ECE 44X Capstone

Project Document

GSM-based Substation Monitoring and Control System

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Project Group #15

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Contents

1 Overview

1.1 Executive Summary

1.1.1 Problem Statement

In the world we live in, almost every thing needs to be powered by electricity, and our daily lives are very dependent on that power. We need electricity to have light, power our machines that makes our daily jobs easier, and even for heating and cooling to survive in ext ream hot and cold weather. All of this power is usually coming from a nearby substation that receives power from a power generating facility, it then steps up that power to high levels and distributes it to local communities. The process of the power transmission is highly risky and every substation needs to be implemented with safety regulations to consider risks associated with a substation.

After the pandemic, the online working environment is growing rapidly, and at this time,some countries require companies to have remote working environments as an option for employees. In a traditional substation, engineers are always looking for a new tool to control and monitor the operations of the substation without the need to be there in person as the risk for the employees in a substation is very high.

1.1.2 Proposed Solution

A solution such as designing a system that allows engineers working on the substation to monitor various parameters of the substation through the network, enabling better access to multiple parameters at the same time would be very beneficial and efficient in such operation. It also allows for easy remote control, so that any issues related to the monitored parameters can be dealt with from a distance when they are detected. We will also provide an alert function for the system, so that when the substation reaches a preset threshold, employees will be notified and the system will automatically stop the substation to assure the safety of the local communities and the components of the substation and employees there.

The objective of the project is to obtain remote control over electrical parameters such as voltage, current, etc.This can be achived by using a GSM communication device to allow users to collect real-time values and the status of the power station through the network[1]. The user can send commands in the form of SMS messages to read the electrical parameters in addition to shutting off/on the substation remotely. The system will also be capable of sending SMS alerts[2] whenever a risk is detected such as the voltage or current exceeding a predefined limit. Using this method rather than an web page to to veiw the monitored values and control the operatino would be more secure for some substations as the GSM module operates based on cellular connection such as 4G connection where a web page would require additional network implementation so that the substation is always connected to an online server. Online options such as a web page would have a larger risk on the attack of hackers where a GSM module would only recive commands and send data to a registered number.

1.1.3 System's Circuit Board

The project makes use of a custom-made PCB for micro-control processing and to fit the specific needs of the project. This PCB can effectively communicate with the different sensors that are being used. The controller is provided with some internal memory to save the code. This memory is used to transfer assembly instructions into the controller. The operation of the controller depends on these assembly instructions. The controller is programmed in the embedded C language.

1.2 Team Communication Protocols and Standards

Team Members Contact

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1. Team Protocols and Standards Table

Protocol Description	Standard of Satisfaction
Communication	All team members should communicate with each other and be active. Also, team members should update each other about their progress. Team members should ask questions, contribute ideas and give feedback.
Meetings	Showing up to every set meeting is very important as there will be items discussed about the project which will be pertinent and relevant for the project's success. All team members will show up in order for the project process to go smoother. Unless other matters which are urgent appear, all team members should be at meetings. If urgent issues arise for a team member, they will notify the rest of the team ahead of time.
Submissions	Every submission must be submitted in the time domain given.
Budget	All bought components must be proposed to and discussed with team members explaining why it should be bought and how it will benefit the project in addition to being included in a BOM for the project.
Individual Tasks	Every team member should be informed of every task that they have been given and if they find any trouble or need help, they should inform the team members.
Ethical Behavior	Every team member is responsible for their action's, they should be honest in their progress towards their work and individual parts,and fair towards treating other team members equally as an individual.If failed to do so, the member who violated the ethical agreement will receive a warning from the team before reporting the matter to appropriate officials.
Problems	Every individual is responsible for reporting all and any issue that may arise during work such as components not arriving on time, or their block is not functioning as the team agreed on how it should. Confusion and not fully understanding the task or the functionality of that block is considered an problem and should be reported and discussed with the team at the earliest possible so that we can come up with possible solutions or alternatives for that matter, or helping with understanding the task fully for a better outcome.
References	All work and research that has been accumulated for the project must be referenced and cited.

1.3 Gap Analysis

The GSM-Based Substation Monitoring and Control project seeks to ease the actions of substation maintenance and operation both on the local and national level. Consequently, this project will be marketed towards local electric utilities and federal/national electric providers/generators.

