Smart Assessing Breaker for Residential Estates (SABRE)

Initial Divide and Conquer Document
EEL4914 - Senior Design I

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Department of Electrical and Computer Engineering

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Chapter 2 - Project Description

2.1 Background and Motivation

Electricity is everywhere in the modern world. In North America the rating at which an outlet operates at is 60 Hz, 120 VAC and a maximum of 20 Amps According to the National Electrical Manufactuerer's Association (NEMA) [17]. Power at this level is enough to not only kill a person by itself but if improperly regulated, could burn down an entire building hurting or possibly killing anyone inside. When electricity such a high voltage/amperage is implemented into nearly every home in the country, safety implements have to be in place. In comes the modern breaker. A device that not only protects the circuitry inside your home from receiving irreparable damage but also prevents intense heat from generating inside the wirings that can cause potential fires. However, the breaker is rather simple in its design, as such the breaker itself is prone to damage with repeated use and if left unchecked can cause shortages and faults leading to circuit damage, insulation burns, and even fires [14]. Furthermore with the modern digitizing age, there is an increasing demand on every electrical grid in the world requiring an upgrade to the old. With the Smart Assessing Breaker for Residential Estates (SABRE), these issues can be a thing of the past.

The Smart 1 Phase Breaker for Residential Buildings looks to act as a low power prototype for a future full scale Smart Breaker that is able to optimize the conventional breaker by providing real-time monitoring and control of energy consumption of power within the home. The prototype also allows for a smarter way to trip power rather than causing strain on the mechanical aspect of a conventional breaker by including a Microcontroller device into the hardware making the breaker more reliant on circuitry giving it a safer, more reliable, and fast acting breaking than traditional means [5]. With a built-in antenna, the prototype also provides all this information to the user at any place in the world as long as it is connected to WiFi, which allows the user to check in on any irregularities while they are away from home, allowing them to remotely trip the breaker in case of a potential hazard predicted by the app [1].

Throughout the past 70 years, overall electricity consumption has increased 14 fold in residential homes, consuming 1.42T kWh of electricity in 2022 alone. This includes a doubling in Miscellaneous Electrical Loads (MEL) over roughly the past 50 years, which is a measurement of power consumption that excludes systems that are a part of the building's main function such as HVAC and lighting. These MELs do include devices such as computers, consoles, televisions and other digital devices that have increasingly become something of a standard within homes across the United States [13]. These are just consumption statistics relating to residential buildings, without factoring in elements such as new large scale data centers which are being invested into more and more by commercial ventures and consume even more electricity than residential areas. In essence, society as a whole is reliant on electricity, and any way to minimize the consumption should be a necessity. This inspired our team to implement a solution on an individual level to reduce energy consumption from a ground up approach, if everybody is reducing their energy consumption, the overall strain on the grid can be managed more effectively, and have a significant reduction in electricity consumed. The Smart 1 Phase Breaker for Residential Buildings design is sponsored by Dr. Qun Zhou from the University of Central Florida, who has previously supported projects relating to minimizing energy consumption. Specifically, in a previous year, she sponsored a team that implemented a smart water heater that was designed to improve energy efficiency and manual control over the usage via wireless communication through a web-app service. To expand on this idea Dr. Zhou has tasked our team to design a Smart Circuit Breaker that innovates the conventional functionality of today's breakers by directly managing and optimizing power usage at the branch circuit level. Dr. Zhou also emphasized the potential market applications of this work through her collaboration with Grid Interactive Things Inc., which will serve as the intended customer for this project.

2.2 Goals & Objectives

The primary objective of this project is to develop a functional Smart Circuit Breaker capable of remotely monitoring power consumption in real time. The system will provide live power readings, incorporate protection features to safeguard the electrical system, and enable direct communication to enhance safety, efficiency, and user control in both residential and commercial applications.

For safety and demonstration purposes, the project will be implemented at a reduced scale, operating at 24 VAC and 5 A.

