

How to build Battery-Monitoring-Control Circuits

(10/18/2010)

This report describes how to build an energy efficient voltage monitoring-controller system for lead-acid storage batteries.

At our primitive site we needed a battery monitoring system that had features that we couldn't find to purchase off the shelf. We (two of us) ended up designing, building and testing one that works very well. Both water and wind charging systems need this functionality as a minimum. One would need to be built and test before needing to use it in a primitive environment.

Functions desired and designed for when we started:

- Sounds an alarm when battery needs charging.
- Turn on a ventilation fan (for hydrogen gas) when charging.
- Turn on a diversion dump load only when voltage is above safe limit for charging.
- Very low current drain on the battery when monitoring in OFF condition.
- Very accurate voltage measurements.
- Works and is accurate with and without high amounts of AC ripple.
- Does voltage averaging over about 1 sec interval.
- Switching accurately and repeatable given varying input conditions including temperature.
- Adjustable voltage to trigger ON conditions.
- Adjustable difference between ON and OFF for each trigger voltage (hysteresis).
- Able to withstand accidental hooking up with reversal of battery voltage.
- Able to withstand over voltage of static discharges (close lightning strikes).
- Flexibility to control each device near the point of need. Break up functions into separate circuits.
- Is protected from continuously wet and high humidity conditions.
- Works over wide range of temperatures (-40C to 80C) with out much variation in voltage.
- Minimize number of components without sacrificing flexibility and reliability.
- Low cost, reliable, and repairable.

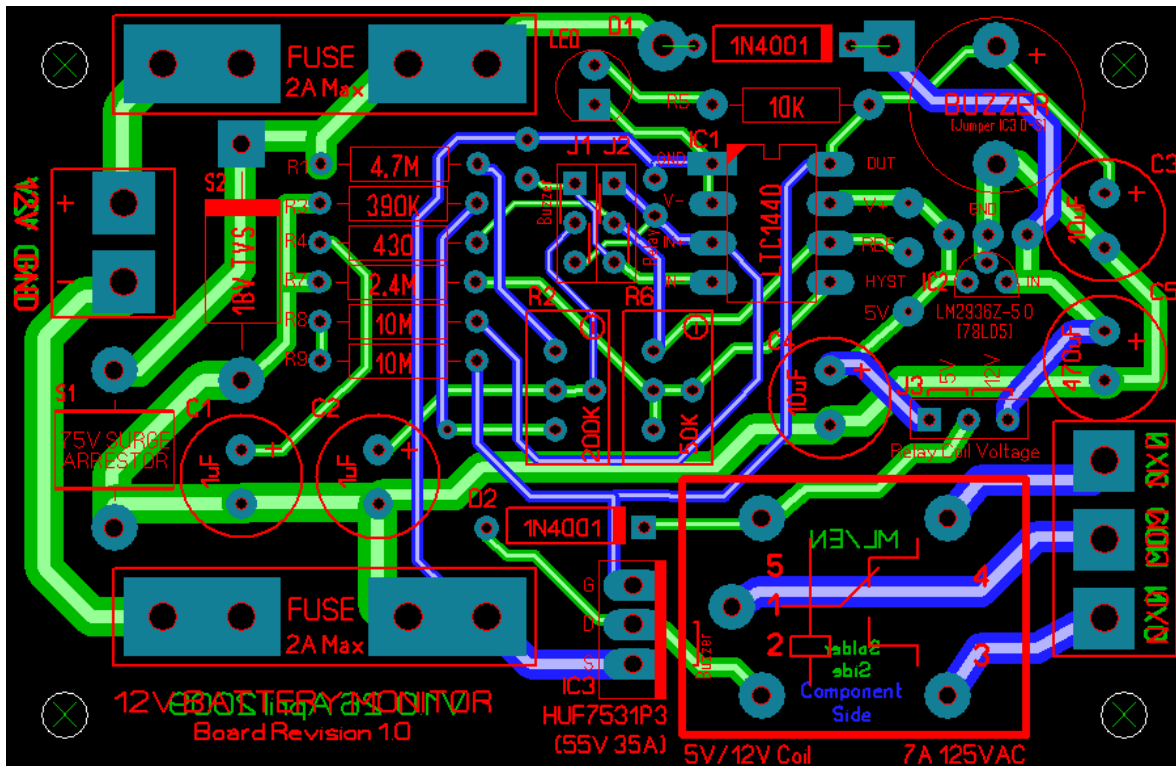
12 Volt Battery Monitor Ver 1.0

The resulting circuit turned out to be more flexible than originally envisioned. The following circuit can be used to turn on or off something over a very precise but adjustable voltage range. A number of controlling circuits can be made from the result.