At the current moment, substations have to operated and maintained by an individual or groups of individuals at all times to ensure proper functionality and safety. In some instances, individual substation operators are assigned multiple substations to operate. Having to operate multiple substations and other times have individuals at each substation is unnecessary; therefore, the GSM-based Substation

Monitoring and Control System will provide the means to eliminate unnecessary strain on operators by allowing them to remotely access and control substation controls and monitoring equipment from any location.

It is assumed that this project will be able to completely replace the need for on-site substation operators and instead reduce the role down to one individual that can remotely control and operate all systems and monitors within the substation.

Various stakeholders of this project would be local power utility companies and federal agencies such as the Department of Energy. This project will benefit these organizations due to its ability to simplify and expedite substation operations and tasks.

1.4 Timeline/Proposed Timeline

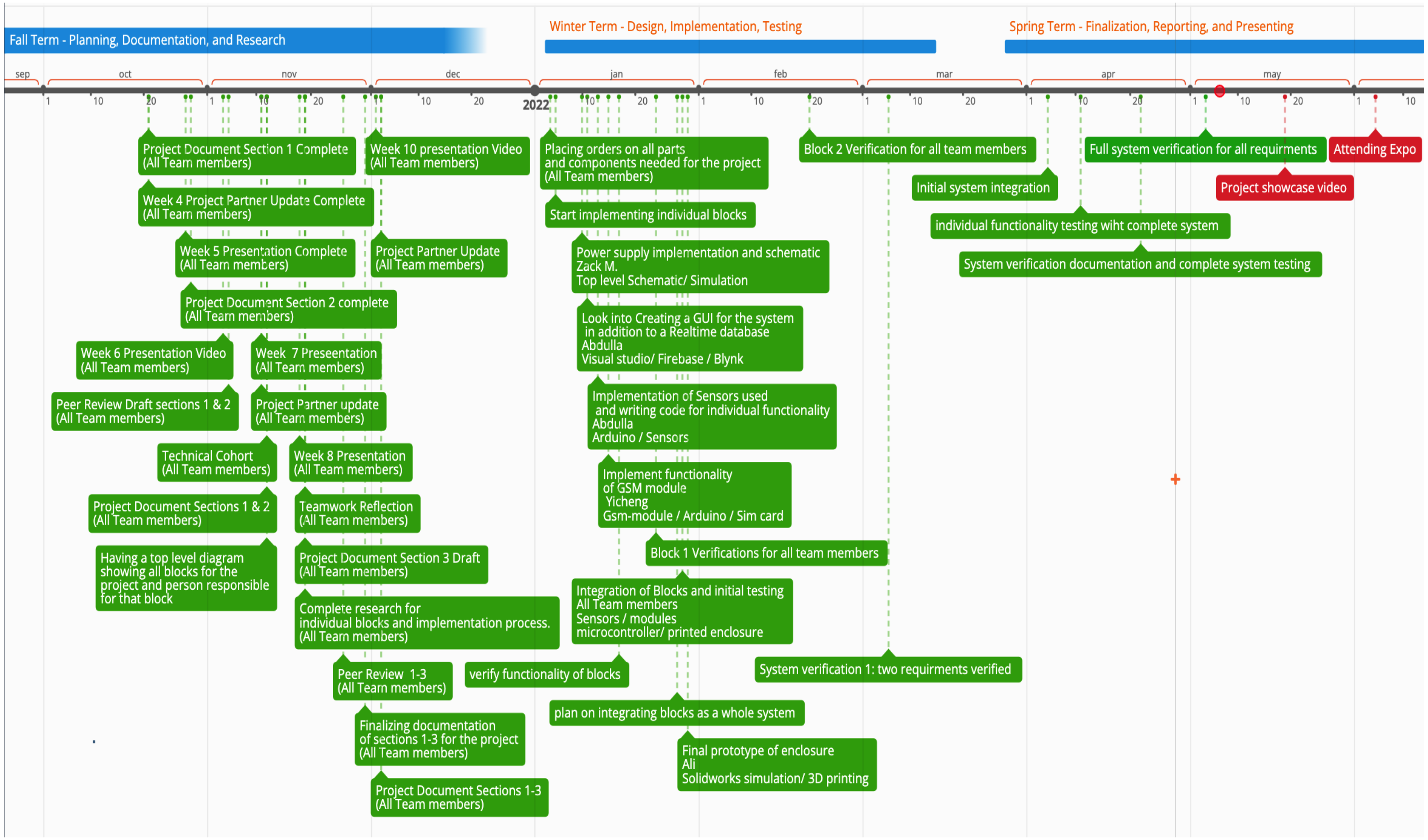

Figure 1: Overall proposed Timeline for project over the next 2 terms where the critical path of the project is th eevents above the term timeline and the base time for starting that process is below.

