AZTEC FEC

High Efficiency, High Density AC/DC PFC Power Supply

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Abstract

The Aztec Future Energy Challenge is a project with a goal of creating a cost, energy, and size efficient AC/DC PFC power supply for general applications. The end goal is to create a power supply capable of up to 1300W output with efficiency above the 80 plus platinum standards of greater than 92% at varying loads, while keeping the size of the device below 1300 cubic centimeters.

Table of Contents

Project Description

The future energy challenge is intended to create an AC/DC converter PFC power supply with better specifications than the typical power supply available on the market today. The main constraints of the project will be to keep both size and costs down while maintaining a high efficiency with a high 1300W power output. Cost, size, and efficiency will all depend primarily on an advanced and accurately calculated topology design which will lean heavily on an advanced microcontroller. The microcontroller will dictate performance throughout the various stages of the device to achieve a high efficiency.

There are several options for circuit topology when designing an AC to DC power supply. The typical model uses a bridge rectifier to match the output polarity for either input polarity of an alternating input and convert it to a DC value. The DC current then feeds into an flyback system to reduce power for low power applications, or a boost converter to amplify the power for high power applications as in this project.

Some boost power supplies incorporate a multiphase boost converter to achieve higher efficiencies, however such a design requires complex circuitry to maintain exact currents which could very slightly due to mismatches and inconsistencies in real life component values, greatly affecting performance of the entire system. A multiphase design would also require more expensive lower tolerance components on a larger PCB to achieve desired performance. For these reasons we have chosen to incorporate a single boost phase design which will depend heavily on an advanced microcontroller to maintain high efficiency and consistent operation.

Design component values will be calculated, verified, and adjusted using simulation software. A PCB design team will map the design onto a circuit board for testing. The prototype board will be assembled on the PCB and carefully tested and adjusted for expected real life discrepancies. Benchmarks, deadlines, and budget for the project are detailed later in this document. The testing and adjusting the physical design is expected to make up the majority of the time spent on the project.

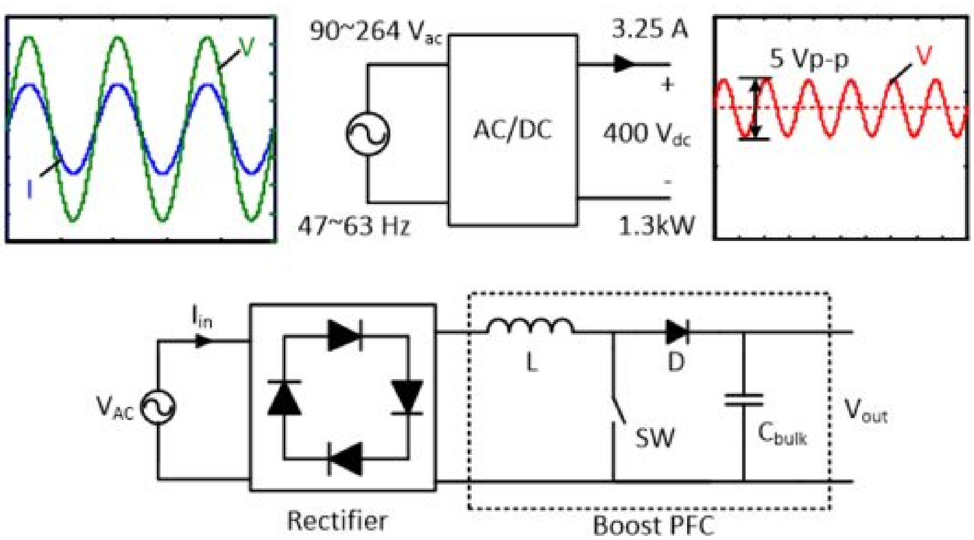


Figure 1 Simple diagram which demonstrates basic design layout and theory of a bridged PFC supply.

System Design

Most of the theory can be pulled from the Texas Instruments UCC28019a Evaluation Module. We will hack this evaluation board and scale up with larger component values to see how much extra power we can achieve from the design. If modifying the evaluation module proves to be unsuccessful, we will attempt design and develop a second power supply based on similar topology using the same UCC28019a microcontroller. Once we have experience in designing a power supply from the ground up, we will produce a second 1300W prototype using the Infineon ICE3PCS01G microcontroller. The Infineon controller is made for higher power application and the design will be based on a reference 1200W design. The figures below display a potential physical appearance of the device as well as board layout with anticipated component values.

