LEE HART'S RECTACTOR CIRCUIT

The rectactor circuit has two diodes and one SPST contactor per stage. Here's an example using two "modules" of 3 golf car batteries each, for 18 or 36 volts (approximately, see below) to the motor:

```
   _______________B+
  |           |
 _|_ D1     __|__+
 /_\         ___ 18v
  |  S1 /     |  -
  |____/ ____|
  |           |
__|__+       _|_
 ___ 18v     /_\ D2
  |  -        |
  |___________|____B-
```

With S1 open, the batteries are in parallel -- you get 17v between B+ and B-. Each has a diode in series, so you lose about 1v (silicon) or 0.5v (Schottky). You can load the parallel batteries (draw current from them to run a motor), but can't do regen or charge them in parallel (because the diodes block reverse current flow).

With S1 closed, the batteries are in series -- you get 36v between B+ and B-. The diodes are out of the circuit. You can both drive the vehicle and charge the batteries in series.

This is the basic building block you use to produce larger arrays. Treat B+ and B- as the two terminals of a "battery" that has two switchable voltages. This in turn could be used as the building block for even more series/parallel circuits. This setup can give you any final voltage that is a multiple of the basic module voltage. If each module is 18v and you have four of them, you can get 18v, 36v, 54v, or 72v.

For example, here is a complete three-step rectactor controller for four 12-volt batteries, providing 12, 24, or 48 volts to the motor, with a series resistor for a smoother start.

```
           _________________________________||__________||___
          |         _|_        __|__+   |   ||   |  |   ||   |
          |      D1 /_\  S4a   ___ B1   |   S1   |  |   S2   |
         _|_         |_____||_____| -   |        |  |_      _|
     D5  /_\       +__|__  ||   _|_     |___|/___|    \/\/\/ |
          |      B2 ___         /_\ D2     +|\-         | R1 |_
          |        - |____________|         C1         _|_   _| MOTOR
          |     S3         |                       S5 ___   _| FIELD
          |_____||__________|                           |    _|
          |     ||          |                           |    |
     _____|_____            |                           |____|
    _|_       __|__+      _|_                               |
D3  /_\  S4b   ___ B3     /_\ D6                          _|_
     |____||____|  -       |                      MOTOR   /   \
  +__|__  ||    _|_        |                    ARMATURE |     |
B4  ___        /_\ D4     |                               \___/
     |__________|___________|________________________________|
```

B1-B4 are your four 12v batteries. S1 is your main contactor, and has capacitor C1 across it as a snubber. R1 is your starting resistor, and S2 is the bypass contactor for it.

S4 is your 12v/24v series/parallel contactor. When open, B3 and B4 are in parallel via diodes D3 and D4; and B1 and B2 are in parallel via diodes D1 and D2. When you close S4, it connects B1 and B2 in series, and B3 and B4 in series.

S3 is your 24v/48v series/parallel contactor. It works with diodes D5 and D6 to select 24v or 48v.

S5 is a field weaking contactor. It wires part of the starting resistor across the field to get a speed halfway between two voltage steps.

Notice that at full voltage (48v), there are no diodes in the power path. At 24v, there is only one diode in the power path (D5 and D6 are effectively in parallel, each carrying 1/2 the motor current). At 12v, there is two diode drops in the power path (D1, D2, D3, and D4 are effectively in parallel, each carrying 1/4th the motor current).

Also note that no contactor ever needs to switch the full 48v. In an emergency shutdown, opening all contactors doesn't have more than 12v across any of them.

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Sizing the parts for a rectactor requires that you first decide what current and voltage each part must withstand. In a contactor controller, nothing but operator common sense limits the peak current (unless you add some sort of current sensing and automatic limiting). The simplest form of current limiting is to put fuses or circuit breakers in series with each 18v battery string. This also prevents trouble if a diode shorts or a contactor welds.

Diodes and contactors both have peak and average current ratings. Pick your fuses to set these limits. Every fuse has its own typical current-versus-time curves, which you can find on the fuse manufacturer's data sheet. For example, an inexpensive Bussman type NON 100 amp 250vac/125vdc general-purpose fuse can carry:

100 amps for 1 hour
140 amps for 5 minutes
250 amps for 10 seconds
600 amps for 1 second
2000 amps for 0.1 second

An Albright SW80 contactor's current-versus-time curve is

100 amps continuous
150 amps for 15 minutes
250 amps for 3 minutes
600 amps for 10 seconds

A 1N3736 200v 250a diode is rated:

100 amps at 70 deg.C case temperature
250 amps at 140 deg.C case temperature
4000 amps peak for 0.1 second

So this fuse would protect this contactor and diode (i.e. the fuse is likely to blow before the contactor or diode fail). You just have to go through the data sheets for the parts you pick to see what it takes.

In a single rectactor, in series, at 100 motor amps, both batteries and the switch are carrying 100 amps. In parallel, at 100 motor amps, each battery and diode carry 50 amps.

An advantage of contactor controllers is that properly arranged, no single contactor ever sees the total voltage. Many of them see only a small fraction of the total. So you can use relatively inexpensive contactors. In sizing your contactors (and diodes), you have to analyze the circuit to see what voltage is across each diode and contact when they are not conducting. Or, build a little breadboard and measure it (and scale up accordingly).

A reasonable guess for the starting resistor current is around 250 amps. Most of these resistors are a big open coil of nichrome wire, so it's not hard to experiment; get one a bit bigger than you need, and tap along it to find the resistance that gives you a normal acceleration from a dead stop.

Sizing the diode is harder. The time it can take any given current depends on the heatsink, and that is something you supply. Crudely speaking, if the case gets too hot to touch, you ran too much current for too long.

(Adapted from Lee Hart’s EVDL posts of 2 May 2005 and 3 May 2007)