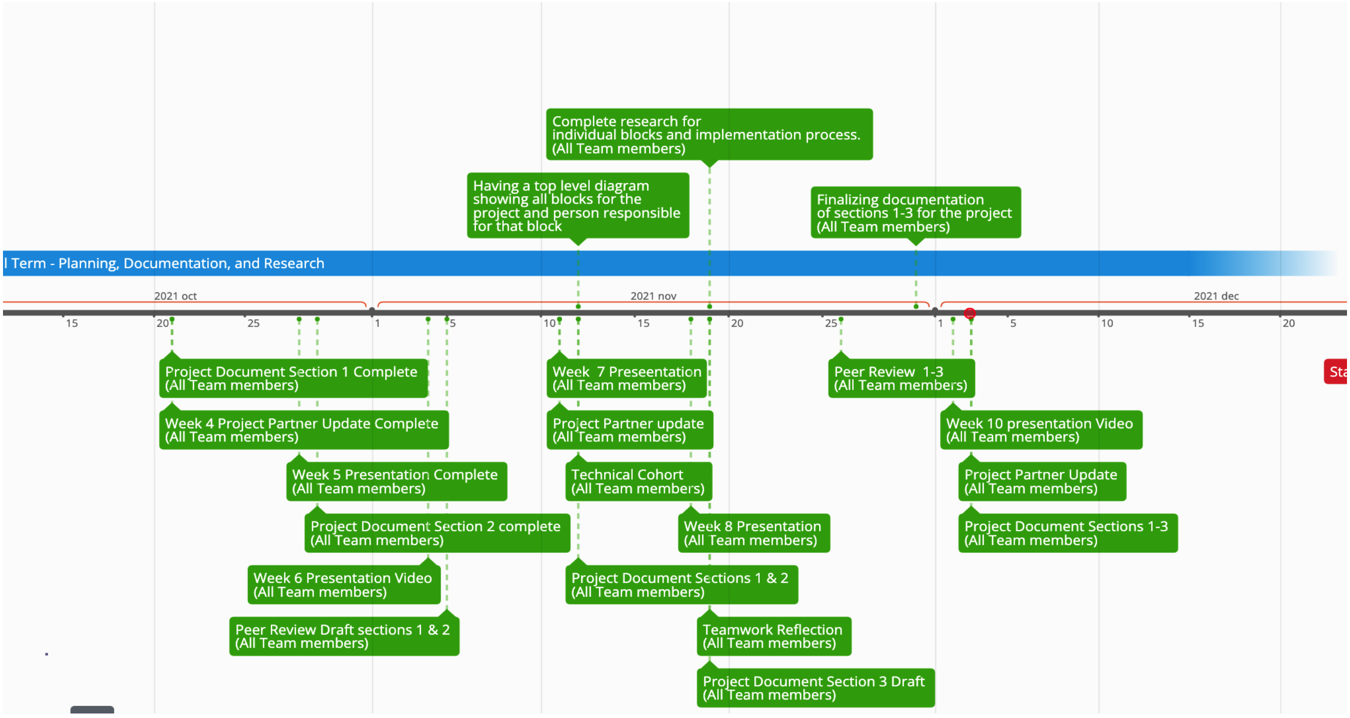

Figure 2: Timeline for Fall Term where green events are considered as complete and Red as working progress, events under the blue label are documentation for the project and events above are the project design progress.

1.5 References and File Links

1.5.1 References

[1]Tinyosshop.com, 2021. [Online]. Available: https://www.tinyosshop.com/datasheet/GSM%20Shield%20Datasheet.pdf. [Accessed: 20- Oct- 2021].
[2]A. Industries, "Adafruit FONA - Mini Cellular GSM Breakout - SMA Version", Adafruit.com, 2021. [Online]. Available: https://www.adafruit.com/product/1963?gclid=Cj0KCQjwtrSLBhCLARIsACh6Rmj3_xxCy2rLj94FqS1uUE_A9JohMBP6pRByXN1YPN95OvC_sQAhIbUaAqGQEALw_wcB. [Accessed: 20- Oct- 2021].

