Design of a Lead Acid Battery Charger System

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

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In

Electronics and Instrumentation Engineering

By

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CERTIFICATE

This is to certify that the thesis entitled, **"Design of a Lead Acid Battery Charger System"** submitted by Sri Abhik Datta in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Electronics & Instrumentation Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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An assemblage of this nature could never have been attempted without reference to and inspiration from the works of others whose details are mentioned in reference section. I acknowledge my indebtedness to all of them.

Last but not the least to all of my friends who were patiently extended all sorts of help for accomplishing this undertaking.

Date Abhik Datta

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ABSTRACT

With the lack of centralized power grids, lead acid batteries have taken the place of one of the main energy sources available in developing countries. With this in mind, our objective was to design a cheap, versatile and efficient lead acid car battery charger which will interest and appeal to the “cost-minded” customer. Lead-acid batteries are finding considerable use as both primary and backup power sources. For complete battery utilization, the charger circuit must charge the battery to full capacity, while minimizing over-charging for extended battery life. In our circuit we have used a voltage regulator and comparator to regulate the voltage supply to the battery for effective charging. Four LED’s are used to indicate the status of battery charge. This circuit was simulates using a simulation software called Multisim, a product of National Instruments.

CHAPTER 1

INTRODUCTION

INTRODUCTION

A **battery charger** is a device used to put energy into a cell or (rechargeable) battery by forcing an electric current through it. Lead-acid battery chargers typically have two tasks to accomplish. The first is to restore capacity, often as quickly as practical. The second is to maintain capacity by compensating for self discharge. In both instances optimum operation requires accurate sensing of battery voltage.

When a typical lead-acid cell is charged, lead sulphate is converted to lead on the battery's negative plate and lead dioxide on the positive plate. Over-charge reactions begin when the majority of lead sulphate has been converted, typically resulting in the generation of hydrogen and oxygen gas. At moderate charge rates, most of the hydrogen and oxygen will recombine in sealed batteries. In unsealed batteries however, dehydration will occur.

The onset of over-charge can be detected by monitoring battery voltage. The figure on the next page shows battery voltage verses percent of previous discharge capacity returned at various charge rates. Over charge reactions are indicated by the sharp rise in cell voltage. The point at which over-charge reactions begin is dependent on charge rate, and as charge rate is increased, the percentage of returned capacity at the onset of over-charge diminishes. For over-charge to coincide with 100% return of capacity, the charge rate must typically be less than C/100 (1/100 amps of its amp- hour capacity). At high charge rates, controlled over-charging is typically as quickly as possible.

To maintain capacity on a fully charged battery, a constant voltage is applied. The voltage must be high enough to compensate for self discharge, yet not too high as to cause excessive over-charging.

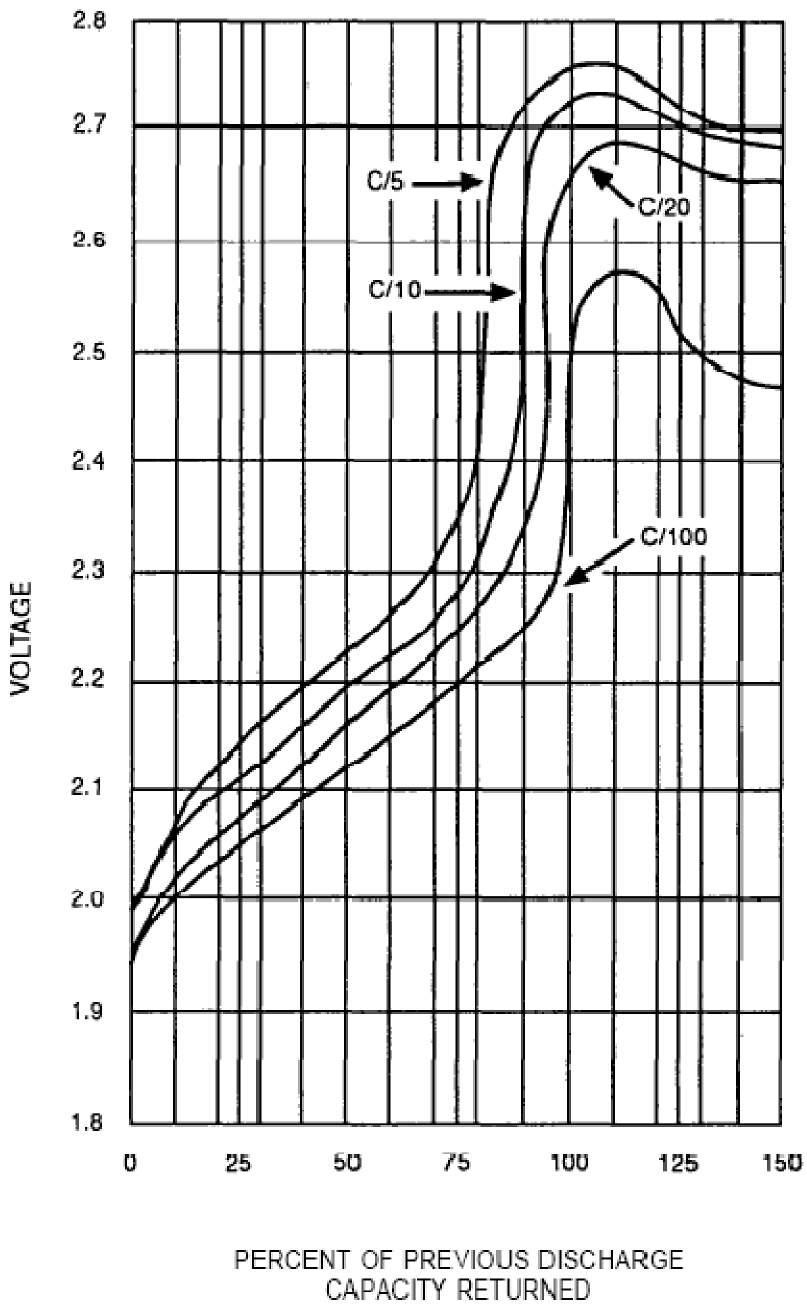


Figure:- Over-charge reactions begin earlier (indicated by the sharp rise in cell voltage) when charge rate is increased.

CHAPTER 2

CHARGING PROCESS OF BATTERIES

CHARGING PROCESS OF BATTERIES

Charging a lead acid battery is a matter of replenishing the depleted supply of energy that the battery had lost during use. This replenishing process can be accomplished with several different charger implementations: "constant voltage charger" , " constant current charger" or a " "multistage" constant voltage/current charger". Each of these approaches has its advantages and disadvantages that need to be compared and weighed to see which one would be the most practical and realistic to fit with our requirements.

Constant Voltage charger:-

Constant voltage charging is one of the most common charging methods for lead acid batteries. The idea behind this approach is to keep a constant voltage across the terminals of the battery at all times. Initially, a large current will be drawn from the voltage source, but as the battery charges and increases its internal voltage, the current will slowly fold and decays exponentially. When the battery is brought up to a potential

full charge, which is usually considered around 13.8V, the charging voltage is dropped down to a lower value that will provide a trickle charge to maintain the battery as long as it is plugged into the charger. The best characteristic of this method is that it provides a way to return a large bulk of the charge into the battery very fast. The draw back, ofcourse, is that to complete a full charge would take a much longer time since the current is exponentially decreased as the battery charges. A prolonged charging time must be considered as one of the issues to this design.

Solar cells are one of our main portable power sources. Inherently, they provide a constant current which is dependent on light intensity and other uncontrollable variability in the environment. This characteristic fits well with a constant voltage charge design, which does not depend on the current provided by the input source, which in turn eliminates the dependence of the charger on external variations like the time of day, weather conditions or temperature. The effects of the changing voltage are also minimized since the voltage is being regulated.

Constant Current Source:-

Constant current charging is another simple yet effective method for charging lead-acid batteries. A current source is used to drive a uniform current through the battery in a direction opposite of discharge.

This can be analogous to pouring water into a bucket with a constant water flow, no matter how full the bucket is. Constant current sources are not very hard to implement; therefore, the final solution would require a very simple design.

There is a major drawback to this approach. Since the battery is always being pushed at a constant rate, when it is close to being fully charged, the charger would force extra current into the battery, causing overcharge. The ability to harness this current is the key to a successful charger. By monitoring the voltage on the battery, the charge level can be determined, and at a certain point, the current source would need to be folded back to only maintain a trickle charge and prevent overcharging.