1. Low Voltage Buzzer warning. Provides an audible warning when battery voltage is low and needs charging.
2. Low Voltage Load or device Cutoff (with and without buzzer). Turns OFF the source of drain (the load) on the battery automatically when battery is low in charge.
3. Turns ON an exhaust fan when the batteries voltage is such that it can give off hydrogen gas. During charging when the voltage per cell gets above a given amount (about 2.2 volts) the water in the cell will electrolyze and give off hydrogen and oxygen. This can accumulate and cause an exposition if there is a spark or fire.
4. Turns on a diversion load (dump load) when over voltage due to charging. Useful for wind and hydro power when it is not desirable to disconnect the charging circuit due to over revving.

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Note the location of J1, J2 and J3. They are referred to in the text below and are used to configure the board for its various uses. One could connect a DPDT switch to the holes for J1, J2 for complete flexibility. It would configure the circuit so as to turn on the relay as voltage goes below a given value (Buzzer position) or to turn on the relay as voltage goes high to some set point (Relay position). Most of the time, circuits dedicated to a single task are more desirable.

Construction Notes

Depending on whether a component is used (soldered on the board) or not determines the resulting functional circuit.

1. Low Voltage Buzzer warning circuit is made by leaving off the board IC3, D2, both R8's, Relay, and 5-12 Volt jumper. Jumper J1 and J2 is configured by shorting center to the buzzer marked side.
2. Low Voltage Load or Device Cutoff (with and without buzzer) is made using all components except for both R8's and the buzzer is optional. Jumper J1 and J2 is configured by shorting center to the buzzer marked side. The 12 volt jumper is used for the relay specified below.
3. Turn on an exhaust fan circuit is made using all components except for both R8's and the buzzer is optional. Jumper J1 and J2 is configured by shorting center to the relay marked side. The 12 volt jumper is used for the relay specified below. Usually the buzzer is not needed for this use.
4. A diversion load (dump load) circuit is made using all components including both R8's and the buzzer is optional, but usually not used. Jumper J1 and J2 is configured by shorting

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center holes to the relay marked hole side of the PC board. The 12 volt jumper (on the output end of the board) is used for the relay specified below. The buzzer is optional and usually not needed.

5. Disconnect charger when fully charged: The circuit is made using all components including both R8's and the buzzer is optional. Jumper J1 and J2 is configured by shorting center to the relay marked side. The 12 volt jumper (on the output end of the board) is used for the relay specified below. The buzzer is optional and usually not needed.

The load is hooked to the relay terminals. In parallel across the load is either a capacitor or a diode to minimize surges when the load is disconnected. Also DC cooling fans tend to generate AC spikes and radio noise; a capacitor can help absorb this.

It is important that a separate wire is run from the battery to relay-load. The normal-closed or normal-open and the common terminal are wired in series with the load and hooked with it's own wires to the battery. This keeps the voltage drop of the load from affecting the sensing control circuit that is now on another separate wire direct from the battery. If your hook up oscillates at some input voltage; that is it turns on and off on it's own, then one of several things are the probable cause. The sensing circuit is not electrically separated enough from the load circuit (one is using the other path for a distance) or the load is too much for the battery or you need to widen your hysteresis (ON OFF) range.

Operation and Adjustment Notes

Depending on which terminals of the relay are used, the resulting circuit can default to being turned on or off. This is when input sensed voltage is low and the relay has not tripped. The resulting circuit when the LED is off will use about 13 micro-amps of current while monitoring voltage. In an OFF state it uses less than .12 Amp-hr of electricity per year while being connected monitoring voltage. This is well below most internal battery leakage self-discharge rates.

