Line Operated Variable Voltage Power Supply

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1. Introduction

1.1 Problem

Many low-cost bench power supplies are noisy with bad accuracy and are sometimes unsafe. Even the top positive reviews of Amazon's best-selling bench power supply (Kungber 30V 10A) [1] have serious complaints about its performance, such as drift, inaccurate display readings, excessive voltage error, and outright failure. Low-cost bench supplies with poor power factors inject harmonics into the power lines, and their switching noise and other distortions can disrupt precision circuits. Additionally, basic protections are sometimes lacking, leading to unsafe conditions that could damage the supply, the circuit, or you.

1.1.2 Solution

We intend to build a line operated variable voltage power supply that is relatively low cost. To provide for low cost, isolation, and high efficiency, switched mode conversion will be used in order to correct the power factor, as well as to ultimately transform the voltage from line levels down to the selected voltages while providing for the output error specifications. Its subsystems will include isolated input rectification & power factor correction, DC-DC conversion, microcontroller unit, and case & hardware. Its output should be adjustable from 5V to 25V at 50W, at less than 1% total deviation under a static full load, with PF > 0.9 while meeting IEC 61000-3-2 standards for harmonic current.

1.3 Visual Aid

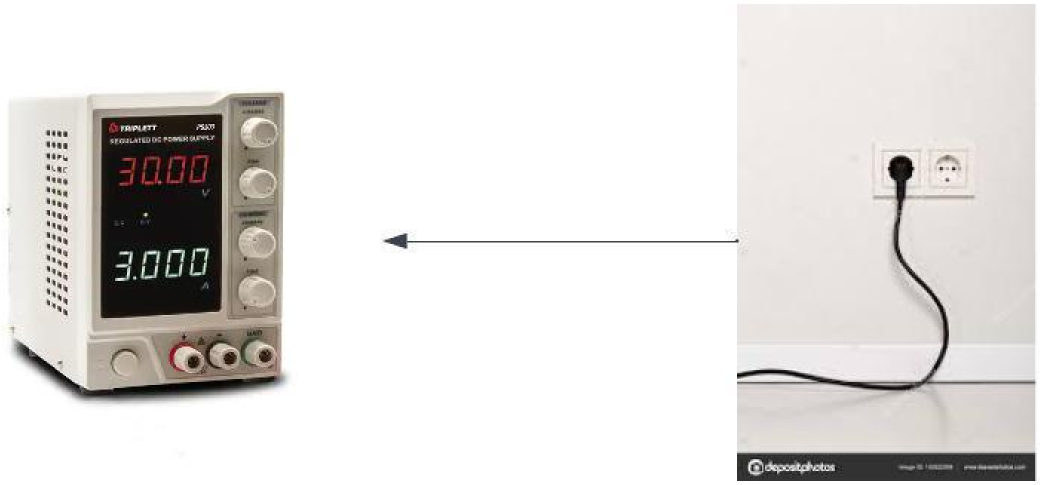

Figure 1. Visual Aid

As shown above, we intend to build a power supply that can accurately deliver 5V to 25V at 50W. This power supply will have adjustable knobs to adjust the output voltage and will also show accurate readings within 1% of both the output voltage and output current under a static full load. Our device will use a three prong plug that will have a grounding wire that goes to a ground on Earth. This is an important safety feature since we will be working with high voltage and want to eliminate any damage to the circuit and the user. Our device will also have connectors for banana plugs that will be used for testing and displaying readings to the oscilloscope. A bad LED and good LED will also be a part of our external power supply to indicate whether we have a fault condition or if the output power is active and ready to go. Finally, we will have a switch that will turn our power supply off or on.

1.4 High Level Requirements

i. The power factor for the device will be greater than 0.9.
ii. The device will meet or exceed IEC 61000-3-2 standards for harmonic current.

iii. The device will deliver 5V - 25V at 50W with 1% accuracy to a static load across the whole voltage range.