2.2.1 Goals

Basic Goals

- Build a Smart Circuit Breaker capable of protecting against overcurrent, short circuit, arc fault, and ground fault conditions being able to meet standard electrical safety code (NEC/UL/IEE/NEMA) on a reduced scale [14].
- Create a built-in communication system allowing for remote controlled access via a website to allow for real-time monitoring, remote control operation, and predictive maintenance insights through a user-friendly interface.
- Provide predictive fault-detection analysis to inform the user of irregularities during power consumption of a home allowing them to respond accordingly.
- Minimize power consumption of each individual breaker branch circuit within the home.

Advanced Goals

- Integrate Sensors able to send data through to communication systems with minimal error with quick response time through the app/website.
- Incorporate components capable of withstanding surges to prevent replacements and repairs at later times.
- Implement temperature monitoring to warn users of potential heat surges or fires within the system.

Stretch Goals

- Develop a mobile app version of the web-app that includes all of the same functionalities of the web app, but with a more convenient access by having it right on the users home screen.
- Within the app, incorporate live power consumption that will also tell you total charge of electricity consumption that month/pay period.
- Add machine-learning-based fault prediction and load optimization
- Incorporate integration with smart home/IoT platforms (Alexa, Google Home, etc..).
- Integrate live demonstration of power regulation with a device that clearly shows power consumption over time.

2.2.2 Objectives

Basic Objectives

- Develop an antenna system connected to the Microcontroller via an interchangeable PCB to provide real-time communication between the website and the Smart 1 Phase Breaker for Residential Buildings.
- Use a potential step-down transformer to run signals through Analog to digital converters directly into the microcontroller unit to use as a fault detection system.
- Implement signal analysis to predict fault detection within the entire power system of residential homes.
- Integrate power consumption regulation to minimize overall power consumption in a scaled down simulated residential home.

Advanced Objectives

- Communication Systems
  - Provide proper frequency range in order to communicate effectively with other systems and without noise distorting data.
  - Isolate PCB and antenna inside insulated material so any fault condition will not damage the system and also allow radio waves to send from the device effectively.
- System can be set to self-test regularly or manually test through the app or website
- Data
  - Incorporate database to allow for multiple months worth of data to be stored and analyzed at any given point.
  - Automatically delete information from the database after a set period of time to remove the need of the user to manually enter the app/website and remove their previous information to store new information while also minimizing software restraints.
  - Keep data password protected inside website and smartphone to ensure data privacy using two factor authentication
- Remove reliance mechanical aspect of conventional breakers and replace it with standard microcontroller board **for testing**
- Implement Depletion mode, N-type MOSFET as a method for the prototype to cut off current from the main power consumption circuit.

<u>Stretch Objectives</u>

- Replace microcontroller board with faster MCU or FPGA to implement into residential and commercial areas for faster real-time monitoring and reaction capabilities.
- Install LED light indicators inside the Breaker that illuminate when a specific voltage/current range is reached. For example, within a good reading we will see that a green LED illuminates, when the system predicts that a potential burnout or outlet replacement is required a yellow LED will illuminate and a red LED indicates that the breaker has been tripped and must be reset or replaced.
- 3-D print a usable case to place the prototype inside so that it can actually be tested inside a real home.
- Create a user-friendly, easy to install system where one can easily pick up and place the entire system without having to hire an electrician to install the entire device.
- Make the device as cost-efficient as possible while also reaching the maximum effectiveness that can be reached.

2.3 Descriptions of Features/Functionalities

2.3.1 Hardware

Overall Functionality: The idea of the project is to stop an overload from occurring in a home system's main power breaker preventing damage to the circuitry and to the building itself. Instead of using a mechanical design, which is what the mechanical breaker has, the Smart 1 Phase Breaker for Residential Buildings uses an almost entirely electrical and digital design. The prototype will provide real-time monitoring over a residential building's energy usage providing information on any irregularities and predict potential disruptions to the website as long as it is connected to WiFi. The website will also allow the end user to remotely trip their breaker in the event of any abnormalities.