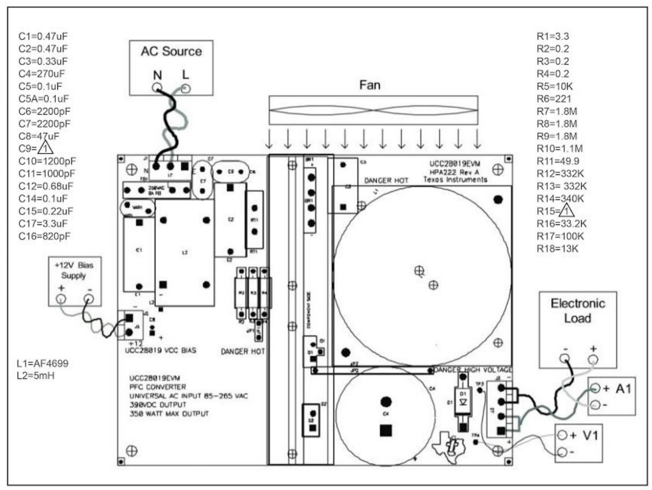


Figure 2 (a) anticipated physical appearance and (b) board layout with component values

The general design of the power supply is as follows. The microcontroller senses currents from the bridge rectifier stage and voltages from the boost PFC stage and uses internal feedback topology to control the mosfet in the boost PFC via a gate driver to maintain optimal operation.

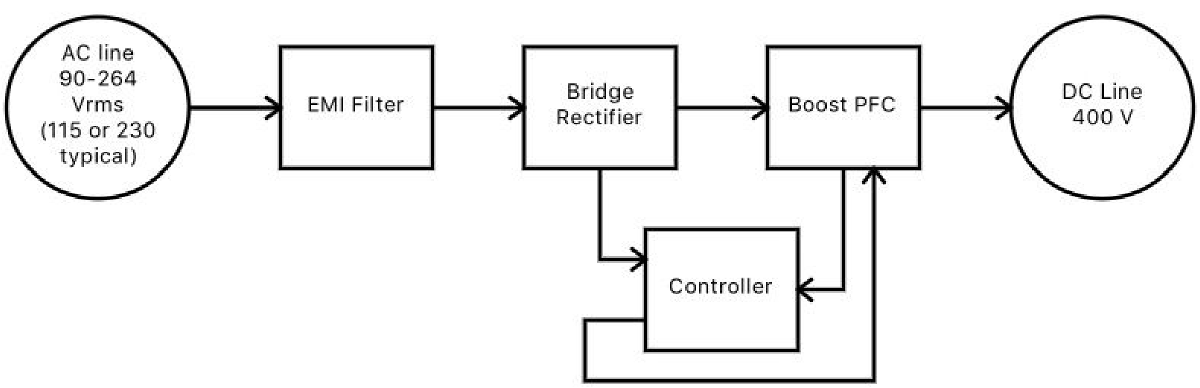


Figure 3 Design diagram.

Since this design will be entered in the IEEE IFEC International Future Energy Challenge AztecFEC will be following all of the performance requirements call out by the completion. All of the requirements are the intended features of our desired final and finished project.

