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PROJECT REPORT

100 WATT POWER SUPPLY

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Project Statement

Create a charger for lithium polymer batteries. This charger may also be used for balancing up to a 6 cell lithium polymer battery and discharging a lithium polymer battery.

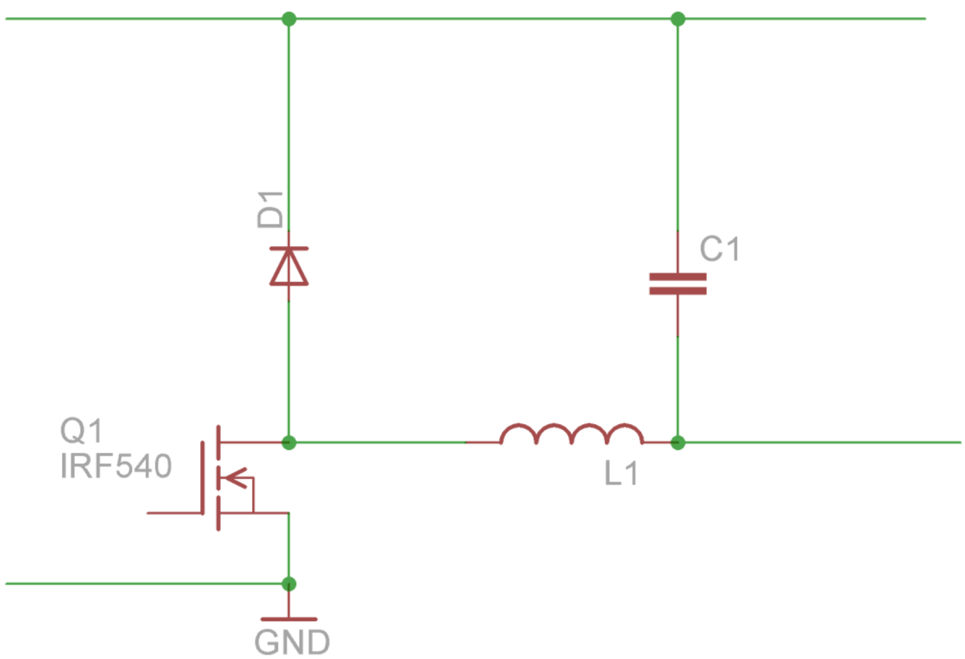
Modifications

The original project statement was deemed to be too divergent to be done in one course. Hence, while keeping the spirit of the project intact, the following modifications were suggested:

1. The project was trimmed down to making a microcontroller based 24V / 5A power supply.
2. Once, such a control is achieved, it is simple matter to setup an interface and allow for charging of different types of batteries.
3. The power supply must also have the following features so as to make it compatible for use in the original product idea
    a. Power factor control so as to meet regulatory requirements
    b. Current limiting to stop overloading and allow for constant current charging modes
    c. Temperature control for reliability
    d. Isolation

Selection of Topology

1. The basis of the SMPS is a high frequency DC-DC converter.
2. Various such converter designs are available. Each such design is called a topology.
3. Common topologies include buck, boost, 1 and 2-switch flyback, and half-bridge.
4. Choosing the appropriate design as per the requirements forms the basis of the circuit formation.
5. The project requirements state that isolation of the line and the output is essential.
6. Hence, non-isolated topologies such as the buck and boost convertor are directly ruled out.
7. Working with 2-switch circuits is also complicated.
8. This is because supplying the control signal to the high side switch is a problem.

9. If the high side device is a PMOS, the control voltage has to be within 20V of the regulated voltage which is 300V and may vary.
10. Using a NMOS for the high side requires use of a method called "boot-strapping".
11. Since, at our output powers, such designs do not justify the use of the complicated circuits, we decided to stick to one switch topologies only.
12. Our purview included:
    a. One switch flyback topology
    b. One switch forward topology
13. We started with the simpler of the two, the flyback convertor.
14. However, the transformer created could not bear the total current required by the output circuit.
15. Hence, we had to shift to a non-isolating topology.
16. The topology used was a standard buck converter.
17. However, we modified it so that we could use it with a standard N-channel MOSFET.
18. The resulting circuit avoided the problem of boot-strapping.
19. However, the added disadvantage was that the input and output circuits do not have the same ground. In fact, they have the same high side voltage.
20. 

