Electric Vehicle Charger for Plug-In Hybrid Electric Vehicles

PROJECT PROPOSAL

By:

Matt Daly
Peter Burrmann
Renee Kohl

Project Advisers:

Dr. Woonki Na
Dr. Brian Huggins

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INTRODUCTION

A plug-in hybrid electric vehicle (PHEV) is a hybrid vehicle which utilizes a battery to power the vehicle's electric motor. This battery can be recharged when it is plugged-in to a power source (typically 120 [V_{rms}] from the grid). PHEV's have much higher fuel efficiency and lower operating cost than the typical vehicle. These vehicles help keep the environment clean by reducing the amount of toxins emitted from standard exhaust systems. This also removes the need for annual emission inspections. These advantages of a PHEV are some of the reasons why they are now increasing in popularity and have a growing market.

PROJECT SUMMARY

The primary goal of this project is to design a system that will function as an electric vehicle charger. A Digital Signal Processor driven power electronics system shall be designed such that the system can convert 120 [V_{rms}] AC grid power to the required 48[V_{pp}] DC value to charge an electric vehicle battery. This system will consist of a single phase diode rectifier, boost converter, and bi-directional converter for discharging the battery into a variable load or charging of the battery itself.

In order to implement this system, a control algorithm must be developed using the TMS320F2812 DSP board. Values for all circuit elements need to be calculated and specific devices and circuit elements need to be selected and purchased to match specifications.

GOALS

- Create a model of PHEV that does not exceed 1000[W] of power
- No circuit element shall exceed 25[A] for safety purposes
- Develop a control algorithm using a DSP for the purpose of driving the MOSFET gates in the system

SYSTEM BLOCK DIAGRAM

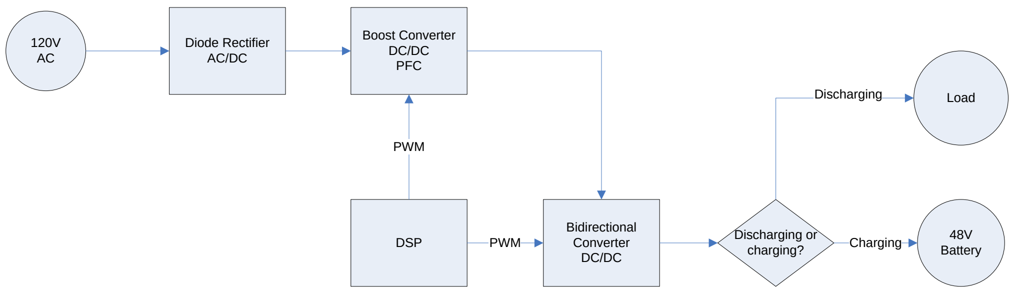

Figure 1. High Level System Block Diagram

The input to the system will be 120 [V_{rms}] from the grid and this shall be fully rectified. The rectified sine wave will then be passed through a boost converter driven by the DSP in order to correct the power factor as necessary. The output of the boost converter shall then be reduced to 48 [V] via a bi-directional converter for charging the battery. Once the battery is completely charged to 48 [V], the DSP will sense a voltage drop of zero from the battery to the battery input in order to prevent the battery from over-charging. The battery shall also be able to discharge to a variable load through the bi-directional converter by "boosting" 48 [V] to an appropriate amount for the load.

SUBSYSTEMS

Diode Rectifier:
The Diode Rectifier is used to convert 120 [V_{rms}] AC grid power to a rectified sine wave that will then be used by the PFC circuit. The current through the diode rectifier shall not exceed 20A and shall dissipate the smallest amount of power possible to keep the system power below 1k [W].

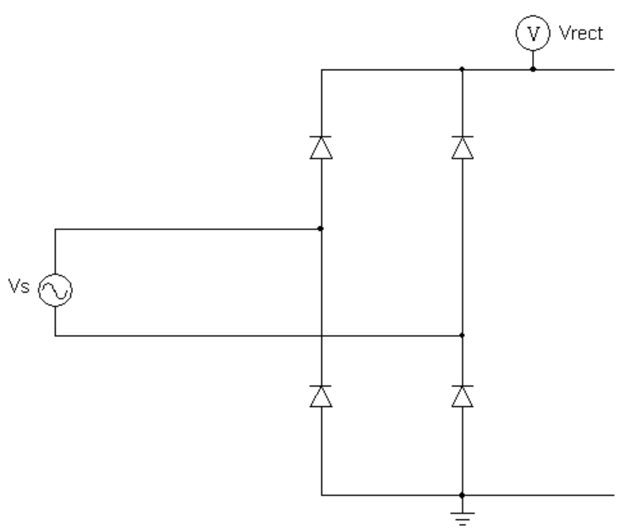

Figure 2. Diode Rectifier Circuit

Boost Converter:
The rectified sinusoid passes through a boost converter driven by the DSP. This is where power factor correction happens for providing the appropriate voltage at the Load and input to Bi-Directional Converter. The elements in this system will be selected to limit the amount of power dissipation to keep the system power below 1k [W].

