Electricity-Generating Device Retrofitted for Spin Bikes with Wall Outlet Plug Connected to Gym's Grid

ECE 445 Design Document

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Problem and Solution Overview:

Something we take for granted everyday is energy. There is energy consumed constantly in malls, offices, schools, vehicles, gyms, and more. The special thing about gyms is that there is almost always someone using the exercise machines like the elliptical, treadmill or bike. Now what if, along with losing those extra pounds, you can also generate some electricity using these machines? Our device is a straightforward and cheap alternative for gyms to have retrofitted spin bikes that generate electricity, and for the gym to save money by connecting the exercise bike to the gym's grid by simply plugging the device into the wall outlet.

Bike generators have been made in the past, however the difference from our project is the synchronization to the grid. Bike generators typically produce energy for a very specific and limited function like charging a battery, lighting up LEDs, etc, but having the bike's energy go to the gym's grid is something that will expand the range of what the generated electricity from the bike can be used for.

Visual Aid

Figure 1: Exercise bikes in a gym. Our device components are drawn in red
Original image source: "Upright Exercise Bikes for Commercial Gyms" from Life Fitness

1.3 High-Level Requirements

- **[Electricity Generating Efficiency]** Rider is able to generate at least 40W of electricity while pedaling exercise bike at moderate biking speed
- **[Grid Synchronization]** Power output from bike is able to synchronize to the gym's grid
- **[Metering Success]** Display is able to show current power being generated and total energy generated since the last reset

[Electricity Generating Efficiency]

The average biker can generate around 100W for about an hour on a bike [1]. Due to inefficiencies from harvesting this power, not all of the energy can be converted into electricity. The power consumption of a TV is usually 80-400W, and a typical 42 Inch LED TV consumes about 80W [2]. Based on these numbers, we want to verify that our efficiency is good enough by having one of our group members use the spin bike at a moderate speed for 1 minute and maintain a power output of at least 40W, which is half of the required power needed to run a low-power TV. This success can be verified with our display.

[Grid Synchronization]

The final bike output signal will be synchronized with the grid. That is, the frequency, voltage and phase of the signal must line up with the grid. The grid will be from an AC voltage generator and will be used as a reference for the bike output to match (we will not actually be plugging our device to the grid). The bike output signal will be measured to see if the two signals match.

Our bike would be considered a distributed energy resource (DER). IEEE 1547-2018 [3] is the IEEE standard for interconnections between DERs and the grid. The table below from the IEEE 1547-2018 shows the maximum difference in frequency, voltage and phase angle between our output and the grid. Our system would be rated less than 500 kVA, so the first row of the table below provides the corresponding requirements. Additionally, our system will be able to output up to 100 W at 120 Vrms ±10%.

Table 5—Synchronization parameter limits for synchronous interconnection to an EPS, or an energized Local EPS to an energized Area EPS

Aggregate rating of DER units (kVA)	Frequency difference (Δf, Hz)	Voltage difference (ΔV, %)	Phase angle difference ($\Delta\Phi$, °)
0–500	0.3	10	20
> 500–1 500	0.2	5	15
> 1 500	0.1	3	10

Table 1: Bike Output Requirements

[Metering Success]

This is based on our electricity-generating success in the first high level requirement (Electricity Generating Efficiency), but instead of biking for 1 minute, our group member will bike for two minutes. The display in Mode 1 will show the current power output during those 2 minutes, and after pressing the button which switches the display to Mode 2, the display will read at least 1 Wh (display outputs whole numbers). In addition, the total energy generated will reset to 0 when the button is held down for 2 seconds.

