EduGRID MicroGrid Demonstrator Design Document

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1. Introduction

The complexity of power grid protection and the role that power engineers play in designing it is not well supported or introduced in early education. Even within universities, grid infrastructure design and methods of protection for our grid is a subject where many students go through their whole educational careers without learning.

We propose a solution to this gap in education by creating a product aimed at all levels of education that give students varying levels of complex grid-scale problem solving opportunities. All of this will be achieved within a single tabletop package that provides numerous fault clearing objectives of increasing difficulty for the student, allowing for an intuitive hands-on approach to learn about the broad range of risks and corrective measures for our grid.

1.1 Problem

Students often have limited understanding of how the electric power grid is designed to stay safe and reliable, especially the protection systems, breakers, relays, and fault isolation methods that prevent small failures from becoming large outages. Because these concepts are not taught in a fun and accessible way, many students do not see what power engineers actually do or why the field matters, which can reduce interest in pursuing power and energy careers. Recent large scale outages, such as the winter storm related failures experienced in Texas, show how grid reliability, planning, and protection directly affect daily life and the safety of the public, highlighting the need for clear, hands-on educational tool.

1.2 Solution

Our product will include an interactable tabletop power grid that allows the user to see the flow of power from source to load, all while having access to switches and controls that aim to isolate faults, correct the power factor, understand automatic protection, stabilize grid frequency, and visualize the flow of power on our grid. Our system will simulate fault scenarios that occur in real world power grids, such as feeder short circuits, ground faults from vegetation contact, and arc faults at substations, and guide the user through the correct isolation and restoration steps. Our system will accomplish this by utilizing both a microcontroller-based state machine system as well as an on board display screen, rotary encoder, status LEDs, sound emitting device, and capacitive/inductive component recognition for power factor correction.

Users will be able to choose from multiple capacitor and inductor values to achieve the desired power factor correction. Our PCB will identify the selected component's magnitude using DC based RC and RL time constant circuits to measure the time it takes for the voltage across a known resistor to reach the 63.2% threshold. This time constant, tau, will be used by our simulated model to solve for the capacitive/inductive value added to the board. The microcontroller will then mathematically compute the expected power factor correction using a predefined target value. Based on this calculation, it will determine whether the chosen capacitor/inductor value is correct and present the result on the display. The user will see a message that reads: "meets target," "Increase C / Decrease L," or "Decrease C / Increase L". Additionally, our system will contain energy consumers/loads, such as family homes or factories, and we are going to model energy sources, such as a solar farm, nuclear plant, and a natural gas turbine plant. The system will react to the loads and sources in order to determine and display the simulated frequency of the grid. Our simulation state machine will also store breaker statuses, fault states and status, as well as LED states and clear fault logic conditions. Both the software and hardware systems will provide students with an intuitive and engaging tool to learn more about the important role of power engineers.

1.3 Visual Aid

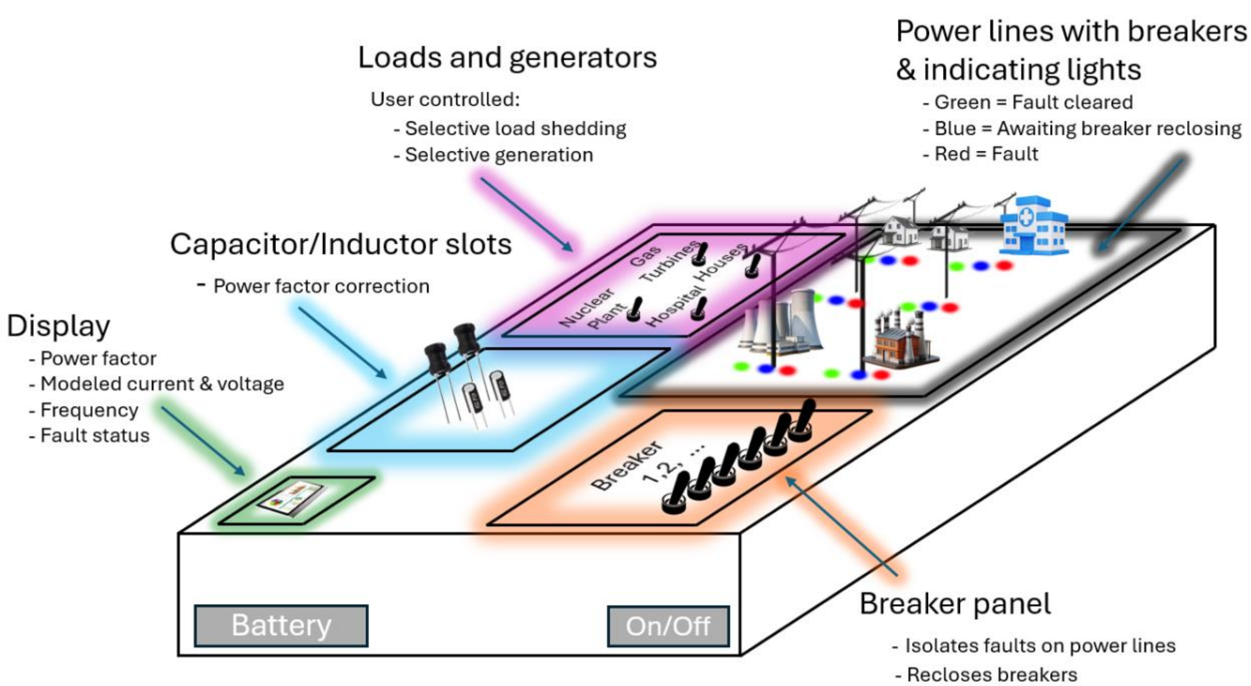

Figure 1: EduGrid Board Visual Aid

1.4 High Level Requirements

1. The user can select and clear the five available fault scenarios (permanent faults, transient faults, power factor correct, load shedding, selective generation).
2. The on-board display shows the relevant information for each fault scenario (power factor current state and target, frequency, voltage, and current simulation values).
3. The user input capacitance and inductance values are accurately computed and displayed on the on-board screen.

2 Design

There were many alternatives possible for the design of this product. A few that we considered included a fully stepped down AC system relying on real time voltage and current measurements on multiple parts of the board to inject faults, check for cleared states, provide power factor correction measurements, and real time frequency monitoring. Another alternative was to create a software defined grid model that takes user input on buttons and components to update the model simulation and reflect changes to fault status visually. We chose to create a middle ground that involves a full DC based microgrid system that will include hardware and software defined solutions.

The hardware defined systems within the PCB will measure and compute the RC/RL time constant from user input capacitance and inductance through RL/RC circuit, OLED display of state-relevant grid quantities, and MOSFET logic to drive the buzzer system, LEDs, and current controlled rails. The software defined systems include our grid simulated measurements of voltage, current, frequency, load balancing, and power factor triangle.