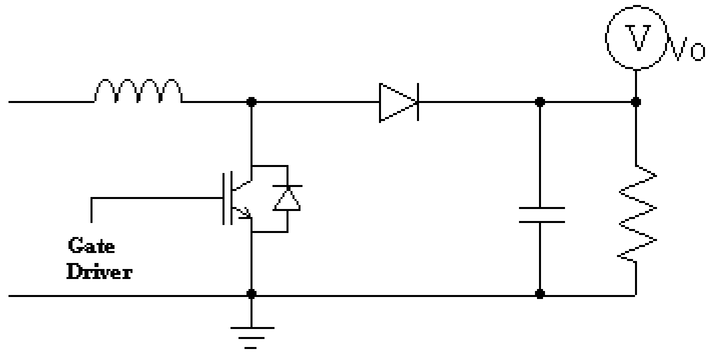

Figure 3. Boost Converter Circuit

Interfacing Circuitry:
The rectified sinusoid passes through a current sensor. The sensed current will be used by a PI controller implemented in the DSP. The current straight out of the rectifier shall be run through protective circuitry before going into the A/D converter of the DSP. The protective circuitry shall lower the current to a safe range for the DSP.

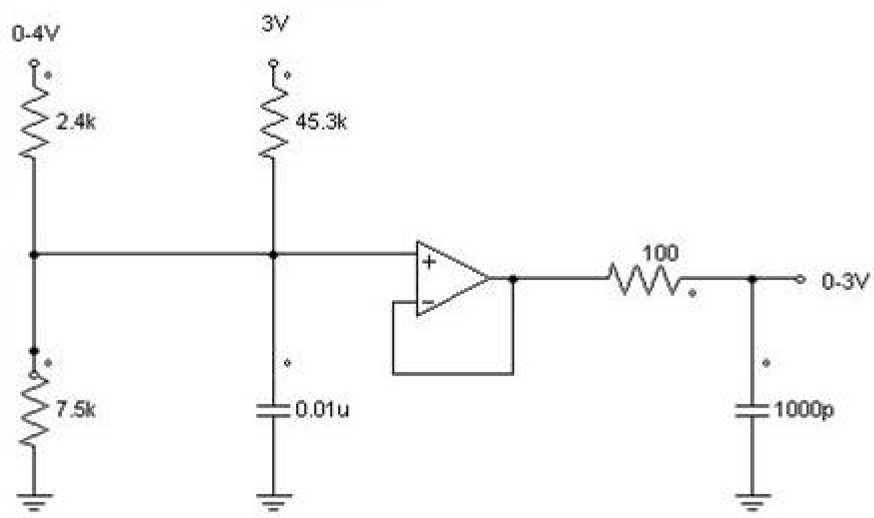

Figure 4. Interfacing Circuit

Bidirectional converter:
The bidirectional converter offers the option of lowering voltage one way and boosting it the other way. For our purposes, it shall convert the output voltage at the load to 48[V] for charging the battery and also convert the 48[V] battery back to the necessary load voltage. The necessary duty cycles for determining the mode of operation shall be determined by the DSP via the current and voltage sensors. The DSP will output the appropriate PWM to the switches.

