ECE 445 – Senior Design

Design Review

Multi-Source, High-Power Converter

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Team #29

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I. Introduction

Motivation:

The motivation for this idea is to bridge the gap between power converters and provide a universal platform that allows for multiple functions in one convenient package. The current products that are commercially available mainly focus on one type of power conversion (e.g. AC/DC, DC/AC, DC/DC, or AC/AC) and do not allow for much flexibility and user control in terms of input and output. This project aims to meet a broad range of power supply needs both in the household and on the road.

Objective:

The goal is to design a console that can accept three commonly available power sources (14Vdc, 115Vac/60Hz, 230Vac/50Hz) and convert any one type into either 115Vac or 230Vac. For instance, if the input were 14Vdc the user could choose an output of either 115Vac or 230Vac. This converter will be capable of meeting the demands of high-power items such as sump pumps, small microwave ovens, mini refrigerators, power tools, etc., in the event of a power outage or a roadside application (see Table 1 at the end of the document for typical appliance power consumption). In DC/AC mode it will be able to handle up to 1,000 Watts, and in AC/AC mode it would support up to 650 Watts.

Benefits:

- International compatibility
- Compact design
- Helpful in emergency situations (e.g. power outages)

Features:

- 1,200 W overprotection for DC/AC mode
- 780 W overprotection for AC/AC mode
- 3 types of input options available
- 2 types of output options available
- Efficiency target of 70%

II. Design

Block Diagram

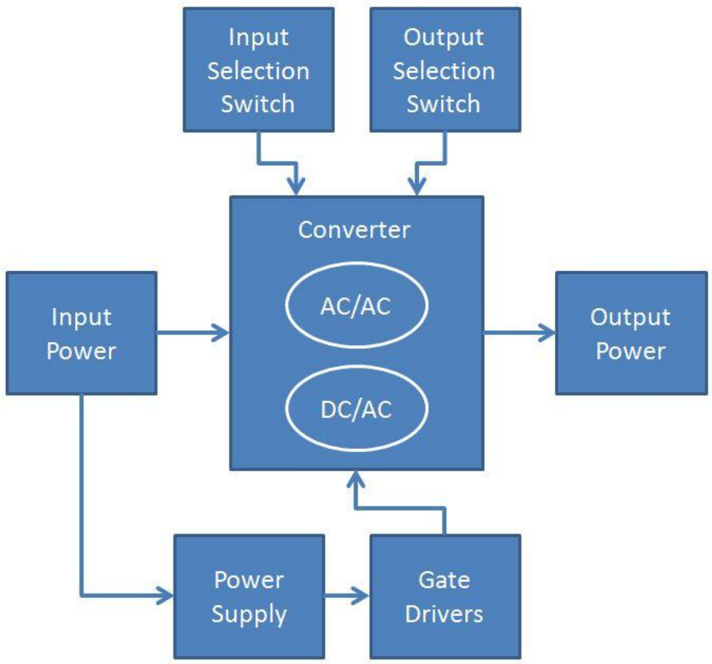

Figure 1: General Block Diagram

Block Descriptions

Input Power: 115Vac/60Hz, 230Vac/50Hz, or 14Vdc.

Input Selection Switch: A dial that selects which input the user will provide (either AC or DC) and enables or disables relays that will help choose the correct conversion path.

Output Selection Switch: A dial that selects which output the converter will supply (either 115Vac or 230Vac) and triggers relays that will finalize the conversion path.

For example, if the input selection switch is set to AC, the conversion path chosen will be AC/AC. Then the output selection switch will determine whether to provide 115Vac/60Hz or 230Vac/50Hz at the output.

Converter: All power conversion will take place here and it would be determined by the above described switches.

AC/AC: If the input is 115Vac/60Hz, it would be stepped up to 230Vac/50Hz using a 1:2 transformer. If the input is 230Vac/50Hz, it would be stepped down to 115Vac/60Hz using a 2:1 transformer. After the transformer, the appropriate sinusoidal signal will be rectified by a full-wave diode bridge and a capacitor in parallel in order to achieve a near-constant DC voltage. The next step would involve inverting this DC signal into the appropriate AC signal through four MOSFET switches arranged in a bridge.

DC/AC: The 14Vdc input will be fed into a two-stage boost converter which will step up the voltage to either 115Vdc or 230Vdc, depending on the setting of the output selection switch. This voltage will then be sent to a bridge inverter (consisting of the same four MOSFET switches again) to produce either 115Vac/60Hz or 230Vac/50Hz.

Output Power: 115Vac/60Hz or 230Vac/50Hz.