MCU

The Microcontroller Unit that we are using is the ESP32 board which carries a dual-core processor of up to 240 MHz and 520 KB of SRAM. The board also allows for WIFI connectivity of up to 2.4 GHz and Bluetooth. Furthermore the board uses Digital to Analog and Analog to Digital Converters. Lastly, the board contains an ultra-low power co-processor to allow for sensor monitoring in sleep modes [5].

The dual-core processor cascaded with the power relay in conjunction with the ultra-low power co-processor will allow the ESP32 board to monitor live power readings in case of any power fluctuations and if triggered, the board will "activate" and react accordingly. Acting in low-power mode would give the most ideal results for power consumptions. The dual-core processing speed and RAM will allow for quick reactions and reaction speeds of up to speeds within the nanoseconds range. The WIFI capabilities of the board assist in the need for live readings of the power system to the app and website that we will require in our final design, when applied with the antenna this allows for full communication capabilities.

Antenna

The Adafruit microcontroller Feather V2 w.FL Antenna8 MB Flash + 2 MB PSRAM allows for 2.4 GHz range bandwidth suitable for the application to which we want to install [1]. Furthermore it easily installs to our microcontroller board, this removes the need to use modulation, demodulation, and encoding techniques as the board in conjunction with the antenna will handle this information for us. The latency for the antenna is roughly 2-10 ms on a local network sending 2-5 megabytes per second which can easily support our purposes of real-time monitoring and implementation. An alternative solution to the antenna could be a wired connection depending on how fast the end user would like their data to be accessed.

Multimeter Sensor

A desired multimeter must be able to withstand voltages of up to 24 VAC and currents of 5 A at the minimum in order to reliably monitor a power system continuously for years at a time. Furthermore the data from this sensor must be able to be accurately read and sent to remote devices in real-time to allow the end-user to decide what action should be taken. Furthermore, an additional component will be added to this multimeter sensor that picks up on potential spikes, potentially a power relay which can step down the high voltage that is being used and transfer this data to the microcontroller board and let the board react accordingly to whatever situation is being presented. Minimal power usage within this multimeter sensor is a priority to provide the most accurate data.

Power Relay

The power relay will act as a means to be able to obtain data from the intense power coming from the power supply without having to directly connect the microcontroller board to said power supply, otherwise the limited capabilities of the board will be overloaded and burnt. IT will act as a sort of transistor where we will get our small gate voltage to control the flow of current from one end to the other. Though the prototype is only meant to operate under 24 volts and 5 amperes at the maximum, the power relay will simulate these intense voltages without actually using them. We are looking to experiment between a power relay and a solid state approach using MOSFETs. However, MOSFETs may not handle the and current demands in the context of mains power, possibly making the relay a more suitable choice

The power relay was brought up as an idea by Dr. Qun Zhou Sun in the sponsor meeting on September 2nd, 2025 after researching previous smart breakers for intense power needs, though for these kinds of power applications it has not been seen before, it was only natural to implement brand new methods of power scaling in order to get the most accurate data into our microcontroller board without completely destroying it.

MOSFETs

A configuration of MOSFETs may be used in place of the power relay to be used as the actual breaker portion of our system. Utilizing MOSFETs can provide switching speeds on an order of magnitude faster than that of traditional breakers, or the power relay mentioned previously. However, with use in the context of mains power, a configuration of MOSFETs may not be able to provide the necessary protections against arc faults, ground faults, and or short circuits.

Temperature Sensor

The temperature sensor will serve as means to be as safe in the system as possible and as a second source of power readings. Normally in a conventional breaker, the mechanical aspect of the system will heat up to a certain extent, this will cause the breakage in the current stopping any further damage to the system. The temperature sensor will act in a similar manner but in this instance it will serve as a back up for the MCU if it were to fail abruptly. In terms of priority the MCU will take priority, then temperature will read for intense heat. Furthermore it will detect any fires in the main system and immediately alert the end user through the app or website.