Multi-stage Constant Voltage/Current Charging Solutions:

Both constant voltage and current approaches have their advantages; that is the reason multistage chargers have been developed which combine the two methods to achieve maximum charge time, with minimum damage to the charging cell.

Stage 1: Deep Discharge Charging Pulse Mode

The Charger starts charging at 0.5V and give pulse current up to 5V. This has effect of removing loose sulphation formed during deep discharge state of the battery.

Stage 2: Constant Current Mode (CC)

The charger changes to constant current 2.5A. When the battery voltage reaches up to 14.4V, the charging stage changes from (CC) Constant Current to CV (Constant Voltage) mode.

Stage 3: Constant Voltage Mode (CV)

The charger holds the battery at 14.4V and the current slowly reduces. When the current reaches at 0.5 C (C= Battery Capacity), this point called the Switching Point. The Switching Point is one of the great features of this battery charger that it can adjust the current automatically according to the battery capacity. Other chargers without microprocessors are not capable to adjust the current.

Stage 4: Standby Voltage Mode

The charger maintains the battery voltage at 13.8V and current slowly reduces to zero. Charger can be left connected indefinitely without harming the battery.

Recharging:

If the battery voltage drops to 13.8V, the charger changes from any mode to Constant Current mode and restart charging. The charging cycle will go through Stage 2 to Stage 4.

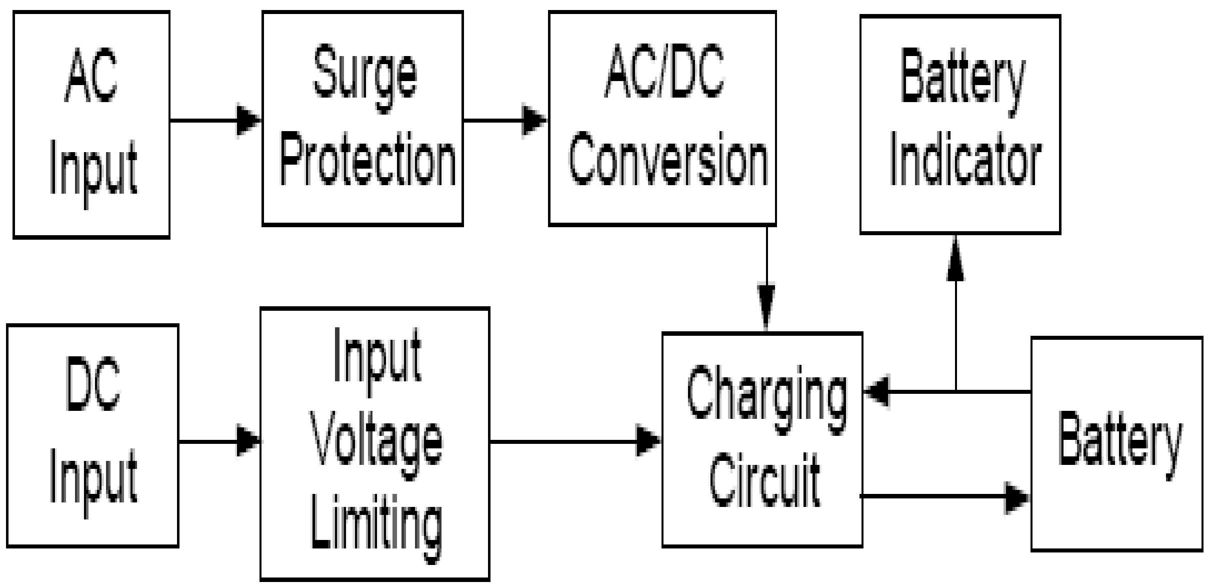
As much as multi-stage chargers are enticing in terms of their features, for our purposes, the complexity and the control logic needed to implement this kind of solution would make our project unrealistic given the time constraints.

CHAPTER 3

HARDWARE DESIGN AND SIMULATION

Hardware Design and Simulation

The design of the hardware of lead acid battery charger is clearly illustrated by the block diagram shown below:

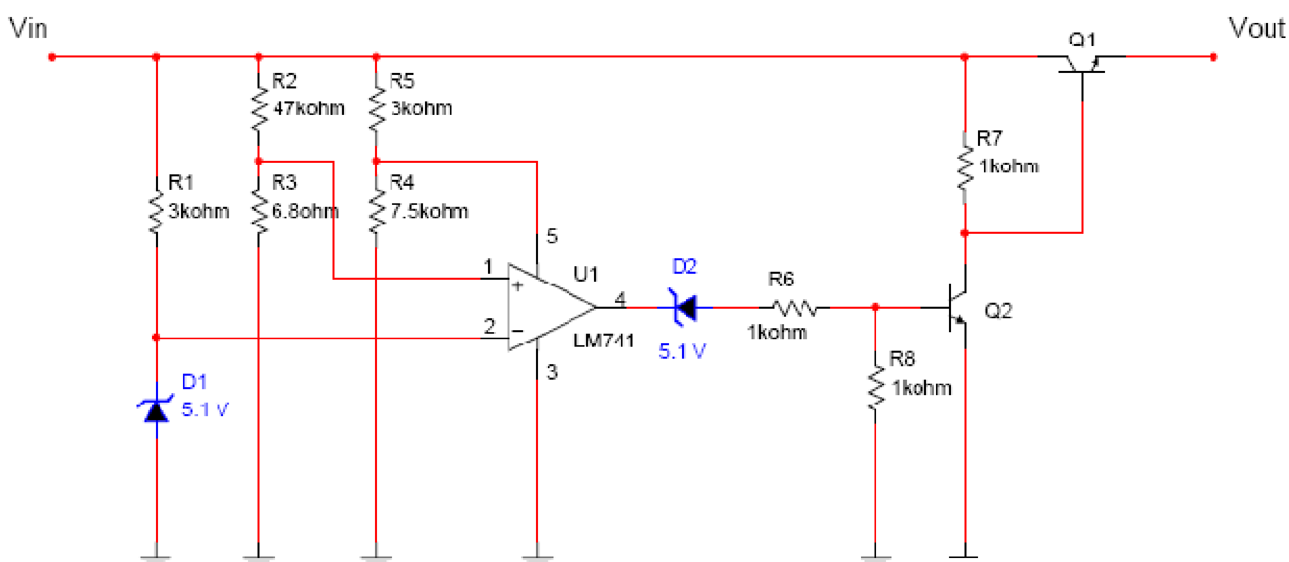


Each individual module was designed and tested separately. After successful simulation and testing, they were put together to get the finalized version.

Input Voltage Limiting

The input voltage limiting capability is necessary to protect the voltage regulator in the charging circuit from input voltage above the maximum allowable value. This value is determined by the input output differential. It may not exceed 36V.

The figure in the next page shows the voltage clamp circuit that was taken out of our prototype at the last minute. The specification of the pass-through transistor added a voltage drop of 4V at the maximum current, which was not acceptable since the charging circuit requires 17V for steady voltage regulation. This circuit compares the zener diode reference to a fraction of the input voltage. Based on this comparison, the op-amp controls transistor Q2, which either turns off or turns on the transistor Q1; therefore disconnecting the charging circuit from the input.