<u>Sub-Module Circuit Schematics</u>

AC/AC Converter Schematic

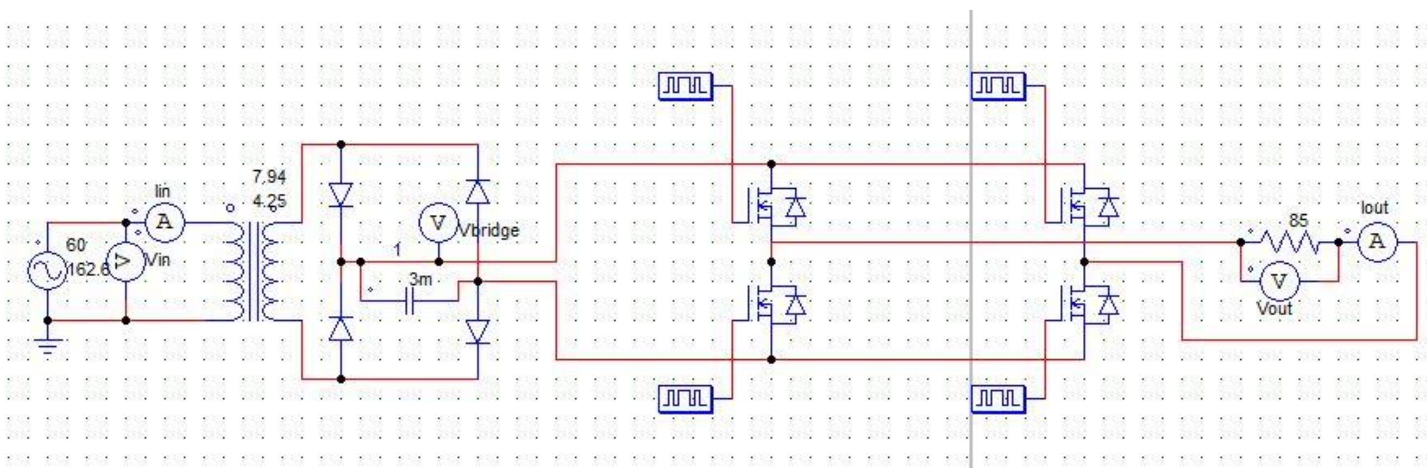

Figure 2: AC/AC Converter (115-230V example shown)

The AC/AC converter circuit consists of three stages. First, the input goes through either a step-up (1:2) or a step-down (2:1) transformer, depending on the type of conversion desired. In the example above, the input of 162.6 $V_{p\text{-}p}$ (115 V_{RMS}) is entered into a 1:2 transformer (4.25:7.94 experimental values) which steps up the RMS voltage to 230 V. The second stage involves a full-wave diode bridge with a capacitor, which rectifies the 230 Vac to 230 Vdc. The third and final stage of the design incorporates four MOSFETs that switch at a frequency of 50Hz in order to output the proper 230Vac/50Hz waveform.

115-230V AC/AC Conversion Waveforms

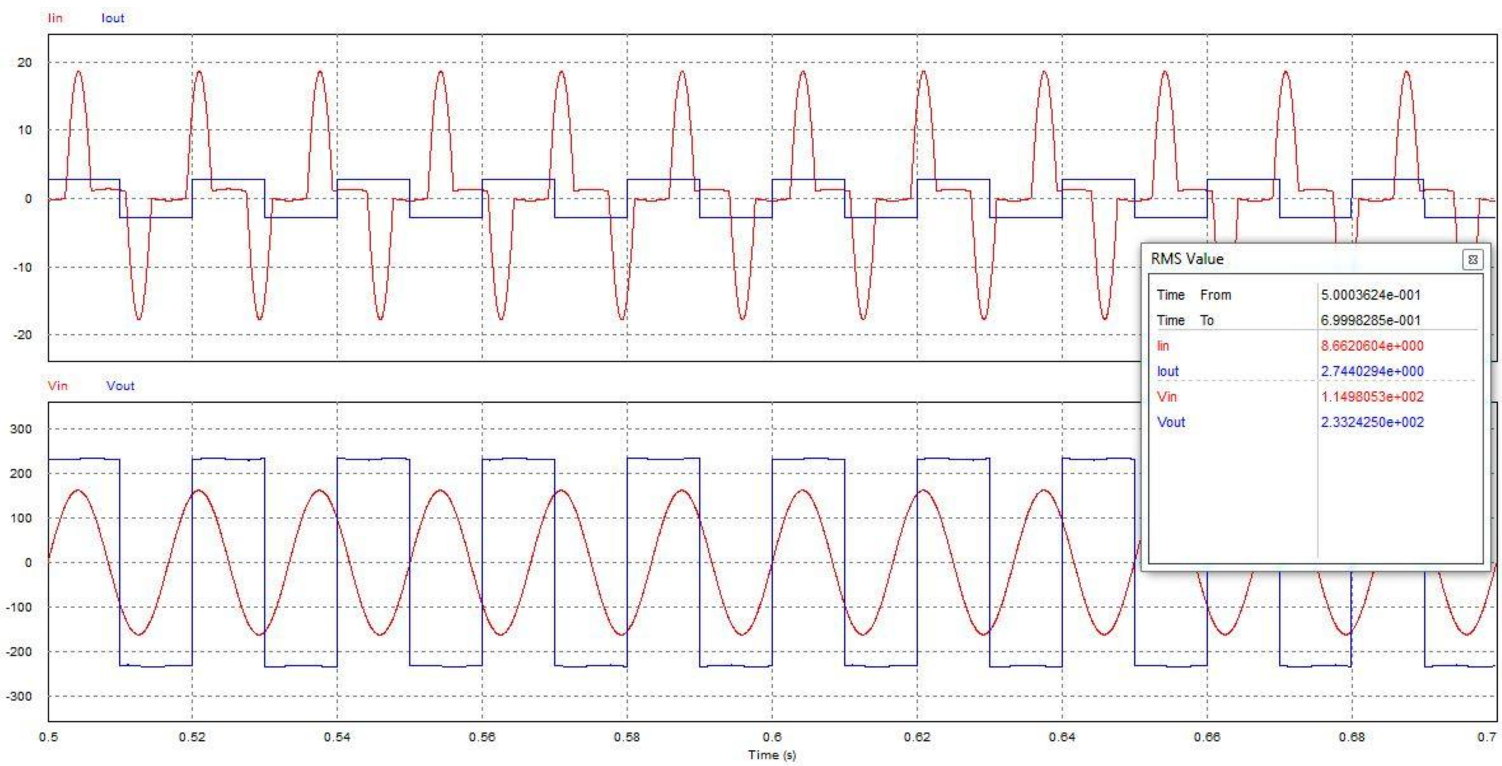

Figure 3: 115-230V AC/AC Converter Voltage and Current Waveforms (Full Load)