(1) Input Voltage Vin: 90~264 Vac
(2) Input Current Iin: 15 A **(max)**
(3) Input Frequency *f*ac: 47~63 Hz
(4) Input Power Factor PF: >0.95 @20% load
(5) Input Current Harmonic ITHD: <2% @100% and 50% load
(6) Input Inrush Current Iinrush: <60Amax @264Vac
(7) Output Power Pout: 1.3 kW **(max)**
(8) Output Voltage Vout: 400 Vdc
(9) Output Voltage Ripple Vout,p-p: 5 Vdc
(10) Hold-Up Time Thold: 12 ms (Vout>360Vdc @100% load)
(11) Power Density: >1 W/cm^3
(12) Efficiency η
(13) EMI Requirement: CISPR CLASS A (Shall have a minimum of 3dB margin)
(14) Maximum AC Leakage Current: 3.5 mA @240 Vrms
(15) Reliability: The AC-DC converter will be tested in an environmental chamber @65C full load for 10 minutes
(16) Protection: Input under/over voltage and over current protections are required. No damage caused by output short circuit or open circuit.
(17) Safety: No live electrical elements are to be exposed when the unit is fully configured. The system is intended for safe and routine use by non-technical customers. It is recommended to follow industry safety standards such as UL1741-2000.
(18) EMI Requirement: CISPR CLASS A (Shall have a minimum of 3dB margin)
(19) Maximum AC Leakage Current: 3.5 mA @240 Vrms
(20) Reliability: The AC-DC converter will be tested in an environmental chamber @65^{0}C full load for 10 minutes.
(21) Protection: Input under/over voltage and over current protections are required. No damage caused by output short circuit or open circuit.
(22) Safety: No live electrical elements are to be exposed when the unit is fully configured. The system is intended for safe and routine use by non-technical customers. It is recommended to follow industry safety standards such as UL1741-2000.

Testing and Verification

Testing will make up the majority of time spent on this project. Theoretical designs will be tested and verified using simulation software. Once the physical boards are assembled, extreme caution must be taken in testing the physical device as the power supply operates with high voltages and currents. Special equipment provided to us by the advisors is necessary for our project to be successful. For reference purposes, we have purchased a Texas Instruments PFC evaluation board which our primary designs will be based off of. The evaluation board will also allow us to debug the faults in our board as we will be able to probe and compare test points on either board to locate and diagnose potential problems or errors. We plan to segment the board into several parts to further facilitate the appropriate operation of the board. Doing so will aid us in knowing what parts of our circuit works and where exactly it lacks performance. Furthermore, we can address the dysfunctional parts of the board without having to disassemble working components.

Shown below is the recommended testing setup taken from the Texas Instrument's UCC28019a evaluation board. As can be seen, an oscilloscope, voltage meter, ammeter, and electronic load is required in order to test the board properly. The microcontroller is powered by its own +12V power supply. Since the circuit contains very high current flow and voltage throughout, a heatsink and or fan configuration is necessary to help dissipate heat from the board. Due to the high power output of the board, some of the standard equipment used in the electronics laboratory on campus is not suitable for testing. For instance, a high-power intake variable AC load will be needed to properly verify the functionality of the power supply. Other high-power application testing equipment such as oscilloscopes and testing cables are provided at our advisors laboratory.

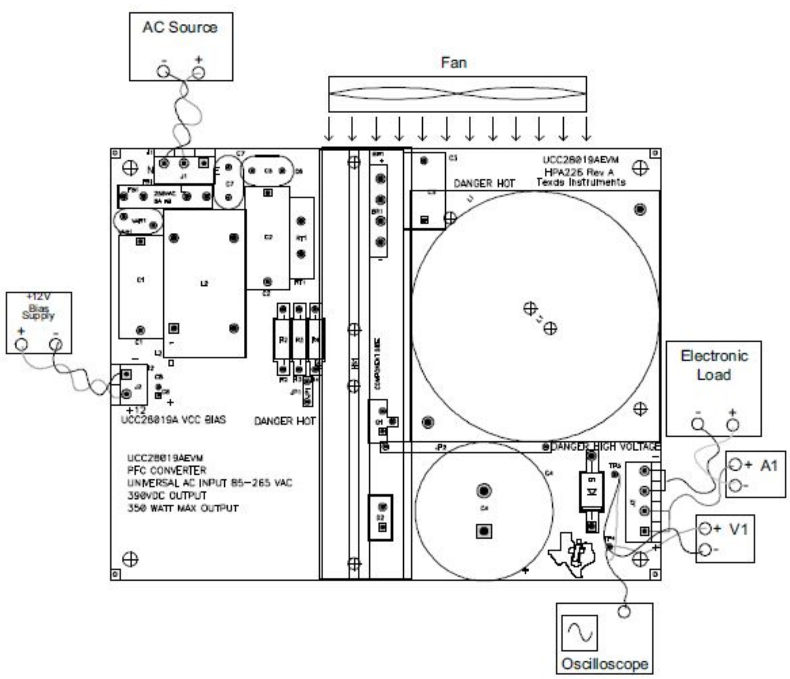


Figure 4 Potential testing and verification setup.