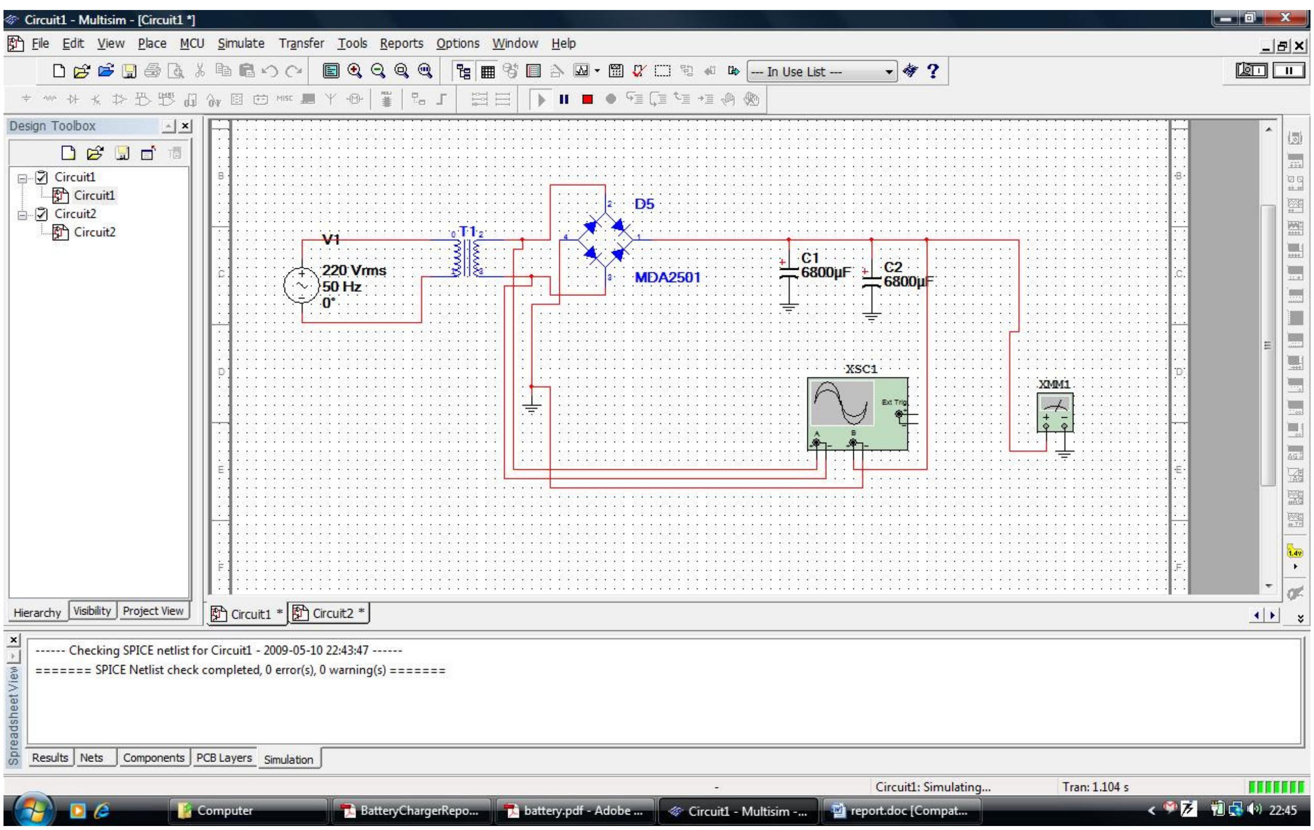
Voltage clamp Circuit Schematic

AC/DC Conversion

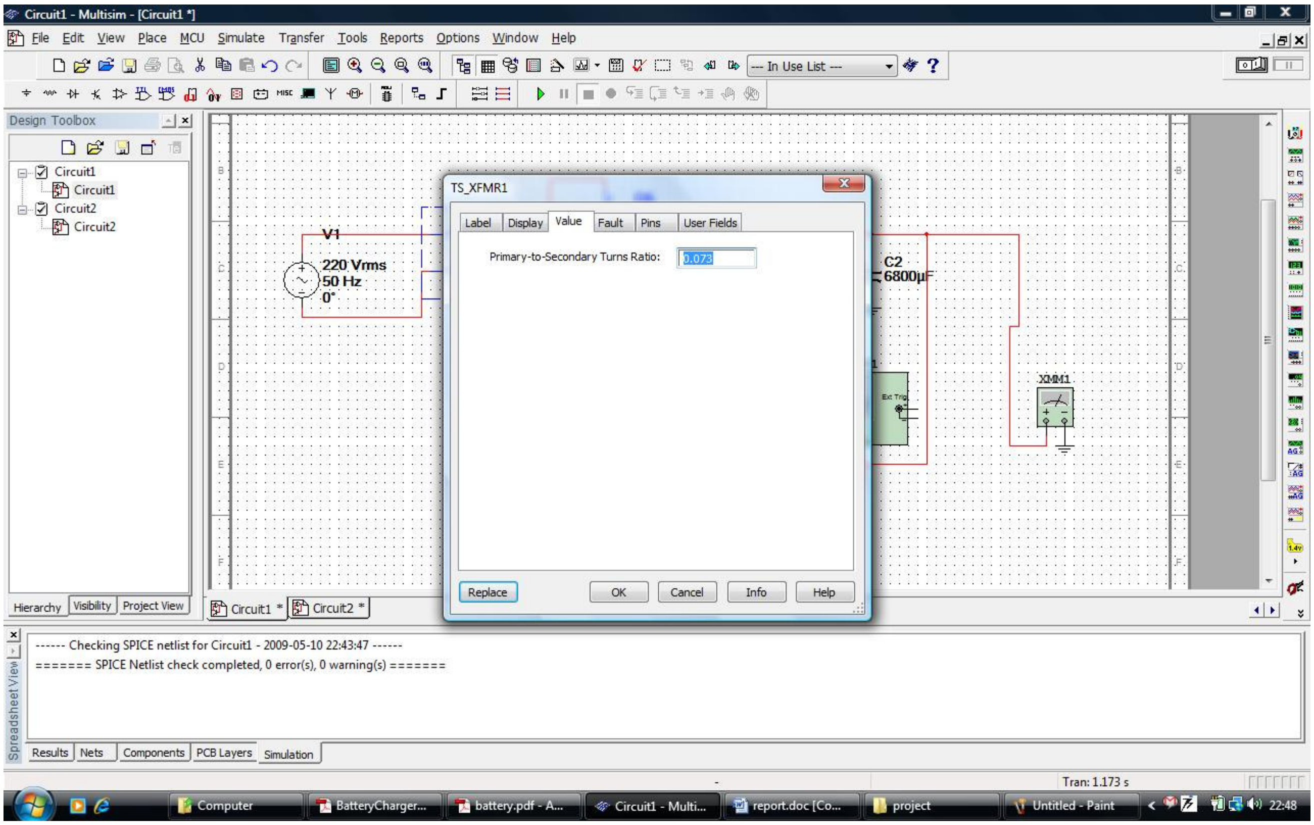
This module converts the AC input of 230Volts, to a usable DC output greater than 17V for the charger circuit. The design includes an internal transformer, bridge rectifier and a filter capacitor.

Operation:-

1) Input signal from the outlet lowered to 16Vrms.
2) 16Vrms gets rectified going through the full-bridge rectifier, with 2 diode voltage drop loss(~1.4V)
3) Capacitor is charged to peak value of the signal.
4) Capacitor is discharged by the rest of the circuit until the voltage on the capacitor isn't increased by the rectified AC signal wave.



Our transformer needed to step down 230Vac to 16Vrms with a current of atleast 3Arms. Hence the transformer ratio is so calculated to be 16Vrms/220Vrms = 0.073 as shown in the simulation



Following the transformer output, the next stage in the AC/DC conversion process involved inverting the negative cycles of the AC input. This process requires the use of a full wave rectifier diode bridge. We determined the required specifications for the bridge rectifier based on the input voltage and current. We determined that our rectifier would have to be able to handle the peak voltage of 22.6V as well as 3 A that the charging circuit would be pulling. We used the MDA 2501 rectifier for simulation purposes. Next we needed to decide the value of the capacitance. The Ac output from the transformer consisted of 16Vrms at 50Hz. We tested for different known values of the capacitor to see how they would affect the output. The current source was 3A which was the maximum current drawn by the charger circuit due to internal current limiting of the voltage regulator. We computed the required capacitor values using the formula:

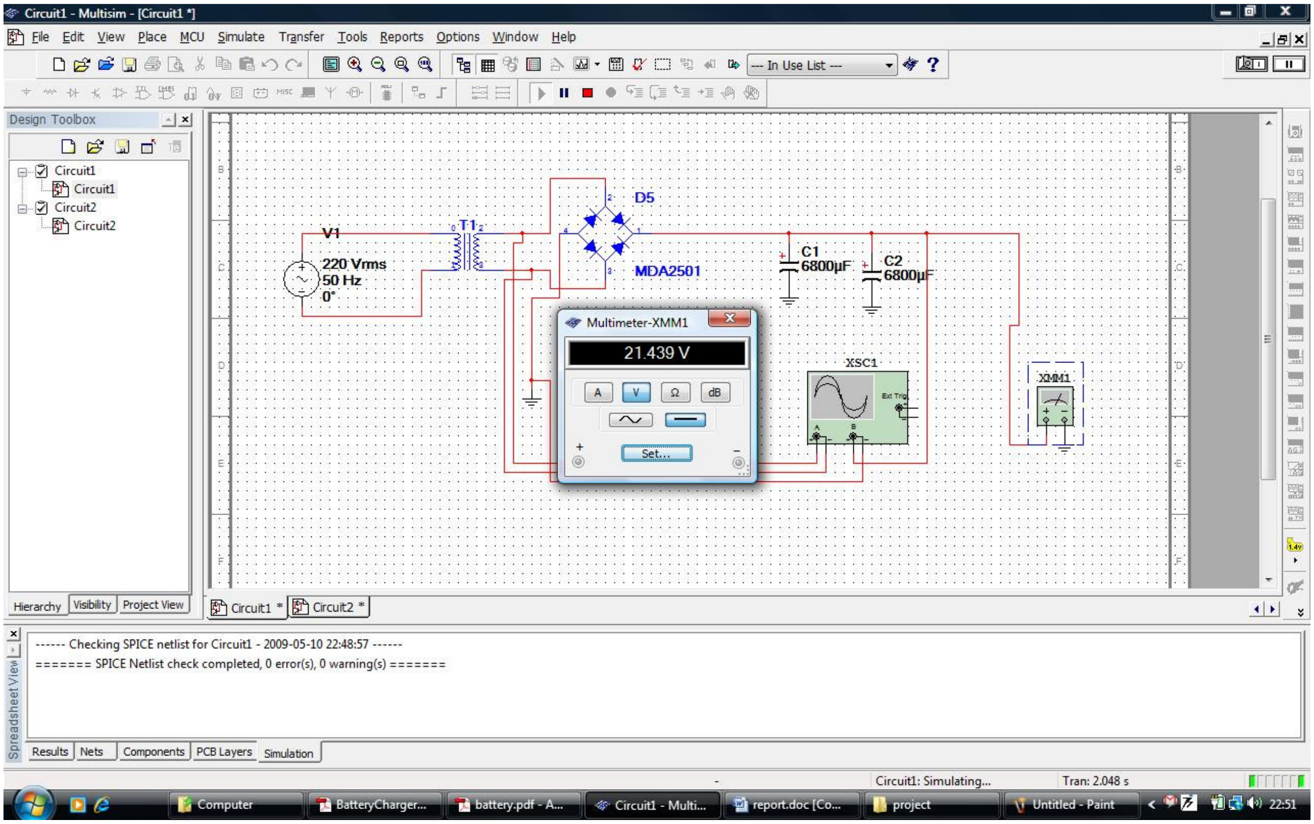
$$I = C\,\frac{dv}{dt}$$

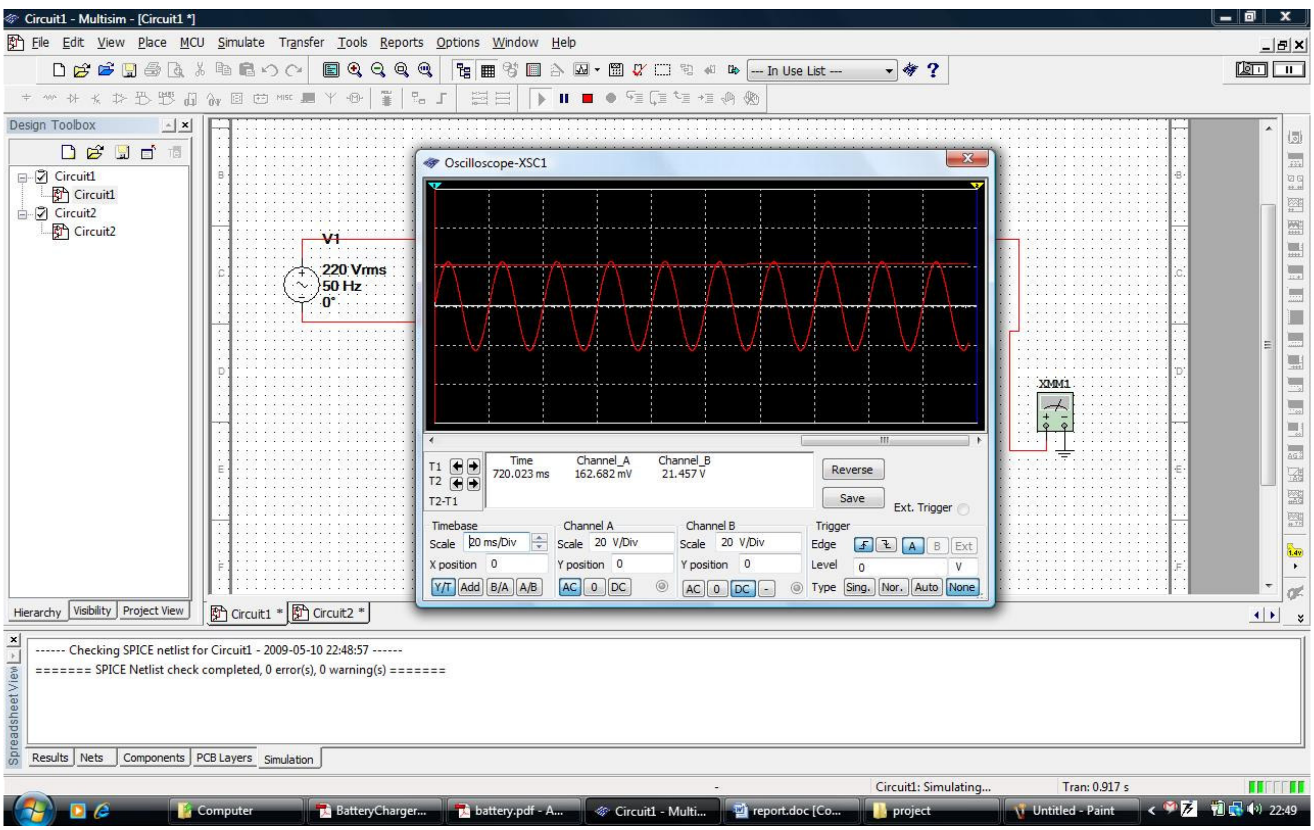
I= 3A ie the maximum load current of the charging circuit

dv= 22.6V-17V, i.e the amplitude of the input signal minus the minimum voltage required by the charging circuit.

dt= 1/100Hz, because the frequency of the rectified signal is twice the frequency of the input.

C= 5357.14uf. Since the calculated value is not a common value we choose the next highest value, 5600uf. We choose a higher value as higher capacitor values decrease the ripple voltage. But in Multisim we found a 6800uf capacitor with a better voltage rating than a 5600uf capacitor so we chose it for the simulation purpose. The voltage output from the multimeter and the spectrum analyser output is as shown in the simulation in the next page.


Circuit1 - Multisim - [Circuit1 *]
V1
220 Vrms
50 Hz
0°
T1
D5
MDA2501
C1
6800µF
C2
6800µF
Multimeter-XMM1
21.439 V
XSC1
XMM1
------ Checking SPICE netlist for Circuit1 - 2009-05-10 22:48:57 ------
======= SPICE Netlist check completed, 0 error(s), 0 warning(s) =======
Circuit1: Simulating...
Tran: 2.048 s


Circuit1 - Multisim - [Circuit1 *]
Oscilloscope-XSC1
Time
Channel_A
Channel_B
720.023 ms
162.682 mV
21.457 V
Timebase
Scale 20 ms/Div
Channel A
Scale 20 V/Div
Channel B
Scale 20 V/Div
Trigger
------ Checking SPICE netlist for Circuit1 - 2009-05-10 22:48:57 ------
======= SPICE Netlist check completed, 0 error(s), 0 warning(s) =======
Circuit1: Simulating...
Tran: 0.917 s