Figure 3 displays the input versus output current on the top and input versus output voltage on the bottom. The input signal is an expected sinusoidal wave with an RMS value of 115 V. The output wave produced by the design in Figure 2 is a square wave with RMS value of 233.2 V. The circuit behaves properly and produces sufficient results. The efficiency of this stage is calculated below, based on the RMS values given in Figure 3:

$$\eta = \frac{V_{out}I_{out}}{V_{in}I_{in}} = \frac{(233.2)(2.7)}{(115)*(8.7)} = 62.9\ \%$$

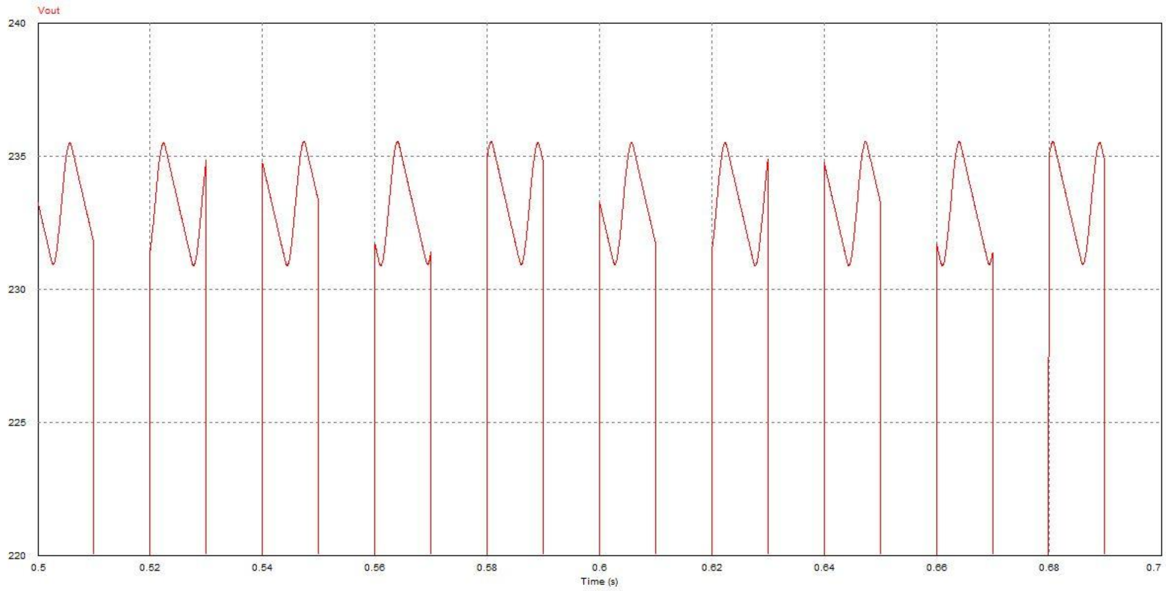

Figure 4: 115-230V AC/AC Converter Output Voltage Ripple

Figure 4 shows the output voltage ripple from the 115-230V conversion process. The calculated percentage is shown below:

$$\% \text{ Ripple} = \frac{V_{max} - V_{min}}{V_{RMS}} = \frac{235.5 - 230.9}{233.2} = 1.9\ \%$$

DC/AC Converter Schematic

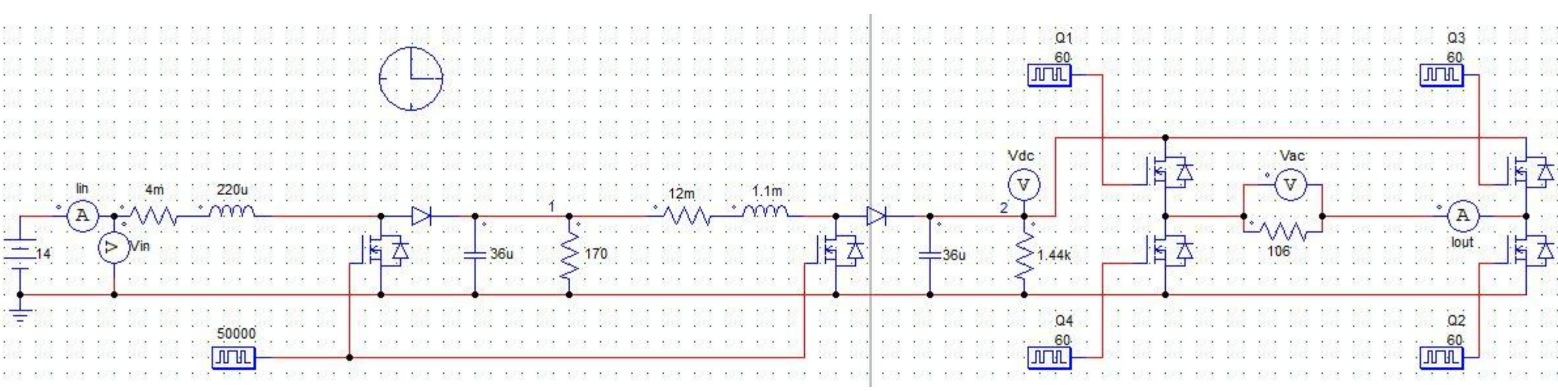

Figure 5: DC/AC Converter (14-230V example shown)