Project Management

AztecFEC comprises 8 personnel. Each contributes to certain aspects toward the design goal, building a high density, high efficiency, switching power supply. The table below lists each individual's non-design and design tasks.

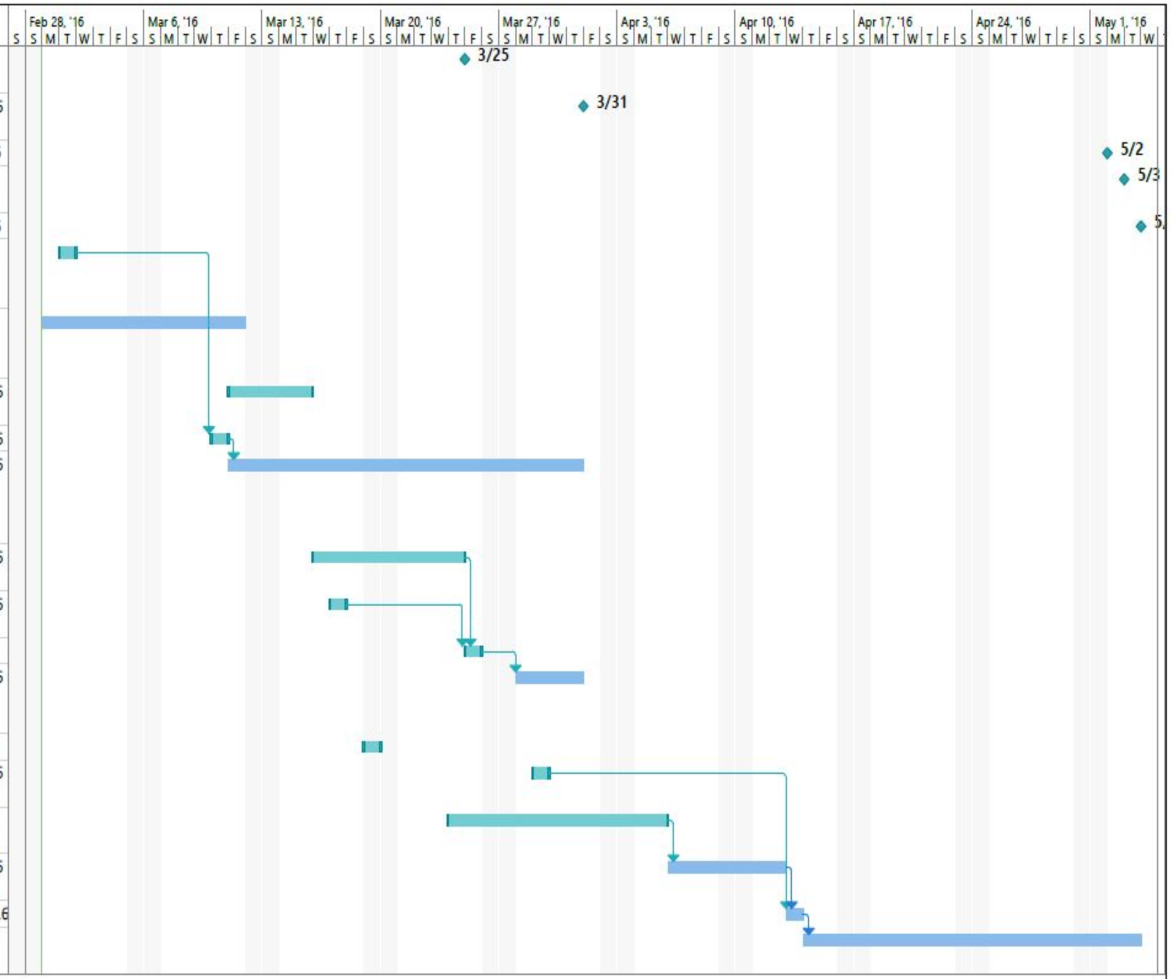
John Brinsko	Project Manager	
Elbert Guico	Secretary	Theory and Testing
Charles Plank	Repository Manager	Theory and Testing
Armando Flores	Tech Illustration	Theory and Testing
Arash Moradinejad	Editor	Theory and Testing
Ricardo Rivero	Website	PFC Programming
Ryan Rivera	Powerpoint Presentation Mgr	PCB Design
Omar Flores	Parts Manager	PCB Design

Theory and Testing group calculates component values and design of the circuit schematic. As parts are assembled onto the PCB, this group will evaluate each section of the circuit and determine the best design to meet specifications. This group provides the signals for the PFC. PFC Programming group will process those signals with the PFC. PCB Design group lays the printed circuit board onto the confined space of 1300 cubic centimeters.

