" with the BMS to use the Cells of the battery. It is critical to understand the operational limits of the battery you are choosing and whether it is compatible with how you want to use it and the charger you intend to use.

Using Lithium Batteries:

Lithium Batteries start at a higher voltage and maintain that voltage to a deeper discharge level. When used to power a trolling motor that was designed to maximize its output when powered by Lead/Acid Batteries this will generate significantly more heat in the lower unit; to prevent damage to the lower unit you should limit the use of the motor to 85% speed.



Boat Wiring

Philosophy:

Electricity is the "life blood" of the Minn Kota electric fishing motor. If electricity is the "life blood" then the "heart" of the Minn Kota motor is the battery (or batteries). The boat wiring becomes the "circulatory system" in this analogy.

Just as a constricted artery or blockage can cause problems for the human body inadequate guage wire or poor electrical connections can cause a trolling motor to malfunction.

Conductor Guage:

Wire, while functioning as a conductor, also has a resistance value. The smaller the wire the greater the resistance it produces. The greater the amperage being carried the greater the resistance the wire generates. The chart below shows voltage lost per foot at designated amp draws:

AWG	5 Amps	10 Amps	20 Amps	30 Amps	40 Amps	50 Amps
4	.0012 v	.0025 v	.0050 v	.0075 v	.0100 v	.0125 v
6	.0020 v	.0040 v	.0080 v	.0120 v	.0160 v	.0200 v
8	.0032 v	.0064 v	.0128 v	.0192 v	.0256 v	.0320 v
10	.0051 v	.0102 v	.0204 v	.0306 v	.0408 v	.0510 v
12	.0081 v	.0162 v	.0324 v	.0486 v	.0648 v	.0810 v

To figure the voltage lost multiply the total conductor length in feet times the number on the chart above at the amperage you expect the motor to operate at. If the batteries are 20 feet from the trolling motor your total conductor length is 40 feet (a postive and negative conductor).

According to the ABYC adequate wiring will result in less than 5% voltage loss. So no more than .6 volts is a 12 volt system, no more than 1.2 volts in a 24 volt system, and no more than 1.8 volts lost in 36 volt system.

Using an example of a 12 volt bowmount motor drawing 50 amps with the battery at the transom of a 20 foot boat. We have 40 feet of total conductor and need a total voltage loss of less than .6 volts, .6/40 = .015 so we need to loose less than .015 volts per foot. Looking at the chart the only AWG that meets that requirement at 50 amps is 4 AWG. This math is how we came up with the chart that we include in our manuals:

CONDUCTOR GAUGE AND CIRCUIT BREAKER SIZING TABLE

Motor Thrust / Model	Max Amp Draw	Circuit Breaker	Wire Extension Length *				
			5 feet	10 feet	15 feet	20 feet	25 feet
30 lb.	30	50 Amp @ 12 VDC	10 AWG	10 AWG	8 AWG	6 AWG	4 AWG
40 lb., 45 lb.	42		10 AWG	8 AWG	6 AWG	4 AWG	4 AWG
50 lb., 55 lb.	50	60 Amp @ 12 VDC	8 AWG	6 AWG	4 AWG	4 AWG	2 AWG
70 lb.	42	50 Amp @ 24 VDC	10 AWG	10 AWG	8 AWG	8 AWG	6 AWG
80 lb.	56	60 Amp @ 24 VDC	8 AWG	8 AWG	8 AWG	6 AWG	6 AWG
101 lb.	46	50 Amp @ 36 VDC	8 AWG	8 AWG	8 AWG	8 AWG	8 AWG
Engine Mount 101	50	60 Amp @ 36 VDC	8 AWG	6 AWG	4 AWG	4 AWG	2 AWG
112 lb.	52	60 Amp @ 36 VDC	8 AWG	8 AWG	8 AWG	8 AWG	8 AWG
Engine Mount 160	116	(2) x 60 Amp @ 24 VDC	2 AWG	2 AWG	2 AWG	2 AWG	2 AWG
E-Drive	40	50 Amp @ 48 VDC	10 AWG	10 AWG	10 AWG	10 AWG	10 AWG

Boat Wiring (continued)

The chart included in the manuals (shown on the previous page) does simplify total conductor into "extension length"; extension length assumes a 2 conductor system (4 conductor systems that make series connections at the trolling motor are no longer recommended because the amp draw of modern trolling motors would require very large gauge wire to make these systems work).