Charging Circuit

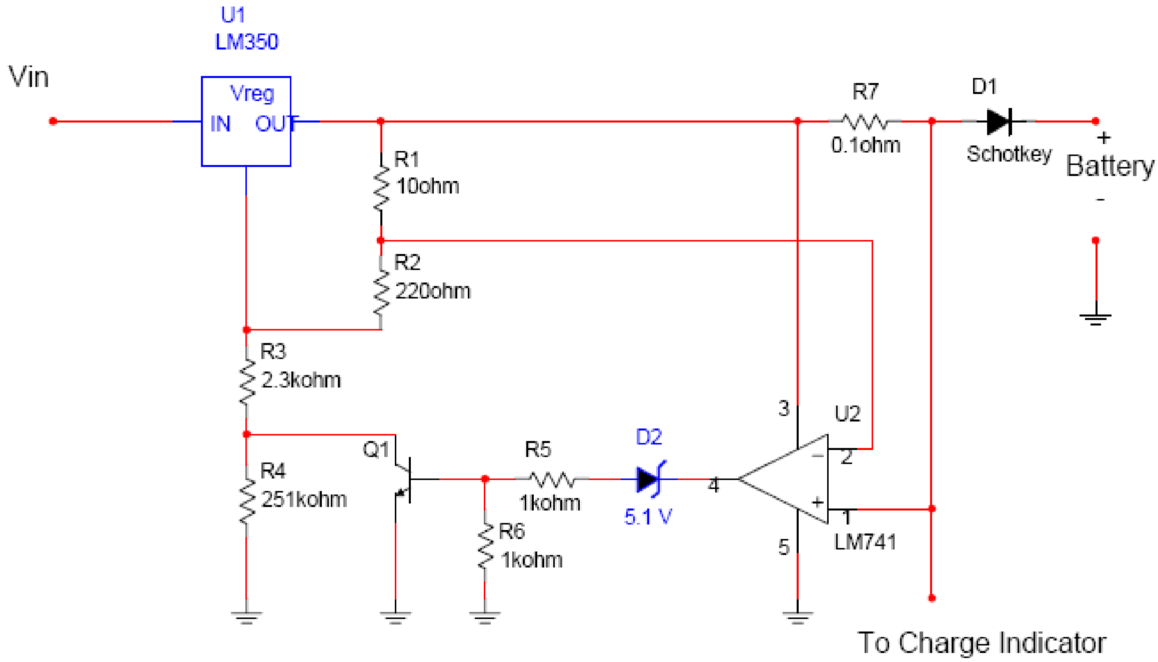
General Description

The full charger feedback control circuit can be seen in Figure below. This circuit implements a three stage charger algorithm: constant current state, constant voltage full charge state, and constant voltage float charges state. This circuit will require an input voltage of at least 17 volts to output the 14.7V for charging because of the 2V drop across the regulator.

The comparator is used to provide feedback of the current that the battery is drawing from the circuit: as the battery charges, the current drawn decreases. The current sensing resistor is used to convert that current into voltage, which can be used to compare to a reference within the circuit. This will be the logic needed for the state switching mechanism. The full charge state will provide 14.7V or 2.45V/Cell on the battery and float charge will provide 13.8V or 2.3V/Cell. The battery will try to draw maximum current, in this case:

(14.7V-10.5V)/.1Ohm= **42A** (assuming the battery is completely dead)

The current limiting of the voltage regulator will force the current to 3A. The charger will continuously pump this 3A until the battery current falls below the limit of 500 mA. This will bring the voltage of the battery above the reference point, therefore causing the comparator to turn on the transistor switch, pulling the output voltage to the float charging level.



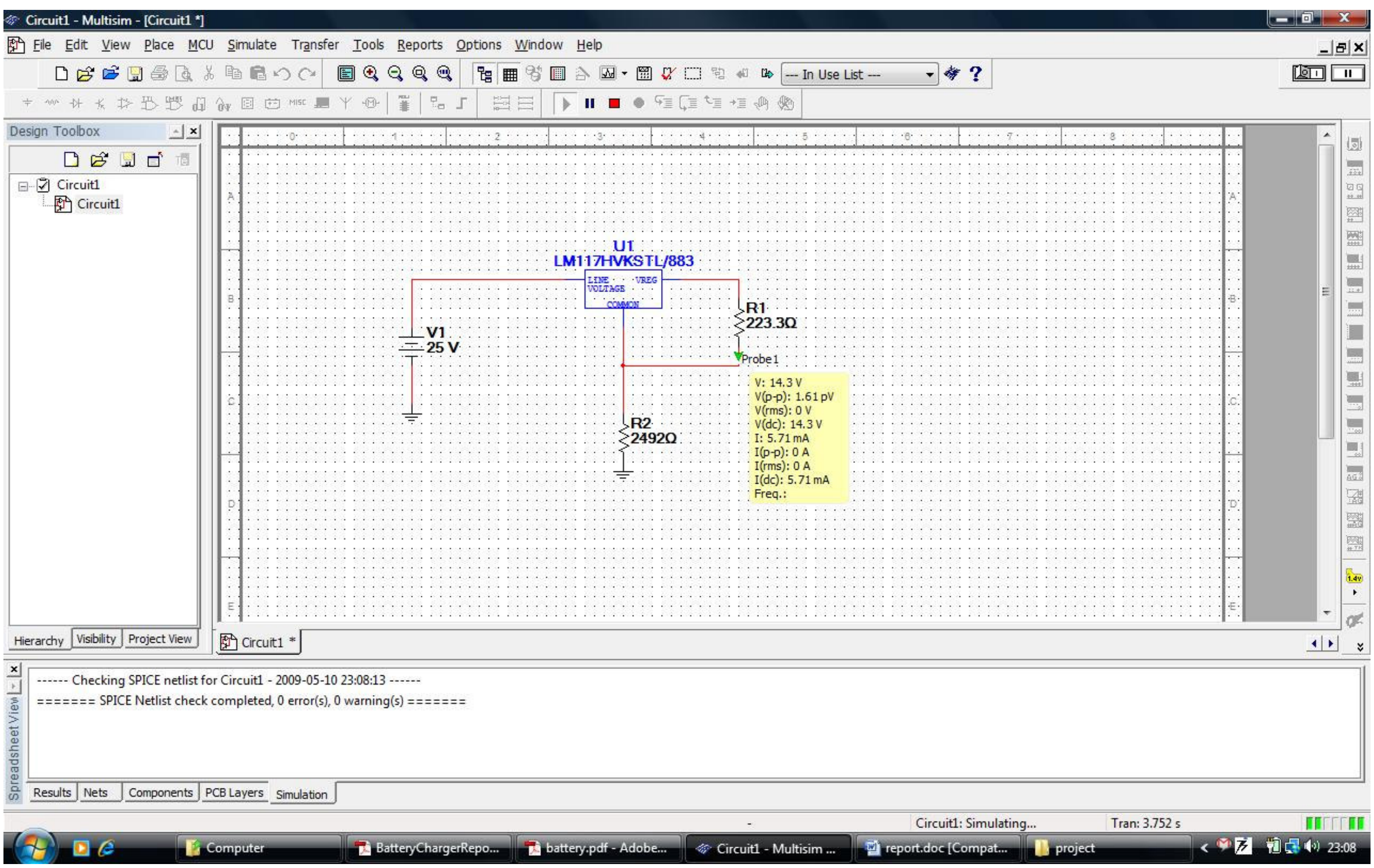
Complete Charging Circuit module

Simulation

The simulation was slowly built up piece by piece to ensure proper simulation of the complete circuit, as well as catch any simulation problems that might be encountered.

Step I: Testing Voltage Regulation

Our circuit will include an LM350, 3-Amp, adjustable voltage regulator, but since the model for this regulator was not available in Multisim, a comparable adjustable regulator was used for simulation purposes.



The input to the regulator was chosen to be at least two volts higher above the set output voltage. In the figure above the resistor values were chosen so that the voltage regulator is configured to the output 14.5V DC for testing purposes only. An interesting note, the simulator applies a 1.3V potential between the adjustment and the output pins. This somewhat varies from the specification of the LM350, which tries to maintain 1.25V across the same pins. Using the simulator's voltage across R1, the voltage was calculatedto be 14.5V:

Vout = 1.3V + (1.3V/R1)*R2

This was confirmed by the simulation.

Step 2: Varying Vout through a Single "Switch"

Controlling the output voltage to the battery is an essential part of multi-stage charging circuitry.