2.1 Block Diagram

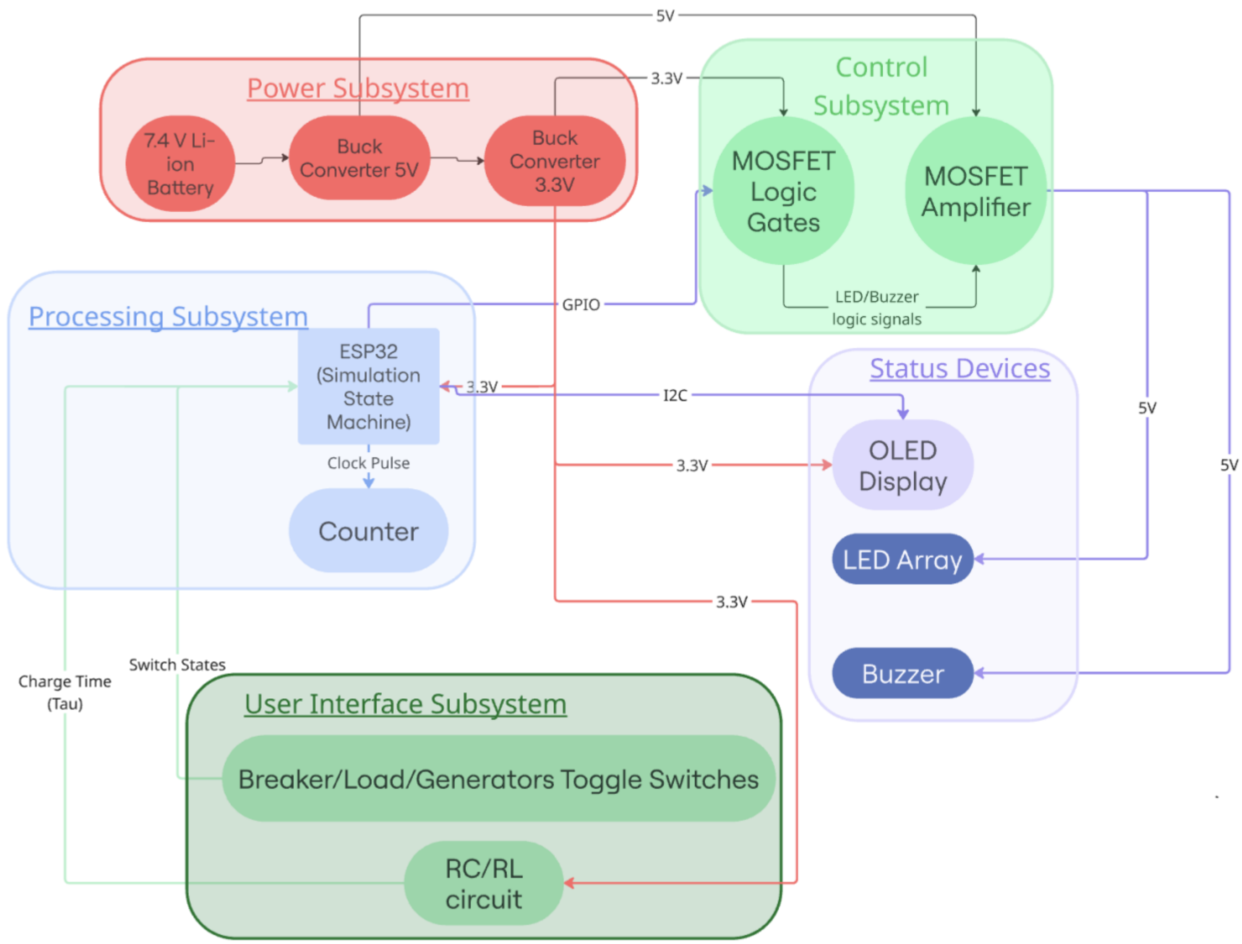

Figure 2: Block Diagram

2.1.1 Block Diagram Subsystems

2.1.1.1 Power Subsystem

The power subsystem handles power distribution and DC/DC regulation. It provides stable regulated power rails for every subsystem. This allows the ESP32-S3, display, LEDs, noise devices, and indicators to operate reliably. This subsystem converts the main input supply of 6 AA batteries connected in series with a nominal voltage of 9V into a clean 5 V rail and a clean 3.3 V rail, with protection and power indication.

2.1.1.2 Control Subsystem

The control subsystem contains the MOSFETS used for both low level logic control as well as the current amplification to drive the buzzer and bulk LED array. This ensures that the ESP32 does not experience any brownouts due to excess current draw. This subsystem communicates to the status devices subsystem to both drive the high current for the LEDs as well as to provide the buzzer component with the required voltage to sound only when the user has made a mistake in each fault scenario.

2.1.1.3 Processing Subsystem

The processing subsystem acts as the brain of the system, storing the simulation's electrical values, feeder states, fault type, phase angle, impedance, simulated feeder IV measurements, display text, and breaker status. It drives the control subsystem for MOSFET-based LED switching and the status display subsystem for the OLED, which shows feeder voltage, current, and power factor based on physically added capacitance or inductance on the board.

2.1.1.4 Status Devices

The Status Devices Subsystem contains the small OLED display, the LED array, and the Buzzer. This subsystem is used to display all of the important information of the simulation. The LED array will be used to display which power lines are active or dead. the OLED display will show information such as the Power Factor, voltage, and progress and status information about the user's progress in the current level. The Buzzer will play when the demo begins, the user makes correct moves or mistakes, and when the user completes the demo successfully.

2.1.1.5 User Interface Subsystem

User Interface Subsystem is comprised of parts of the board that are controlled by the user. These include: the Capacitors and Inductors the user chooses for power factor correction, breakers the user has to trip in order to separate faulty loads from sources, generator toggle switches that the user can decide to cut from the system in order to balance the power/frequency of the simulated grid.

2.2 Subsystem Requirements

2.2.1 Power Subsystem

The Power Subsystem converts the input from a six-cell AA battery pack into two independent regulated rails, +5.0 V and +3.3 V, used by the rest of the system. The battery pack is treated as a portable DC source with an operating input range of 6.0 V to 9.6 V and a nominal voltage of 9.0 V. To improve efficiency and isolate sensitive logic from higher-current loads, the subsystem uses two parallel TPS54202 buck converters, each connected directly to the battery input, rather than deriving the 3.3 V rail from the 5 V rail. The +5.0 V rail supplies the LED power stages, buzzer, and any 5 V peripherals, while the +3.3 V rail supplies the ESP32-S3, Display, and all control circuitry. This model reduces unnecessary conversion loss, prevents the processing subsystem from depending on the 5 V rail for regulation, and improves stability during transient load events such as simultaneous LED switching and activity on the ESP32-S3. The 5 V converter includes an enable-divider-based undervoltage setup so it disables when the battery is too low to regulate 5 V reliably, while the 3.3 V converter enable pin is tied directly to the battery so that the processing subsystem remains powered over the widest possible battery range. Each converter includes dedicated input bypass capacitors, bootstrap capacitors, an output filter network, and a feedback network sized for its target output voltage. Together, these circuit elements allow the subsystem to provide stable power rails that support reliable operation of every functional block in the design.