When turned on, could use 24 to 55 ma depending on whether using a buzzer only or buzzer-relay combination and what voltage it is operating at. For dump load applications use one or more heavy duty relays 40 to 60 amps and close them by hooking them up as the load for the above circuit. In other words to control more power use the circuit as designed to control one or more heavy duty relays.

These circuits are small and portable. They can be hooked up to 12 volt DC so as to be close to the living area or area of use. If 24 or 48 volts is common, one can use this circuit across 6 cells to monitor 12 volts of a lead acid battery. What the 6 cell will show will be close to the state of charge for the rest of the batteries cells.

R2 adjusts the overall turn-on voltage. Clockwise (CW) gives higher voltages. Usefully adjustment range for R2 measures to be about 10.9 to 16.3 volts. One turn of the 25 turn pot equals about 0.22 volts. R6 is the hysteresis or delta voltage between on and off. Its adjustment is non-linear. Its final adjusted delta voltage (difference between ON and OFF) is narrowed by .06 volts for a 8.5 volt peak to peak AC ripple added to the DC input.

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Adjusting or setting ON-OFF voltages to the range needed. Using an adjustable DC-voltage-source, like the one describe at the end of this report, test the circuit and adjust the delta or hysteresis (the difference between on and off voltages) to close to what is needed. Do this first, and then adjust voltage of a temporary adjustable source supply to the desired turn-ON voltage. Temporally connect this voltage source to the battery monitor board. If the LED is ON turn the pot R2 CCW (counter clock wise) until the LED turns off. If the LED is off then turn CW (clock wise) slowly until the LED just turns ON. This sets the turn on voltage to very close to what is needed. The procedure works for Fan and Dump load circuits. However, if wired for low voltage buzzer circuit, use the above procedure with CW and CCW interchanged.

Low Battery Voltage turn on Relay or Buzzer Circuit (1 & 2)

Currently this circuit is recommended to start with it adjusted to turn ON at 12.0 volts and turn OFF at 12.1 volts with no AC ripple. When 3 Volts of RMS AC ripple (8.5 volt Peak to Peak) is added to the DC, the turn ON voltage changes to 12.03 volts and the turn OFF voltage is 12.07 volts. Thus it narrows the voltage delta by .06V. OFF battery current is 13 micro amps and ON current is 23 ma. With a relay and buzzer the ON current is about 55 ma.

During construction R2 should be set to between 54 kohms to 68 kohms on the side close to the adjustment screw and between 140 kohms and 145 kohms from center to furthest away from adjustment screw. R6 should be adjusted to about 6.8 to 8.4 kohms for the side closest to the adjustment screw. This will get one into the ball park of the above voltage range.

Hysteresis (difference between on and off voltages) is adjustable from .01 volt (R6=0 ohms) to .55 volts (R6=50kohm). When R6 = about 7.5Kohms the Hysteresis is about .1 volt.

Ventilation Fan Circuit

Small 12 Volt venation fans are common place in the computer electronics industry. Some are small enough (3" by 3") to fit inside a large PVC pipe. The pipe can then be vented to the outside to harmlessly pump the hydrogen gas fumes to the outside. In this way the batteries can be enclosed in a closed housing that protects those living in the area from the hydrogen gas as the batteries charge. See separate report on how to make these.

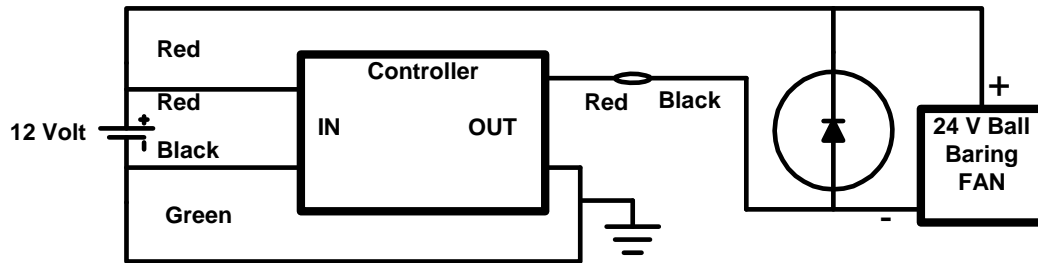
This circuit was adjusted to 13.2 volt turn ON and 13.0 volts turn OFF. An 8.5 volt peak to peak AC ripple on top of the DC narrows range to 13.17 volts ON and 13.03 volts OFF. As batteries are new or gel cells or higher ambient temperature, then one could go a bit higher for ON-OFF voltages (approximately plus 0.10 volt). As Cells get older one may adjust for a little lower for ON-OFF voltages (approximately minus 0.10 volt). 13.2 volts ON and 13.0 volts OFF is for the average lead-acid battery.