2. Design

2.1 Block Diagram

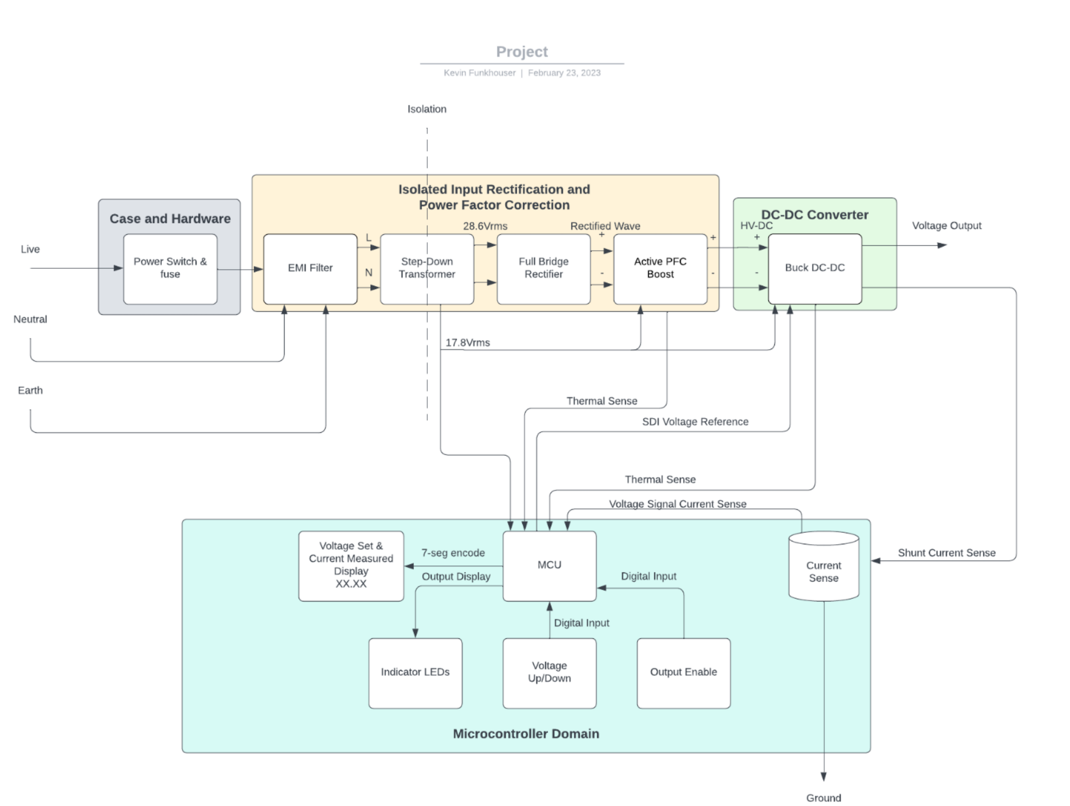

Figure 2. System Block Diagram

2.2 Subsystem Overview

2.2.1 ISOLATED INPUT RECTIFICATION & POWER FACTOR CORRECTION

The current proposed system entails an EMI filter followed by a line voltage step down transformer, which feeds a full bridge rectifier followed by a boost power factor corrector. The rectified output is then boosted to a high voltage DC (HVDC) intermediate bus at 70Vdc, which is later switched down to output levels. There are a variety of chips that can control a boost converter for PFC use, such as the UCC28180. The full bridge can be a simple packaged component or individual general purpose diodes. The step down transformer, while inelegant, provides us with immediate galvanic isolation while lowering the HVDC rail voltage. This allows us to avoid isolated DC-DC switching topologies, which have degraded performance generally due to optocoupler limitations. Additionally, inductors are much more varied and cheap off the shelf, whereas transformer choice is more particular - this could save us from having to use a custom transformer or winding our own. It is of note that there is a power switch and fuse “upstream” of this subsystem. This circuit should meet IEC 61000-3-2 standards for line harmonic current. This subsystem will have a chip regulator to deliver power to control circuitry. When looking at the circuitry of this subsystem we will be using Fig. 3 taken from Texas Instrument [2]. We will of course make sure to have a transformer between the EMI filter and the four bridge circuit in order to isolate the system.