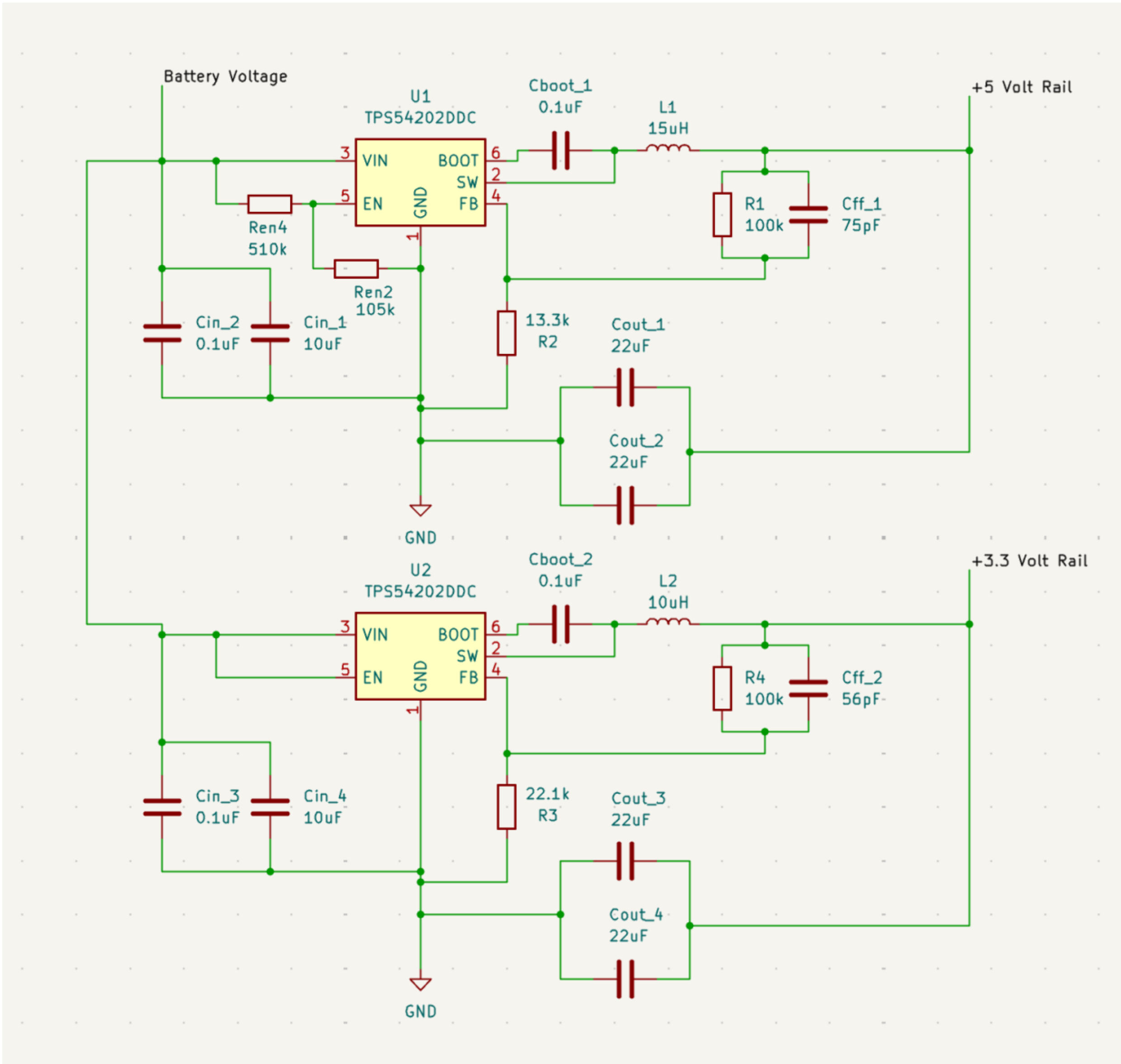

Figure 3: Power Subsystem KiCAD Schematic

Requirement	Test Equipment	Verification Procedure	Pass Criterion / Recorded Result
The Power Subsystem shall operate from an input source between 6.0 V and 9.6 V applied to the Battery Voltage input.	Bench power supply	Replace the battery pack with a bench supply. Apply 6.0 V, 7.5 V, 9.0 V, and 9.6 V to the Battery Voltage net. Confirm both rails start and remain present.	+5 V and +3.3 V rails are present and within their specified ranges at all four input voltages.
The subsystem shall regulate the +5.0 V rail to 4.5 V to 5.5 V for load currents from 0 mA to 600 mA.	Bench power supply, resistor bank	Apply nominal input voltage. Sweep the +5 V rail load from 0 mA to 600 mA. Measure rail voltage at each load point.	Measured +5 V rail remains between 4.5 V and 5.5 V over the full load range.
The subsystem shall regulate the +3.3 V rail to 3.10 V to 3.50 V for load currents from 0 mA to 600 mA.	Bench power supply and a resistor bank.	Apply nominal input voltage. Sweep the +3.3 V rail load from 0 mA to 600 mA. Measure rail voltage at each load point.	Measured +3.3 V rail remains between 3.20 V and 3.40 V over the full load range.
During a transient event equivalent to 15 LEDs switching simultaneously, the +3.3 V rail shall not drop below 3.20 V, and the ESP32-S3 shall not brown out or reset.	Oscilloscope	Load the firmware that toggles the maximum LED set simultaneously. Monitor +3.3 V with an oscilloscope during switching and confirm processor operation continues.	+3.3 V stays at or above 3.20 V and no ESP32 reset or brownout occurs.

2.2.2 Controls Subsystem

The control subsystem facilitates the function of our entire project by allowing the safe operation of our LED array, buzzer component, and the safekeeping of our microcontroller. Without this system, the current draw from our MCU will cause a brownout in the device. The control subsystem requires the sufficient supply of voltage from the power subsystem as well as the correct GPIO logic signals from the ESP32. Without these, then the logic and amplification capabilities of the control subsystem would not function. This would result in the status device subsystem failing to send the required current and voltage to the necessary LEDs and buzzer when needed.

- MOSFETs used to drive higher current for LEDs and buzzers (controlled by esp32) along with current limiting resistors to avoid esp32 brownout

The success of the controls subsystem is dependent on its communication with the status devices subsystem to deliver safe and reliable current flow to each device. Additionally, this subsystem is required to read control signals from our processing subsystem's MCU to coordinate the digital logic and amplification of current through the circuit.

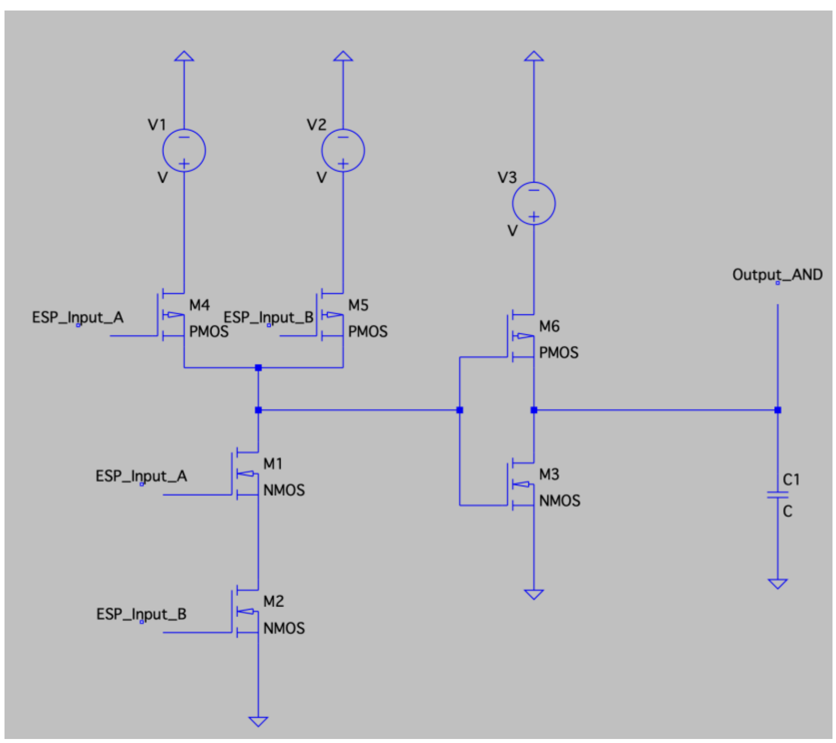

Figure 4: Control Subsystem LTSpice Schematic

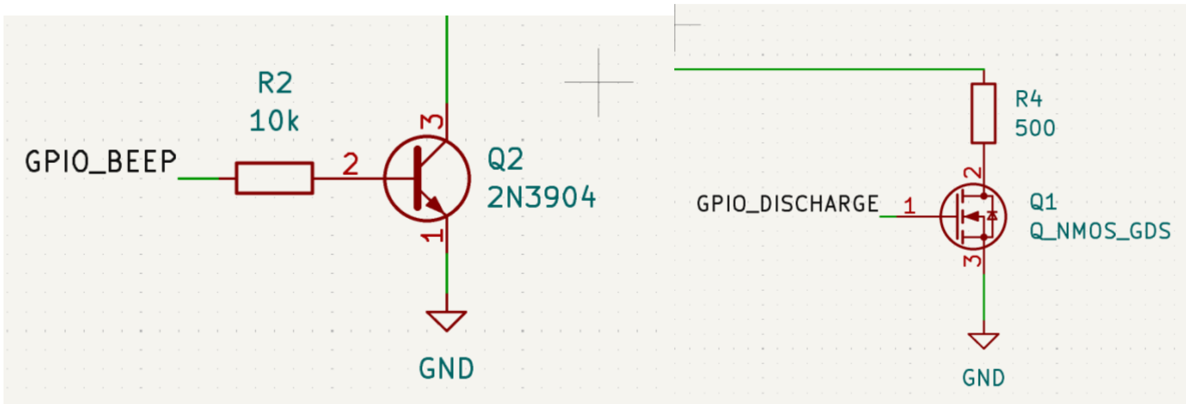

Figure 5: Control Subsystem KiCAD Schematic

Requirement	Test Equipment	Verification Procedure	Pass Criterion / Recorded Result
The current amplifying MOSFETS sends 3.3V +/- 0.3V through to complete the circuit for our buzzer upon GPIO buzzer signal	Power supply, multimeter	Apply 3.3V through the buzzer and trigger the gate of the transistor to complete the circuit through drain and source. Measure current flow and verify correct voltage value across transistor.	Multimeter shows voltage drop of 3.3V across the buzzer, ensuring the device is no longer open circuited.
Digital logic transistors compute accurate truth tables upon their configuration	Power supply, multimeter,	Apply all valid input combinations to the logic inputs for a 2-input gate: 00, 01, 10, 11. For each case, measure the output node and compare the result to the expected truth table for the configured gate.	Pass if the measured output matches the intended truth table for all input combinations. For a 3.3 V logic system, a logic HIGH shall be >= 2.5 V and a logic LOW shall be <= 0.5 V.
The power MOSFET section will not have excessive voltage drop above 15% and	Power supply, temperature	Operate the LED/buzzer load in the worst-case state for 1 minute. Measure the MOSFET	Pass if the measured MOSFET temperature remains <= 70°C after 1