2.1 Block Diagram

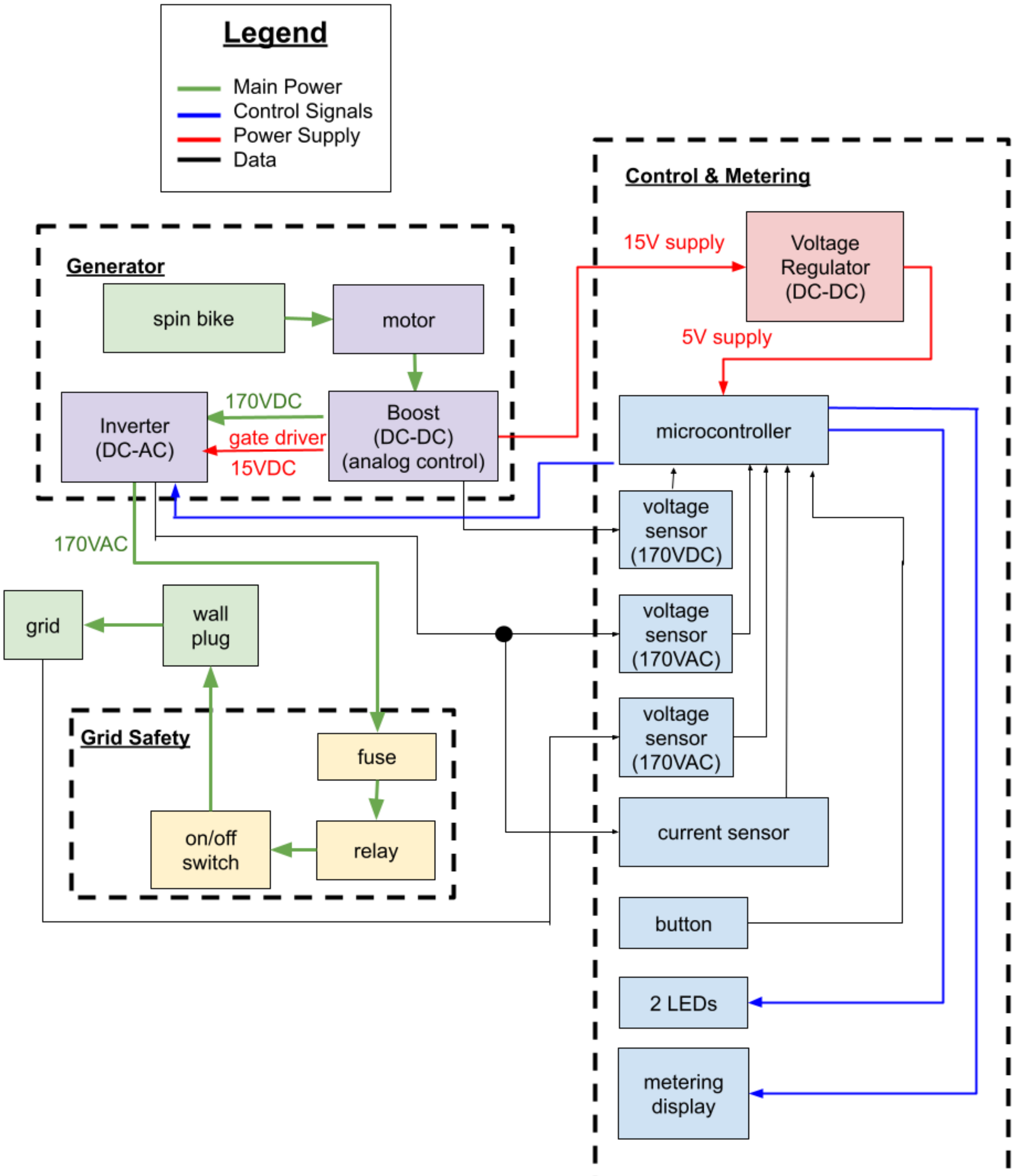

Figure 2: Block Diagram

2.2 Physical Design

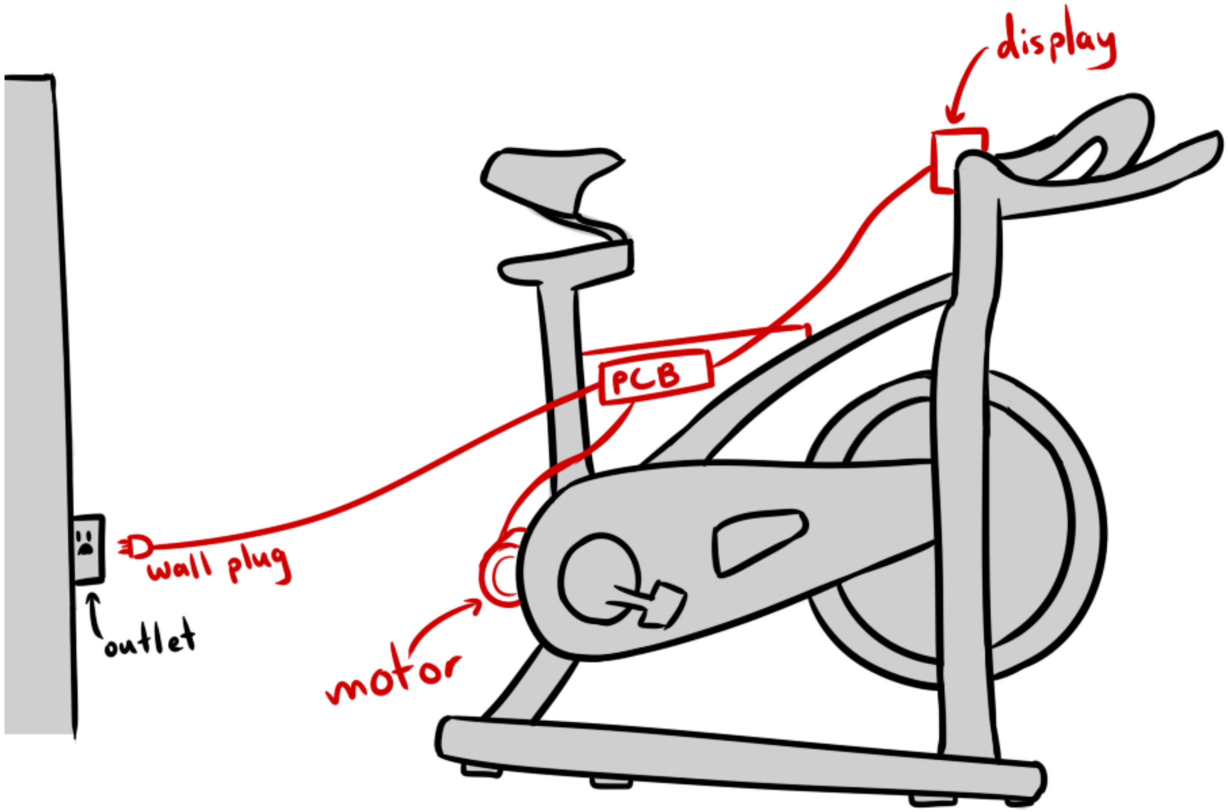

Figure 3: Drawing

The motor is attached to the back wheel of the bike. The PCB includes the microcontroller, relays, fuse, hex displays and LEDs. We are planning on having a connector to the hex display and LEDs so that we can place it in the front of the bike for easy access to the rider. Display includes the display, the button, and the two LEDs.

2.3 [External Interface Devices]

Grid (Simulated)

The bike generator will output power to the gym's grid. For testing, the bike will not actually connect to the power grid. Instead, the "grid" signal will be generated using a function generator, a sinusoidal signal of 60 Hz. Our device will be attached to this signal to sync up with it. See tolerance analysis for simulation results.

Wall plug

This will be the plug that connects the grid-synchronized power generated by the bike to the grid using the wall outlet. We will be using a generic wall plug that can run up to 5A.

2.4 [Generator]

Spin bike

For this project, we will need an exercise bike to attach our generating system to. In lab room 4026, there was already a bike available which we were given permission to use. It has the back open to allow the motor to be attached to the spinning wheel.

The spin exercise bike will be the source for generating electricity. A mechanical device will couple the flywheel of the bike to a motor.

Motor

There will be a motor attached to the wheel of the bike. The motor will start up once the person starts pedaling the bike. The motor is made of a spinning magnet within a coil of wire, and as the magnet spins, the electricity flows through the coil.

Output of the motor will have a diode in case the motor output wires are connected in reverse to the inverter.

Since the motor was already attached to the bike's wheel, we were able to characterize the motor and verify the power outputs. We tested out multiple loads and recorded the various voltage, current and power outputs. The overall voltage range for nominal speed was 20-30V. In a gym, people will be using the bikes at a greater speed than our test capabilities, so for safety cautions, we are staying within the 30-40V range.

	Voltage [V]	Current [A]	Power [W]
three 45**Ω** in parallel	30	3.4	103
two 45**Ω** in parallel	34	2.3	78
one 45**Ω**	40	0.9	37

Table 1: Characterization of Motor-- Maximum Experimental Values

Boost

The first part is the DC-DC converter. This is to help stabilize the voltage supply. It passes a current through a "switching element" such as a diode. Then it turns the signal into a square wave and passes it through another wave to change back into the DC signal. This will increase the voltage output of the motor to the nominal voltage of the grid. The DC-DC converter is necessary to boost the voltage up to 170V, the peak value of the final sinusoidal voltage output. [5]

A flyback topology was chosen due to the large difference between the minimum input voltage of 5V and the desired output voltage of 170V. The additional voltage gain from the transformer windings ratio helps us to manage the wide range of input voltages. A flyback topology also allows us to use a secondary output as a voltage supply for our gate drivers. This eliminates the need for any external batteries or voltage supplies.

However, there were some disadvantages found with the flyback topology. A snubber circuit is needed to demagnetize the transformer every switching cycle. This circuit will introduce losses to the system. The components may also need to be rated for high voltage as well. It was also difficult to find a transformer for the flyback converter. Many of the transformers are not made for dc-dc conversion or they were not rated high enough to handle 170V and 200W. The transformer chosen was a significant portion of our budget.