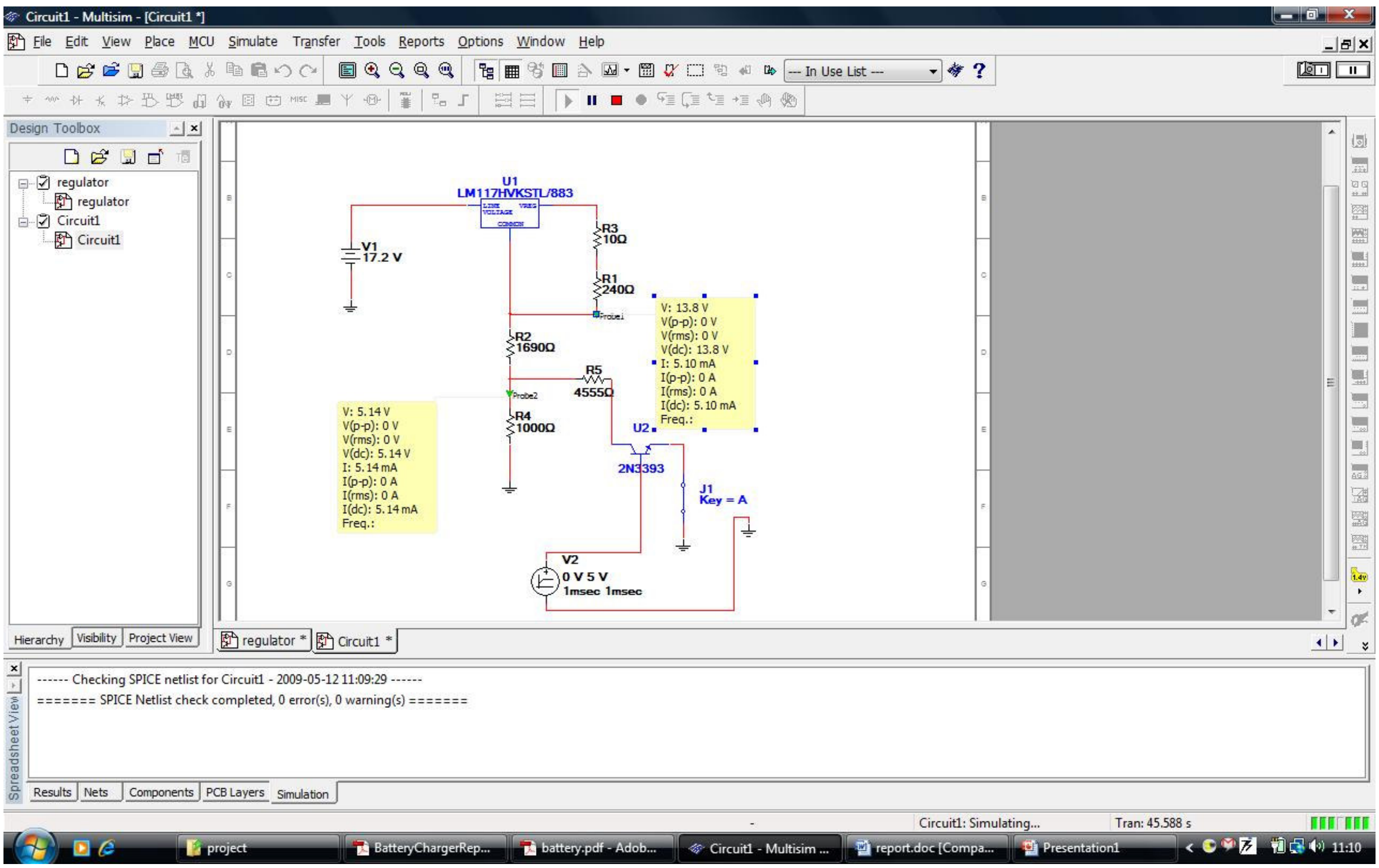
Adding a transistor will act as a switch to ground, and therefore vary the equivalent resistance of R4 which will provide control over the voltage regulator. When the "switch" is turned on, R5 is connected to ground, putting it in parallel with R4. This lowers the equivalent resistance of both resistors, and therefore lowers the voltage across both of them. Since the voltage is lower, the total output voltage is brought down the same amount. The voltage on the first stage needed to be 14.7V or 2.45 V/Cell and during the float state, 13.8V or 2.3V/Cell.

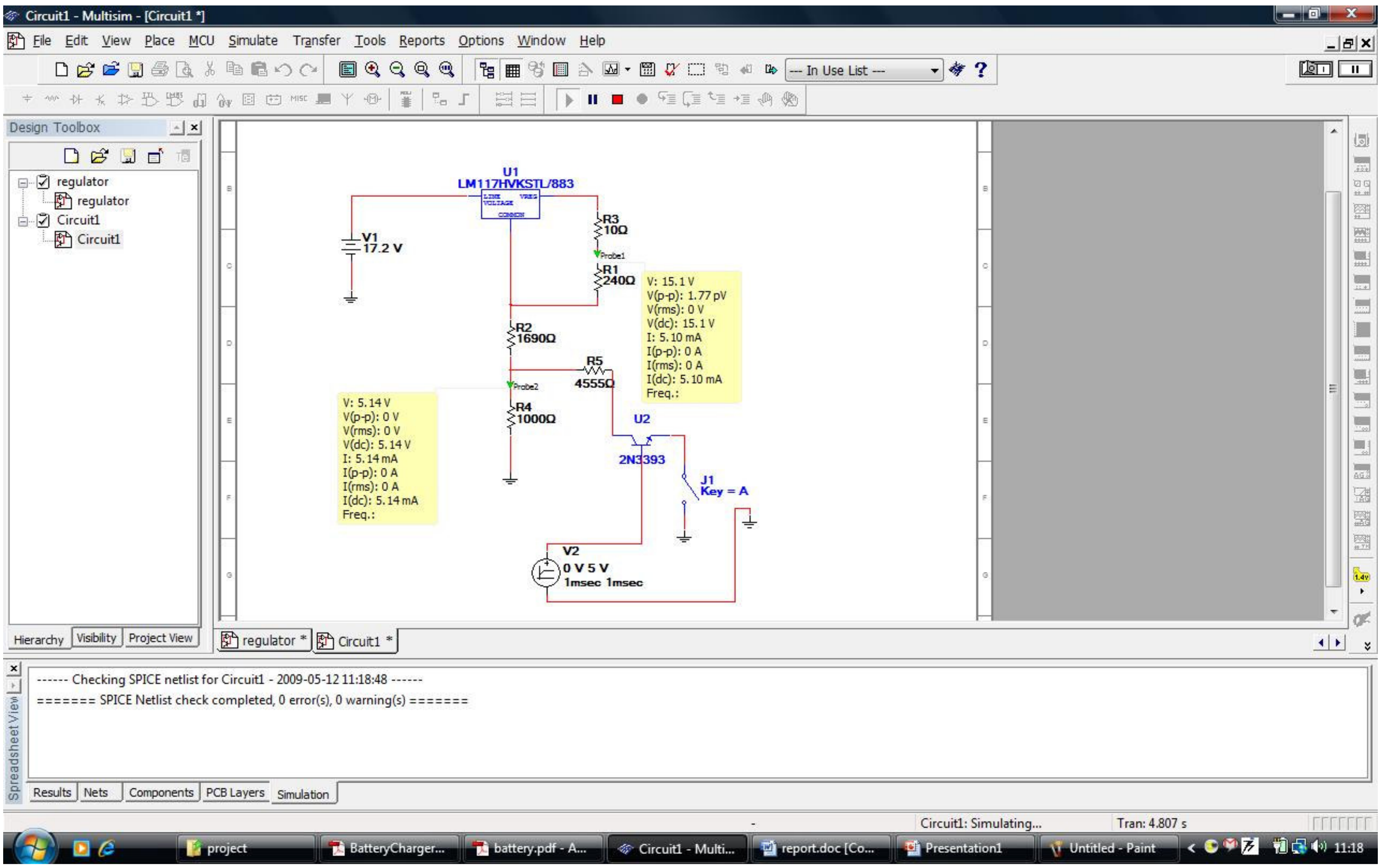
The current through R1, R3 and R2 is

1.25V/250Ohms=.005 A as shown in the simulator

The output voltages was calculated to be:

Transistor State	R4||R5	VR4	Vout
OFF	1000	5.0	14.7
ON	820	4.1	13.8

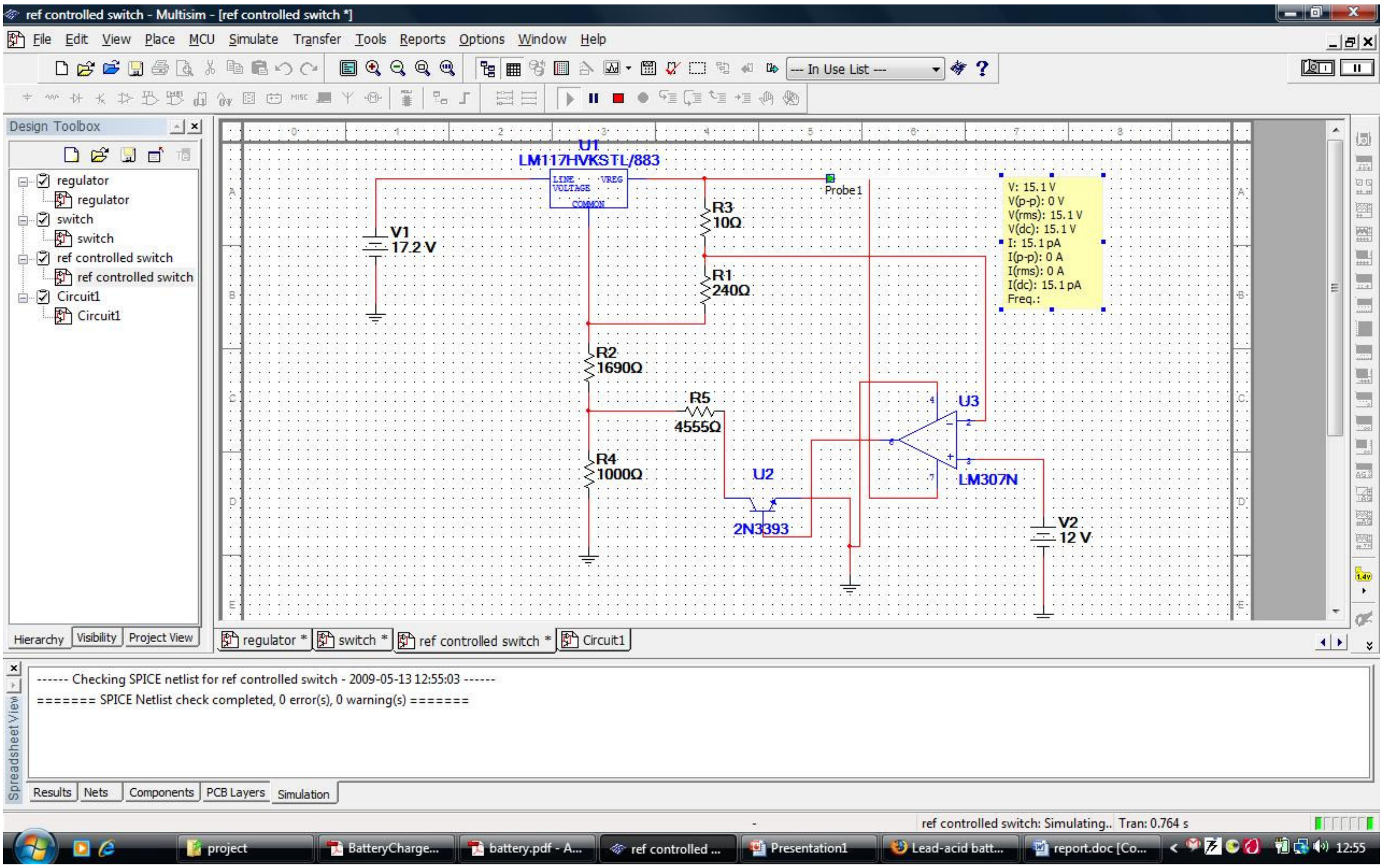


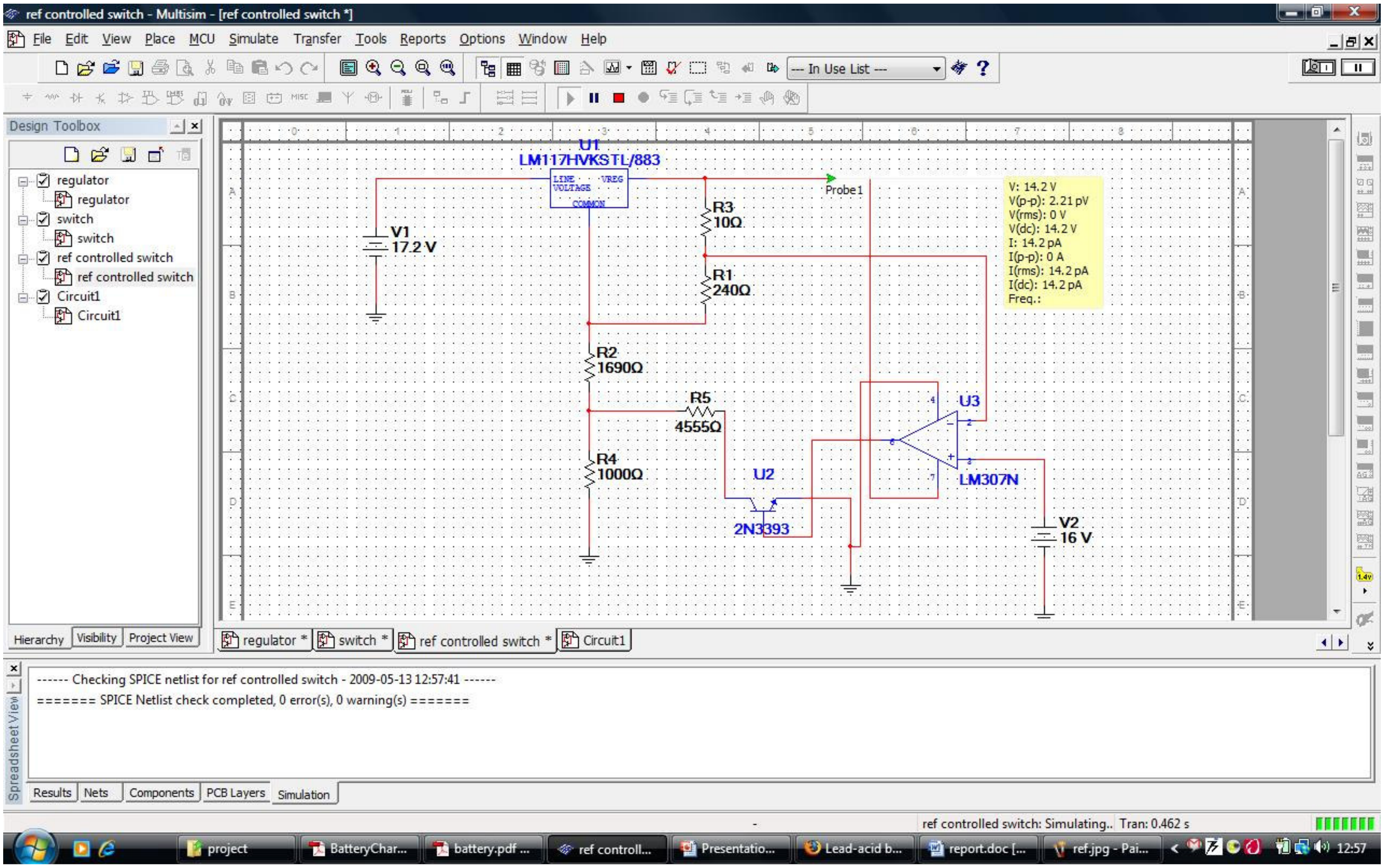


Simulating the circuit the output voltage was measured to be 13.8 and 15.1 V when it was completely off. This .4V difference is due to the fact that the potential difference between the adjusting terminal and the output pin is 1.3 rather than 1.25; therefore producing a larger current, while increasing the output voltage. Another possible reason could be the voltage drop across the transistor which does not completely pull the resistor to ground when it is on, and also has leakage currents.

Step 3: Reference Controlled Switch

Providing automatic switching based on voltage level was implemented using a comparator. The logical state change happens when the battery reaches a certain potential below the full charging voltage.