Requirement	Test Equipment	Verification Procedure	Pass Criterion / Recorded Result
not exceed a temperature of more than 70 degrees C.	sensor, multimeter	case temperature at the end of the test.	minute of continuous operation.

2.2.3 Processing Subsystem

The processing subsystem allows the entire design to operate according to the user inputs and internal current state of the simulated model. The processing subsystem requires the functionality of the power subsystem to distribute a clean 3.3V rail to the ESP32 as well as requiring the simulated model and state machine to be accurate in terms of the current state and corresponding logic signals associated with each fault scenario.

Simulated fault scenarios (to be picked by the user)

- Short circuit fault (line to line fault) & Ground fault (Line touches earth/ground) (Fallen tree), blown fuse
    - When the permanent fault scenario is activated, the MCU flags the power line feeder segment as faulted in the grid model and updates the board's display. Fault detection is implemented by checking whether the faulted line is down within the MCU, and the red LED illuminated accordingly. Protection is seen as successful when the user opens the correct nearest surrounding breakers to the feeder segment so the faulted section is optimally isolated, or else the red fault LED remains on and the buzzer alerts during solution check. The user controls the state of the breakers through toggle switches on the bottom right corner of the board, where each one is labeled with its corresponding breaker.

- Lightning-induced fault, arc faults
    - <u>Transient fault</u> scenarios where the user must wait until either the primary automatic breaking isolates the fault or the secondary breakers downstream (on a time delay) break the fault upon primary breaker failure (demonstrating real world operation to the user). If the user reclosed the breakers too early (before the simulated clearing delay), the fault reappears. If they wait and reclose at the correct time, the line returns back to functional.

- Undervoltage (voltage and frequency droop under heavy load)
  - A load shedding scenario where too many loads are on the grid (factories, hospitals, houses) and the frequency and voltage droop. The user must selectively load shed in order to raise the frequency back to 60 hz and correct the voltage droop. This voltage droop and frequency change will be displayed to the user as the scenario occurs. Successful completion is determined when the correct load option (residential) is load shed (3D printed house piece is removed from the board) to preserve high priority loads just like in real grid operation.
- Generation disconnect to solve frequency droop
  - A frequency stability scenario where the frequency rises above 60 Hz because there is too much generation and not enough loads on the grid. The user selectively turns off generation sources that are quick to turn off and on (like natural gas turbines), and the MCU simulates the frequency response to load changes. Sources that are difficult to start up, like coal and nuclear behave differently than dispatchable sources like natural gas turbine generators. The display shows the resulting simulated frequency deviation and recovery. The user will correctly solve the scenario when they choose to disconnect the natural gas turbine from the set of generation sources on the board. If any other source is disconnected (nuclear or solar/wind) then the buzzer will sound.
- Power Factor Control
  - A power factor correction scenario where the user adjusts the system's reactive behavior by inserting capacitors/inductors into the board. The PCB physically measures the inserted L/C using DC RC/RL timing circuits by measuring the time it takes for an inserted voltage to reach 63.2% of the max across a known resistor to find tau. The MCU uses the measured values in a mathematical PF correction model referenced to a predefined target PF for the user to attempt to match. The display shows the computed PF and recommends actions ("increase C / decrease L" or "decrease C / increase L") until the target PF is met and the light goes green to show success.
- Correct isolation conditions
  - The microcontroller will initialize fault scenarios that will require the user to manually trip breakers nearest to the fault on all necessary ends to isolate the fault. Correct isolation will be detected using internal logic that

determines if the nearest breakers in the zone of protection were tripped. If not, then the user will hear a buzzer sound upon checking their solution correctness while seeing red lights continue to illuminate the faulted region.

- For the fault scenarios involving automatic tripping, the user's success will be checked upon their decision of when to reclose the circuit. If they reclose the breakers too early before the primary and backup breaker protection has activated, then the buzzer will alarm. In this case, they must wait until the LEDs on the board show signs of effective simulated isolation before reclosing the breakers and hitting the test button to check accuracy.
- Our software defined symmetrical fault types include short circuit faults on various distribution lines, ground faults, or arc faults. The user will see the causes of these faults displayed to them via the on board display panel, whether caused by animal interference, vegetation, or lightning/earthquakes.
    - LEDs Indicates state of line (faulted, cleared, in progress) (Red, Green, Blue)
    - "In progress" signals that the automatic breaker scenario is attempting to isolate the fault using primary breaker protection before its time delay triggers the secondary breaker protection to trigger. Once it's isolated, the user is then responsible for reclosing the correct breakers to bring the line back online. (For the automatic tripping demonstration scenario only)