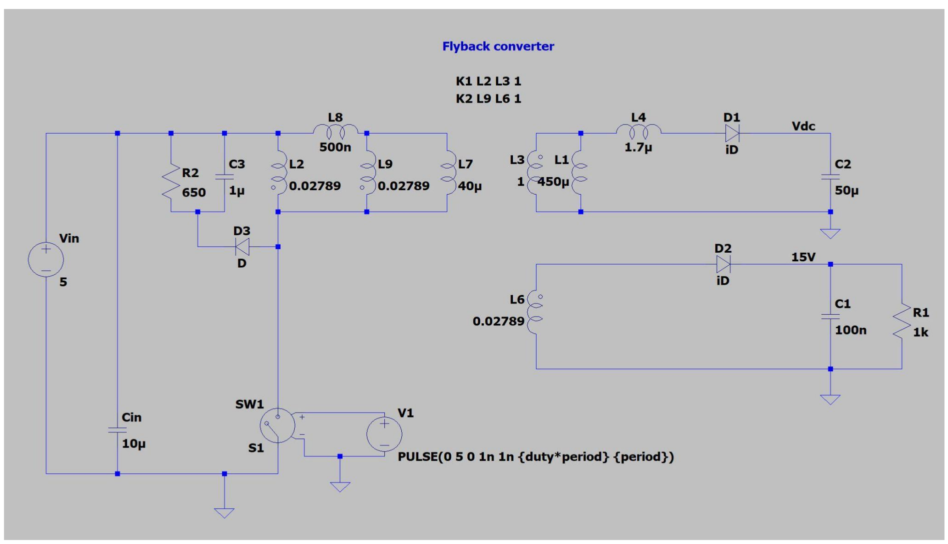

Figure 4: Flyback converter circuit

Requirements	Verifications
DC-DC converter must be able to output 170VDC ±5%.	(a) Connect a dc voltage supply to the input of the DC-DC converter.

	(b) Connect a 360 Ohm resistor across the output of the DC-DC converter. (c) Connect an oscilloscope to the output of the DC-DC converter. (d) Slowly sweep the voltage generator from 5VDC to 50VDC. (e) Verify that the DC-DC converter outputs 170V ±5%.
DC-DC converter must be able to output 80W while meeting the first requirement.	(a) Connect a dc voltage supply to the input of the DC-DC converter. (b) Connect a 360 Ohm resistor across the output of the DC-DC converter. (c) Connect the output of the DC-DC converter to a wattmeter. (d) Slowly sweep the voltage generator from 5VDC to 50VDC. (e) Verify that the DC-DC converter outputs 80W and the output voltage remains within ±5% of 170V.
DC-DC converter must generate a 15V ±5V supply for the voltage regulators.	(a) Connect a dc voltage supply to the input of the DC-DC converter. (b) Connect a 7.5 Ohm resistor across the output of the DC-DC converter. (c) Connect the output of the DC-DC converter to an oscilloscope (d) Slowly sweep the voltage generator from 5VDC to 50VDC. (e) Verify that the DC-DC converter outputs 15V ±5V for the entire input voltage range.

Inverter

The DC voltage generated by the motor needs to be converted to AC since the grid is an AC system. An inverter is used to convert our DC current to AC in order to connect to the grid.

We chose to use a PWM inverter instead of a resonant inverter. A resonant inverter would need a larger filter than a PWM inverter, so with our limited budget and space on the bike, we chose to use the PWM inverter. The duty cycle is varied sinusoidally and the output inductor filters the output so the output voltage is also approximately sinusoidal. In order to limit distortion of the output voltage, a fairly large inductor is needed for the filter.

One other consideration for the inverter is the sizing of the capacitors linking the flyback converter to the inverter. The dc voltage could potentially droop without capacitors to stabilize it while the inverter is operating. The capacitors ensure the voltage stays approximately constant and the peak of the output of the inverter is the desired voltage level.

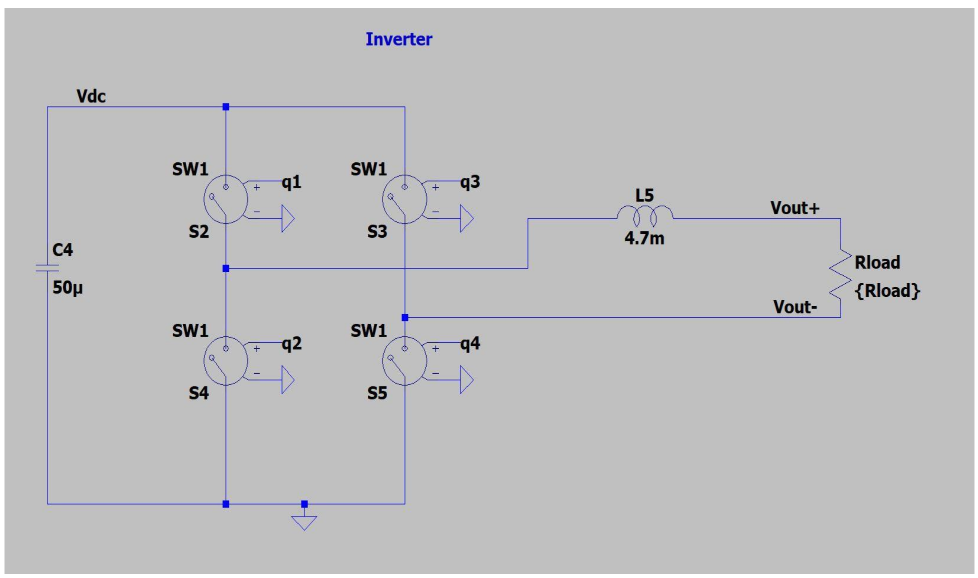

Figure 5: Inverter circuit

Requirements	Verifications
Inverter must be able to output 50/√2 Vrms ±10% with a power factor of 0.7 or greater.	(a) Connect a voltage generator to the input of the inverter. (b) Connect a differential voltage probe to the output of the inverter and to the oscilloscope. (c) Connect a voltage probe across the

	input of the inverter and the output of the inverter to the oscilloscope. (d) Place a current probe around the wire from the voltage supply to the input of the inverter to measure the input current. Connect the probe to the oscilloscope. (c) Create a 50VDC signal from the voltage generator. (d) Verify that inverter output is 50/√2 Vrms ±10%. (e) Calculate the average input power from the input voltage current measurements on the oscilloscope. (f) Confirm the power factor is greater than 0.7.
Output voltage frequency must be able to synchronize to an external sinusoidal signal's frequency within ±10% and have no more than a 20° phase angle between the two.	(a) Connect a voltage generator to the grid voltage sensor. Connect another voltage generator to the input of the inverter. Connect both voltage generators to the oscilloscope. (b) Connect an oscilloscope to the output of the inverter. (c) With the voltage generator connected to the grid voltage sensor, create a 50VAC 60 Hz signal. With the voltage generator connected to the input of the inverter, create a 50VDC signal. (d) After 10 seconds or more (see Microcontroller Requirements and Verifications table), freeze the oscilloscope measurement. Measure the phase difference between the grid signal and the output of the inverter using the oscilloscope. (d) Verify that the inverter output's frequency is within ±10% and has no

	more than a 20° phase angle compared to the AC voltage generator's signal.