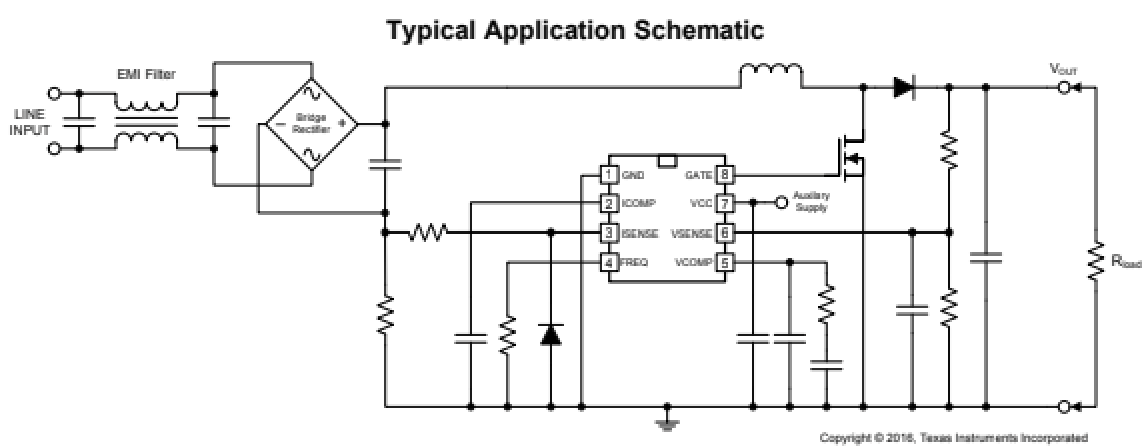

Figure 3. Boost Power Factor Correction Controller

2.2.2   DC-DC CONVERTER

This regulated converter will transform from 70Vdc down to the desired voltage. The topology will most likely be a buck converter. Control circuitry will entail a PWM controller and compensation system. A fortified output filter, with possible topologies of a capacitance multiplier or a noise clipper circuit, will provide thorough output regulation and good transient response. The converter must also be able to enable and disable the output on command. This subsystem will have a chip regulator to deliver power to control circuitry. The following topology for the buck converter will be used and will be adapted from the Texas Instrument datasheet [3].

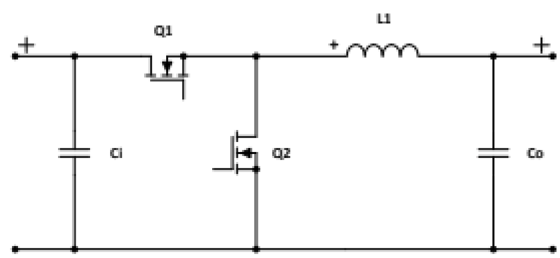

Figure 4. Synchronous Buck Converter

2.2.3 MCU

The microcontroller unit must be able to process the temperature, the current sense, the voltage selection, and the output enable input signals. It must output a SPI bitstream for the DAC, encoded voltage and current display data, an output enable/disable signal to the DC-DC converter, and outputs to the indicator LEDs. We have chosen an Atmega 328p microcontroller for this purpose because of its familiarity, ease of use, and generous GPIO and ADC inputs. This subsystem will have a chip regulator to deliver power to the MCU. The following is the block diagram of the Atmega 328p microcontroller taken from Microchip Technology [4].