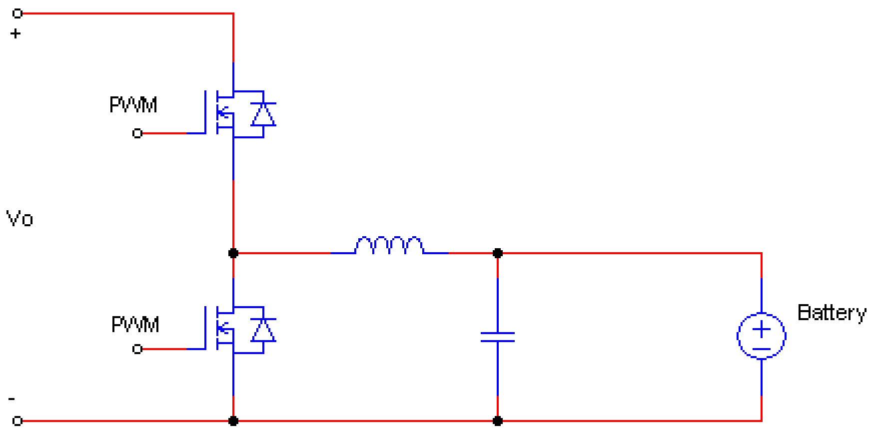

Figure 5. Bidirectional Converter Circuit

Microprocessor Control:
The DSP will control and monitor the system for charging and discharging of the battery while performing the power factor correction and protecting the system from the high voltage and current. The switching frequency shall be within 10-15 kHz and the sensing frequency shall be between 1-10 kHz.

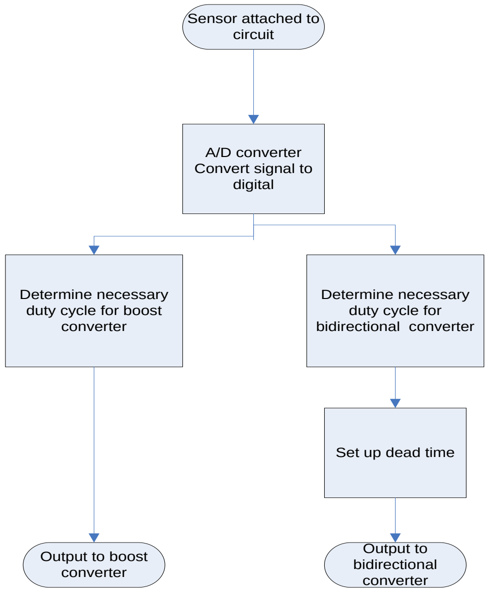

Figure 6. Microprocessor Flow Chart

SIMULATION RESULTS

The below schematics and their matching simulations correspond with their respective subsystems from above. At the current time, the bi-directional converter is represented with individual buck and boost converters. Bi-directional converters are difficult to simulate because of the condition on which direction the current flows. Implementation will be less of an issue. Note from the simulation results that the converters are able to lower the output voltage for charging the battery and boost the battery voltage back to necessary specifications. The PFC simulation results show the outputs of both the rectifier and boost converter.