Switching PSU

As opposed to standard linear power supplies that look to step down higher voltages through transformers, switching PSUs makes this conversion through pulse width modulation. Switching PSUs tend to be noisier components as opposed to their linear counterparts, but they can be stuffed in a much smaller form factor while also operating at higher power efficiency. An example of a class small form factor switching PSU is actually the circuit used for the 5W block for Apple chargers. This exact same premise is what we will utilize to step down the 24VAC to 5VDC to provide low power to our MCU and auxiliary sensors.

2.3.2 Software

Website/App Interface
The Website and App interface are two key components in ensuring a user friendly experience with our entire system, it will allow for live readings of the power supply at any given notice and give any irregularities that were found in this proposed system. Furthermore when said irregularities are found the website/app will be able to inform the end user and ask how they would like to proceed. Any options chosen will allow the user to remotely control their SABRE as long as they are using the correct software. The microcontroller board in connection with the antenna and the multimeter sensor are the key aspects providing this live data, the app/website will then store this information in its own database for the end user's own personal use. After a selected period of time, the data from this database will then be deleted allowing for new data to be stored inside the database providing a perpetual process of consistent data acquisition never forcing the end user to manually go in and correct any issues, the entire point is so that this prototype can be self-sufficient.

The website is already a requirement but the team and the sponsors believed it would be better for residential and commercial use if the entire system was able to be accessed anywhere in the world.

2.4 Review of Prior Related Work

2.4.1 Devices on the Market

Similar products can be found from brands such as Lutron and Leviton. These will include all of the standard features of a conventional breaker while also implementing smart properties such as monitoring individual breakers, but it comes at the cost of having an entire new panel installed. Lutron panels specifically leverage integrated breakers with DPMs that can receive commands from a centralized source within the main panel itself to manage respective functions for each load.

Current Market Offering – Leviton
15A 1-Pole AFCI Branch Circuit Breaker with Thermal Magnetic Trip Technology and Plug-On Installation. 120V
•EASY – Leviton's revolutionary design allows the entire Load Center to be wired at rough-in without any circuit breakers present
•SAFE – Leviton GFCI, AFCI and dual-function circuit breakers feature patented reset lockout technology, and will not reset if ground or arc fault protection is compromised
•INTUITIVE – LEDs communicate trip condition and type of fault, and remain illuminated even when tripped
•COMFORTABLE – Rocker-style switches require less activation force than traditional circuit breakers

Current Market Offering – Eaton
Eaton BR Thermal Magnetic Circuit Breaker, Type BRRP Industrial Remote Operated Circuit Breaker. 120-240V.
•SWAPPABLE – Individual breakers can be switched in and out of a single panel without having to do any replacements to the load center.

•SAFE – Includes GFCI, AFCI and dual-function circuit breakers feature patented reset lockout technology, and will not reset if ground or arc fault protection is compromised
•RELIABLE – Built with standard thermal-magnetic trip technology to ensure consistent protection against overloads and short circuits.

2.4.2 Previous Projects

In addition to this, Dr. Qun Zhou Sun had provided materials to a previous project that involved a similar idea, but like Lutron before, the design would require the switch of an entire panel box before the individual smart breakers could be utilized.

2.5 Specifications

Table 2.5.1 Specification of Overall Design

Overall System Specifications		
Specification	**Target Value**	**Tolerance**
Operating Voltage	24 VAC (single phase)	±10%
Rated Current Capacity	5 A	±5%
Trip Response Time (short)	< 5ms	IEEE Standard
Interrupt Rating	500 AIC	Scaled Down Proportional to the UL 489 Standard
Continuous Load Rating	80% of rated value	±5%
Comm. Range	≥ 15 m (indoor)	N/A
Operating Temperature Range	-10 °C to 60 °C	IEC 60068 Standard
Power Consumption (electronics)	< 5 W	±10%
Dimensions (HxWxD)	≤ 120 × 25 × 70 mm	Stand. Size - 0 tolerance