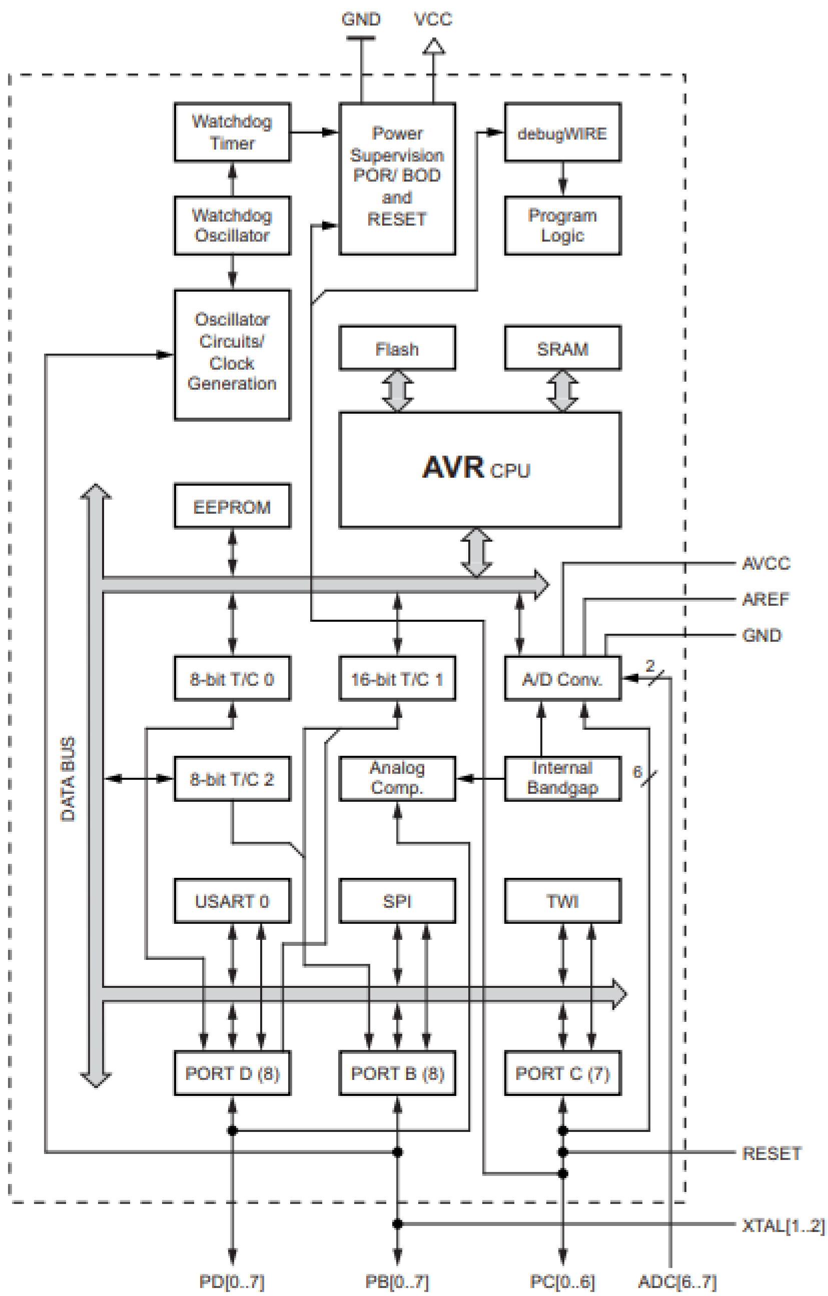

Figure 5. Block diagram of Atmega 328p

2.2.4 CASE & HARDWARE

This instrument will need to be operable. It will need to have a case with adequate venting and heatsink capabilities, a three prong plug with strain relief, a fused input, and a power switch. Shielding will be investigated. It will also need to have simple displays to tell real time voltage and current conditions. There must be a dial or buttons to select voltage and output enable, and banana plugs or other connectors for power, ground, and earth. There must be LED indications for ‘output active’ and ‘fault condition’ signals. The case must be adequately grounded if applicable.