Boost Converter

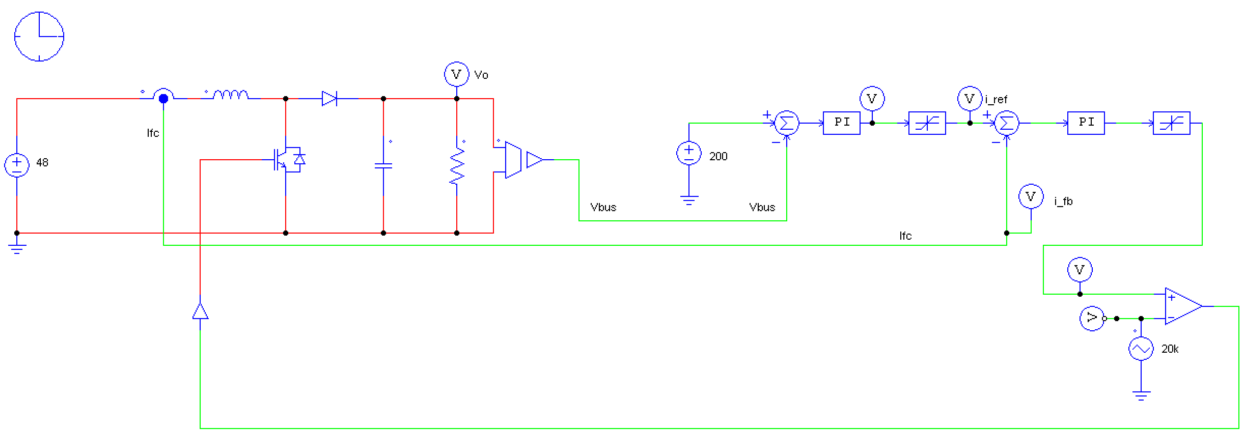

Figure 7. Boost Converter w/ Controller

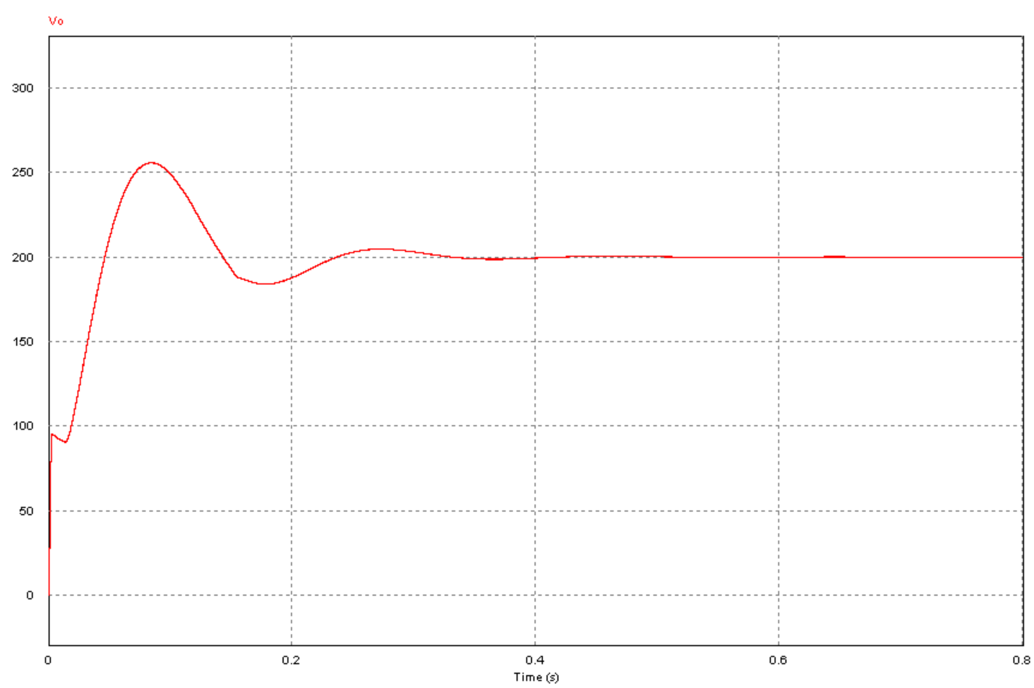

Figure 8. Boost Converter Simulation Result