With no fan or buzzer being driven the ON current is 30 ma and the OFF current is 13 micro-amps. Both R2 (Voltage) and R6 (Hysteresis) are 25 turn pots. Hysteresis (the delta between ON and OFF) can be adjusted from .01 volts to .55 volts. R6 when set for .2 volt hysteresis measures to be about 18 Kohms for the end closest to the adjustment screw. A ball park range for R2 is about 102 kohm for side closest to the adjustment screw and about 92 kohms for the other end.

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Charging Fan Hook UP for 12 Volt



The above shows how one can use the controller to power a ventilation fan when charging a 12 volt battery bank.

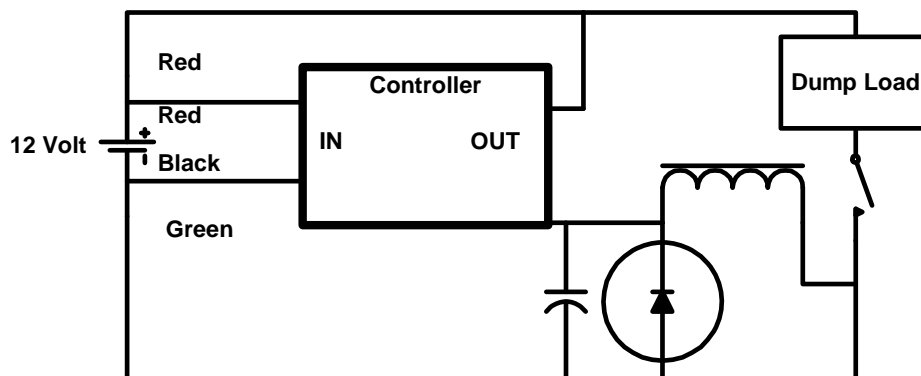
Diversion Dump Load Circuit

The small relay on the PC board (7 amp contacts) can be used to power one or more external to the PC board high current relays as the load. The voltage currently is adjusted to turn ON at 14.8 Volts and turn OFF at 13.4 Volts (delta of 1.4 volt). The large amount of hysteresis is accomplished by using two $R8 = 10$ Mohms in series to make a total of 20 Mohms. 20 mohms has a range for hysteresis of 1.21 V to 1.84 V about .025 V/turn (non-linear). $R2$ is about .26 volts/turn. Otherwise the circuit and components are similar to the Fan controller circuit.

$R6$ adjusted to about 15 Kohms for the adjustment end of the pot is a good starting point. $R2$ adjusted to about 154 Kohms for the adjustment end of the pot and about 49 kohms for the other end is also a good ball park starting point.

14 volts OFF current is about 13.2 micro-amps. 13.5 volt ON current is about 30.7 ma for the circuit driving the on board relay with no buzzer. At 14.8 Volts this is about 34.6 ma.

12 Volt Dump Load Controller



The above shows how one could use the controller to dump extra charging power (such as in the case of using wind and water power to charge battery banks) to any given load.

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Turn OFF Charging Controller circuit

This is similar in construction to the above “diversion load circuit”. Instead of using the output terminals common and normally open, one would use the common and the normally closed terminals. If a different range of hysteresis is need then a different number of 10 Mohm R8 feedback resistors will be needed in series.

A total of 10 Mohms feedback for R8 will give a hysteresis range for R6 of 2.43 volt delta (full CCW) to 3.11 Volts delta (full CW) between turn ON and OFF voltages (R2).