The DC/AC converter consists of three stages. The input is fed directly into a 2-stage boost converter. Based on duty ratio control the second stage output produces the required AC voltage in DC form. In this example, this voltage is 325.3 $V_{p\text{-}p}$ (230 V_{RMS}) supplied to the next stage, which again consists of an inverting MOSFET bridge that in this scenario is switching at 50 Hz.

14-230V DC/AC Conversion Waveforms

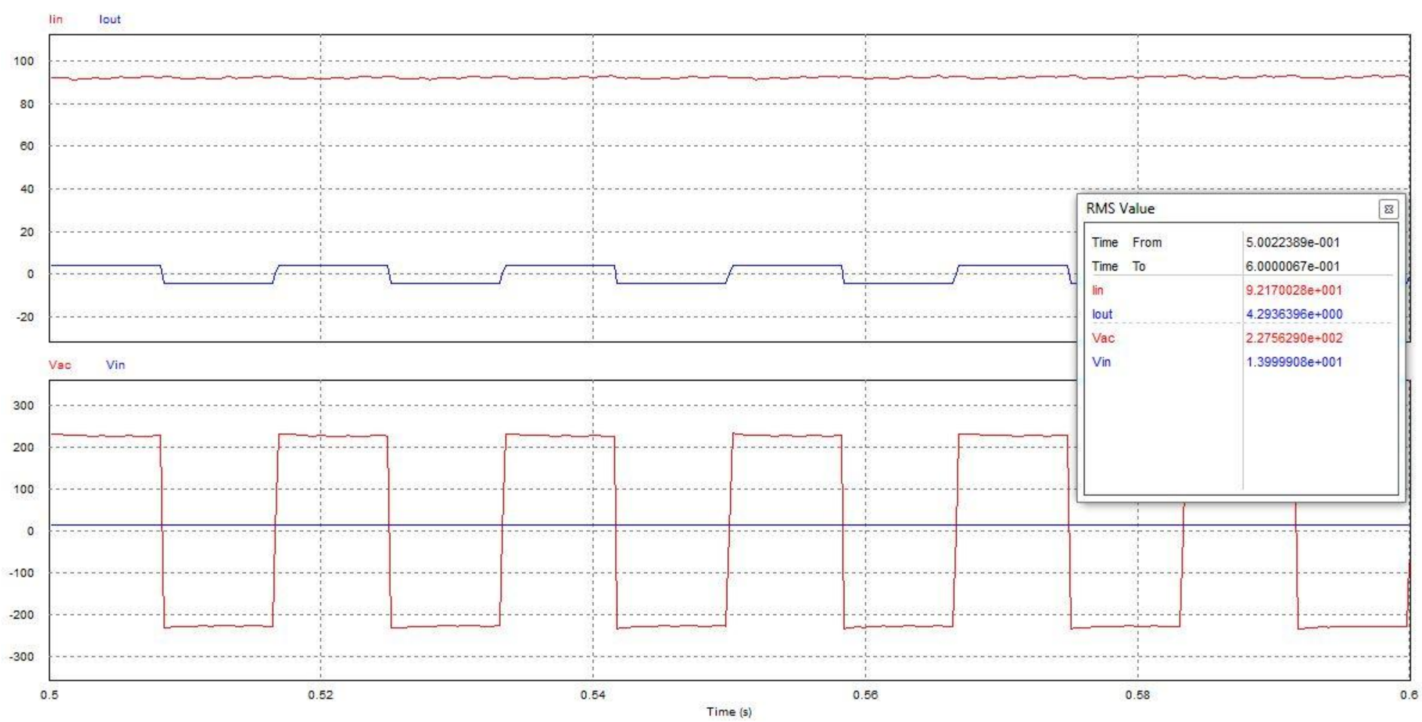

Figure 6: 14-230V DC/AC Converter Voltage and Current Waveforms (Full Load)

Figure 6 displays the input versus output current on the top and input versus output voltage on the bottom. The input signal is an expected constant value of 14 V. The output wave produced by the design in Figure 5 is a square wave with RMS value of 227.6 V. The circuit behaves properly and produces sufficient results. The efficiency of this stage is calculated below, based on the RMS values given in Figure 6:

$$\eta = \frac{V_{out}I_{out}}{V_{in}I_{in}} = \frac{(227.6)(4.3)}{(14)(92.2)} = 75.8\ \%$$