Table I: Subsystem Requirements and Verifications

Subsystem	Requirements	Verifications
Isolated Input Rectification & PFC	1. The power factor of the subsystem must be greater than 0.9. 2. The input current must meet or exceed IEC 61000-3-2 standards for harmonic current. 3. The output voltage must be maintained between 60VDC and 80VDC. 4. The input and output must be galvanically isolated.	1. We can analyze the power factor using a power factor meter. 2. A spectrum analyzer will allow us to measure harmonic current. We will need to reference the IEC 61000-3-2 document. 3. We can easily measure this by oscilloscope or DMM. 4. A continuity tester will determine if the transformer windings are isolated.
DC-DC Converter	1. The converter must convert the HV DC bus voltage to the specified output voltage between 5Vdc and 25Vdc within 1% static error at 50W. 2. The converter must be able to respond to the MCU signal to enable and disable its output.	1. The output voltage and current could be measured with an oscilloscope or a DMM. 2. The fault can be simulated using a signal generator. The disconnection can be measured with an oscilloscope or continuity tester.
Case & Hardware	1. The case must be able to contain all of the circuitry	1. This can be verified by inspection.

	and allow mounting with adequate venting. 2. The case must have displays, buttons, switches, and plugs for user interaction.	2. We can verify with a DMM that the case is not electrically live.
Microcontroller Unit	1. This system must process the voltage selection input and output a SPI bitstream for the DC-DC converter. 2. This system must respond to the current sense signal and the thermal sense signals to produce and display a fault condition signal. 3. This system must be able to process the set voltage and the measured current for display. 4. This system must be able to appropriately determine and display an output enable signal based on the circuit conditions and the output enable button. 5. The system must have connections for programming.	1. The SPI bitstream can be verified by a logic analyzer, or by inspecting the DC-DC converter DAC output. 2. Current overload and thermal overload conditions can be simulated using signal generators, the response can be observed by DMM. 3. The display can be observed visually, or by logic analyzer, upon forcing MCU input signals with a signal generator. 4. The programming success can be determined by the Arduino IDE.

2.3 Tolerance Analysis

The only requirement that has strict tolerance that may provide difficulty is the 1% output tolerance. Active PFC modules generally achieve PF>0.9 with relative ease, whereas SMPS controller ICs generally guarantee a few percent static error, which is unacceptable.

1. Precision PWM generator systems such as the TIPD108 [5] (<0.11% offset, <0.02% gain errors) are available more readily than precision controller ICs. A discrete error amplifier (as good as the op-amp and sampling resistor tolerance), isolation amplifier (though generally poorer, <0.5% is common and the $25 ISO124 achieves[6] <0.010%) and PWM generator system combination may be used to achieve better accuracy as compared to a controller IC. This option could afford us greater precision at the cost of higher expense and greater complexity.

3. Cost & Schedule

3.1 Cost Analysis

Each member in the group expects a salary of $\$40/hr \times 2.5 \times 56hr = \$5600.$ If we include every team member that number is equal to $\$5600 \times 3 = \$16,800.$

Table II: Total Cost of Components

Description	Part Number	Price	Quantity	Extended Price
Switching Controllers CURR MDE PWM CNTRLR FWD FLYBCK APPS	NCP1252BDR2G	$0.94	2	$1.88
PFC boost controller IC	UCC28180	$1.056	2	$2.11
Microcontroller chip	ATMega328p	$1.66	2	$3.32

Single 12-/10-/8-Bit Rail-to-Rail DACs with Integrated Reference in SC70	LTC2630	$6.54	2	$13.08
Temperature sensor	NTE7225	$1.79	5	$8.95
LED (red)	L513SRD-C	$0.18	2	$0.36
LED (green)	754-1731-ND	$0.37	2	$0.74
Power button	RF1-1A-DC-2-R-1	$1.26	2	$2.52
Tactile switches	1825910-6	$0.13	5	$0.65
SMPS Controller IC	TEA1892TS/1H	$1.16	2	$2.32
100 Ω resistor	CFR-50JB-52-100R	$0.11	10	$1.10
1kΩ resistor	CFR-25JB-52-1K	$0.10	10	$1.00
10kΩ resistor	CFR-50JB-52-10K	$0.11	10	$1.10
100kΩ resistor	CFR-50JB-52-100K	$0.11	10	$1.10
0.1 μF capacitor	C320C104J5R5TA7301	$0.49	10	$4.90
10 μF capacitor	C322C106K3R5TA	$0.79	10	$7.90
0.33 μF capacitor	C322C334Z5U5TA	$0.46	10	$4.60