Table 2.5.2: Hardware Component Specifications

Component Specifications			
Component	**Specification**	**Target Value**	**Notes**
Microcontroller Unit (ESP32 Board)	Processing Speed	240 MHz	Handles sensing + comms
	SRAM	520 KBits	Memory Type

	Wifi Connectivity	2.4 GHz	Bandwidth of Wifi
	I/O Pins	34	Programmable Analog/Digital Pins for data transfer
	Supply Voltage	3.0 V - 3.6 V	Voltage required for power
	Communication Error handling	UART, I^2C, SPI	Error detection and handling mechanism
	ADC Resolution	≥ 12 bits	For current/voltage sensing
Antenna	Connector Type	w.FL	External antenna attachment
	Impedance	50Ω RF Path	WiFi and Bluetooth Transmissions
	Antenna Style	RP-SMA	adapter to board
Current Sensor	Measurement Range	0 - 10 A	Overcurrent Detection
	Accuracy	±2%	
Voltage Sensor	Measurement Range	0 – 24 VAC	For Monitoring
	Accuracy	±2%	
Temperature Sensor (TMP36)	Operating Range	-40 °C to 125 °C	Overheating Detection
	Voltage Input	2.7 V - 5.5 VDC	Power Supply
	Accuracy	± 2 °C	Accuracy Ranges over Temperature
Wireless Module	Protocol	Wi-Fi (802.11 b/g/n)	Could also support BLE
	Range	≥ 15 m	Indoor Environment
Relay Module (103020132)	Control Voltage	5 V	Logic signal for switching the relay between on and off
	UL Certified Load Capacity	10A 125VAC / 10A 110VDC	Signal being controlled by MCU
	Operating Time	15 ms	Switching Time

	Power Consumption	~0.45w	Energy Usage
	Ambient Operation Air Temperature	-40 °C to 55 °C	Operating Temperatures
N-Channel Power MOSFET (IRLZ44N)	V_{DSS}	55 V	Drain to Source Max Voltage
	$\text{Resistance}_{DS(ON),max}$ 25°C	0.022 Ω	Resistance Occurring in transistor
	$I_{D,\ cont}$ 25°C	47 A	Maximum Drain Current
	$V_{GS,\ off\text{-}max}$	±16 V	Maximum Gate to Source Voltage
Hall-Effect Sen.	Operating Voltage	3V - 12V	Converts high current into low volt. signal for MCU
	Output Operating Current	0A - 35A	
	Sensitivity	72 mV/A	
Switching PSU	Input Operating Voltage	24VAC	Converts 24VAC into constant 5W output
	Output Operating	5VDC, 1A	