Power Factor Correction

1. Power factor is the ratio of the actual power consumed (watts) to the apparent power requirement (VA)
2. In a way, it is a measure of the efficiency of the circuit in using the power (VA) supplied to it.
3. High power factor implies efficient utilization of the supplied apparent power and is desired for maximum efficiency of the transmission lines.
4. The importance of power factor can be judged from the fact that a European EN61000-3-2 regulatory standard actually specifies power factor requirements.
5. Power factor correction may be passive or active.
6. Since we already have a high capacity microcontroller in the control circuitry, we decided to go through with an active power factor correction.
7. An active power factor correction device is essentially another DC-DC convertor with feedback based switching.
8. However, as the circuit does not directly run of the mains and the circuit itself includes only a buck convertor, we decided that the power factor control circuitry would be unnecessary.

EMI Filter

1. As mentioned before the SMPS uses high frequency switching to convert DC voltages.
2. This high frequency switching causes generation of high frequency voltage components.
3. These components will find their way into the transmission voltages and cause high frequency spikes and electromagnetic interference, damaging a variety of devices.
4. This is undesirable.
5. Hence, the high frequency components need to be filtered and not allowed to flow into the line.
6. This job is done by the EMI (Electromagnetic Interference) Filter

7. We did some research for EMI filters and found out that they were essentially a series inductor and a parallel capacitor on each line.
8. However, an actual SMPS does not contain any such circuit.
9. Further research showed us that the power cable connector also doubles up as EMI filter.
10. We acknowledge that creating any cheaper and better circuit than the commercially available connector is almost impossible.
11. Hence we have decided to use the same filter in our circuits too.

12. We have been able to find such a filter and have it connected.
13. Since the circuit current does not run of the mains at this stage, we have not physically connected the filter
14. The filter can however be easily connected once the circuit is ready to be fed by the AC mains.

Transformer Design

1. The project requires that the output voltage must be isolated from the line.
2. This job is done by a transformer.
3. However, instead of using a normal 50Hz transformer, the SMPS uses a transformer at the DC-DC converter.
4. This is done so as to use the high frequency to reduce the size of the transformer.
5. Note that all the load currents flow through this transformer.
6. Hence, the design of the transformer is a crucial to the final design.
7. The two turns of a transformer can be found out using the following method.
8. Find the turns of the primary by using the maximum flux density.

$$V = 4 \times f \times A \times N \times B$$

9. Put in the following values
    a. f = 125kHz Switching frequency
    b. A = 1cm^2 Cross sectional area
    c. B = 0.4T Max flux density of CRGO core
    d. V = 300V Rectified Voltage
10. This gives the number of turns in the primary to be 75.
11. Depending on the output voltage reduction desired, the number of the turns in the secondary may be decided.
12. Although we have calculated the transformer turns, we have not been able to physically wind the transformer.
13. Hence, we are using a commercial transformer rated at our switching frequency, a picture of which is attached below.

14. The transformer was bought and connected in the circuit.
15. A sudden spike current of 10 A caused the transformer windings to melt and shorted the transformer.
16. Thus the transformer was rendered useless.
17. In the absence of the transformer, the normal non isolating power supply was built and connected.

Inductor Design

1. Most DC-DC converters also use an inductor as a device to store energy.
2. Thus, the inductor may have to withstand high currents at the given frequency.
3. High current inductors available in the market may not be suitable to our product requirement.
4. Hence, it is best to design inductor, by winding a wire around the commercially available core, so as to satisfy our requirements.

5. Inductor design is simplified by the direct application of two formulas.
    a. $L = \frac{\mu_0 \times N^2}{x}$
    b. $B_{max} \times A = \frac{\mu_0 \times N \times I}{x}$
6. We put in the following constraints
    a. B = 0.4T for CRGO core
    b. μ_0 is the permittivity of free space
    c. I = 5A Max current
7. These give us the following values
    a. x = 0.19mm Air gap
    b. N=12.5 Turns
8. Following is the picture of the inductor with the aforementioned properties.

9. This inductor is successfully incorporated in the circuit and works upto specifications.

PWM Generation

1. Normal switching of a DC-DC converter may vary anywhere from 10kHz to several MHz
2. The entire operation of the circuit is dependent on the switching frequency.
3. Thus, it is important to fix a switching frequency.
4. We also need to be able to adjust duty cycle of the signal so as to control the power flow into the load.
5. We had decided to settle onto a switching frequency of 25 kHz.
6. Such low frequencies may be achieved with both a dedicated PWM chip or by using the microcontroller itself.
7. Both of these options allow for acceptable variations in the duty cycle.
8. The presence of a multi-function microcontroller with built in PWM system in the circuit caused us to use the microcontroller directly.