Figure 6: Processing Subsystem Flowchart

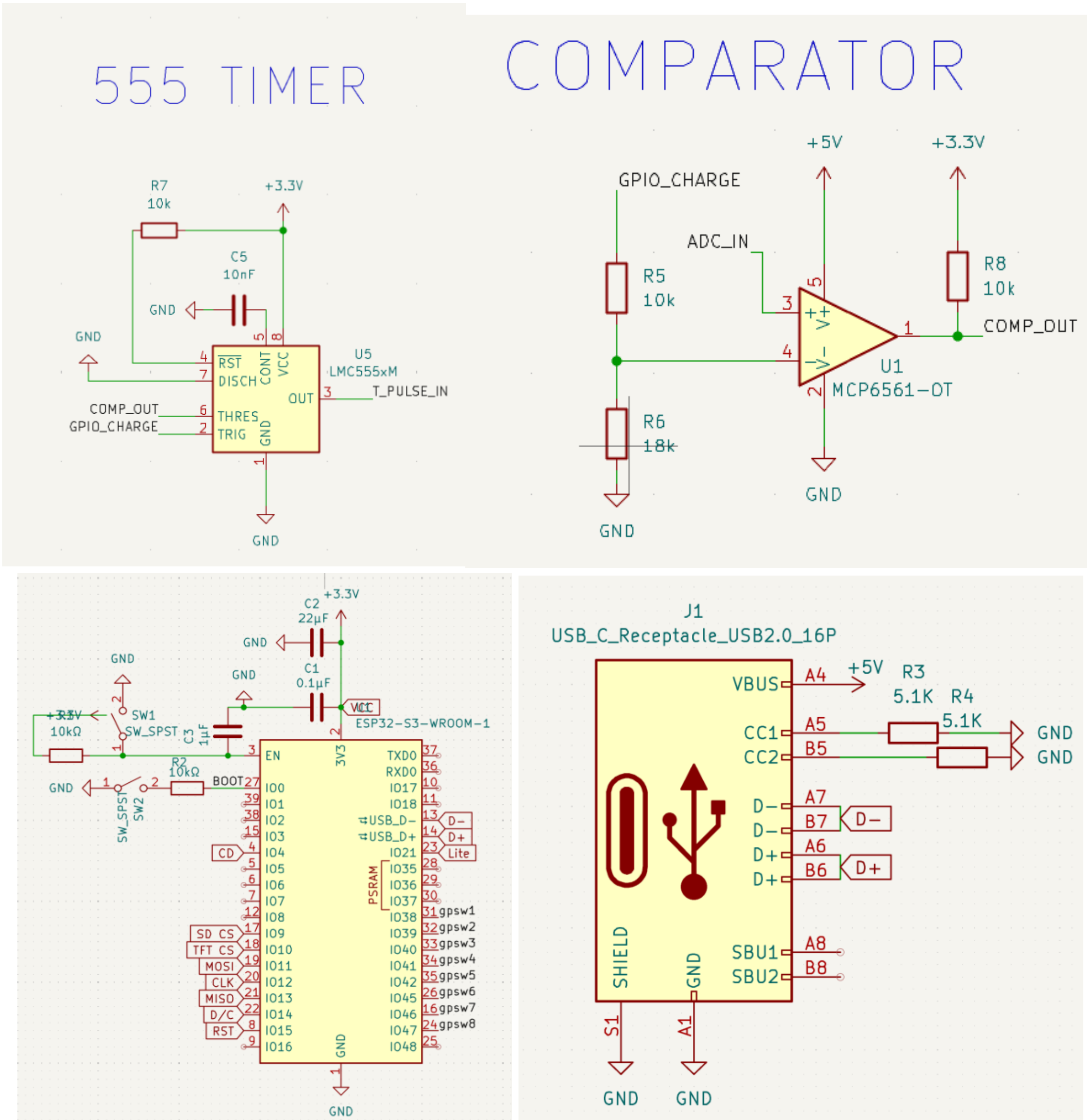

Figure 7: Processing Subsystem KiCAD Schematic

Requirement	Test Equipment	Verification Procedure	Pass Criterion / Recorded Result
The MCU recognizes the rotary encoder selection and updates both the display and the state machine accordingly	stopwatch and oscilloscope	Rotate the selector to each scenario position. Measure the time from selector movement to the correct scenario state appearing on the Display.	Pass if the displayed scenario and active state match the selector position for all scenarios, and update time is <= 250 ms.
The counter starts upon MCU signal and stops upon the comparator trigger signal to measure RC/RL time constant within +/- 20% accuracy.	known capacitors/inductors, and oscilloscope	Insert known reference C and L values. Trigger the measurement routine. Compare the MCU measured value to the reference value. Repeat across the supported range.	Pass if computed C and L values are within +/- 20 % of the reference for all tested values. Record measured error.
The MCU recognizes the current state of the toggle switches on the board and updates its internal variables accordingly.	multimeter probe, stopwatch	Toggle each breaker/load/generator switch individually and verify that the displayed state output matches the physical switch position. Measure the update delay.	Pass if every switch state is read correctly and internal state updates within 100 ms.

2.2.4 Status Devices Subsystem

The Status Devices Subsystem is the primary user interface for the simulation, giving users real-time visual and audio feedback. It translates the internal logic of the simulation such as the power line status, electrical metrics, and game logic, and turns it into human-readable signals so the user can easily understand how their actions affect the simulation in real time.

The SSD1306 OLED display must communicate with the ESP32 via the I2C protocol at a rate of at least 100 kbps, preferably 400 kbps for smooth display operation and to ensure that the display lag is minimal. All status components should operate within a 3.3V+- 5% range to prevent damage to the ESP32 GPIO pins or cause logic level mismatches. The CUI CEM-1203 buzzer device must work properly and provide a Sound Pressure Level of at least 85 dB to ensure audibility of the sound.

This subsystem is functionally dependent on the 5V rail from the power subsystem to power the Display and 3.3V for the LEDs. If the voltage drops below 3.0V, the display will fail. It is also dependent on the processing subsystem to provide the SPI communication signals, (SCK, MOSI, MISO), as well as the required control lines (CS, D/C, RST) and GPIO triggers. Without the ESP32's SPI clock, data transmission, and control logic, the display and status indicators would remain in an idle or undefined state.

This subsystem does not affect the rest of the subsystems too much. If this subsystem fails, the simulation simply goes "blind", in that the user will be unable to see the state of the simulation demo, and will not understand what is going on, even if the simulation continues to run correctly. The display will be connected to the PCB via a 2x7 connector.

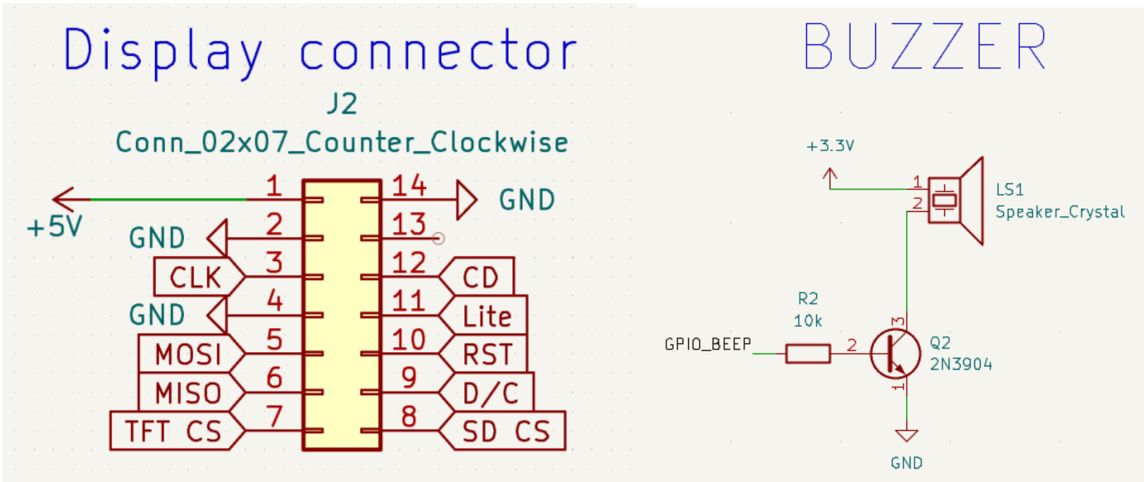

Figure 8: Status Devices Subsystem KiCAD Schematic

Requirement	Test Equipment	Verification Procedure	Pass Criterion / Recorded Result
The display updates with grid information necessary to solve each scenario upon user inputted selection	Oscilloscope and stopwatch	Power the board and use the scenario selection input to cycle through each fault scenario. After each selection, observe the display and verify that the correct scenario name, fault information, and relevant values are shown. Measure the delay between user input and correct screen update.	Pass if the correct grid information for each selected scenario appears on the display within 250 ms of user input for all tested scenarios.
The scenario specific LEDs are red when the fault is active, blue if the fault is in a waiting state, and green when cleared.	programmed test scenarios, visual inspection	Run each scenario and place the system into the three required states: active fault, waiting/in-progress, and cleared. Observe the corresponding LED color for each state. Repeat for all applicable scenarios.	Pass if the LEDs display red during active fault, blue during waiting/in-progress, and green when the fault is cleared for all tested scenarios.

Requirement	Test Equipment	Verification Procedure	Pass Criterion / Recorded Result
The buzzer makes an audible sound upon a failure to clear the fault when the user hits the check status button.	audio observation	Start a fault scenario and intentionally clear it incorrectly. Press the check status button and observe whether the buzzer sounds. Repeat after correctly clearing the fault to confirm that the buzzer does not sound in the success case.	Pass if the buzzer sounds whenever the user checks status while the fault is cleared incorrectly, and remains silent when the fault is cleared correctly

2.2.5 User Interface Subsystem

The user turns the rotary selector and chooses a fault scenario to initialize on the board, which is visible from the display. Depending on which of the five fault scenarios the user chooses, the MCU initializes the corresponding components on the board to show as faulted. The screen reflects this change and gives the user all the necessary information about the current state of the grid to correct the faults. The success of this subsystem requires the communication to the processing subsystem to allow for the current state of the simulation model as well as the board components to be accurately displayed and considered in the fault clearing checks.