Buck Converter

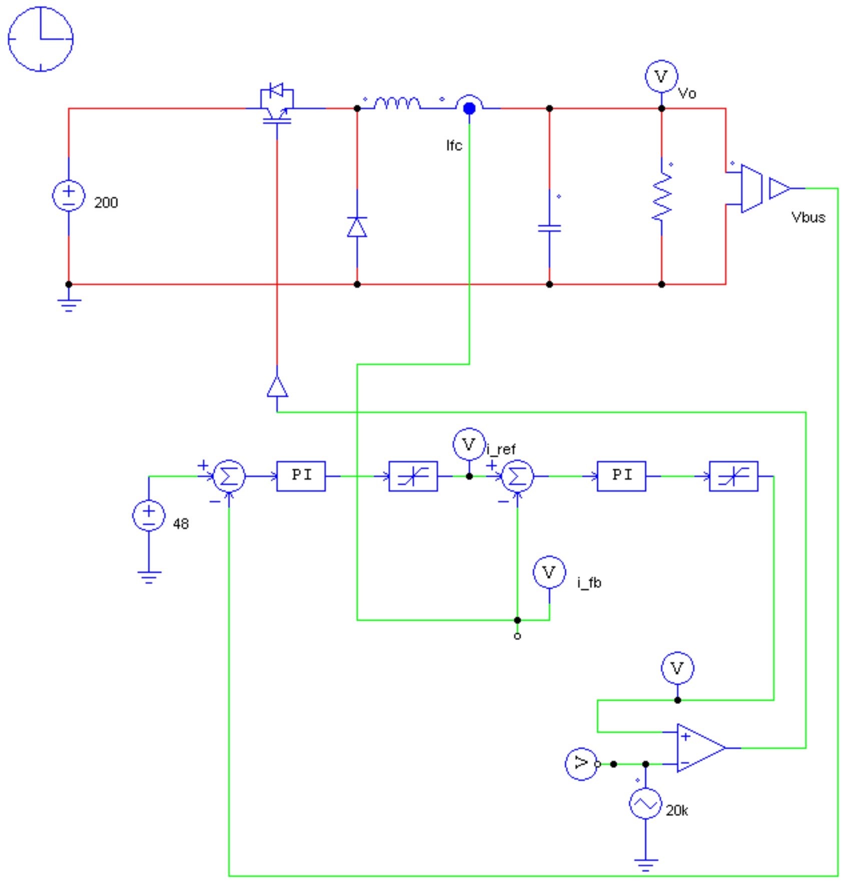

Figure 9. Buck Converter w/ Controller

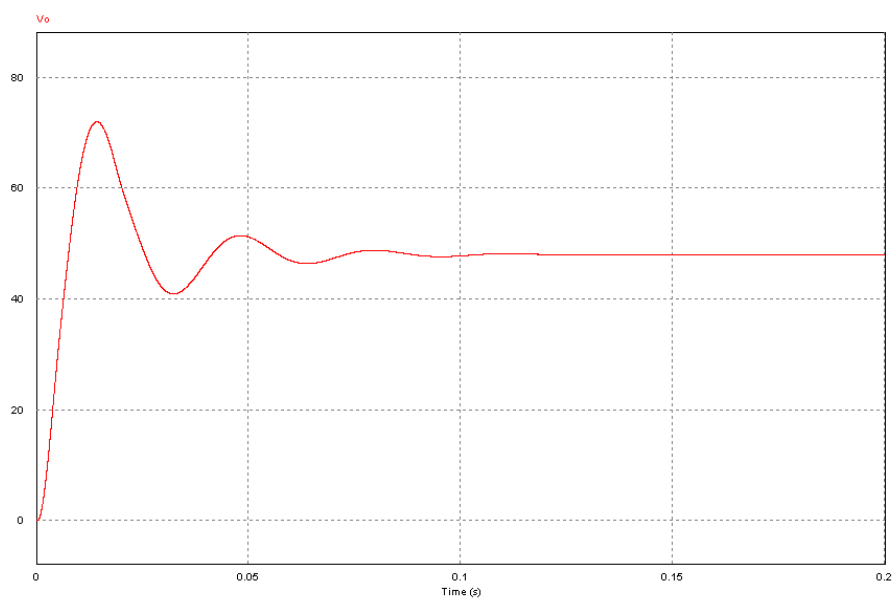

Figure 10. Buck Converter Simulation Result

PFC System