9. Usage of a low frequency of 25 kHz caused excessive losses in the system.
10. This could be remedied by the use of a higher frequency switching system.
11. Hence, the frequency was increased to 100 kHz.
12. The higher the frequency, the more efficient is the device
13. Thus, the higher frequency is limited by the PWM generator.
14. In our case, the use of a microcontroller limits the max frequency
15. Had a dedicated PWM chip been used, the frequency used would have been 300 kHz or higher.

Decoupling Control and Power Flows

1. The circuit essentially consists of two parts, one being the controller part with the microcontroller in it and the other being the power part, which includes the switching elements.
2. It is very important that the control part is completely decoupled with the power flow so as to maintain independence of the circuits.
3. Thus, if any problem occurs in the power part, the control part is unaffected and is able to take appropriated action including switching the circuit off.
4. Thus, the circuit is protected from complete destruction due to the failure of one part.
5. Such protection is required in very high power circuits.
6. We have decided on the MOSFET to be our switching element.
7. If a PWM chip is used, the chip itself decouples the control and power circuits.
8. If a microcontroller is used, it will require a MOSFET driver to control the switching element.
9. This driver will now decouple the circuits.
10. As the finalized circuit uses a microcontroller, the decoupling has to be via a driver IC.
11. A variety of MOSFET drivers are available in the market today.
12. We looked at the portfolio of Texas Instruments due to the availability of free samples easily.

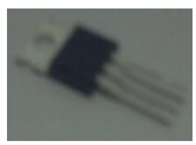
13. We do not require a boot-strapping driver because the circuit is adjusted so as to use only a low-side NMOS.
14. Thus, only a standard driver would be required.
15. The current capacity of the driver should be around 3A because of pulse currents through the gate capacitor while switching.
16. We zeroed in the UCC27425 driver IC.
17. It provides 4A of pulse current.
18. It can easily switch and 100 kHz.
19. It is non-bootstrapping and has a simple circuit with very no external components required.

House-Keeping Power Supply

1. In power electronic circuits, it is very important to note that there is only one single power input.
2. This implies that both the power and the control parts have to run of the same power supply.
3. Since, the AC power in is unsuitable for use on a microcontroller, some sort of conversion has to be done.
4. This implies that the <u>microcontroller controls the voltage on which it runs</u>!
5. To avoid this, a house-keeping power supply is generated by the SMPS.
6. This power supply may remain on while the main circuit is actually off.
7. It supplies power to the control circuitry which in turn controls the main power supply.
8. Creating this power supply is a challenge since it implies generating a regulated output without any control circuitry.
9. We have, unfortunately, not been able to find a satisfactory circuit design to create the housekeeping power supply.
10. To begin, we are using an external isolated power supply to run the control circuitry.
11. In the worst case, this external power supply will be replaced by a 50Hz transformer and a linear regulator.

Switching Element

1. A variety of power transistors are available in the market today. For example BJT, MOSFET, IGBT
2. The max voltage across the power terminals of the device is expected to be around 300V (rectified voltage).
3. The peak current is around 2A.
4. Due to our previous experience in using them, we decided to go for a MOSFET if possible.
5. Thanks to advanced technology, our requirements were met by many power MOFETs.
6. We zeroed in on IRF740, which can stand voltages up to 400V and currents up to 10A, and is locally available.
7. A picture is attached below.

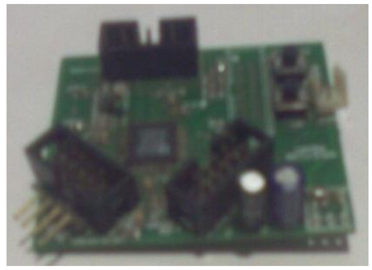


8. Unfortunately, these transistors were not able to take a load of even 5A.
9. Any loading of the power supply caused excessive heating of the MOSFETs
10. This causes failure of the device and hence the power supply.
11. As a result, they were replaced with IRF540 series transistors.
12. The result was that the circuit can run currents upto 5A without any heating.
13. However, it cannot now run directly from a power supply. The maximum voltage it may receive is 100V.

Controller

1. The microcontroller in the control circuit should satisfy the following conditions
    a. Availability of an on-chip ADC. This will be used to sense voltage, current and temperature.

    b. Possible creation of a PWM of 25 kHz frequency with a large range of duty cycle values.
2. We are inclined to use either an atmega8 or an ADuc7128 as the microcontroller, as we are familiar with them.