1.5.2 File Links

How a substation Works
Libraries for different sensors using Arduino

1.6 Revision Table

Revision Table		
Date	Revision Description	Revision done by
20 October 2021	sections 1-3 where added to the document and each group member responsible for a specific subsection of section one added their material to finish the draft of section 1	Yicheng Section 1.1 Ali Section 1.2 Zach Section 1.3 Abdulla Sections 1.4, 1.5
27 October 2021	The timeline background and the event's blocks colors were changed. Section 1.4 Section 1.5	Abdulla
27 October 2021	Executive Summary has been updated and explained in depth regarding the nature of the project. Section 1.1	Yicheng
27 October 2021	Team protocol and standards table was updated to have a clear example of an possible problem or issue that may arise. Section 1.2	Ali
29 October 2021	Gap Analysis and Executive Summary expanded upon and edited based on Section 1 Draft feedback Section 1.1 Section 1.3	Yicheng X. Zach M
9 November 2021	Timeline was updated adding design progress and goals for the project. Section 1.4	Abdulla
9 November 2021	Table for team protocols and standards was updated to add details for Budget, Ethical behaviour, and problems protocols Section 1.2	Ali
9 November 2021	Indentation issue was fixed and updated were references where used in section 1.1.1. Section 1.5	Abdulla
12 November 2021	Executive summary updated to briefly explain what is a substation and what is the use of it, additionally section 1.1.2 heading was updated to better describe its content. In addition to adding the overall project goal and what the project is trying to achieve. Section 1.1	Yicheng
3 December 2021	Updated section 1.4 to include critical path and member responsible for that event	Abdulla

2 Requirements, Impacts and Risks

2.1 Requirements

2.1.1 Accuracy

PPR: Reading parameters within 5% accuracy

ER: The voltage and current sensors must be able to read voltage, current, and frequency within an error percentage of 5%

Verification Method: An Commercial amp/voltage meter should be connected to the output of the system while connecting a load that consumes power, check by sending the request to get values sent via GSM module as SMS and compare with the reading from the voltage/amp meter connected.

1. Connect the commercial voltage/amp meter to the output of the system.
2. Connect the load to the output of the system.
3. Turn on the power delivery form the system.
4. Request for the values being read from the sensors by pressing the proper button on the GUI to be sent via SMS to the registered phone.
5. Compare the value that was sent from the system with the value being displayed on the voltage/current meter.

2.1.2 Enclosure

PPR: Enclosure must be functional if flipped over 180 degrees from a starting position of the lid top facing up.

ER: The enclosure that the electrical devices reside in must be able to withstand being flipped over 180 degrees from start position.

Verification Method: After the enclosure is designed and printed, the enclosure must be sealed and placed upright and then flipped over 180 degrees. All components must remain functional and not be damaged.

1. Fully close enclosure.
2. make sure lid is facing up towards the ceiling/sky
3. Turn system on via power supply
4. Flip box over 180 degrees
5. Test by sending commands from the GUI to control the system by turning on and off the output of the system
6. Check for light bulb if it is turning on and off.
7. Flip box over 180 degrees to its original position.
8. Remove lid to inspect components within the enclosure and verify that they are not damaged and continue to function properly by controlling the system from the GUI.

2.1.3 Alert

PPR: Alert when risk detected

ER: The system must alert the user via text if there was a risk detected from an increase in the voltage/current safe operating levels (>2A).

Verification Method: A commercial amp meter would be attached to the output of the system while connecting a load that requires more current than the safe level of operation. The system should automatically shut off and the user should receive an SMS saying that the system has detected a risk.

1. Connect the commercial amp meter to the output of the system.

2. connect the test load to the output of the system.
3. turn on the system from the GUI to enable power transmission.
4. Check for the reading on the amp meter.
5. Check phone for possible SMS sent form the system stating that the system was turned of for safety purposes.

2.1.4 Shutoff

PPR: Auto-shutoff when risk detected.

ER: The System must be able to automatically shut off the substation via relays when a risk (>2A). is detected to protect the substation components.

Verification Method: An Commercial amp/voltage meter should be connected to the output of the system while connecting a load that consumes more than the operating levels.

1. Connect the commercial voltage/amp meter to the output of the system.
2. Connect the load to the output of the system.
3. Turn on the power delivery for the system.
4. check the displayed values on the voltage/amp meter.
5. Check the phone for SMS received from the System stating that the relay was turned off with the detected risk value

2.1.5 Power

PPR: Powering the Arduino UNO and SIM7000 through an external power source

ER: The system will be powered by a step-down converter that will convert 120VAC to 5VDC so that it can power an Arduino UNO and charge the battery for a SIM7000 communication module. The power will also be used to power voltage and current sensors through the Arduino UNO. The range of voltage will be between 4-5V.