For power factor correction, the PCB will physically measure the user chosen component using DC RC and RL time constant circuits within the PCB. A known resistor will be used with a step voltage input into it, and a 555 counter will capture the time it takes to reach 63.2% of the max voltage across the resistor. This will be done by having the MCU start the 555 and the comparator will have a know threshold voltage that it is comparing against the active voltage across the resistor in the RC/RL circuit. Once the comparator sees the resistor voltage hit the set threshold that is 63.2% of the step voltage applied, then the comparators output triggers the 555 timer to stop and the MCU reads the length of the pulse from the timer. This time is read in the simulation as tau and used to compute the capacitance or inductance based on the equation associated with a capacitors discharge pattern (gradual) or an inductors discharge pattern (instant). This will give us the tau value that the simulation model will use to calculate the value of the capacitor or inductor that the user chose to add to correct the power factor. These measured C and L values will be used by the MCU to compute the new PF and reflect it on the display.

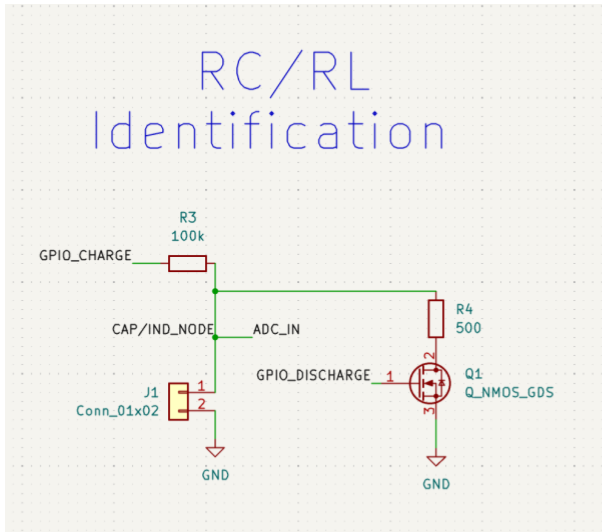

Figure 9: User Interface Subsystem KiCAD Schematic

Requirement	Test Equipment	Verification Procedure	Pass Criterion / Recorded Result
The breaker, load, and generator toggle switches both update the state machine variables as well as the on-board LEDs within 500ms.	stopwatch or oscilloscope, visual inspection	Toggle each breaker, load, and generator switch individually. Verify that the internal simulation state changes correctly and that the corresponding LED/output state updates. Measure the delay from switch movement to visible update.	Pass if all switches are correctly recognized and the LED/state update occurs within 500 ms for all tested inputs.
The RC/RL circuit correctly identifies the capacitor or inductor	known capacitors and	Insert known test capacitors and inductors into the measurement socket. Trigger the measurement	Pass if the system produces a valid component measurement

Requirement	Test Equipment	Verification Procedure	Pass Criterion / Recorded Result
inserted by the user within 5 seconds.	inductors, stopwatch	routine and observe the time required for the MCU to compute the measured component value. Compare the result to the reference value.	within 5 s for all tested values.
The rotary selector shall allow the user to select one of the fault scenarios, and the selected scenario shall be recognized by the MCU and shown on the display within 500 ms.	stopwatch or oscilloscope, visual inspection	Rotate the selector to each fault scenario position. Verify that the display updates to the correct scenario and that the MCU enters the corresponding state. Measure the time between selector movement and display update.	Pass if each selector position correctly maps to the intended scenario and the display updates within 500 ms.

2.3 Tolerance Analysis

Because our PCB identifies user-inserted capacitors and inductors by measuring an RC/RL time constant, the measurable component range is limited by the microcontroller's ability to time short intervals. The ESP32 does not measure C or L directly, instead, it will timestamp when the RC or RL response reaches a fixed fraction of its final value the 63.2% point. This measured time is the time constant τ, which is then converted into C or L using $\tau = RC$ or $\tau = L/R$. If the selected capacitor or inductor is too small, τ becomes very small and the current increases too quickly. In this case, the measured time is on the same order as the counter's tick size and software latency, so the measurement becomes inaccurate meaning one or two timer ticks of error becomes a large percentage of τ. This directly increases the relative error in the computed component value and can cause the system to misclassify whether the user's C or L choice meets the power factor correction target. We must constrain the selectable capacitor and inductor values so that τ remains sufficiently larger than the timer resolution, making sure that the 63.2% crossing occurs over a time interval that can be measured accurately.

RC step response for capacitance measurement

$$v_C(t) = V_{step}\left(1 - e^{-\frac{t}{RC}}\right)$$

At the 63.2% point**:**

$$v_C(\tau) = 0.632\,V_{step} \Rightarrow \tau = RC$$

Capacitance estimate from measured $\tau$and known R:

$$C = \frac{\tau}{R}$$

$$t = -RC\ln\left(1 - \frac{V_{th}}{V_{step}}\right) \Rightarrow C = \frac{t}{-R\ln\left(1 - \frac{V_{th}}{V_{step}}\right)}$$

A second tolerance related risk is possibilities of brownouts to the ESP32-S3 because it can not directly source the current needed for several LEDs without creating transient load steps that can cause a brownout. To prevent this, GPIO pins are used only as low current control signals with pull-up/pull-down resistors to guarantee defined startup states and avoid floating nodes. The LED current is handled by MOSFETs, which let the microcontroller control higher-current loads without stressing the GPIO improving rail stability and system reliability under worst case LED activity.