Connections:

Good metal to metal connections of lead, aluminum, or copper that are mechanically tight and free of corrosion typically very low resistance. Loose connections, corroded connections, or connections that use less conductive metals can cause resistance that will lead to voltage loss at the motor.

Results:

Voltage loss to the trolling motor can show up a number of ways, including:

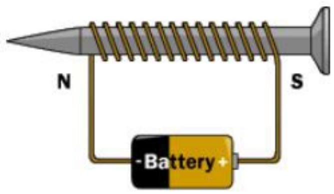
- ☹ Reduced Performance
    - Lower voltage to the motor causes a reduced operating speed
- ☹ Reduced Battery Life
    - Running the motor at higher speeds to get the same performance consumes the battery faster (the voltage lost due to bad connections or inadequate wire is lost as heat)
    - This symptom may also be caused by a bad battery; it rarely is caused by the motor
- ☹ Erratic Performance (electric steer motors)
    - Autopilot (traditional or i-Pilot direction functions) logic assigns directions a voltage, changes in voltage to the motor after a direction has a voltage assigned to it can cause the motor to spin randomly.
    - Remote range and oversteering issues can also be caused by inadequate voltage getting to the motor
    - Components going off-line
        - In PowerDrive V2 motors with Autopilot the compass will not turn on and the motor will have no steering when voltage is too low.
        - In i-Pilot equipped motors the GPS receiver is the first component to shut off when voltage gets low.

Since these issues are not caused by the motor itself no motor repair will address them. On occasion these same issues may be the result of a trolling motor malfunction, but when taking a motor in for repair with any of these symptoms it is best to prepare the customer for the fact that you may find nothing wrong and suggest that while you have the motor in they should have the batteries tested and inspect their wiring.

Motor Theory

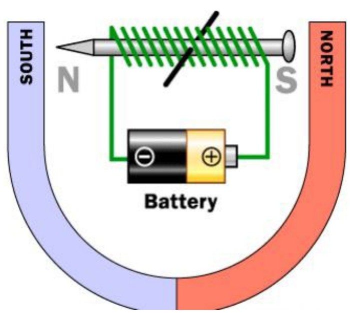
Electromagnatism:

A wire carrying electric current has a magnetic field; when wrapped around an iron bar that magnetic field is transferred to and amplified by the iron bar. As long as current is running through the wire the iron bar will be magnetic, when current is removed the magnetism is quickly lost. A basic example may look like this:



Note that like any magnet the elector magnet has a North and South pole. Like poles repel each other and opposite poles are attracted toward each other (North pushes North, South pushes South, North and South pull toward each other).

If we position this electromagnet within the field of a permanent magnet it will want to be in the position shown here:

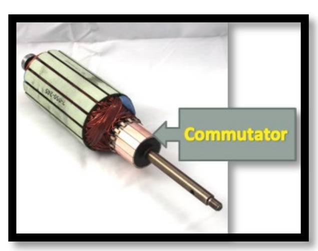


The North pole is always associated with the negative wire and the South pole with the positive, reversing the direction the electric current is flowing will reverse the polarity of the magnet. This is the basis for an electric motor.

Commutation:

To keep the motor spinning you must constantly switch the electrical path, to accomplish this we use a process called commutation.

Defining a few parts of a Minn Kota Armature (windings, stack, and commutator):



Motor Theory (Continued)

The windings are the wire that caries the current which creates the electromagnet that is the basis for our motor. The stack is the iron bar in our basic electromagnet example; on the armature each segment of the stack represents a separate path and therefore a separate electromagnet. Electric current is carried into the windings through the commutator, each segment of the commutator is associated with a segment of the stack.

Within a Minn Kota motor lower unit a pair of permanent magnets are in a fixed location and a pair of motor brushes have a set location relative to the magnets; current flows from the brushes into the windings through the commutator as the motor turns a different section of the commutator comes in contact with the brushes advancing to a different set of windings. This process keeps the motor in motion as long as current is supplied to the brushes.