Verification Method: Connecting the outputs of the power regulator to a programmable load and plugging the input plug into both the input side of the board and into a 120VAC wall outlet. The programmable load will read the output voltage and the currents that the system is drawing.

1. Connect wires on output side of power regulator to positive and negative leads of programmable load
2. plug 120VAC input into the input side of the board.
3. set current values for range of expected currents that will be drawn from Arduino UNO, sensors, and SIM7000.
4. test for various currents to test for ranges of voltages that are to be expected.
5. repeat process above for all parameters.

2.1.6 Controlling

PPR: Controlling the substation using Computer Graphical User Interface

ER: The user must be able to manually control (Turn ON/OFF) the relay in the substation via a GUI.

Verification Method: Connecting a multi meter to the output of the system and read power levels, and sending a message to the GSM module from Adafruit GSM Module using the turn on or turn off message to assure system shutoff or turn on by reading the power values from the multi meter.

1. An Commercial amp/voltage meter should be connected to the output of the system while connecting a load to the output of the system as well.
2. Connect the voltage/amp meter to the output of the system.
3. Connect a load such as an lamp to the output of the system.

4. Press the ON command form the GUI.
5. Check that the lamp has turned on.
6. Press the OFF command on the GUI.
7. Check that the lamp has turned off.

2.1.7 Analyze

PPR: Build a system that analyzes voltage, current, and frequency data for 2 minutes and sends it to the GSM module

ER: Build a system that analyzes voltage, current, and frequency data for 5 minutes and sends it to the GSM module. The sensors must sample for 2 minutes. This data will be transmitted serially between the GSM module and the users computer.

Verification Method: Run the system for 2 minutes and ensuring that at least 1,000 data points are collected that are within an error % of +- 5%

1. Connect multi-meter to sensors to measure actual voltage, current, and frequency numbers.
2. Record voltage, current, and frequency values observed after transmission from GSM module.
3. Run system for 2 minutes.
4. Compare values to ensure accurate results as well as no errors occurred along the way.

2.1.8 Fitment

PPR: Power Regulator, GSM module, sensors, and Arduino UNO must all fit within 15" X 13" X 7" 3D-printed enclosure.

ER: All components should fit within a 15" X 13" X 7" enclosure.

Verification Method: Fit components, sensors, and boards within enclosure.

1. Place all components within enclosure
2. Attach all cables and wires to boards

2.2 Design Impact Statement

2.2.1 Introduction

The GSM-Based Substation Monitoring and Control Project is being designed and produced to allow power grid substation workers to monitor and control substation systems (i.e. voltage, current, and frequency from transmission lines). The GSM system will work with multiple substations so that workers can monitor multiple stations at once. With the GSM-Based Substation Monitoring and Control project, there are a variety of details with the project that can both negatively and positively impact workers, the environment, and society as a whole if implemented fully. The Design Impact Assessment will analyze and assess the potential negative impacts that GSM Substation project will have: public health, safety, and welfare impacts, cultural and social impacts, environmental impacts, and economics impacts. Public health, safety, and welfare impacts will analyze the impacts of the project on job accessibility, automation of jobs, and power grid security.Job growth/decline and security are important issues to public health and welfare because they directly influence whether more employees can be hired and paid or more employees are fired and lose money. Power grid security affects countries in various aspects: allowing for continuous power to homes and businesses, public transportation, and the tools that run economies. Cultural and social impacts will analyze the impact of the project on the social fabric of United State of America in response to the implementation of the project such as changes to work conditions and work responsibilities. The impact on the environment will be analyzed through the lens of vehicle travel and substation maintenance. Finally, economic factors affected by the implementation of the GSM project will be analyzed to deduce the negative and positive impacts on economies nationally and globally.

2.2.2 Public Health, Safety, and Welfare Impacts

Technology exists to benefit humanity.[1] Whether technology is meant for the health sector, energy, or leisure, the advancement of technology is intended to improve quality of life for humans and the world. However, there are various aspects of technology that are often overlooked that can negatively affect humanity and the world as a whole. The public health, safety, and welfare of humans are both affected positively and negatively by the GSM-Based Substation Monitoring and Control System due to its intended ability to ease the duties of substation workers but could also lead to workers being laid-off for the sake of saving money.