Figure 6: LTSpice simulation of inverter

The flyback converter was connected to the inverter in LTSpice, and the above waveform was the output voltage. The output is approximately sinusoidal with a peak value of 170V.

2.5 [Grid Safety]

Fuse

The fuse will supply feedback protection in case a dangerous amount of power is received from the grid, which could be caused due to a fault in a component. We decided to not use a surface mount fuse in the event that something goes wrong with our testing. We wouldn't want our fuse to keep getting blown and having to re-solder it to our board. This is why we decided to get a cylinder fuse holder which has a current rating of 10A. This is a greater current rating than we need however since it is just the fuse holder we want it to be greater and are looking at the current rating of the fuse. For the actual fuse we decided on using a slow-blow fuse with a current rating of 3A. We decided on a slow-blow fuse since generally when you start up a motor there will be a high current of electricity passed through the circuit and we do not want our fuses to get blown [6]. Once the current of our circuit gets greater than 3A our fuse will open and disconnect the circuit.

Relay

The relay will be connected to the grid as an additional safety measure. If there is no power being generated, this will disconnect the device from the grid. We will be using a general purpose relay with a current rating of 6A and a switching voltage with max 400VAC. Our relay coil type will be non-latching. Since our system will not be in danger when no one is using the exercise bike, it is ok for the relay to return to its NC state. Therefore a non-latching relay will be suitable for our design. So when the bike is not generating any electricity the relay will disconnect the generator subsystem from the grid within 2 seconds.

Requirements	Verifications
The relay disconnects the grid from our device after 2 seconds of inactivity of the bike.	(a) Connect an ammeter between the wall plug and the on-off switch. (b) Start biking. Check that the ammeter value is nonzero while biking. (c) Open a count-up timer app on the phone. (d) Stop biking. Start the count-up timer. Verify that the ammeter measurement goes to 0 within 2 seconds.

On/Off Switch

This will be used to manually disconnect the device from the grid. We want to be able to disconnect the circuit for safety reasons. If someone is working on the grid, we do not want to be outputting power, potentially endangering the worker. For this, we will be using a simple toggle switch with a current rating of 5A. When the switch is turned off, the device must disconnect.

2.6 [Control & Sensors]

Microcontroller

The microcontroller will be the ATmega16U4. The microcontroller will include the PLL (phase locked loop) algorithm for grid synchronization. See other subsystem parts in this section (2.2.4 Controls & Sensors) for more information on what the microcontroller is being used to do. We decided on the ATmega16U4 instead of the ATmega328 because while we were designing our PCB there were a significant amount of pins we would need from the microcontroller.

Requirements	Verifications
The microcontroller is able to generate a PWM signal with a sinusoidal varying duty cycle to drive the inverter switches.	(a) Switch the PCB into test mode. (b) Connect a 15VDC voltage supply to the input of the voltage regulator. (c) Connect a probe to the test point monitoring the output of the microcontroller. (d) Verify the microcontroller generates a PWM signal with a sinusoidal varying duty cycle.
The microcontroller outputs the correct signal for the 4-digit 7-segment pins.	(a) Create code that cycles through a list of numbers 0000, 1111, 2222, … 9999 every second. The code cycles through the list and outputs it to the display. (b) Verify that the display cycles through 0000, 1111, 2222, …, 9999, 0000, 1111… continuously.
The microcontroller's red LED output pin is high when in Mode 1 and off in Mode 2, and the blue LED output pin is high when in Mode 2 and off in Mode 1.	(a) Press the button (less than 2 seconds) repeatedly. (b) Verify that the red LED and blue LED pins toggle from being high and low after each button press.

Voltage Sensors

Five voltage sensors will be needed. Four voltage sensors will be used to sense the output voltages (V+ and V-) of the inverter and grid voltage for voltage control. The fifth voltage sensor will be used to check the DC-DC voltage output. The grid's voltage is input into the PLL algorithm which will sync our output voltage to the grid.

We will not use the same voltage sensor circuitry for all three of the voltage sensors. The DC motor voltage will be measured with a voltage divider, and the AC voltages will be measured with a combination of a voltage divider, a level-shifter op-amp, and a differential voltage op-amp.

For the DC voltage sensor, we will use a voltage divider to get the expected voltage of 170V, and scale down the voltage range to 5V.

The voltage divider will look like this:

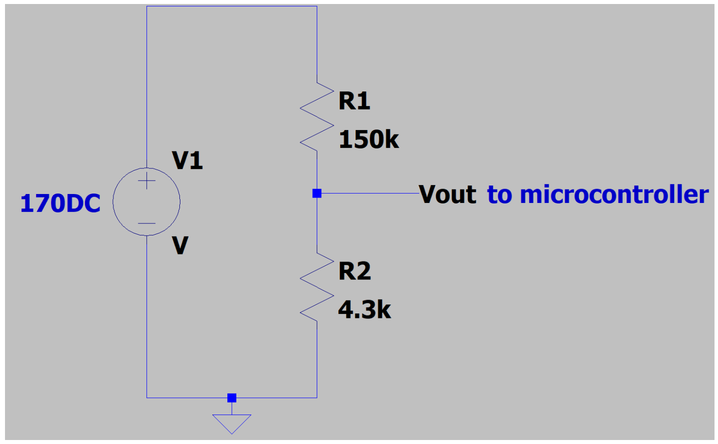

Figure 7: Voltage Divider 170V to 5V

The resistors we plan to use are rated 0.25W with +/-1% tolerance, where R1 = 150 kOhm and R2 = 4.3 kOhm. This maps to the range of 0V to 4.7V. At exactly the R1 and R2 values, the total power dissipated is 187 mW (PR_1 = 182 mW and PR_2 = 5.22 mW). The resistor values can vary up to +/-1%, and the maximum |Vout| occurs at R1 = 148.5 kOhm and R2 = 4.343 kOhm, resulting in 4.83 V. This still fits within the Vout range goal of 0V to 5V.

For the AC voltage sensor, the differential voltage op-amp is needed because the outputs of the inverter and grid are not with respect to ground-- that is, the output voltage is the difference between two voltages. This must be converted to a voltage reading with respect to ground for the microcontroller. The microcontroller that we are using, the ATmega16U4, cannot measure negative voltages.

Below (after the figure) are the steps of the AC voltage sensor. V+ is a 60Hz sinusoidal signal ranging from 0V to 170V (green signal). V- is a 60Hz square wave ranging from 0V to 170V (red signal). See the figure below.