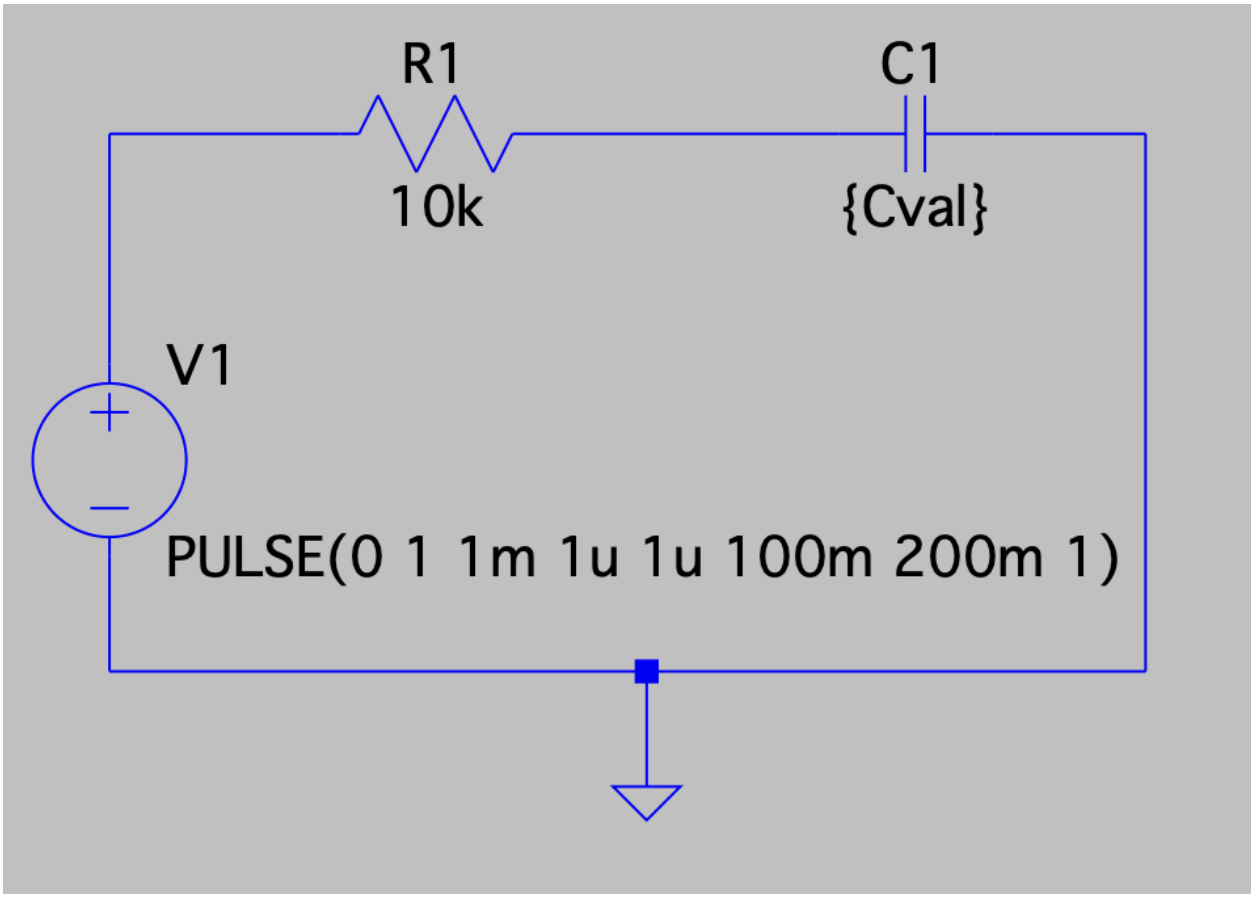

Figure 10: LTSpice Capacitor Circuit Schematic

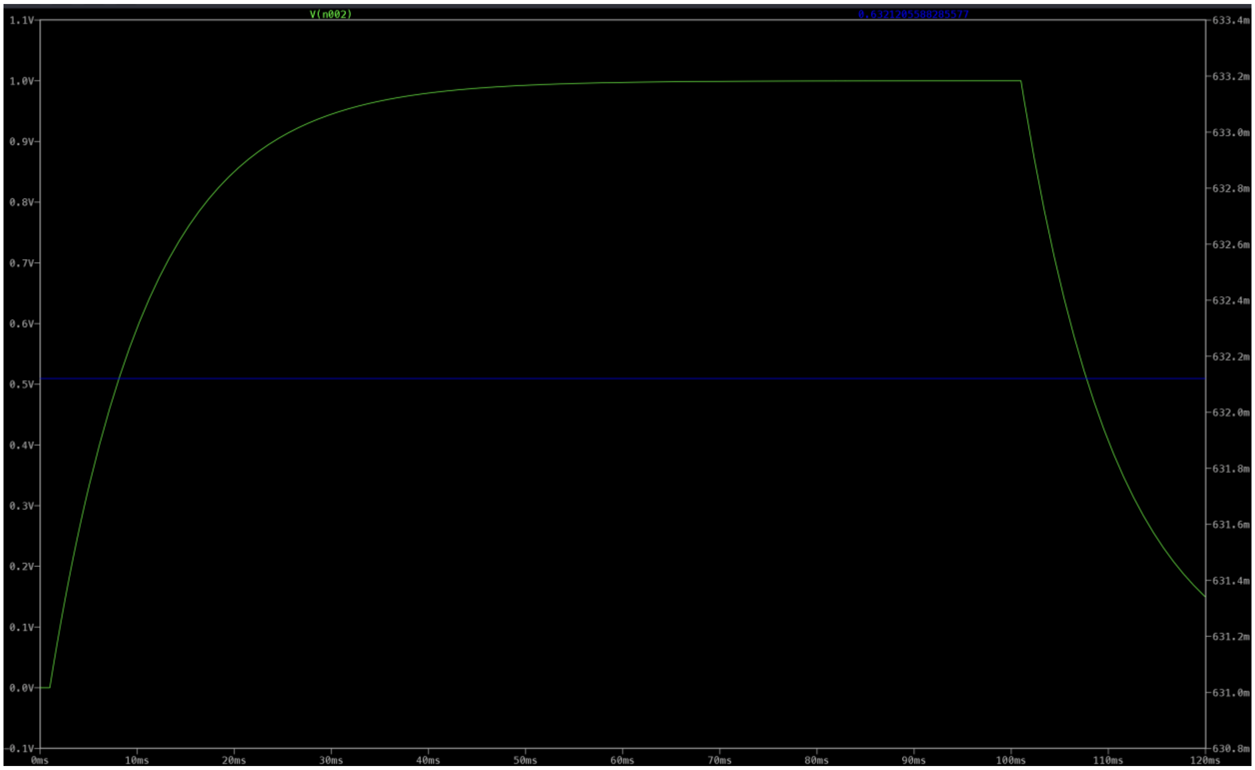

Figure 11: RC circuit 63.2% Simulation Full Graph

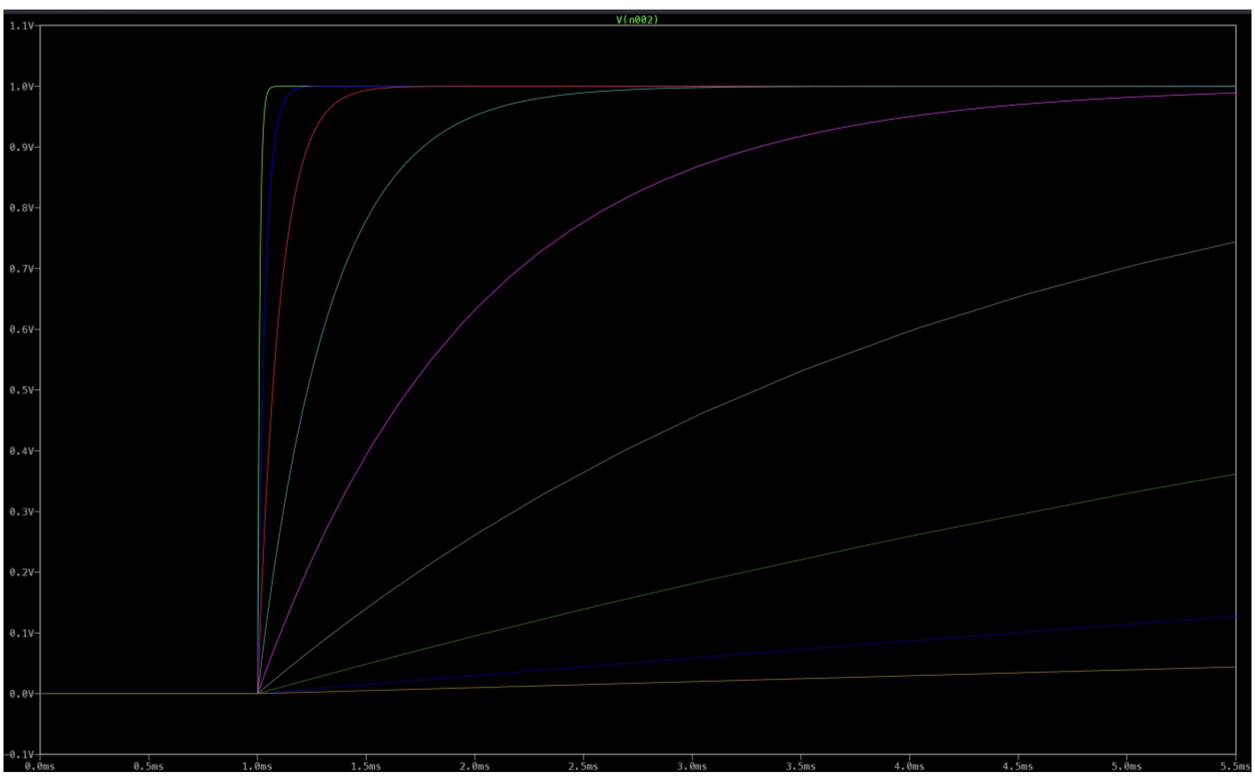

Figure 12: Different Capacitor Charging Times Simulation Full Graph

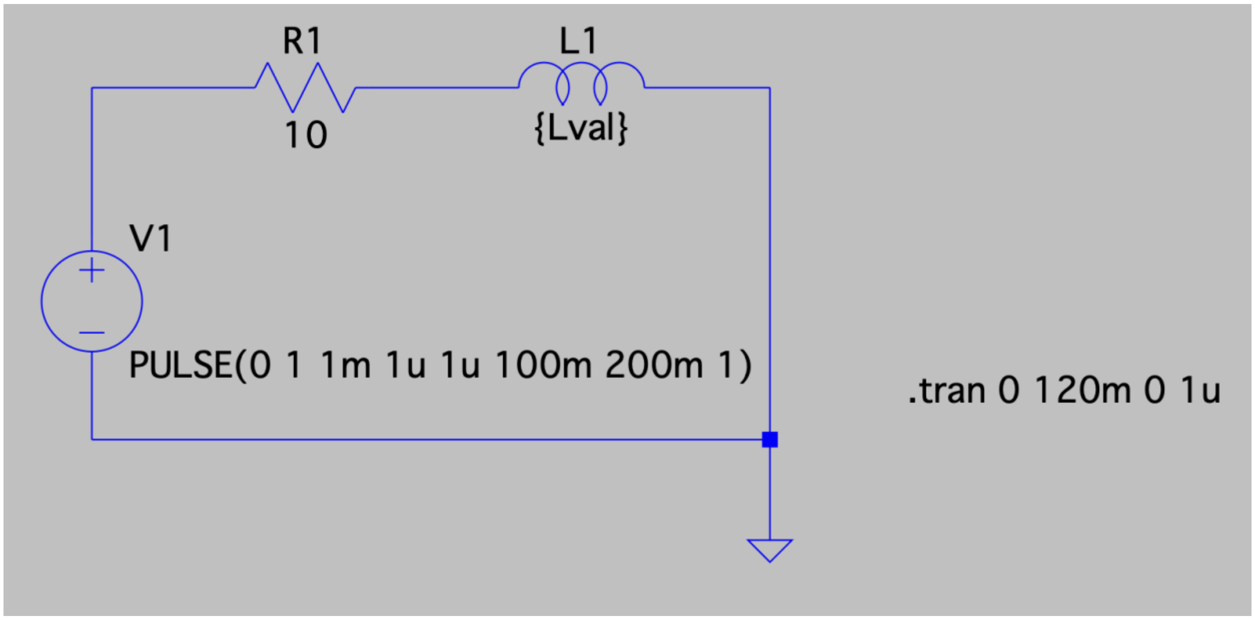

Figure 13: LTSpice Inductor Circuit Schematic

3 Cost & Schedule

3.1 Cost Analysis

Labor Costs Table

Name	$ per hour	Hours per week	Total Weeks	Total Cost
Ahmet Colak	$35	10	16	$5600
Jason Hart	$35	10	16	$5600
Srijan Kunta	$35	10	16	$5600
Machine Shop	$0	0.5	2	$0
				$16800

Parts Costs Table

Part Names & purchase link	**Part**	**Manufacturer**	**Unit Cost ($)**	**Quantity**	**Actual Cost ($)**
switch	EG1218	E-Switch	$0.72	1	$0.72
Buck converter	TPS54202DDCR	Texas Instruments	$1.17	2	$2.34
Voltage Regulator	TLV75533PDBVR	Texas Instruments	$0.36	1	$0.36
diode	SS14TR-ND	Onsemi	$0.29	1	$0.29
Red LED	WP7113SURDK14V	Kingbright	$0.66	10	$4.53 (Bulk)
N-MOSFET	CSD15380F3	Texas Instruments	$0.32	1	$0.32
P-MOSFET	CSD25501F3	Texas Instruments	$0.38	1	$0.38
ESP32-S3	1965-ESP32-S3-ND	Espressif Systems	$1.85	1	$1.85
Display Board	1528-1469-ND	Adafruit	$29.95	1	$29.95
Capacitor 200uF	647-UTH2G201MND	Nichicon	$5.40	1	$5.40
Capacitor 0.1uF	C320C104K5R5TA73	KEMET	$0.30	10	$1.77 (Bulk)
Rotary selector	PEC11R-4220F-N0012	Bourns Inc.	$1.89	1	$1.89
Green LED	160-1142-ND	Lite-On Inc.	$0.14	10	$0.94 (Bulk)

Buzzer	CUI CEM-1203	Same Sky	$0.68	1	$0.68
Switch	100SP1T1B4M2QE	E-Switch	$2.63	6	$15.78
Power MOSFET	CSD15380F3	Texas Instruments	$0.32	10	$1.94 (Bulk)
MOSFET	CSD25501F3	Texas Instruments	$0.38	10	$2.32 (Bulk)
Binary Counter	595-CD4040BE	Texas Instruments	$1.02	1	$1.02
	Total				**$72.48**

3.2 Schedule

Week	Work	Team member distribution
7 3/2	Order all necessary parts, finish first PCB design, design review, then submit for second round PCBway orders. Work on breadboard implementation	Ahmet: power and mosfets Jason: RC/RL, LEDs, buzzer Srijan: MCU, display, switches
8 3/9	Breadboard demo basic/partial functionality, Third round PCBway order if needed	Ahmet: power and mosfets Jason: RC/RL, LEDs, buzzer, combining PCB Srijan: MCU, display, switches, software, dev board testing
9 3/23	AFTER SPRING BREAK: get parts, solder PCB, build box, Fourth round PCBway order if needed	Ahmet: power and mosfets, box Jason: RC/RL, LEDs, buzzer, switches Srijan: MCU, display, soldering, software
10 3/30	Individual progress reports, software state machine, display UI, box setup, RC/RL circuit setup	Srijan: software state machine, display UI Ahmet: box setup, power Jason: RC/RL
11 4/6	Progress Demo, Team Contract assignment, combine software with RC/RL	Srijan and Jason: RC/RL software combination

		Ahmet: Power Testing
12 4/13	Get everything working together	All
13 4/20	Mock demo	All
14 4/27	Final demo	All
15 5/4	Final paper, presentation	All

4 Ethics, Safety, and Societal Impact

4.1 Societal Impact

EduGrid is intended for education and public demonstration. By acting as an educational tool to demystify the electrical grid and grid protection, it teaches and inspires people to learn how the maintenance of reliable power infrastructure works. A well-protected grid is essential to prevent catastrophic failure of important systems during extreme weather events, so EduGrid is meant to educate and inspire people in this important field.