2.6 Hardware Block Diagram

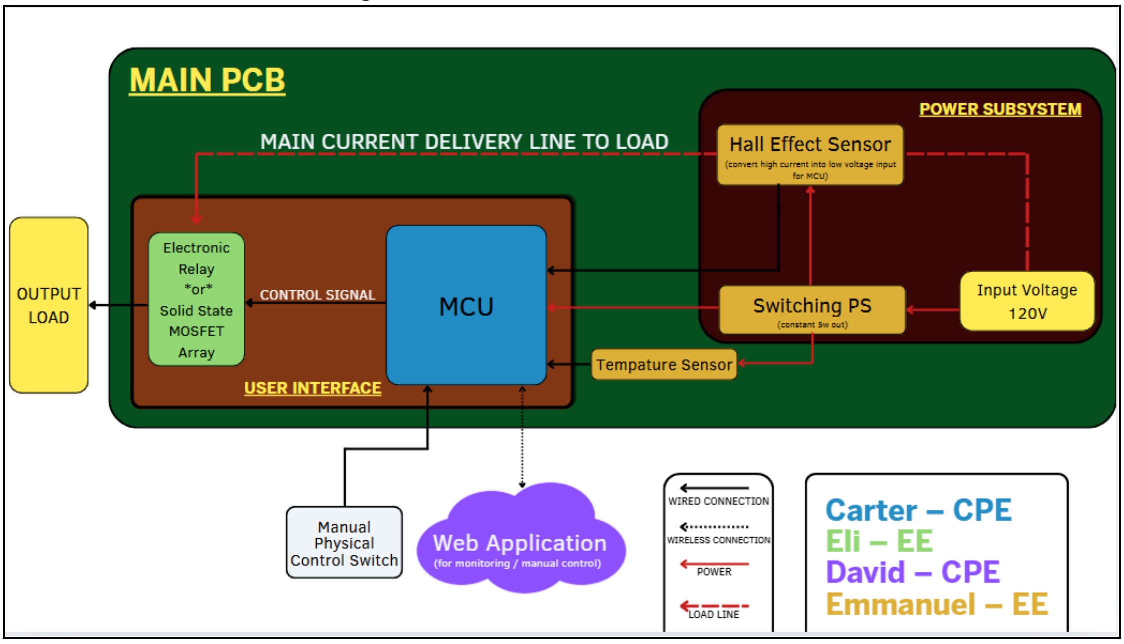

Figure 2.6.1: Hardware Diagram by Authors

2.7 Software Block Diagram

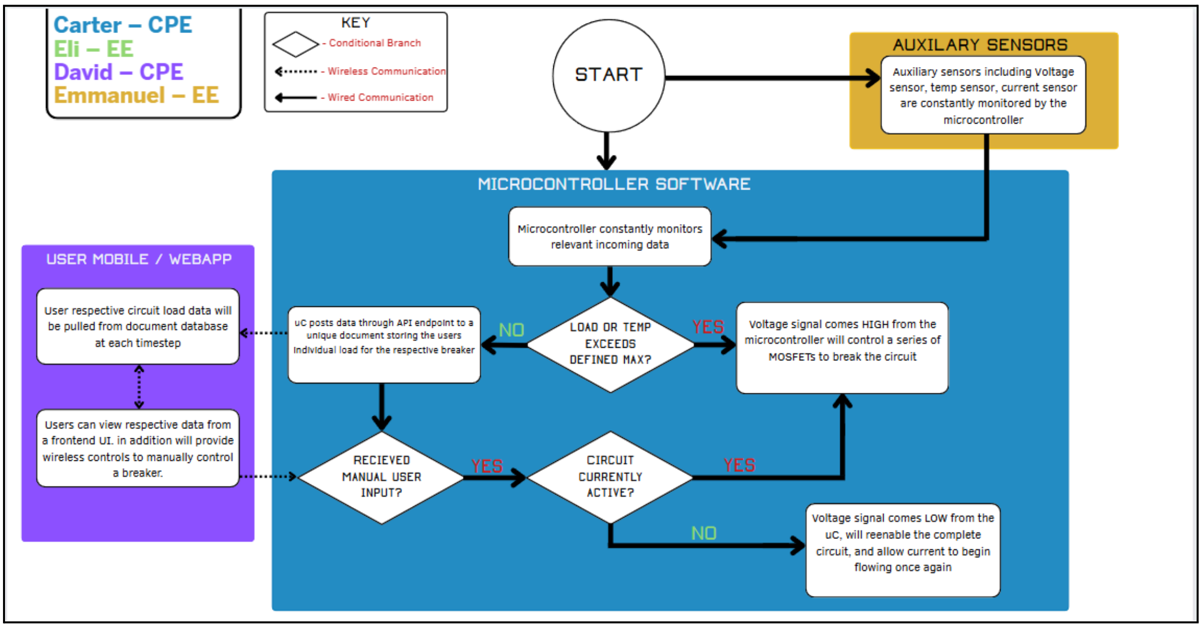

Figure 2.7.1: Software Diagram by Authors

2.9 House of Quality

The House of quality provides us with a good insight into what we should expect when performing cost analysis on our project in areas that include: Safety, Marketability and Efficiency which will be analyzed against themselves.