Components and other devices for the power supply can be sourced from a variety of online retailers. Special components, such as inductors, may require sourcing through manufacturer's distributor. Printed circuit boards up to two layers can be manufactured at San Diego State University.

The chart on the following page indicate design and milestone deadlines for the project.

ID		Task Mode	Task Name	Duration	Start	Finish
1			Preliminary Website Online	0 days	Fri 3/25/16	Fri 3/25/16
2			350W board meets specs	0 days	Thu 3/31/16	Thu 3/31/16
3			Final Website Online	0 days	Mon 5/2/16	Mon 5/2/16
4			1300W board meets specs	0 days	Tue 5/3/16	Tue 5/3/16
5			Design Day	0 days	Wed 5/4/16	Wed 5/4/16
6			Order 350W Evaluation Board and its bill of materials	1 day?	Tue 3/1/16	Tue 3/1/16
7			Assemble IFEC board and conduct evaluation tests	10 days?	Mon 2/29/16	Fri 3/11/16
8			IFEC Qualification Report	3 days	Fri 3/11/16	Tue 3/15/16
9			Parts Received	1 day	Thu 3/10/16	Thu 3/10/16
10			Assemble UCC28019AEVM and conduct evaluation tests	15 days	Fri 3/11/16	Thu 3/31/16
11			350W PCB design out to manufacture	7 days	Wed 3/16/16	Thu 3/24/16
12			Order scaled up parts list with UCC28019 PFC	1 day	Thu 3/17/16	Thu 3/17/16
13			Parts Received	1 day	Fri 3/25/16	Fri 3/25/16
14			Max out the 350W evaluation board with scaled up components	4 days	Mon 3/28/16	Thu 3/31/16
15			APEC Workshop	1 day	Sat 3/19/16	Sat 3/19/16
16			Order parts list for 1300W design	1 day	Tue 3/29/16	Tue 3/29/16
17			PCB layout with Infineon ICE3PCS01G	9 days	Thu 3/24/16	Tue 4/5/16
18			PCB design out to manufacture	5 days	Wed 4/6/16	Tue 4/12/16
19			Parts Received	1 day	Wed 4/13/16	Wed 4/13/16
20			Assemble and evaluate 1300W design	14 days	Thu 4/14/16	Tue 5/3/16



Project: AztecFEC.mpp
Date: Mon 2/29/16

Task · Split · Milestone · Summary · Project Summary · Inactive Task · Inactive Milestone · Inactive Summary · Manual Task · Duration-only · Manual Summary Rollup · Manual Summary · Start-only · Finish-only · External Tasks · External Milestone · Deadline · Progress · Manual Progress