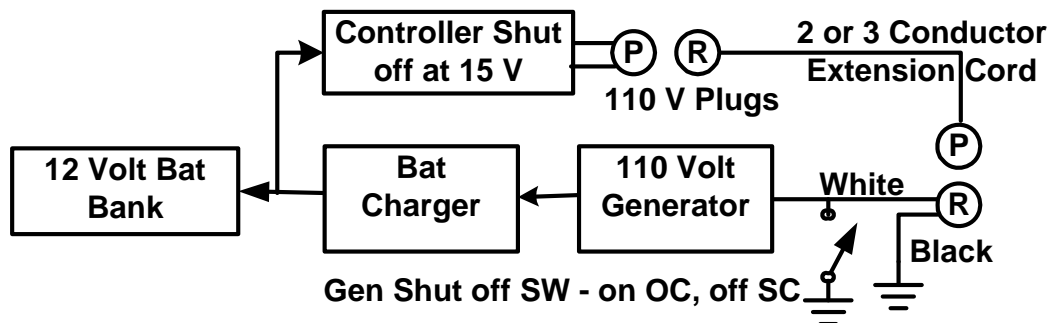
A total of 20 Mohms feedback for R8 will give a hysteresis range for R6 of 1.21 volt delta (full CCW) to 1.84 Volts delta (full CW) between turn ON and OFF voltages (R2).

A total of 30 Mohms feedback for R8 will give a hysteresis range for R6 of 0.88 volt delta (full CCW) to 1.37 Volts delta (full CW) between turn ON and OFF voltages (R2).

When no R8 is used it will give a hysteresis range for R6 of 0.01 volt delta (full CCW) to .55 Volts delta (full CW) between turn ON and OFF voltages (R2).

If a hysteresis is needed between or outside of these ranges then interpolation and testing will give the correct value for R8 to bring it into range for final adjustment with R6.

12 Volt Battery Charging Generator Shut off Circuit



Using a total of 20 Mohms for R8 and adjusting to close the on board relay at 15 volts allows one to use this circuit to do an automatic shut off of a gasoline powered generator. The on-off shorting switch on the generator is wired in to the controller with an extension cord as the above circuit shows.

Temperature Testing Results

Standard 5% carbon resistors with PPM/C ranging between 700 to 1500 or higher do not give very good stability over a wide range of temperature. My test results with these show a high turn-ON voltage when cold and a low turn-ON voltage when hot. The slope of the line is about -0.077 Volts/10degree-C for 5% carbon resistors. Over the range tested from 17 degree F to 156 degree F (or delta of 80 degree C) the voltage change was measured to be about .62 volts. This is outside the range of desirability for most uses.

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The slope of the line is about -0.126 Volts/10degree-C for non-precision metal resistor was even worse. Over the range tested from 17 degree F to 156 degree F (or delta of 80 degree C) the voltage change was measured to be about 1.0 volts. This is outside the range of desirability.

If one solves the temperature resistance equations using values from the temperature reference voltage changes with temperature as given for the comparator-IC one can find the optimum PPM/C for the key input resistors. What one finds is the 4.7 Mohm needs to be about 100 PPM/C when the 390 Kohms is 50 PPM/C.

In practice when both are tested and the results measured. The 50 PPM/C for both resistors R1 and R3 gives better results by about .03 volts at the limits of the test range of temperature. When R1 was 50 PPM/C the deviation measured .00 volts when hot and +.01 when cold when compared to room temperature. When R1 was 100 PPM/C the deviation measured -.03 volts when hot and +.01 when cold when compared to room temperature. Both R1s would work fine for most purpose. .03 Volts is well with in the margin of usability. Most precision 1% resistors have low change with temperature but not always. Be sure to check the specs for PPM/C.

Humidity Testing Results

For open untreated PC boards, high amounts of humidity and dampness of any kind lowers the turn on voltage. I can be of the order of magnitude of .10 volts or so. Covering the components and board with bees wax can lower this to about .05 volts.

Water or something wet in contact with the unprotected board can dramatically change the on off voltage down to 2 to 5 volt range. A coating of wax helps but doesn't totally seal it from water.

It is desirable to seal this board against water and high humidity. It is not possible to completely seal it due to the need for adjustment screws. However, it can be made water resistant.

After testing different sprays like, Lacquer, Clear top coat by Rust-Oleum, Fast-Drying Polyurethane, Plasti-Dip rubber coating, and electrical Liquid Tape by Performix. I found in general one spray is not enough 2 to 3 sprays are much better. In the end I found that the black Liquid Tape (paint on brush in lid of can) sold by harbor-freight works best. I use two to 3 coats with drying in-between. All sprays have a lot of bubbles in the liquid, which tend to leave a porous surface.