In our analysis we found that cost was the most impactful factor when compared against the efficiency and safety of the device. Though we want the device to be as effective as possible to the end user, it would be of no use to them if the cost for materials and building was extremely high. In terms of cost analysis the group had decided that safety was the main objective of the project as the design was being funded by Dr. Qun Zhou Sun from the University of Central Florida. Other factors such as sensor accuracy, current capacity, and scalability fit into the theme of safety which was already discussed to have been of greater importance than the former.

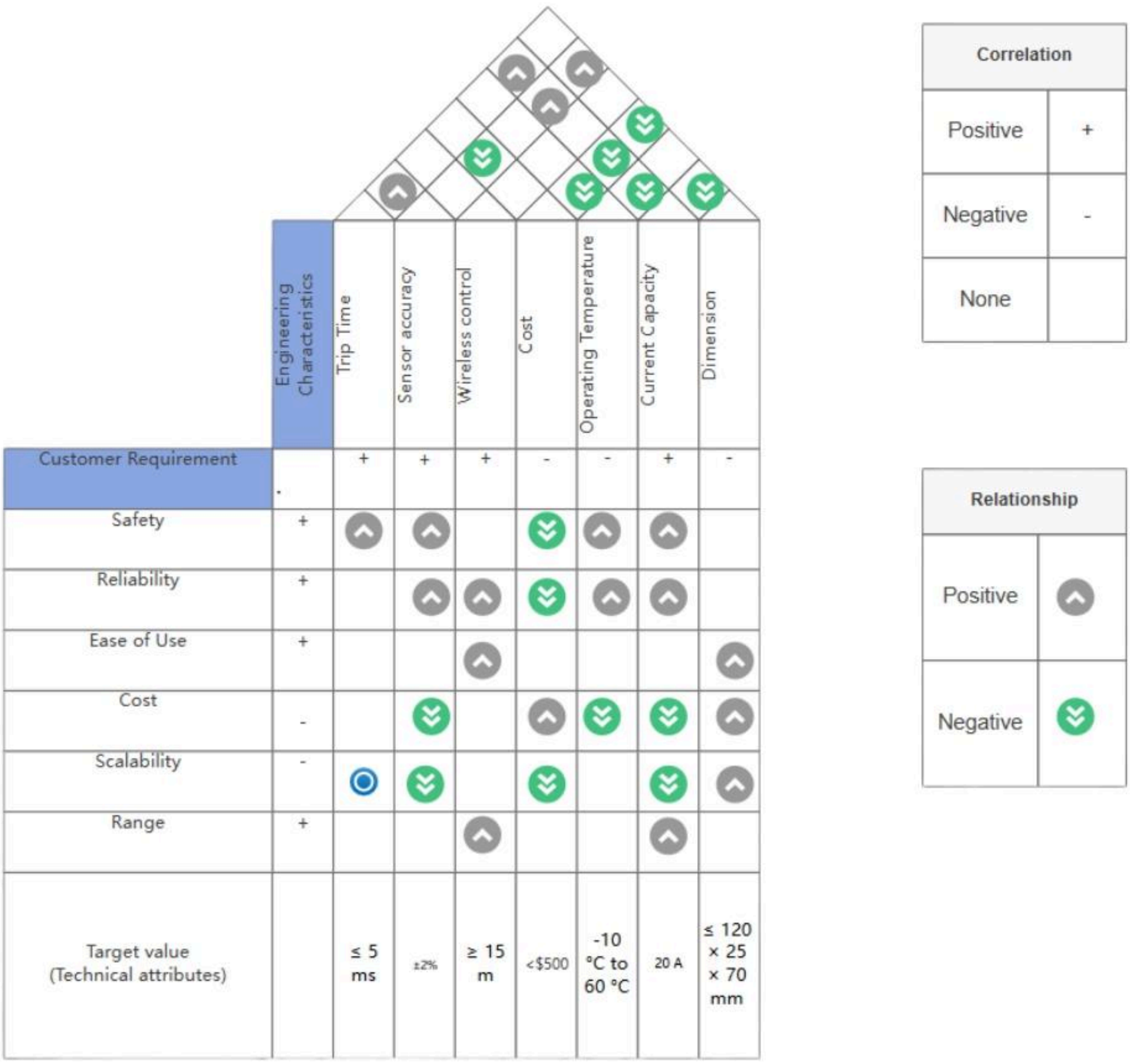

Figure 2.9.1: House of Quality by Authors

Chapter 10 - Administrative Content

10.1 Budget and Financing

The goal of this project is to keep all costs below $500 and within a reasonable cost range for our sponsor, while having enough resources for replacement parts. As of right now we are currently set to be within the set price range however we have not yet accounted for possible damaged parts, replacements, or other expenditures that might occur during the designing, prototyping, and construction of the project.

Figure 2.10.1: Budget table

Sub-System	Budget
Power Subsystem	$170
Web Application	$10
User Interface	$150
Total	**$330**

10.2 Bill of Materials

Figure 2.10.2: Current Bill of Materials

Bill of Materials			
Item	**Qty**	**Cost/Unit**	**Subtotal**
Shunt-trip breaker	1	$120	$120
MCU (ESP32)	2	$9.99	$19.98
CT + burden	2	$20	$40
Voltage sensor module	1	$15	$15
Temp sensors	2	$1.75	$3.50
Antenna (Adafruit ESP32 Feather V2)	1	$19.95	$19.95
Isolated AC/DC supply	1	$30	$30
WCS1800 (Hall-Effect)	1	$10	$10
Switching PSU	1	$10	$10

Relay Module	2	$9.30	$18.60
IRLZ44NPBF – MOSFETs	10	$1.33	$13.33
Total			**$300.36**

10.2 Project Milestones