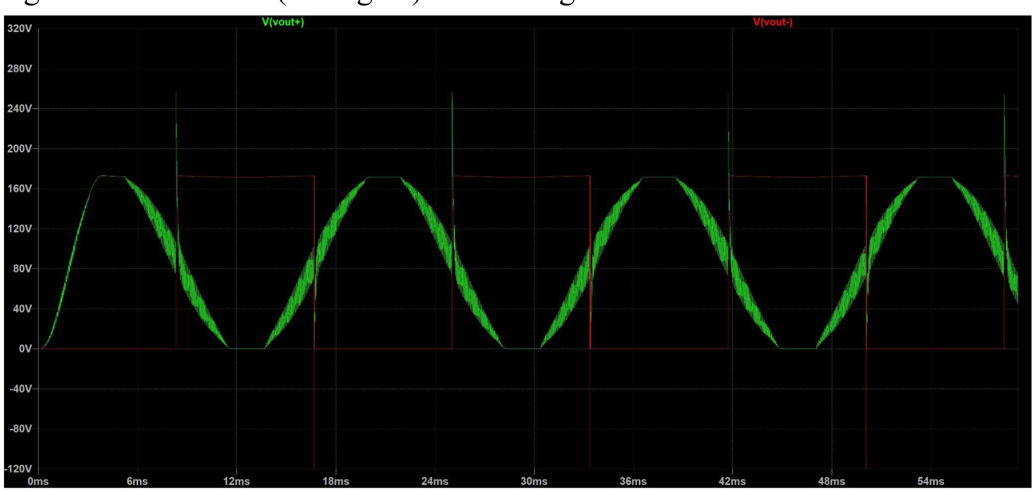

Figure 8: V+(green) plotted with V-(red)

- Step 1: [Voltage Divider] Scale down the magnitude of V+ and V- to a range of 0 to 170V.

- Step 2: [Level-Shifting Op-Amp] Level-shift V+ by 2V so that the range of V+ is now 2V to 4V.
- Step 3: [Differential Op-Amp] Subtract V- from V+ to obtain the scaled-down sinusoidal signal of the inverter/grid output. The inverter/grid output is -170V to 170V, and this final step maps the signal to a 0V to 4V signal.

The reason why we did not map the 170VAC signal to a 0V to 5V signal is because the op-amps are non-ideal and the supply voltage is 5V, so the op-amp cuts off and loses information at slightly below 5V.

Step 1: Voltage divider (4x)

The resistors we plan to use are rated 0.25W with +/-1% tolerance, where R1 = 150 kOhm and R2 = 1.74 kOhm. This maps the 0V to 170V to the range of 1V to 1.95V. At exactly the R1 and R2 values, the total power dissipated is 190.2 mW (PR_1 = 188 mW and PR_2 = 2.20 mW).

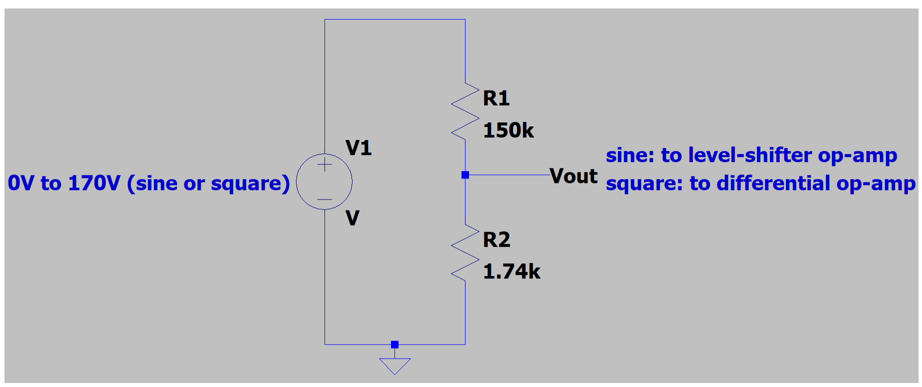

Figure 9: Voltage Divider 0-170V to 0-2V

Step 2: Level-Shifting Op-Amp (2x)

The level-shifting circuit resistances are based on an online calculator [7]. It shifts the V+ signals up by +2V.

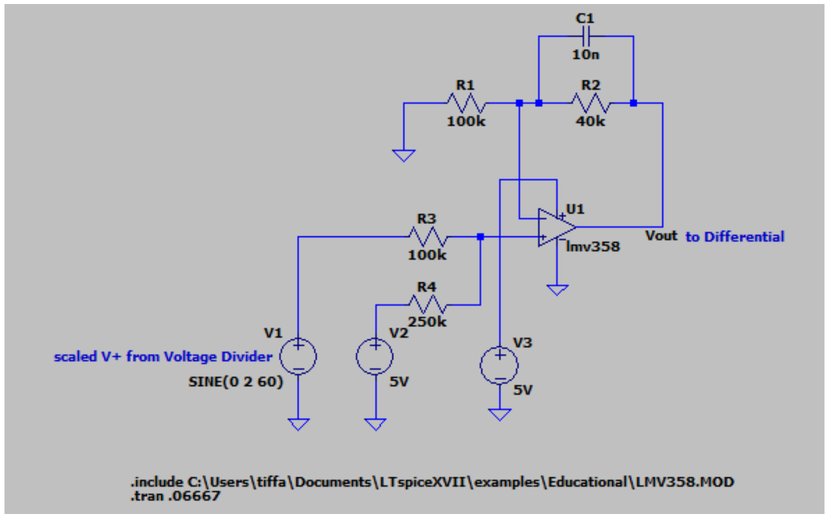

Figure 10: Level-Shifting Op-Amp +2V

Step 3: Differential Op-Amp

The differential op-amp design was based on the information in this website [8].

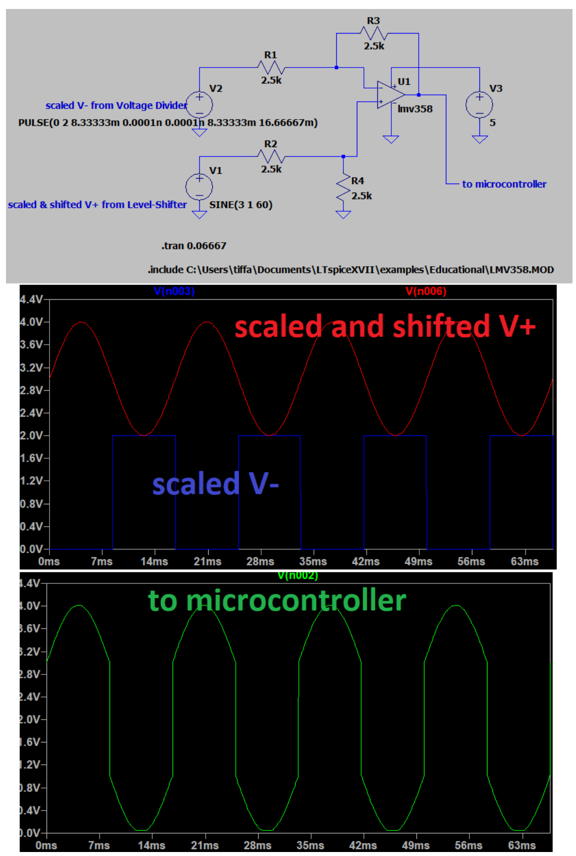

Figure 11: Differential Op-Amp and Input/Output Signals

Requirements	Verifications

Must be able to measure voltage with an accuracy of ±2%.	(a) Create the sinusoidal AC signal (120 Vrms, 60 Hz) using a voltage generator. Connect this to the input of the voltage sensor (voltage divider). (b) Attach the positive oscilloscope probe to the output of the op-amp circuit, and the negative probe to GND. (c) Verify that the high peak of the sinusoidal output signal is 550mV ±2% and the low peak is 4.55V ±2%.