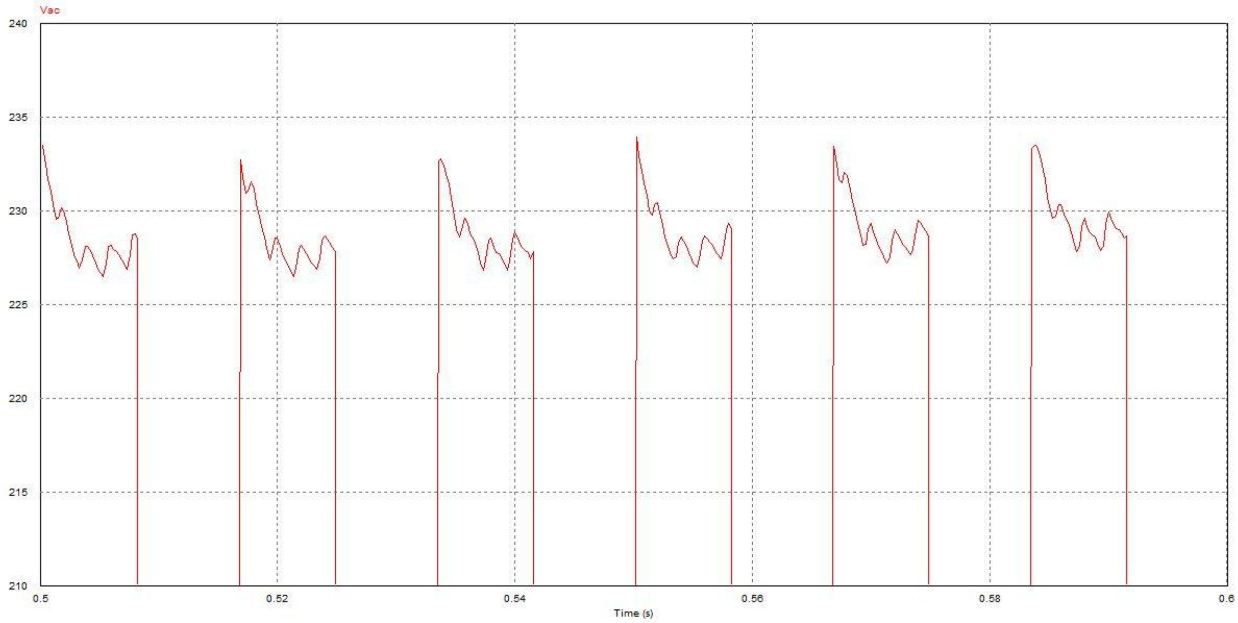

Figure 7: 14-230V DC/AC Converter Output Voltage Ripple

Figure 7 shows the output voltage ripple from the 14-230V conversion process. The calculated percentage is shown below:

$$\% \text{ Ripple} = \frac{V_{max} - V_{min}}{V_{RMS}} = \frac{233.9 - 226.6}{227.6} = 3.2\ \%$$

Input/Output Selection Switch Schematic

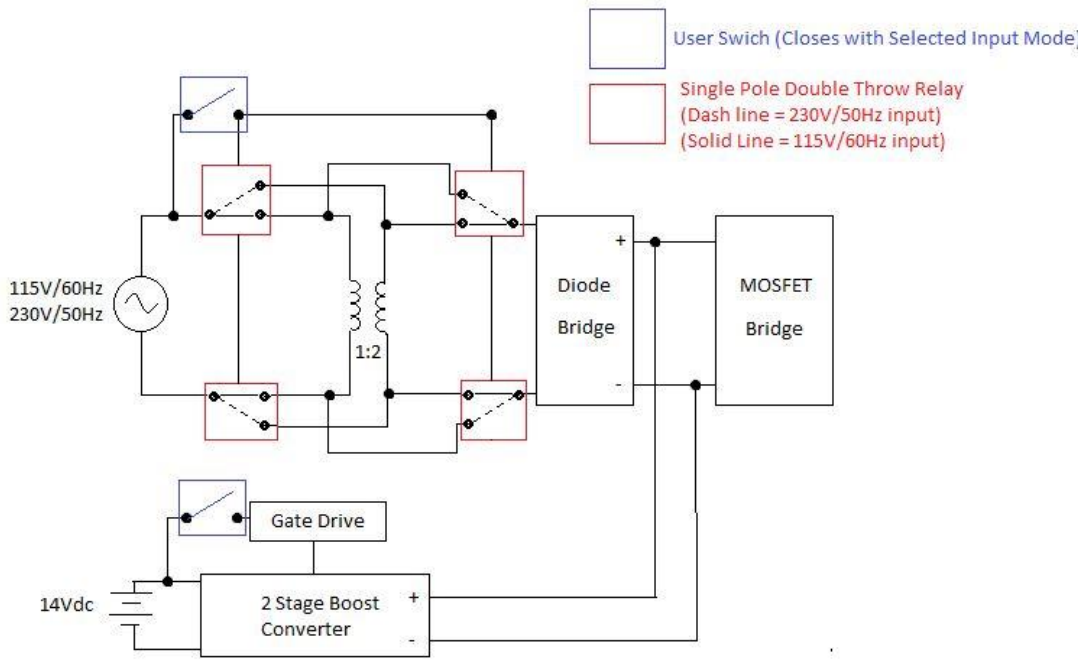

Figure 8: Selection Switch Relay Diagram

The selection switches will function based on a collection of voltage-controlled relays, as shown in Figure 8. The single, solid switches in the diagram represent the electrical analog of the actual physical dial the user will have the option of turning. They either supply power to the AC part of the schematic or the DC. If the input selection switch is set to DC, then the output selection switch will control the Gate Driver (duty ratio) of the 2-stage boost converter and it will supply the desired voltage peak to the MOSFET inverting bridge. On the other hand, if the input selection switch is flipped to AC, then the AC part of the schematic will be active. That section of the circuit will be intelligent and self-contained. The relays around the transformer will remain closed and provide a 1:2 ratio for an applied voltage of 115 V. Otherwise, they will switch into the dashed positions and provide a 2:1 ratio if the supplied voltage is 230 V.