Colophony resin (Pine resin) and denatured alcohol has been discussed on the Homebrew PCB forum as working well, with no mention of concentrations needed to dissolve the resin.

Coating tests were done using salt water and 12 volt DC battery with one wire painted for each type of spray. The current was then measured when the painted end was put in a saturated solution of salt water. A teaspoon was used as the other terminal. It is surprising how much current was passed through one layer testing all the sprays (lacquer through plastic-dip and liquid tape). The Liquid Tape brush on type tested below measurable current. Well below 1 micro-amp where the others measured in the 20-40 ma range for a small wire about 1 in the solution.

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Parts List For all of the circuits described above

All three circuits use similar parts. Some use more parts than the others. Total cost is reasonably low.

REF	Quant- ity	Part Number	Description	Unit Price	Extended Price
				USD	USD
IC1	1	LTC1440CN8 #PBF-ND	IC COMP W/REF LP SINGLE 8-DIP	2.75	\$2.75
IC- SOCKET	1	A08-LC-TT-R	IC SOCKET STRAIGHT 8POS TIN	0.33	\$0.33
IC2	1	LM2936Z- 5.0/NOPB	IC REG ULTRA LOW CURR 5.0V TO92	2.39	\$2.39
IC3	1	HUF75321P3- ND	MOSFET N-CHAN 55V 35A TO-220AB	0.84	\$0.84
S1	1	495-1475-ND	SURGE ARRESTER 75V GASTUBE 2PIN	1.41	\$1.41
S2	1	1.5KE18AGO S-ND	TVS 1500W 18V UNIDIRECT AXIAL	0.66	\$0.66
D1 & D2	2	1N4001FSCT- ND	DIODE GEN PURPOSE 50V 1A DO41	0.09	\$0.18
R1	1	RNF1/4T14.7 5MFRCT-ND	RES MF 1/4W 4.75M OHM 100PPM 1% AXIAL	0.1238	\$0.13
R1 Best	1	CMF4.75MHF CT-ND	RES 4.75M OHM 1% 50PPM 1/2W	0.91	\$0.91
R1 Optional	5	CFR-50JB- 4M7	RES 4.7M OHM 1/2W 5% CARBON FILM	0.058	\$0.29
R2	1	490-2882-ND	TRIMPOT CERM 200K OHM 25TRN TOP	0.86	\$0.86
R3	1	CMF392KHF CT-ND	RES 392K OHM 1% 50PPM 1/2W	0.1386	\$0.14
R3 Optional	5	CFR-50JB- 390K	RES 390K OHM 1/2W 5% CARBON FILM	0.058	\$0.29
R4	5	CFR-50JB- 430R	RES 430 OHM 1/2W 5% CARBON FILM	0.058	\$0.29
R5	5	CFR-50JB- 10K	RES 10K OHM 1/2W 5% CARBON FILM	0.058	\$0.29
R6	1	490-2889-ND	TRIMPOT CERM 50K OHM 25TRN TOP	0.86	\$0.86
R7	1	RNF1/4T12.2 1MFRCT-ND	RES MF 1/4W 2.21M OHM 1% AXIAL	0.1156	\$0.12
R7 Optional	5	CFR-50JB- 2M4	RES 2.4M OHM 1/2W 5% CARBON FILM	0.058	\$0.29
R8	1	RNF1/4T110 MFRCT-ND	RES MF 1/4W 10M OHM 1% AXIAL	0.1402	\$0.14