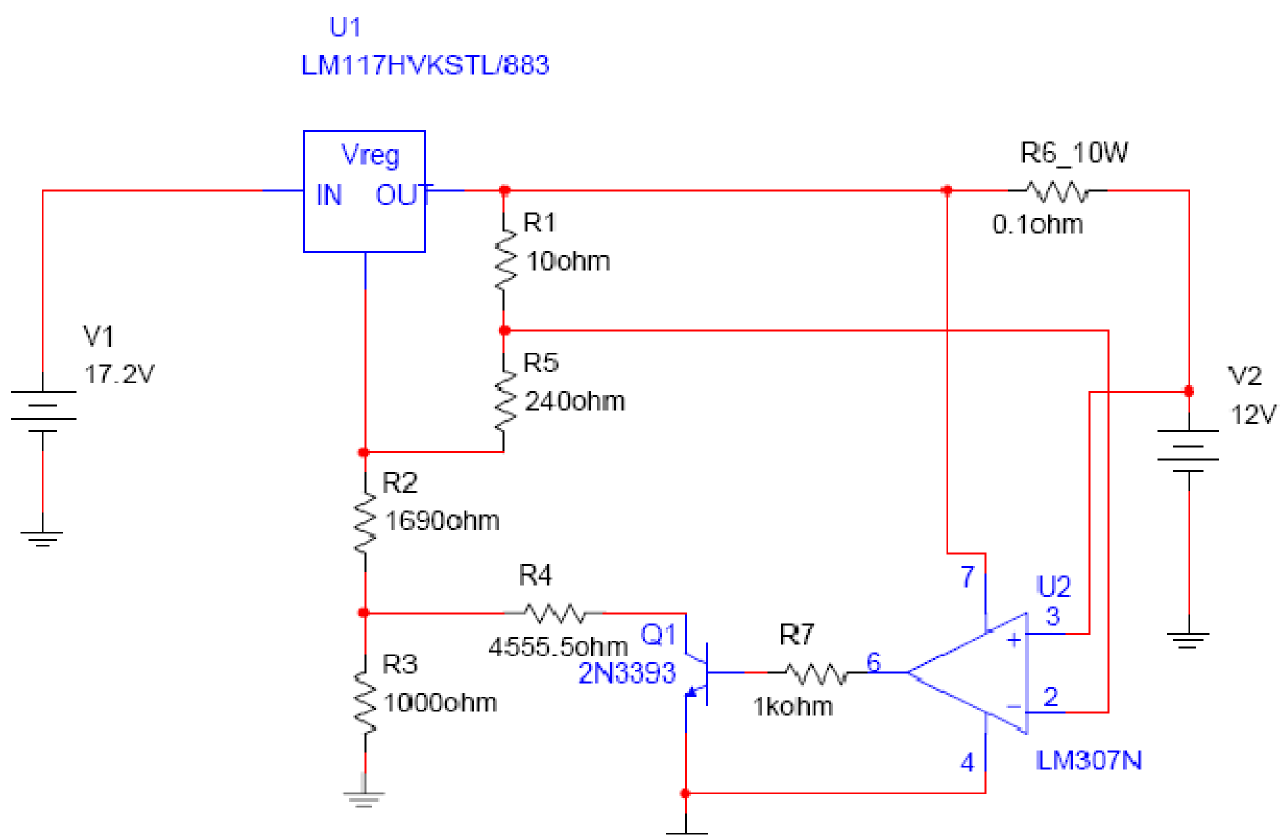


The current through R1 and R5 was calculated to be 5 mA. Breaking the 250Ohm resistor into 240Ohm resistor in series with a 10Ohm, provides a 50mV reference below the output voltage. This reference is used as the negative input for the comparator, and the battery voltage as the positive input. Whenever the battery charge is greater than the reference point, the comparator turns on the transistor, and therefore lowers the output voltage to the float charger state.

This phenomenon was observed as predicted in the simulations above.

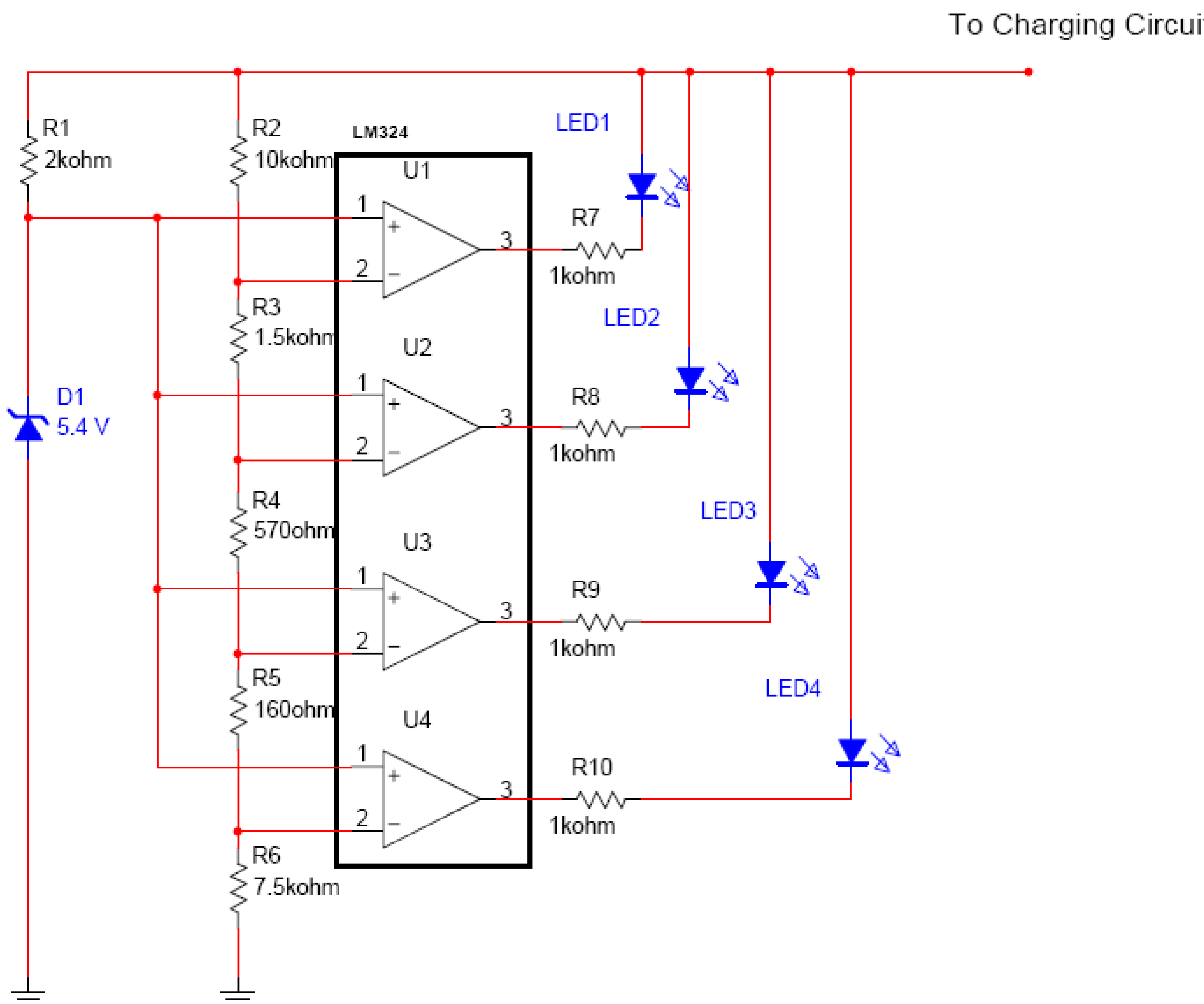
Step 4: Providing feedback through the current sensing resistor

This final step was to build the complete circuit. It proved to be a challenging task. Even though logically the circuit made sense and did not vary significantly from the previous one , we were unable to get the expected output. After trying to appease the simulator for long hours, we came to the conclusion that our analysis is probably correct and that feedback loop through the current sensing resistor R6, added enough complexity to the circuit that the simulator did not provide an accurate answer.



Battery Indicator

We came up with a very simple design for a voltage monitor. Figure 18 depicts a quad-voltage comparator (LM324) that used to control a simple bar graph meter to indicate the charge condition of the 12-volt lead acid battery. A 5.4-volt reference voltage(D1) is connected to each of the non-inverting inputs of the four comparators and the inverting inputs are connected to successive points along a voltage divider. The LEDsilluminate as the voltage at the inverting terminals exceeds the reference voltage. LED 1turns on at 11 volts, LED 2 turns on at 13 volts, LED 3 turns on at 14 volts, and LED 4 turns on at 14.3 volts.



Charging Circuit Module

Conclusion

A simple lead acid battery charger system was designed successfully. The proposed charger can work in constant voltage or constant current mode although constant voltage mode is the most preferred. The battery charger has many advantages like successful 3-stage charging, over charge protection, battery discharge protection and a simple design. However the battery charger would be difficult to operate in hotter temperatures. Further we can improve the heatsink to dissipate the heat better and also indicators can be designed to indicate bulk charge and float charge states.

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