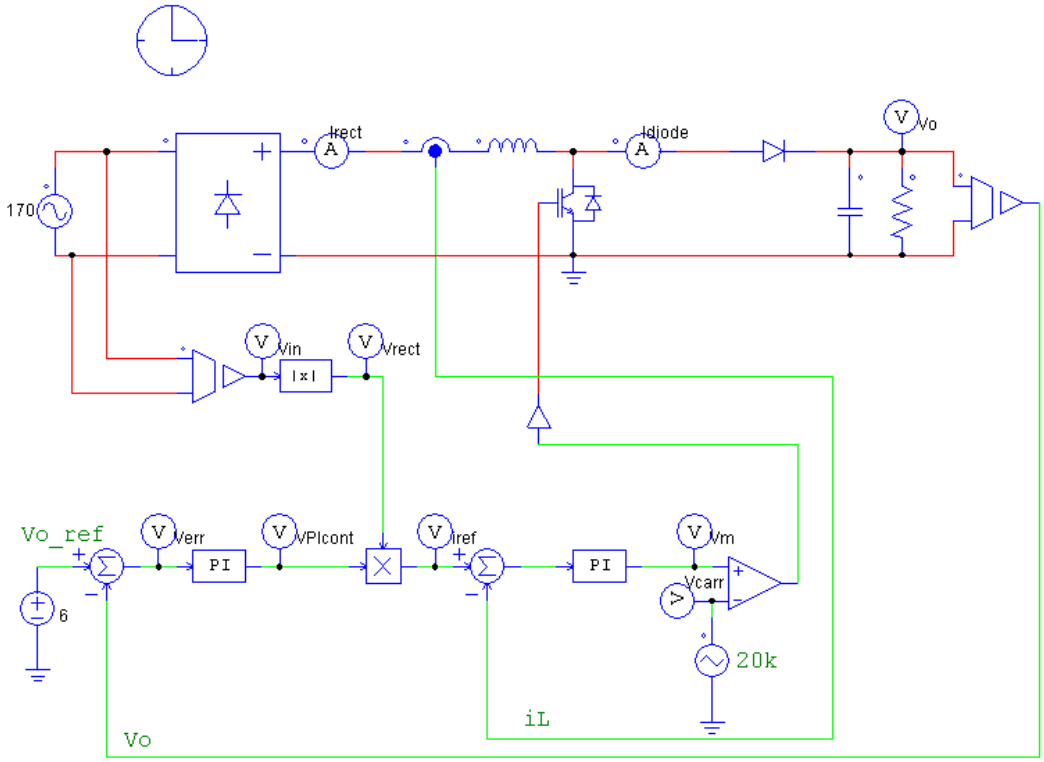

Figure 11. PFC w/ Controller

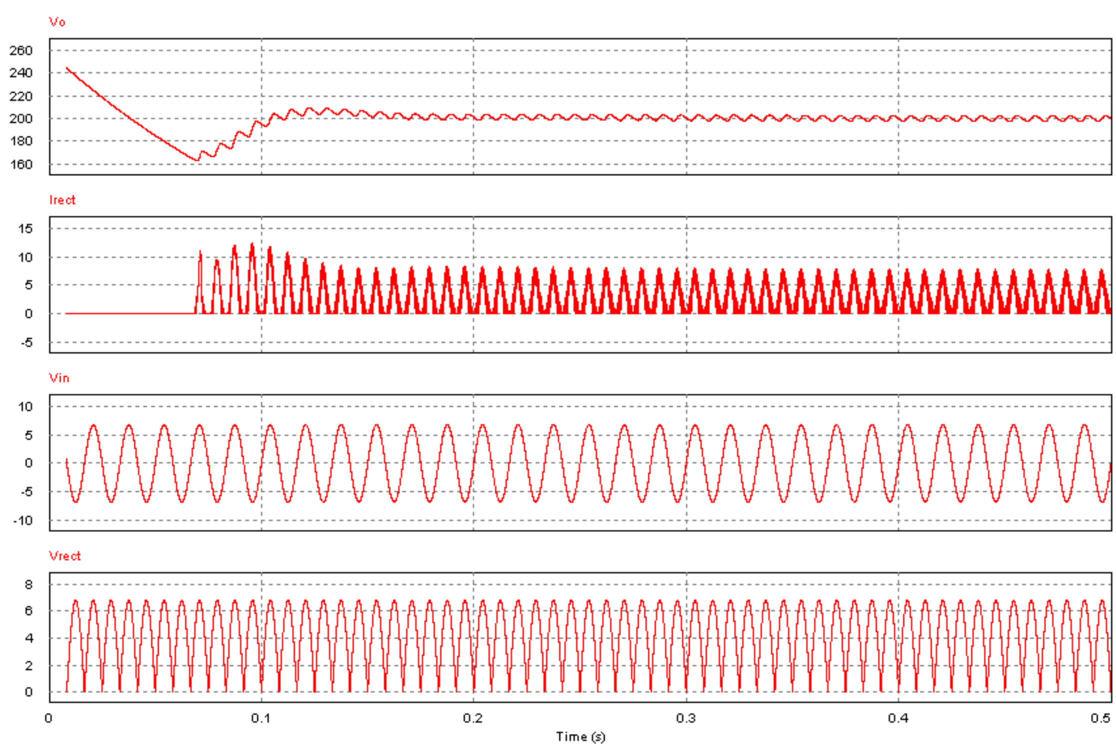

Figure 12. Buck Converter Simulation Result

Small Scale Boost Converter (DSP)