3. In the final circuit an atmega128 board has been used.
4.

Rectifier Diode

1. The rectifier diodes are connected in a bridge rectifier combination.
2. Each diode may have a peak current of up to 2A.
3. It also has to withstand a peak inverse voltage of 325V (Line peak).
4. Many such diodes are commercially available.
5. We chose the locally available WY2A05.

Voltage Sense

1. For feedback control, it is necessary for the controller to sense the quantity to be controlled, in this case – the output voltage
2. This is done using the ADC block on the microcontroller.
3. The ADC senses the analog value and converts it to into a digital number.
4. This number is used for further calculation.
5. The problem is that the microcontroller and the output voltage do not share the same ground.
6. Hence, the voltage has to be sensed without direct contact between the controller and the output voltage.
7. This job is done by an optocoupler.
8. An optocoupler is a device that includes both a photodiode and a phototransistor.

9. The photodiode is connected to the output voltage.
10. The magnitude of the light emitted is sensed by the phototransistor and converted into another signal.
11. This signal is at the voltage of the microcontroller ground.
12. Thus isolation between the sense voltage and the ADC is achieved.

Current Sense

1. Current sensing is done so as to limit the maximum current flowing through the transistor.
2. Current cannot be directly sensed by a microcontroller.
3. Hence, the current has to be converted to a voltage.
4. This can be done using a resistive sensor or by the use of a hall-effect sensor.
5. The resistive sensing causes some loss of power.
6. It is also easier to implement.
7. Hence, a resistor of 0.1 Ω and 10Watt is connected in series with the output voltage source for current sensing.

Control Loop

1. The PID controller calculation involves three separate parameters, and is accordingly sometimes called three-term control.
2. The proportional, the integral and derivative values, denoted P, I, and D.
3. Heuristically, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change.

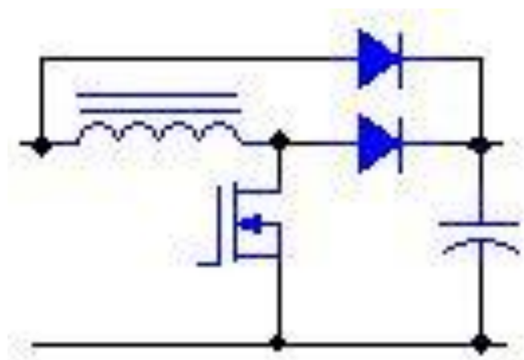
Circuit

This section outlines the current tentative circuit we have in mind. Various components and designs will be changed as we move along with our prototyping

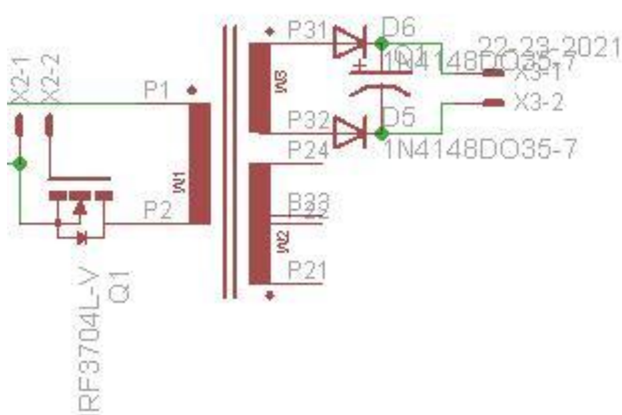
Block Diagram

Circuit Diagram

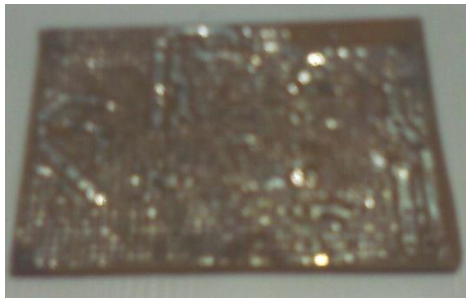
Power Factor Control



Flyback Converter



PCB Photograph



Acknowledgements

1. First and foremost, we would like to thank Professor J. Mukherjee for guiding us in this project. Any progress would not have been possible without his guidance.
2. Professor Dipankar Saha helped us in a lot of the circuit design part.
3. We thank the staff of WEL3 for providing us support in our endeavor.
4. The site http://www.smps.us/ was instrumental in helping us to find the appropriate circuits.