Diode	1N4935-T	$0.21	10	$2.10
EMI filter	DSS1NB31H473Q91A	$0.48	2	$0.96

Total cost of components = $60.69

Total cost = combined labor cost + total cost of components = $16,800 + $60.69

= $16860.69

3.2 Schedule

Table III: Final Project Schedule

Week	Task	Person
February 19th-February 25th	Order parts for prototyping and desoldering parts from scrap equipment	Everyone
	LTspice simulation of power circuit	Cesar
	Researching/developing microcontroller interface	Feroze
	Verify design topology	Kevin
February 26th-March 4th	Start PCB Design	Everyone
	Test PFC > 0.9 using the power factor meter and revise circuit	Cesar
	Verify SPI bitstream with a logic analyzer and inspect DC-Dc converter DAC output	Feroze
	Verify Output Voltage bw 60 & 80 VDC through oscilloscope and DMM	Kevin
March 5th-March 11th	**PCB Orders March 7th**	Everyone
	Finalize PCB Design	Everyone
	Measure harmonic current current with spectrum analyzer	Cesar
	Ensure input/output is galvanically isolated	Kevin
	Simulate overload and thermal overload conditions using signal generators and observe through DMM	Feroze
March 12th-March 18th	SPRING BREAK	Everyone
March 19th-March 25th	Test converter takes HV to 5 and 25Vdc and is within 1% static error at 50W.	Cesar

	Ensure converter is able to respond to the MCU signal and can enable and disable its output	Kevin
	Test system is able to process the set voltage and the measured current for display	Feroze
March 26th-April 1st	**PCB Orders March 28th**	Everyone
	Make final adjustments to PCB board	Kevin
	Ensure MCU is able to appropriately determine and display an output enable signal based on the circuit conditions and the output enable button	Cesar & Feroze
April 2nd-April 8th	Finalize MCU testing and ensure the system has the connections for programming	Everyone
April 9th-April 15th	Fault detection simulations	Cesar
	Thermal Sense protection simulations	Feroze
	Integral tests on subdivision components	Kevin
April 16th-April 22nd	Mock Demo	Everyone
	Final adjustments to MCU	Feroze
	Revisions to PCB Design	Kevin
	Further Integral tests on subdivision components	Cesar
April 23rd-April 29th	Final Demo and attend Mock Presentation	Everyone
April 30th-May 4th	Last minute adjustments for Final Presentation and work on Final Paper	Everyone

4. Ethics & Safety

We will be working with high voltage in this project so it is important that every member in our group take the high voltage safety training assessment. In addition, we will enforce that at least two group members be in the lab at all times to ensure someone will always be there to check on one another. We will use isolation transformers and input fuses when working with line voltages to provide us protection, and use lower voltages to ensure safe operation before using higher voltages wherever possible. We will also address the heat dissipation and have a thermal sensor that can protect against thermal overload conditions, so the user is protected from catastrophic failure. The output display must also be accurate, so that the user can accurately assess emergency situations. The specifications of the device must also be properly measured, characterized, and accurately reported so that the user can operate within a safe and predictable region To protect building infrastructure in the case of uncontrollable overcurrent, the inputs will be fused. Additionally, to respect and credit the work which helped us build our project, we will cite our sources. Citing our sources as well as accurately reporting specifications falls under IEEE Code of Ethics I.5 [7].

References

[1] Kungber, (2021). Kungber Adjustable DC Power Supply, Switching Regulated Power Supply with 4 Digital Display and Voltage Current Adjustments. https://www.amazon.com/Kungber-Adjustable-Switching-Regulated-Adjustments/dp/B08DJ1FDXV/ref=sr_1_3?keywords=Bench%2BPower%2BSupply&qid=1674944329&sr=8-3&th=1

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[5] TIPD108, Texas Instruments Inc. (2013). Data Sheet. Retrieved from: https://www.ti.com/lit/ug/slau508/slau508.pdf?ts=1675981305406&ref_url=https%253A%252F%252Fwww.google.com%252F

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[7] “IEEE Code of Ethics”. IEEE,

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