Speed Variation:

Speed in an electric motor is mostly a function of voltage or effective voltage; the higher the voltage the faster a motor will run. The voltage a motor is rated at is the maximum voltage the lower unit is designed to operate at (running a 12 volt motor at 24 volts would result in a faster speed, but it would burn up very quickly since it is not designed to operate at that speed). Speed variation is accomplished by reducing the voltage (or effective voltage) to the motor lower unit; Minn Kota uses two different methods of doing this, Speed Coils (5 speed motors, SC models) or Pulse Width Modulation circuit board (Variable speed motors, motors with Maximizer).

Speed Coils

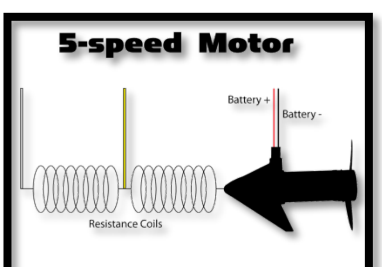
- Current to the brushes is routed through a coil of small guage wire, the resistance reduces the voltage that reaches the brushes.

☺This method of speed variation is inexpensive

☹Offers a limited number of speed choices

☹Ineffecient, the voltage reduction process wastes some energy as heat

A diagram of the speed coil is below. The longer the path through the coil the mor the voltage is reduced. Some of the 5 speeds require multiple connections.



Maximizer

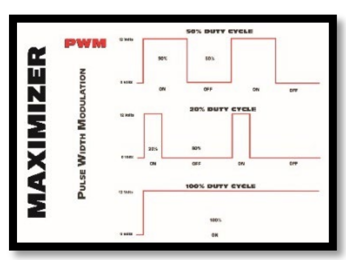
- A control board shuts on and off very rapidly; the user selects the percentage of “on” pulses; this reduces the effective voltage to the brushes.

☺Offers an infinite number of speed choices

☺Highly efficient, very little heat generated, at low speeds up to 5 times the run time of an SC.

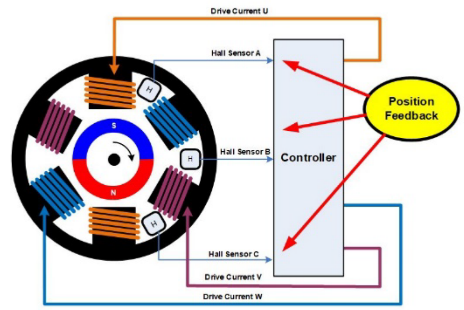
☺More expensive method of speed variation.

A diagram of PWM output is below. The more “on” pulses the higher the effective voltage. **Note:** Testing output voltage without a load will likely give inaccurate information.



Motor Theory (Continued)

Brushless Motors:



Where Permanent Magnet Brushed Motors use commutation to mechanically switch the location of the electromagnet relative to the permanent magnet; Brushless Motors Electronically switch the location of the Electromagnet. Typically for the same function this means reversing the location of the pernament magnet and the electromagnet, so a Trolling Motor would have a rotar with a permanent magnet and windings for the electromagnet in the motor housing.

Speed control in Brushless motors is primarly contolled by the rate of switching and monitoring rotar position, this is effectively full power at controlled intervals like PWM, but is not managing effective voltage to approximate speed, it is directly managing speed.

Brushless/Permanent Magnet Comparison:

Permanent Magnet Motor

- ☹ Arching at Brushes creates RF
- ☹ Speed Contolled by limiting Voltage to the brushes, slowing the motor as desired
- ☹ Brushes wear out over time?
    - Brush life on Minn Kota motors exceeds most use cases
- ☺ Significnatly Less Expensive
- ☺ More Serviceable

Brushless Motor

- ☺ Controller Switches without arcing
- ☺ Speed precisely and efficiently controlled via position sensing and electronics
- ☺ No wear components
- ☺ Distance from the Rotor to the outside of the motor allows for a more powerful magnet to be used.
- ☹ More Expensive to produce and Service