Page 1

Budget

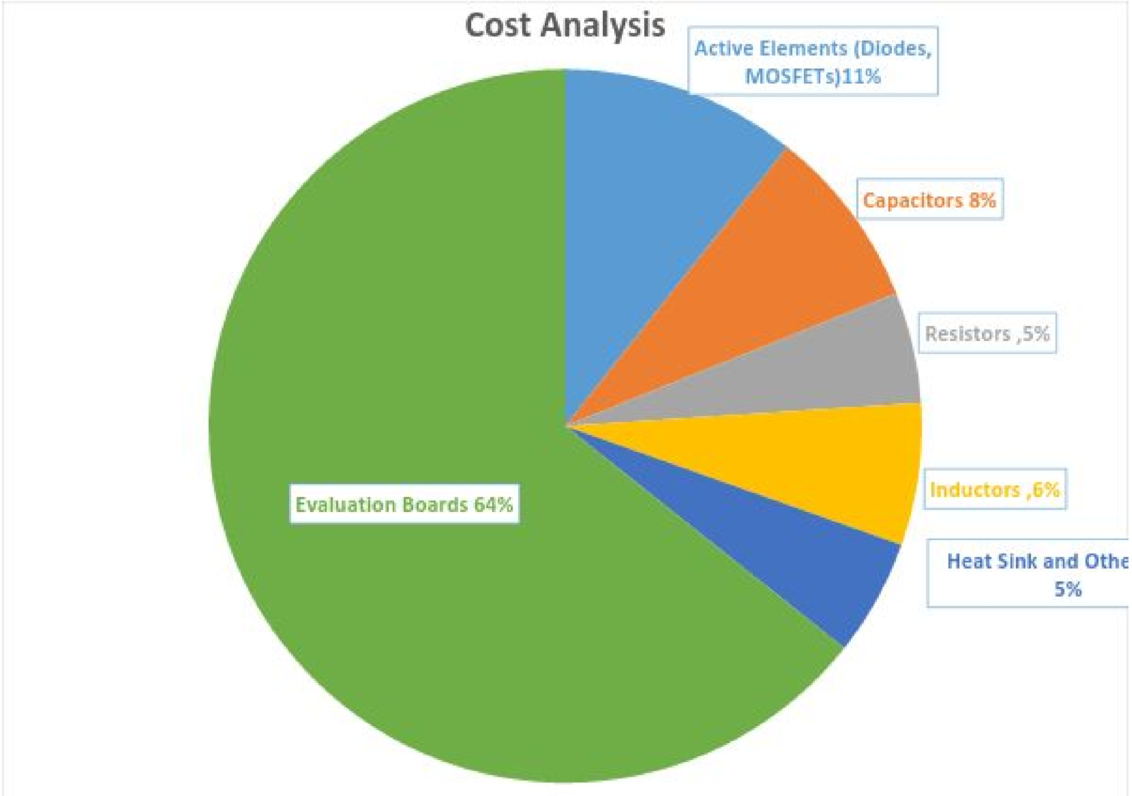


Figure 5 Chart demonstrating anticipated budget allocation.

The figure above displays the rough layout for the percentage of funds we plan to use for each category of components of the switching power supply. A high percentage of the budget will go towards evaluation boards—these are necessary for performance debugging of our own build. Although active elements are the runner up in expense, the quantity of them are actually less than those of the passive components. The reason for this is because the active elements govern the performance of our circuit, and therefore demand more cost. The actual fabrication of our PCBs will be done through SDSU and at no cost to us, as well as the UCC28019AD IC chip we are using since it can be sampled from Texas Instruments. Below is the total cost of the project along with the breakdown cost of each component classification. Note that this is the cost of three board iterations—that is, we will be producing three power supplies throughout the entirety of the project.

Cost requirements	Cost($)
Active elements(DIODE, MOSFETS)	49.95
Capacitor	38.36
Resistors	23.458
Inductors	30.08
Heat sink and other misc	24.65
Evaluation boards	300
Total	466.498

INTERNATIONAL STUDENT COMPETITION

2016 INTERNATIONAL FUTURE ENERGY CHALLENGE

San Diego State University AztecFEC Team Members

Project Management:

Johnny Brinsko

PFC Programming:

Ricardo Rivero

Design and Test:

Elbert Guico

Armando Flores

Charles Plank

Arash Moradinejad

PCB Design:

Omar Flores

Ryan Rivera

High Power Density AC-DC Converter

The goal is to build and present an AC-DC converter which is based on the following specifications:

Input: V_{in}: 90 ~264 V_{rms}; 47~63 Hz; PF>0.95 @20% load; I_{THD} < 2% @50% load

Output: V_{out}: 400 V_{dc}; P_{out}: 1.3 kW; Efficiency > 92% @10% load;

Power Density: >1 W/cm^3

AZTECFEC

Meet the AztecFEC Team on Workshop Day at APEC' 2016

Mar. 20, 2016

For more information http://www.energychallenge.org

Sponsors:

References

UCC28019a Data Sheet, Texas Instruments, "http://www.ti.com/product/UCC28019A/datasheet", (December 2008, Revised August 2015)

UCC28019a EVM 350W PFC Converter User Guide, Texas Instruments, "http://www.ti.com.cn/cn/lit/ug/sluu325a/sluu325a.pdf", (June 2008, Revised May 2009)