Current Sensor

The current sensor's information will be used to measure the amount of electricity generated. It will measure the AC current information being sent to the grid, and this sensor will be connected to an analog input pin on the microcontroller.

The current sensor must handle up to at least 4A (peak) AC current. This is based on the inverter output requirements of up to 200W at 120 Vrms ± 10% with a power factor $\geq$ 0.7. The apparent power S associated with 200W at PF = 0.7 is 285.7 VA. We want to handle the maximum apparent power, and S = Vrms*Irms. With Vrms ranging from 108V to 132V, this results in Irms = 2.16A to 2.64. This means that the maximum of Ipeak is 2.06*sqrt(2) = 3.73 A, which is approximately 4A.

Requirements	Verifications
Current measurements displayed on the Arduino output window must match a reference ammeter measurement within ±5%.	(a) Attach an ammeter between the connection to the on/off switch and the connection to the wall plug. (b) Physically place the ammeter display and the Arduino current measurement window next to each other. (c) Start recording a phone video of the two measurements. (d) Have someone start biking on the spin bike for 1 minute. (e) Look back at the video footage, and take a data point approximately every 10 seconds in the video footage of the

	ammeter display measurements and the Arduino’s measurements. (f) Verify that the bike current measurement is within ±5% of the ammeter’s measurement.

Display, Button, LEDs

The display switches modes when the button is pressed. Mode 1 is when the display shows the current power that is being output to the grid. Mode 2 is when the display shows the total energy generated since the total was reset. Holding down the button for 2 seconds resets the total energy generated to 0. This resets function only works when the display is in Mode 2.

In the case that the display is in Mode 2, the button has been held down for 2 or more seconds but has not been released, and someone starts biking, the display will keep the measurement being displayed at 0 Wh.

Both values are updated every second. In addition, the display will show the numbers as integers (no decimal points). The measurement in Mode 1 will be in W (Watts), and the measurement in Mode 2 will be in Wh (Watt-hours). The measurements will be truncated.

Two LEDs will be used to signal whether the display is in Mode 1 or in Mode 2. Red to represent Mode 1 and blue to represent Mode 2.

The display that will be used is a cathode 4-digit 7-segment display. This reference [9] was used for the wiring of the display.

Requirements	Verifications
Pressing the button for less than 2 seconds will switch modes. The red LED is on and the blue LED is off when the display is in Mode 1. The blue LED is on and the red LED is off when the display is in Mode 2. In Mode 2, holding down the button for 2 seconds resets the display to 0. In Mode 2, holding down the button for 2 or more seconds and biking will keep the display at 0.	(a) Have the display be at Mode 2. The blue LED should be on. (b) Start biking until the display shows that the energy generated is larger than 0. Remember this value for step (d). (c) Stop biking. Press the button (for less than 2 seconds). Verify that the display changes to 0, the red LED turns on, and the blue LED turns off. (d) Press the button again (for less than 2 seconds). Verify that the display changes

	from 0 to the value at the end of step (b), the blue LED turns on, and the red LED turns off. (e) Pull out a phone app count-up timer. (e) Start holding the button down, and simultaneously start the phone app count-up timer. Verify that the display resets to 0 when the phone app reaches 2 seconds. (f) Keep holding down the button and start biking. Bike for 1 minute, and verify that the display stays at 0.

Voltage Regulators

The voltage regulator changes the 15VDC output from the boost's internal voltage regulator to 5V. The 5V will be used to power the microcontroller. The microcontroller has an operating voltage of 1.8 - 5.5V [10].

Requirements	Verifications
Must regulate a voltage of 5±0.5V.	(a) Attach a voltmeter with the positive end to the Vcc pin on the microcontroller, and the negative end to GND. (b) Start biking. (c) Verify that the voltmeter measurement is 5±0.5V.