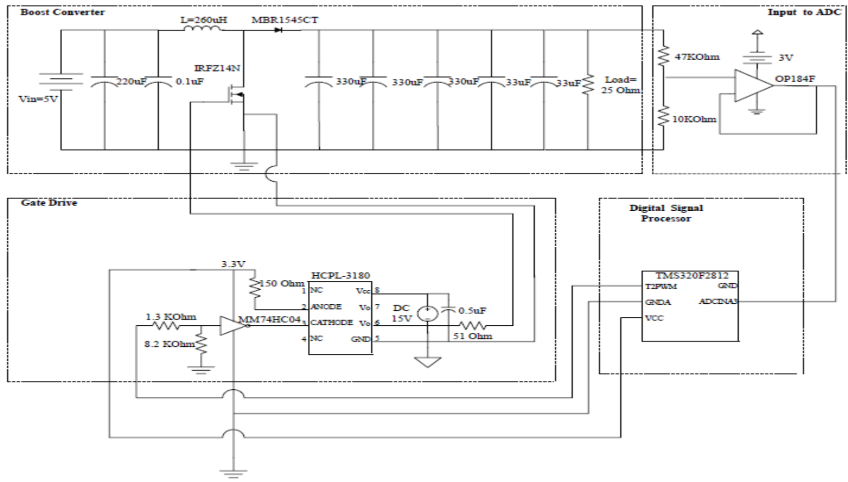

Figure 13. Boost Converter 5V Input

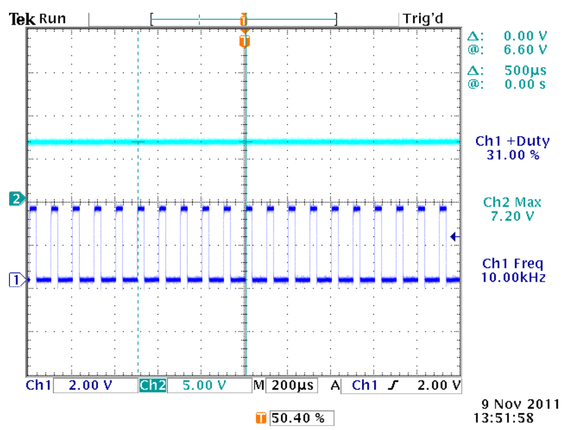

Figure 14. Boost Converter Output at 30%

At a 30% duty cycle and 5V input the output of the boost converter is 7.2V. The calculated expected output is 7.14V.

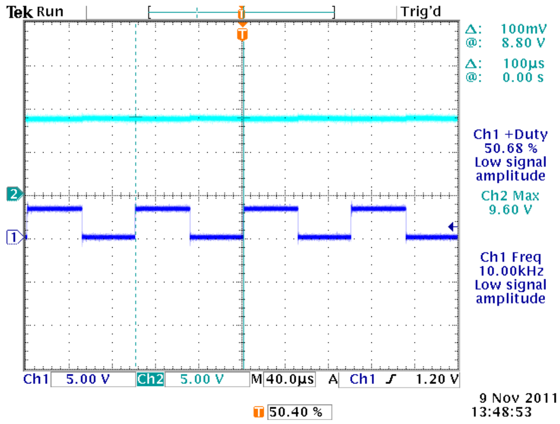

Figure 15. Boost Converter Output at 50%

At a 30% duty cycle and 5V input the output of the boost converter is 7.2V. The calculated expected output is 7.14V.

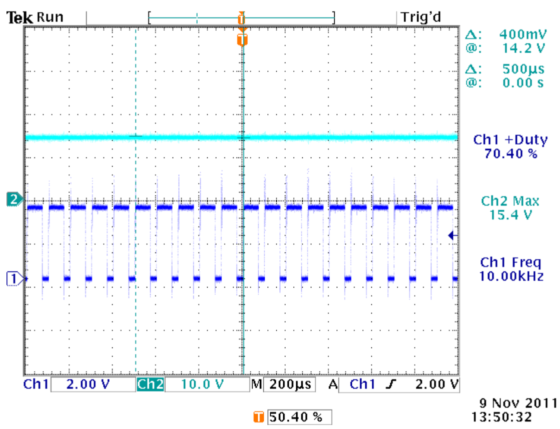

Figure 16. Boost Converter Output at 70%

At a 70% duty cycle and 5V input the output of the boost converter is 15.4V. The calculated expected output is 16.6V

Simulink Model (A/D & PWM)

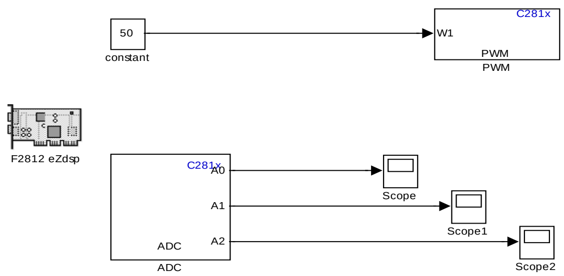

Figure 17. Simulink Model for PWM & A/D

The Simulink Model seen in figure 17 was compiled to Code Composer 3.1 and downloaded to the DSP board.