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R8 Optional	5	PPCHHJ20M CT-ND	RES 20M OHM METAL FILM .50W 5%	0.59	\$2.95
R8 Optional	5	CFR-50JB- 10M	RES 10M OHM 1/2W 5% CARBON FILM	0.058	\$0.29
C1 & C2	2	P4675-ND	CAP 1UF 50V STACK METAL FILM	0.386	\$0.77
C3 & C4	2	493-1192-ND	CAP 10UF 250V ELECT VR RADIAL	0.44	\$0.88
C5	1	493-1182-ND	CAP 220UF 200V ELECT VR RADIAL	1.69	\$1.69
B1	1	CX-0905C	BUZZER MAG 2.73KHZ 5VDC 9.6MM	1.98	\$1.98
INPUT	1	ED2580-ND	TERM BLOCK 5.08MM VERT 2POS PCB	0.28	\$0.28
OUTPUT	1	ED2581-ND	TERM BLOCK 5.08MM VERT 3POS PCB	0.42	\$0.42
FUSE	2	486-1236-ND	FUSE 2A 250V 5X20 FAST GLASS	0.23	\$0.46
HOLDER	4	WK6242-ND	FUSECLIP 5MM 6.3A PC MNT	0.14	\$0.56
Order From		Most can be found at http://www.digikey.com/		SUB TOTAL =	\$23.45

Other Items

LED-1	1	Any Source	White or Red LED	0.2	\$0.20
PC- Board	1	Radio shack or any source	.1" hole to hole PC Board (2" x 3")		
Fan Relay	1	DC-RR002	12 volt dc contacts (12A/125V AC, 7A/250V AC)	0.5	\$0.50
Found at http://www.sureelectronics.net/goods.php?id=184					

D1 & D2 = Any 1 amp 50 volt Diode or bigger will work.

Load Relay off the circuit board = CB1AH-12V or 255-2082-ND Relay Auto SPST 12VDC 70A
QC ---- \$5.51 or PB1039-ND --- 12VDC 40A SPST AUTO ----- \$2.52 Note: ebay.com
often has Auto relays in quantity for much less price.

Fan = .15 Amp 12 volt DC fans or better 24 volt ball barring one or more.

B1 = 5 Volt DC Active Buzzer about 22ma. Some 12 volt units will work between 1.5 and 12 volts
DC. Get only Active Buzzer not a passive or piezo speaker. Ebay.com has them for \$.025
and up depending on quantity. Digi-key.com has CX-0905C ----- \$1.98

L1 = Super Bright White LED (any brand or color will work)

R6 = 50 Kohms is the hysteresis pot with range to .55 volts.

R2 = 200 Kohms and controls the turn ON threshold voltage.

R8 = 1, 2, or 3 series connected 10 Mohms are used for feed back to control large amounts of
hysteresis. One 20 Mohm can replace one of the 10 Mohm resistor when 30 Mohm total is needed.

The size of C2 gives the averaging over one sec or so of varying battery input voltages.

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C6 = 4.7 uf to 470 uf or bigger electrolytic depending on the load type (inductive, noisy etc). C6 will need to be adjusted depending on whether the load is inductive or resistive. It wouldn't hurt to put a diode across an inductive load to dissipate any high voltage spikes. This helps to keep the relay contacts from burning.

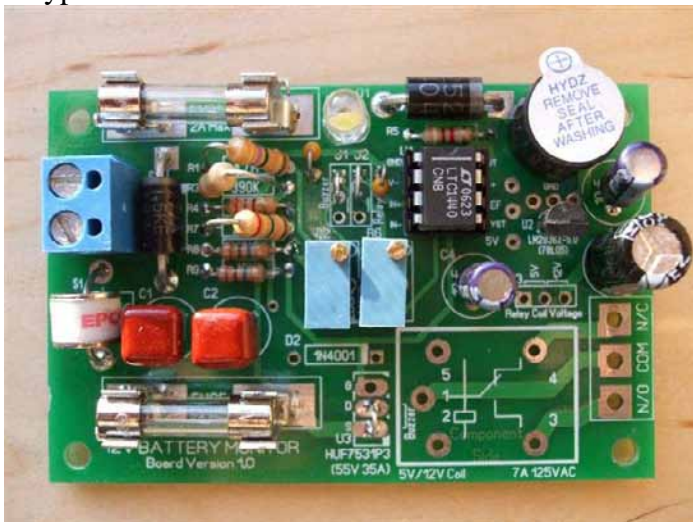
When low coil resistances relay that have high current contacts are used, then C3 will need to be increased (possibly up to 470uF) to keep it from chattering. This is depending on the amount of AC ripple present. The extra capacitance helps when the voltage teeters on make or break levels.