Schematic

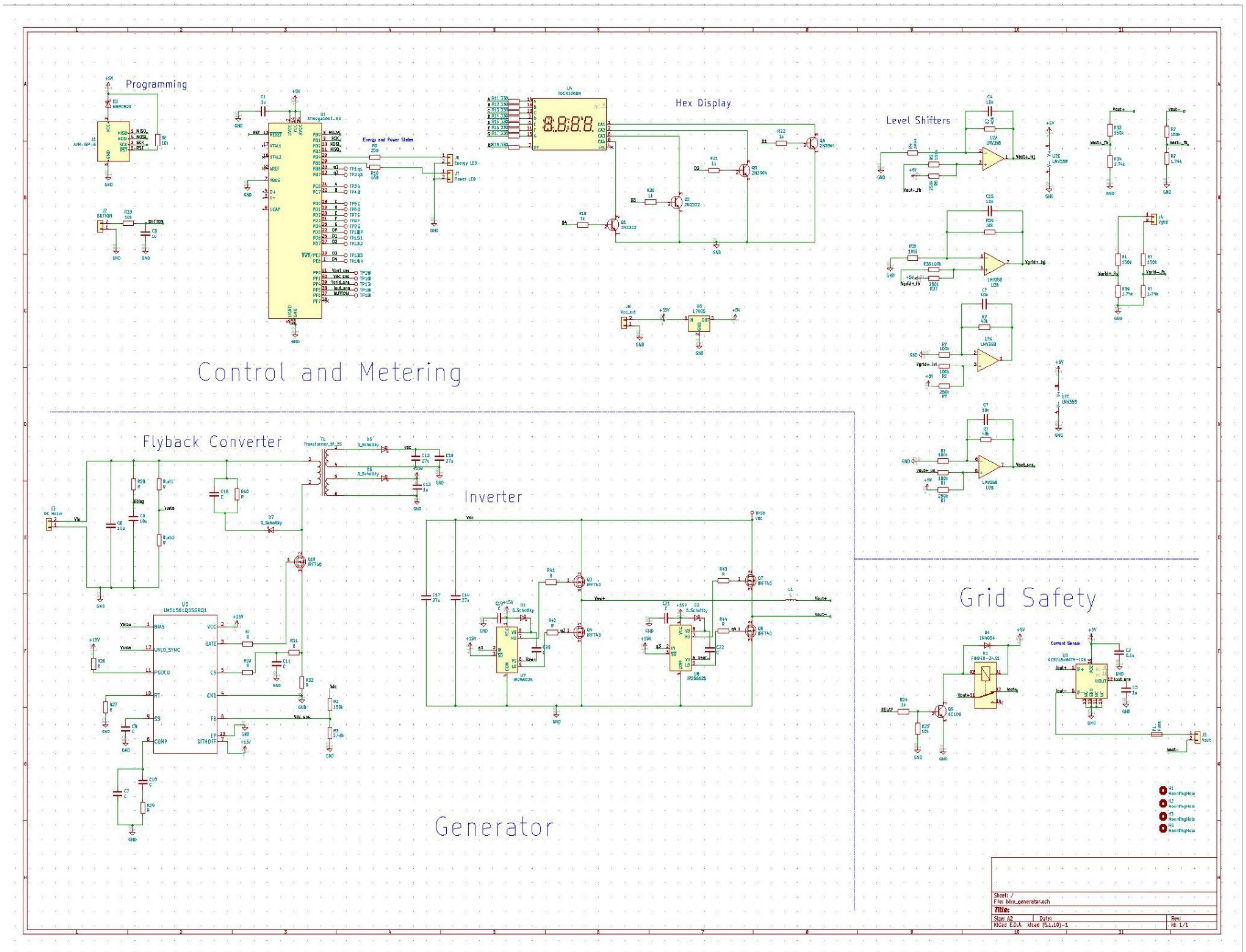

Figure 12 : Overall Schematic of our Circuits

2.7 Tolerance Analysis

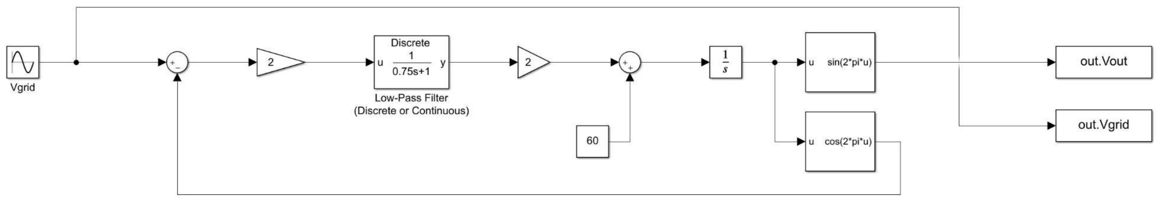

Figure 13: General block diagram of PLL algorithm

Synchronization with grid:

The main issue we will run into for this project is being able to check if the electricity generated by the bike will be able to safely synchronize into a gym's distribution system. Due to safety concerns, instead of directly connecting to the grid, we need some kind of way to test our synchronization. We will need to create a mock setup to simulate the grid. Some problems could arise since we need to figure out an algorithm for the simulation which may or may not accurately reflect the behavior of the real grid.

To initially test the feasibility of synchronization, we created a block diagram of the control in Simulink, as seen in Fig. 13. The control algorithm can be broken up into three main parts.[11] There is a phase detector which compares the phase of the reference sine wave to our output sine wave. Some error is generated and passed through a low pass filter to reject noise. Then the error is input to a voltage controlled oscillator where it adjusts the frequency of the output sine wave in comparison to an initial frequency set. Finally, the voltage controlled oscillator integrates the frequency, resulting in the final output sine wave. The derivative of the sine wave is the feedback to the phase detector. As this adjustment process continues over time, the two sine waves should come together and lock phases.

The results of the simulation can also be seen in Fig. 14. The grid voltage and inverter output voltage waveforms begin out of phase, but converge within one second. In steady-state, there is a difference of 0.5 ms between the zero crossings of the two waveforms, which converts to a phase shift of 10.8°. This is within the limit set by IEEE 1547, so we believe we can achieve this goal of synchronization.