For a project of this scale multiple milestones are mentioned in the table below to keep the entire team updated on what needs to be completed by what time. Furthermore, important other dates that did not require submissions were implemented to remind everyone of what to watch out for and what information to bring up on certain meetings. Because we have a sponsor for this project we incorporated sponsor meetings with both Dr. Qun Zhou Sun and the company she is working with, Grid Interactive Things Inc. The Senior Design I milestones have certain dates attached to them ; however, the milestones for Senior Design II are still able to be changed as the project progresses.

Senior Design I Project Milestones

Project Initialization			
Title	Start Date	End Date	Duration
Project Scope	08/18/2025	08/29/2025	2 Weeks
Divide & Conquer Design Document	08/25/2025	09/05/2025	2 Weeks
Begin Sponsor Meetings (Occur Every Tuesday)	09/02/2025	11/25/2025	1 Hour
Divide and Conquer Document Revision	09/08/2025	09/12/2025	1 Week
Project Proposal Meeting	09/10/2025	09/10/2025	30 Min
60 Page Report Milestone	08/25/2025	10/31/2025	2 Months
60 Page Report Revision	11/03/2025	11/07/2025	4 Days
Final Page Report (120 Pages)	11/01/2025	11/25/2025	3 Weeks
Mini Demo Video	10/20/2025	11/25/2025	1 Month

Senior Design II Project Milestones

Project Fabrication			
Title	Start Date	End Date	Duration
Initial Model Assembly/Software Development (Prototype)	01/05/2026	02/02/2026	1 Month
Initial PCB Order	01/12/2026	01/26/2026	2 Weeks
Bug Testing and Fixing	02/02/2026	03/02/2026	1 Month
PCB Revisión Order	02/10/2026	02/20/2026	2 Weeks
PCB Optimization	02/20/2026	03/01/2026	2 Weeks
Prepare Video	03/02/2026	03/14/2026	2 Weeks
Prepare Website	03/02/2026	03/14/2026	2 Weeks
Final Presentation	TBD	TBD	2 Hours

Appendix A- References

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