The Lightning arrestors are an area where one can not have enough of them. Metal Oxide Varistors tend to have a 1 ma leakage, thus so far we have stayed with capacitors, zeners and gas discharge as the preferred approach. However, this is an area where more protection is desirable when the components can be found that have low voltage and low leakage. The 18 volt bidirectional TVS Zener leakage tests at 17.4 volt with 1 uA and less than that at lower voltages.

The MOSFET is used to interface to the relay. Most relays use more current than the comparator will deliver. The relay in this case can be light duty contacts and high resistance coil. Also the relay turning on and off tends to produce AC feedback. The MOSFET by it's self is not isolated from the comparator enough to properly control AC producing Fans and Loads. Thus a magnetic relay is used for reliability.

Heavy duty wire will be needed between the battery and the load and load-relay contacts. This wire must be a separate from the wire to the monitoring circuit. The monitoring wire needs to be directly hooked to the source battery terminals. Do not use a common positive or negative lead between the sensing/monitoring circuit and the load. This is done so one is measuring battery voltages directly without the drop in resistances in wires or connectors due to high current flows of charging or the dumping loads. This way a small gauge wire of say number AWG 18 to 16 can be used for the monitoring wire without affecting the voltages that arrive to be monitored.

A typical finished Buzzer circuit looks like the following:



A finished Fan controller is next:

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For buzzer circuit the stand off minimum height for a .5" diameter wooden dowel is 12 to 13 mm long used at two corners. For all the rest use 16 to 17 mm long. Two #4 by ¼ sheet metal screws are used to hold down the PC board.



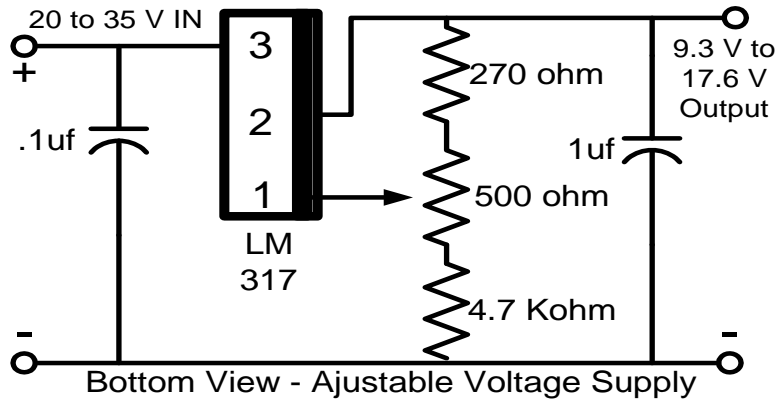
Adjustable regulated voltage source for setting and testing the above controllers

One simple way to test and adjust the trigger ON-OFF voltages for the above controllers is to make a simple DC to DC regulated adjustable voltage source. All that is needed is two small (low power) 12 volt batteries wired temporary in series to give 24 volts or two 9v batteries in series. This used as input the following circuit. The output is adjusted using the 25 turn pot to the desired voltage. This can then be used to adjust the above controllers to turn ON or OFF.

Quantity	Part Number	Description	Unit Price	Extended Price
			USD	USD
1	LM317TFS-ND	IC REG ADJ 1.5A 3 TERM TO-220	0.48	\$0.48
1	CF1/4270JRCT-ND	RES 270 OHM 1/4W 5% CARBON FILM	0.2	\$0.20
1	CF1/84.7KJRCT-ND	RES 4.7K OHM 1/8W 5% CF AXIAL	0.09	\$0.09
1	490-2925-ND	TRIMPOT CERM 500 OHM 25TRN TOP	0.86	\$0.86
2	P824-ND	1.0UF 50V MINI ALUM ELECT (KA)	0.14	\$0.28
Most can be found at http://www.digikey.com/			Subtotal	\$1.91

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A small piece of project PC board was used. Note the adjustment 25 Turn pot in the center.

Labels for boxes:

Low Voltage Buzzer

Volts & Hysteresis
12.0 Volts ON; 12.1 Volts OFF
CW to Increase

Charging Fan

Volts & Hysteresis
13.2 Volts ON; 13.0 Volts OFF
CW to Increase

Dump Load

Volts & Hysteresis
14.8 Volts ON; 13.4 Volts OFF
CW to Increase