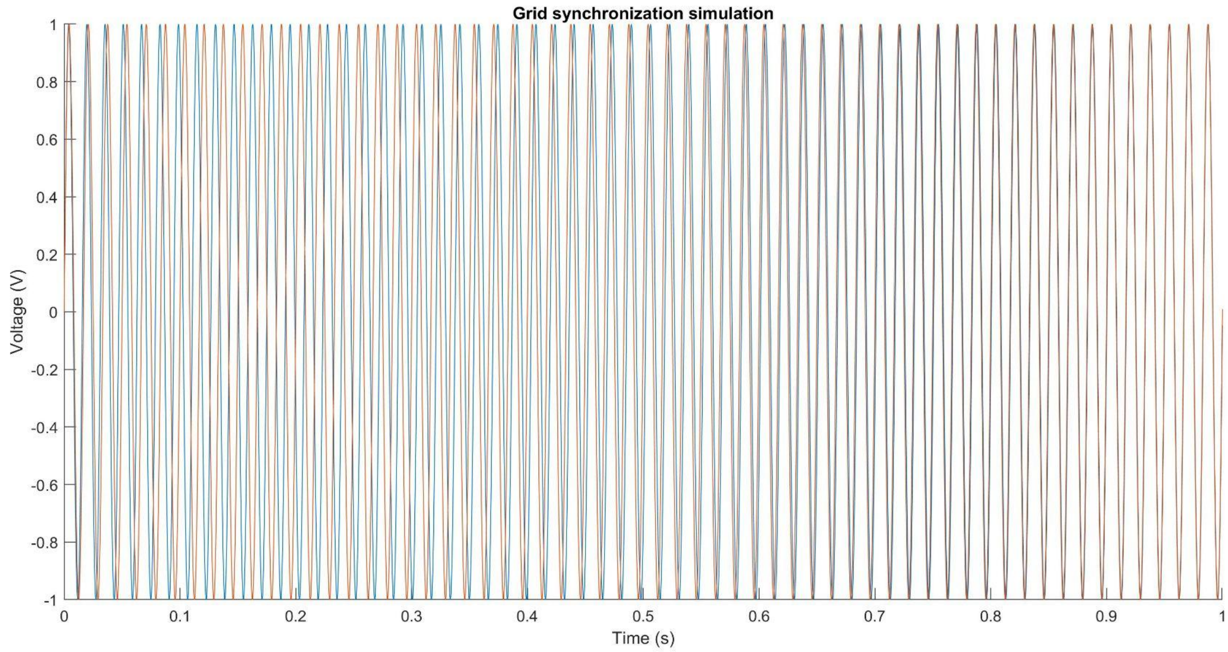

Figure 14: Grid Voltage and Output Voltage synchronization

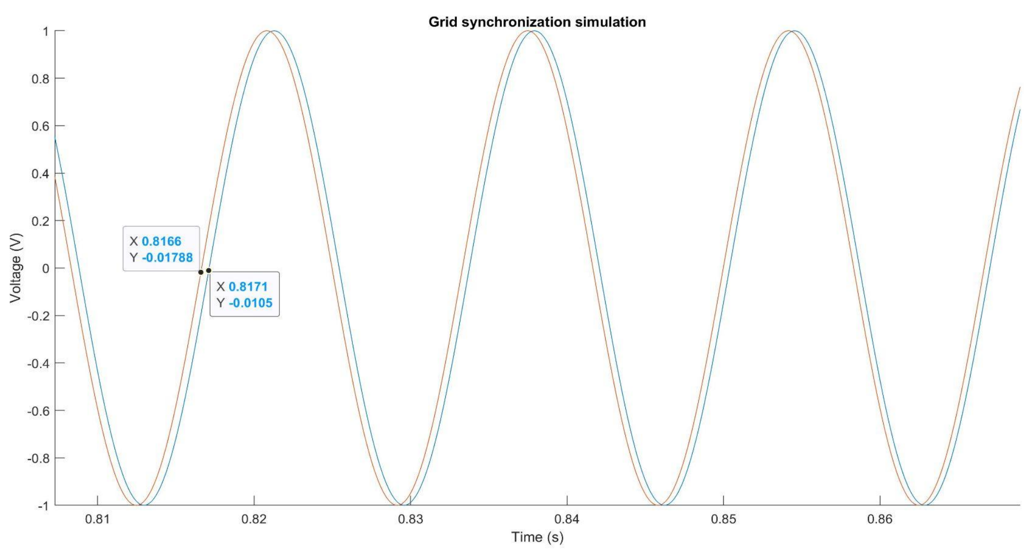

Figure 15: Phase difference between grid and output voltage simulation

3 Cost and Schedule

3.1 Cost Analysis:

Part	Manufacturer	Part Number	Quan-tity	Unit Cost
Red 7-segment display	Vishay Semiconductor Opto Division	TDCR1060M	x1	$2.60
Microcontroller	Microchip Technology	ATMEGA16U4-AUR	x1	$5.18
Op-amp	Texas Instruments	LMV358QDDUR	x1	$0.93
150kOhm resistor	Stackpole Electronics Inc	RMCF1206FT150K	x3	$0.10
4.3kOhm resistor	YAGEO	RC1206FR-074K3L	x3	$0.10
2.49kOhm resistor	Bourns Inc.	CR1206-FX-2491ELF	x3	$0.10
Current Sensor	Allegro MicroSystems	ACS718KMATR-10B-T	x1	$4.87
Transistor	NTE Electronics, Inc	2N2222	x4	$0.63
Fuse	OptiFuse	2298-TCC-3A-ND	x1	$2.74
Fuse holder	Eaton - Electronics Division	PCB FUSE HOLDERS FOR 5 X 20MM FU	x1	$4.32
Relay	Finder Relays, Inc.	34.51.7.024.0010	x1	$6.67
Toggle switch	CIT Relay and Switch	ANT11SEBQE	x1	$1.66
Wall plug	Leviton	3W101-00E	x1	$2.98
Motor	Yaskawa Electronics	P12H-DB11	x1	~$45
Spin bike	N/A	N/A	x1	~$200
Boost Controller	Texas Instruments	LM5156HPWPR	x1	$2.28
Flyback Transformer	Vishay Dale	MTPL-2516-S12V	x1	$17.00
5V voltage regulator	Micro Commercial Co	MC7805CT-BP	x2	$0.46
Switching MOSFETs (400V)	STMicroelectronics	STP7NK40Z	x8	$1.63
Half-bridge driver	Infineon Technologies	IR25602STRPBF	x3	$0.97
Second flyback transformer	Würth Elektronik	750315126	x1	$3.28
Inverter output inductor	EPCOS - TDK Electronics	B82724J8482N040	x1	$5.95
DC link capacitors	United Chemi-Con	EKXJ401ELL270MJ30S	x5	$1.34
Schottky diodes (600V)	SMC Diode Solutions	SK2C0A	x2	$0.23
Electrolytic capacitor (10uF)	Nichicon	UPS2A100MED1TA	x1	$0.43
Filter capacitor (1uF)	Würth Elektronik	860020672005	x1	$0.10

Machine Shop:
This project will take them about 20 hours. According to UIUC's machine shop website, the average cost is $36.65/hr plus materials[12].
Total machine shop cost is 20hr x $36.65/hr = $733

Average salary of ece graduate is $79,714/year [13]
Average person works 2080 hours for full-time per year
$79714/2080 = $38.32/hr
$38.32/hr x 2.5 x 90hr = $8,622 per person
Total Labor cost: $8,622 x 3 = $25,866
Total Project Cost: Parts + Machine Shop + Labor = $333.14 + $733 + $25,866 = $26,932.14

3.2 Schedule:

Week	Elisa	Raihana	Tiffany
10/4	Finalize PCB design	Prepare for Design Review/order parts	Prepare for Design Review/order parts
10/11	Solder PCB	Solder PCB	Solder PCB
10/18	Work on PLL for microcontroller	Work on SPI for microcontroller	Work on SPI for microcontroller
10/25	Unit test boost converter	Unit test safety and display	Unit test voltage sensors
11/1	Debug PCB	Debug Hex Display	Debug Microcontroller
11/8	Test Generator	Test Grid Safety and Metering	Test Control and Metering
11/15	Test complete system	Test complete system	Test complete system
11/22	BREAK	BREAK	BREAK
11/29	Work on final presentation	Work on final presentation	Work on final presentation
12/6	Work on final paper	Work on final paper	Work on final paper

4 Ethics and Safety:

Section 1.1 of IEEE code of conduct states that we must "hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment." [14] The rule applies to the project since it will be dealing with high voltages and synchronization with the grid.

One of the dangers to this project is the high voltage and power. In order to account for this, there will be several safety features in case of power surges, overheating, and loss of voltage regulation. The main safety features will be the fuse and relay. If there is too much power received from the grid, the fuse will break the circuit. The other safety feature will be the relay. If something goes wrong with the connection to the grid, the relay will open the circuit. In addition, there will be an on/off switch to manually cut the device's connection with the grid.

The other issue we may run into is when we are synchronizing to the grid. If our frequency does not match, it might damage the gym's grid. This would affect the welfare of the people in the gym. Since the power we are generating is not large enough to do significant disruption to the grid, this issue will most likely not be our concern. If any issues were to arise, we have multiple safety measures to turn off our power connection.

Another issue we did not account for is protecting our circuit from someone putting in a battery with the wrong polarity. Since we are not using a battery, we did not worry about this. However, someone might have the same problem when trying to connect the motor if they put in the wires the wrong way. In order to protect our circuit if an issue like this occurs, we will put in a diode at the output of the motor. When the cathode of the diode is larger than the anode the diode will simply separate the power supply from the rest of our circuit [15].

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