4.2 Engineering Standards

EduGrid's PCB layout will be developed in consideration of IPC-2221, the Generic Standard on Printed Board Design. This standard gives guidelines for important things like recommended trace width, placement of parts, clearance distances, and thermal management [2]. In our design, power traces for things like the buck converter and DC rails will be sized conservatively to prevent overheating, and we will try to design the board with good spacing and capacitors placed close to important pins to minimize noise.

4.3 Ethics

EduGrid is tied to the IEEE Code of Ethics through point 2: the ethical obligation to improve people's understanding of the capabilities and societal implications of technology [1]. Our system is meant to be educational, so it must be an accurate representation of real-world systems that does not misinform users. In addition, the system should operate at low voltage with no exposed conductors within the user's reach, and electrical design choices (current limiting, protected rails, safe connectors) should reduce the risk of overheating, short circuits, or accidental contact. These safety protocols fulfill point 1 of the code, which requires a prioritization of safety and health of the public [1].

4.4 Safety Concerns

EduGrid is a low-voltage system. It does not require an AC converter, or any other high-voltage applications. It is designed for a classroom environment, so because of its low-voltage and safety-minded design, we mitigated safety concerns. EduGrid development and testing were conducted in consideration of OSHA electrical safety standards. Laboratory procedures followed OSHA guidelines for safe handling of electrical equipment, such as using current-limited bench power supplies and maintaining proper insulation of exposed conductors [3].

4.5 Safety Procedures

EduGrid operates entirely on low-voltage DC power (3.3V and 5V regulated rails). It does not connect to AC, does not generate high energy arcs, and does not include large energy storage elements. Therefore, the project is classified as low-risk electronic laboratory equipment. This low-voltage design is one procedure followed to eliminate many safety concerns. In the design of the PCB, it includes thermal risk mitigation by selecting a buck converter with adequate current margin, operating all components well below the rated temperature, and spacing components well to prevent short circuits, arcing, and overheating.

For development, we make sure to follow soldering safety procedures, such as maintaining proper ventilation, using soldering stands, and eye protection. We also make sure to de-energize circuits before any modifications, setting current supply limits before powering anything, and visually inspecting all connections.

For the user safety, we make sure that all interactions occur through low-voltage switches. No energized conductive pads should be exposed, and the points where the user inserts capacitors or inductors should be current-limited, and the enclosure prevents direct contact with any circuitry.

5 Citations

[1] IEEE, "IEEE Code of Ethics," IEEE.org, June 2020. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html.

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