Gate Driver Schematics

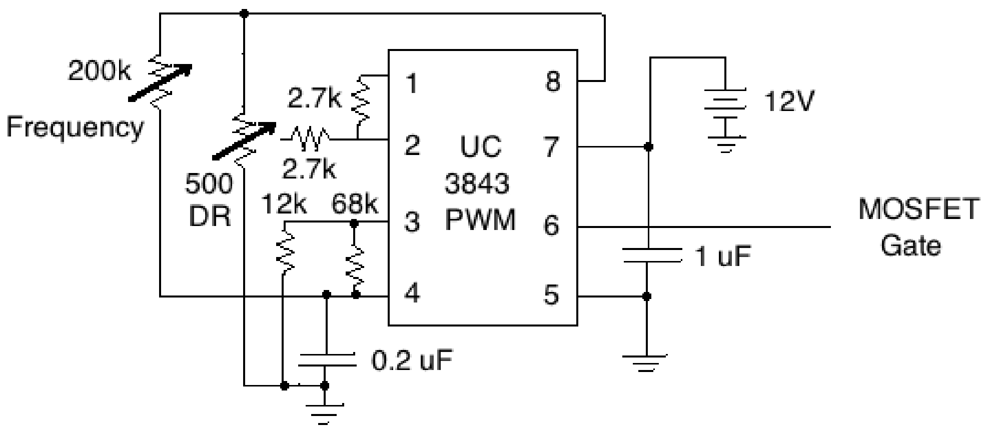

Figure 9: Gate Driver for MOSFET Bridge

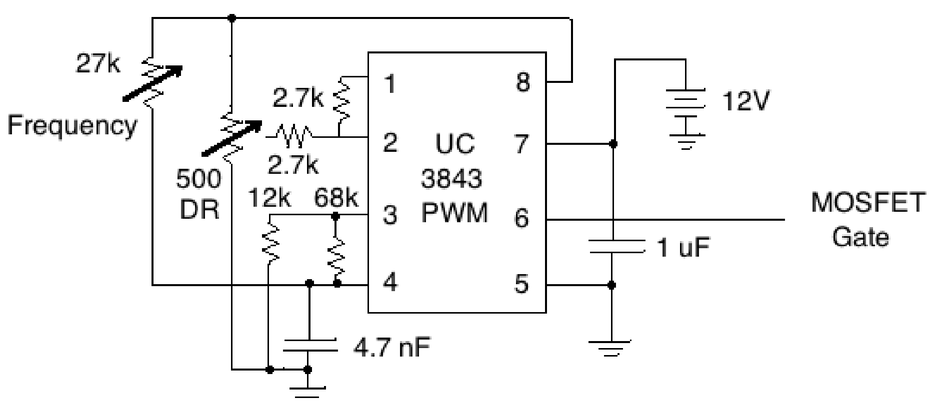

Figure 10: Gate Driver for Boost Converters

Figures 9 and 10 portray how the pulse width modulation signal will be supplied to the MOSFET bridge and boost converters, respectively. Each schematic is comprised of a PWM chip, as well as a potentiometer that could be tweaked to provide the desired driving frequency at the gate of the semiconductor devices.

Power Supply Schematic

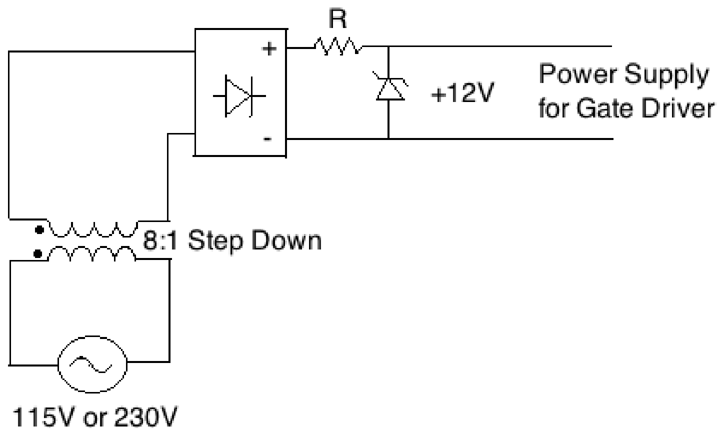

Figure 11: Power Supply for Gate Drivers

Figure 11 displays the power supply circuit for the gate drivers. It consists of a step-down transformer and a bridge rectifier. The output of the rectifier is regulated to 12V by the included zener diode.