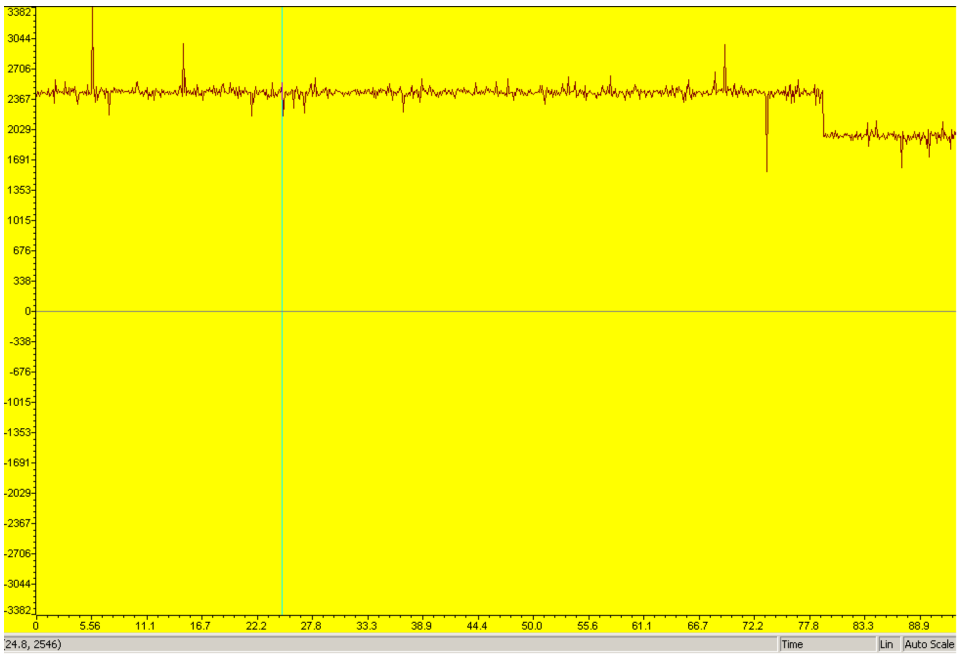

Figure 18. A/D Converter Inputs in Code Composer

The Simulink model seen in figure 17 was downloaded to the DSP board to control the MOSFET with the PWM output. The output voltage was passed through the protection circuitry seen in figure 4 and into the A/D converter on the DSP. Code Composer 3.1 was used to graph the A/D inputs as seen in figure 18. The value measured by the A/D converter is converted to a UNIT16 so in order to calculate the value that is seen at the input to the A/D converter you will have to use the equation UNIT16 value*16*3/$(FFFF)_h$= A/D input.

In Figure 18 the first value seen is the output of the boost converter at 50% duty ratio. The measured value of 2440 can be converted to the A/D input by 2440*16*3/$(FFFF)_h$= 1.76V and the value measured by the oscilloscope was 1.78V. When you multiply by the voltage divider factor the output of the boost converter is 10.99. The expected value is 10V and the value measured by the oscilloscope is 9.18V.

In Figure 18 the second value seen is the output of the boost converter at 30% duty ratio. The measured value of 2000 can be converted to the A/D input by 2000*16*3/$(FFFF)_h$= 1.46V and the value measured by the oscilloscope was 1.46V. When you multiply by the voltage divider factor the output of the boost converter is 9V. The expected value is 10V and the value measured by the oscilloscope is 6.67V.

The discrepancy in the calculated output of the boost converter and the measured value on the oscilloscope can be explained by the tolerances in the voltage dividers.

EQUIPMENT LIST

- IRFP460A N-Type Power MOSFET
  - SK 145 Heat Sink
- IR2110 - 1PBF MOSFET Driver
- NTE5328 – Bridge Rectifier
- VS-HFA50PA60CPBF Power Diode
- L08P050D15 Current Transducer
- OP484FPZ Op-Amp
- NXP - 74HC04N Hex Inverter
- TracoPower - TMPM 10115 Power Supply
- Voltage Regulators
  - LD1117V33C – 3.3V
  - LM1117T-5.0/NOPB 5.0V
- Capacitors
  - Aluminum Electrolytic Capacitor 1500uF, 400V
  - Ultra Capacitor 150F, 2.7V
- Inductor 500uH, 35A
- 48V 13000mAh NIMH Battery Pack
- DSP
  - TMS320F2812 DSP
  - Code Composer Studio 3.1
  - Mathworks Matlab & Simulink 2007

	Schedule of Events/Tasks Spring 2012
Week	Event/Task
1	Test Power Factor Correction Ciructry, Continue developing DSP code
2	Refine Power Factor Correction Ciructry, Continue developing DSP code
3	Test Buck and Boost Converter Circuity, Continue developing DSP code
4	Test Buck and Boost Converter Circuity, Continue developing DSP code
5	Implement Bi-Directional converter with Ultra-Capacitors, Continue developing DSP code
6	Refine Bi-Directional converter with Ultra-Capacitors, Continue developing DSP code
7	Refine Bi-Directional converter with Ultra-Capacitors, Continue developing DSP code
8	Test Entire System and refine DSP Code
9	Swap Ultra Capacitors with 48V battery and test systemmaking changes as needed
10	Refine System/Debug DSP
11	Refine System/Debug DSP
12	Prepare for Presentation
13	Prepare for Presentation
14	Prepare for Presentation

References

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