<u>Performance Requirements:</u>

- Efficiency target of 70%
- Continuous power handling ability of 1,000 W for DC/AC mode
- Continuous power handling ability of 650 W for AC/AC mode
- Overpower handling ability of 1,200 W for DC/AC mode
- Overpower handling ability of 780 W for AC/AC mode
- ±10% maximum output voltage ripple

III. Verification

Testing Procedure:

The main module from the general block diagram that will be examined is the converter. It consists of two sub-modules: AC/AC and DC/AC conversion units. The two most important factors that will be monitored and optimized in regard to these sub-modules are the efficiency and the output voltage ripple. Efficiency, in general can easily be measured by plotting the input and output voltage and current waveforms of a given converter and taking the ratio of the output over the input power. The efficiency in each converter can be maximized by selecting proper components with minimum losses, reducing the amount of parasitic elements (such as long, bulky wires that can act as inductors), and obtaining the right switching functions that would allow for an efficient power transfer from one part of a converter to the next. Output voltage ripple can easily be obtained by plotting the output voltage waveform of a given converter and analyzing the local maximum and minimum values of the function around the desired output value. The ripple can be managed by installing properly sized filtering capacitors to limit the voltage spikes.

Tolerance Analysis:

As previously described, the two most important factors of the conversion units in this design are the efficiency and the output voltage ripple. It has been determined through rigorous testing and computer simulations that a reasonable goal for the efficiency of each converter is approximately 70%. The reason for this number being lower than expected is the characteristics of the transformer that will be only be capable of handling almost 1,000 Watts at its input terminals. It is very difficult and expensive to obtain a transformer of such high power handling abilities that can also be very efficient. Thus, the reasonable efficiency target of 70% will be pursued throughout the design and construction of this project. The output voltage ripple is the second most important performance parameter. A very practical performance target for the ripple was concluded to be no more than ±10%. Multiple simulations showed that the voltage spikes from each converter did not exceed 9% for most of the trials.

Module Description	Requirement	Test Procedure
Input Selection Switch	• Select wiring path for AC step-up/step-down or DC to AC conversion based on user selection and input voltage • Prevent improper operation if multiple sources are connected	• Use ohm meter to test which components are connected/disconnected to ensure current follows correct path
Transformer	• Step-up or step-down AC voltage with a 2:1 ratio • Stable operation with 1,000W input power	• Use function generator and multi-meter to test transformer voltage characteristics • Supply transformer with 1,000W input and monitor temperature, current, and voltage
Diode Bridge	• Rectify AC voltage to constant DC voltage with less than ±10% ripple	• Use function generator and oscilloscope to observe output voltage and ripple • If the desired voltage is 115V, then the measured value should be between 103.5 - 126.5V • If the desired voltage is 230V, then the measured value should be between 207 - 253V
MOSFET Bridge	• Produce a modified sine wave output from a constant DC voltage with desired output frequency determined by user	• Use power supply and oscilloscope to provide constant voltage and observe output voltage waveform • If desired voltage level is 115V, then the measured frequency should be close to 60Hz • If the desired voltage level is 230V, then the measured frequency should be close to 50Hz

Gate Driver for MOSFET Bridge	• Provide square wave switching function for the MOSFET bridge	• Use oscilloscope to measure output signal frequency, delay, duty ratio, and voltage • Voltage should be close to 5V • Frequency should be close to either 60Hz or 50Hz, whichever is desired • Duty ratio should be close to 50%
Output Selection Switch	• Select Bridge Gate Driver switching frequency of either 50Hz or 60Hz • Provide desired user output voltage at MOSFET bridge from 2-stage DC boost converter if DC input is selected	• Use oscilloscope to observe switching frequency at the MOSFET bridge • Use multi-meter to determine test voltage output of 2-stage boost converter
2-Stage Boost Converter	• Take input of 14Vdc and step it up to either 115Vdc or 230Vdc • Handle continuous output power of 1,000W	• Use power supply to provide 14Vdc at input and use multi-meter to measure output voltage • Output of first stage should be around 56V • Output of second stage should be either 115V or 230V, whichever is desired • Attach 1,000 Watt load and measure component temperature, voltage, and current characteristics
Gate Driver for 2-Stage Boost Converter	• Provide square wave switching signal to boost converter MOSFETs	• Use oscilloscope to observe and measure duty ratio of switching signal • Voltage level should be 5V • Duty ratio should be close to 65% for 115V • Duty ratio should be close to 76% for 230V

Ethical and Safety Considerations

With high amounts of power there is always a question of safety. In order to protect the user, a simple system of circuit protection will be utilized. A circuit breaker will be installed at the input of each AC pathway inside the AC/AC converter. A 100A fuse will be used to protect the input to the DC/AC converter. Those systems would be enough to protect from equipment failure, erosion, and explosion, but when dealing with high amount of current there is also the problem of excessive heat dissipation. In order to effectively deal with that issue, each semiconductor device will be complemented with another two of the same kind in parallel to divide the power flow evenly and dissipate overall less heat from each component. In addition, appropriate heat sinks will be put into place to ensure ample conduction of the heat generated inside the converter unit.

IV. Cost and Schedule

Parts

Part Description	Model Number	Supplier	Quantity	Price / Unit	Total
MOSFET (N-channel)	IXFX140N25T	DigiKey.com	10	$11.45	$114.50
Power Diode	R5020413LSWA	DigiKey.com	4	$4.75	$19.00
Diode	1N4004	DigiKey.com	4	$0.34	$1.36
Transformer (1KVA)	1100-OF	DigiKey.com	1	$104.50	$104.50
Inductor (1mH)	RD7127-36-1m0	Mouser.com	4	$23.29	$93.16
Capacitor (2.7mF)	LNX2V272MSEG	DigiKey.com	1	$31.10	$31.10
Capacitor (47uF)	EEU-EB2V470	DigiKey.com	3	$1.64	$4.92
USA/Euro Plug Adapter		Amazon.com	1	$4.94	$4.94
3 Prong USA Plug		Amazon.com	1	$3.89	$3.89
3 Prong USA Socket		Amazon.com	1	$15.85	$15.85
Euro Wall Socket		StayOnline.com	1	$7.00	$7.00
4 Gauge Jumper Cables		Amazon.com	1	$23.91	$23.91
Relay	RT314730	DigiKey.com	4	$5.47	$21.88
Rocker Switch	M2023TJW01	DigiKey.com	2	$7.92	$15.84
Gate Driver	UC3843	DigiKey.com	4	$0.94	$3.76
PCB Board		ECE Shop	1	$50.00*	$50.00*
Assorted Wires		ECE Store		$25.00*	$25.00*
Aluminum Housing		ECE Shop	1	$20.00*	$20.00*
Circuit Breaker	281-2401-ND	Digikey.com	2	$18.60	$39.20
100A Fuse	F3093-ND	Digikey.com	1	$2.93	$2.92

* Estimated Price

Subtotal = $602.73

Labor

Name	Salary	Hours	Total
Viktor Terziysky	$30.00 / hr	150	$11,250.00
Eric Kapinus	$30.00 / hr	150	$11,250.00

Subtotal = $22,500.00

Total Cost = $23,102.73

Schedule

Week	Description of Task	Group Member
2/6	Research Circuit Parts and Start Proposal	Viktor Terziysky
	Finish Proposal and Meet with Professor Krein	Eric Kapinus
2/13	Design AC/AC and DC/AC Converters on Paper	Viktor Terziysky
	Calculate Component Values and Perform PSIM Simulations	Eric Kapinus
2/20	Finalize Circuit Diagrams and Start Design Review	Viktor Terziysky
	Perform Detailed Component Analysis and Finish Design Review	Eric Kapinus
2/27	Order Parts and Begin Assembling and Wiring AC/AC Converter	Viktor Terziysky
	Gather Freely Available Parts and Design and Construct Gate Driver Circuits for AC/AC Converter	Eric Kapinus
3/5	Finalize and Optimize 115 to 230V Section of AC/AC Converter	Viktor Terziysky
	Finalize and Optimize 230 to 115V Section of AC/AC Converter	Eric Kapinus
3/12	Design and Construct Gate Driver Circuits for DC/AC Converter	Viktor Terziysky
	Begin Assembling and Wiring DC/AC Converter	Eric Kapinus
3/19	--------------------------------SPRING BREAK--------------------------------	-------------------------
3/26	Finalize and Optimize 14 to 115V Section of DC/AC Converter	Viktor Terziysky
	Finalize and Optimize 14 to 230V Section of DC/AC Converter	Eric Kapinus
4/2	Design and Assemble Relay Controlling Paths	Eric Kapinus
	Integrate Relay Controls With Existing Converters	Viktor Terziysky
4/9	Design PCB Layout in Eagle	Viktor Terziysky
	Finish PCB Design and Submit for Manufacturing	Eric Kapinus
4/16	Install Connection Cables	Viktor Terziysky
	Assemble Entire Unit in a Box	Eric Kapinus
4/23	Prepare Circuit for Demo	Eric Kapinus
	Prepare Presentation for Demo	Viktor Terziysky
4/30	Make Final Presentation	Eric Kapinus
	Compose Final Report	Viktor Terziysky

Table 1: Power Consumption of Typical Appliances

(https://www.cobra.com/detail/cpi-1575-1-500-watt-power-inverter.cfm)

Power Inverter Sizing Guide	
Application	Typical Watts
Appliances	
Can Opener	100
Electric Knife	100
12" 3-Speed Fan	250
Mixer/Blender	300
Food Processor	400
Portable Vacuum	550
Mini-Refrigerator	600
Toaster Oven	1000
Coffee Maker	1000
Microwave Oven	1000 min.
Audio/Video Equipment	
Video Game System	20
12" Black and White TV	30
Video Cassette Recorder (VCR)	30
Mini CD Changer System	50
13" Color TV	80
19" Color TV	160
25" Color TV	220
13" Color TV/VCR Combo	230
2 Amp Stereo Amplifier	240
Mobile Office Equipment	
Inkjet/Bubblejet Printer	40
Laptop Computer	50
Fax Machine	120
14" Color Monitor	125
Laser Printer	800
Battery Chargers	
Laptop Computer Charger	25
Cellular Phone Charger	25
Camcorder Charger	25
7.2V Cordless Drill Charger	25
Cordless Saw Charger	35
Hot Melt Glue Gun	40
Power Tools	
Finishing Sander	190
1/4" Drill	300
Soldering Gun	300
6" Bench Grinder	400
790 F Heat Gun	400
3/8" Reversible Drill	700
10 Gallon Wet/Dry Vacuum	900
6" Circular Saw	950
Router	1000
1200 F Heat Gun	1000
Disk Sander	1200
14" Chain Saw	1200
Pumps	
1/6 hp Submersible Sump Pump	880
1/4 hp Submersible Sump Pump	925