The ability for workers to perform their duties remotely has been shown to lead to increased work performance over their on-site peers.[2] The GSM-Substation system would allow substation operators, workers that normally need to be on-site at substations at all times during the work day, to work from home while completing the same tasks. This could also open opportunities for disabled workers to be able to complete the same tasks as their non-disabled peers by providing more options for them to complete their tasks. Disabled employees need accommodations in order to help them to work on equal footing as their non-disabled peers, so a remote monitoring tool can aid in equalizing the work.

However, the process of making substation operation remotely controllable can lead to the loss of jobs due to automation and less workers needing to be had for the same amount of work. According to the World Economic Forum, an estimated 85 million jobs will be lost due to automation [3] The automation of jobs can negatively affect an individual's income, health, and relationships as an economic burden would be placed on them. This negative impact causes hardships for individual's and could, at the extreme, cause death due to said hardship. It is of great importance for the GSM project to address this issue and implement designs that will encourage the growth of jobs and not the reduction of jobs. A neutralization or growth in jobs will come from a series of checks and balances on the part of the user. Since a worker will not have to be present at substations to monitor them, it can be assumed that less operators are needed; however, with the vast importance of the power grid, the same amount of workers, if not more, will be needed to make sure all systems continue to run and function properly and what the monitoring operator is seeing is correct. Any changes needed to the system that the operator can perform will also follow a chain of command before implementation can occur to ensure proper operations.

Another major negative impact the GSM project can impose would be the potential for a necessary and fundamental system to be hacked into and controlled by unknown third-party entities. It is already an issue that other countries will try to commit cyberattacks against the US and its electric grid to cause disruption to critical infrastructure.[4] The GSM Substation project will have the responsibility to its customers/stakeholders to provide the best security it can to protect the electric grid from hostile entities. A potential cyberattack on the electric grid would be catastrophic as the electric grid is one of the most important infrastructure sectors within the country. it will be of utmost importance to the project to prioritize security measures for the system in order to make the project viable for use.

Another positive aspect that the GSM Substation project contributes to public health, safety, and welfare is by providing the ability for workers to conduct work on substations that are in different locations. Many substation operators operate multiple substations that will be in various locations. By implementing a remote access monitoring and control system, substation operators would be able to save time and effort traveling to various substations to perform their duties.

2.2.3 Cultural and Social Impacts

Any piece of technology that affects a major pillar of a nation's infrastructure will have lasting, if subtle, effects that are both positive and negative. With the GSM Substation project, a negative that can be attributed to the remote working aspect of the project would be the degradation of company culture. Engaging and aligning with the culture of a company can lead to long term satisfaction with an employee's work and their engagement with their work.[5] If an employee isn't satisfied with their work or doesn't find much engagement with their work, then productivity will decrease and necessary work won't be completed; consequently, it would not matter if a system that allowed users to remotely access, monitor, and control was available since it would ultimately lead to less productivity instead of more. Also, a substation operator could be more effective at work in the substation, and by having work be remote could cause an issue with work-life balance. By providing access to a remote option should not mean that all users should move to a remote work scenario, but instead should work with their strengths and use the GSM Substation project if wanted. It will be recommended that the project will be designed in a way that will accommodate for work to be done both from home or at a work site, whichever so that will be best desired. Work at home and at the work site can be accommodated by having strong wireless signals in the users chosen work area. The Adafruit GSM module can wirelessly communicate up to 850/900/1800/1900MHz, which is sufficient for communication through various surfaces and distances.

On the other side of the argument, it can be seen as a positive to allow more options for employees to choose from in how and where they conduct their duties. Giving more options to employees regarding their work has been shown to improve said employee's health and well-being. [6] For work productivity to be greater and work quality to be better, then prioritizing employee health and well-being is of utmost concern. By giving the option for workers to work remotely with the GSM Substation system, employees can benefit themselves and have the choice in how and where they wish to perform their work. The GSM Substation project will provide the means for employees to have a choice in their work and have individuality in their lives.

2.2.4 Environmental Impacts

The environment and the overall health of the Earth is vastly important, especially for future generations that will have to live with the condition of the Earth no matter what state it's in. Any project being made needs to assess how it will affect the environment due to the already existing conditions in which climate change is already performing well. The GSM Substation project performs well in various aspects in terms of protecting and helping the environment, as well as creating detrimental conditions for the Earth. The issue with designing systems that require electrical components and integrated chips is the environmental cost to manufacturing all of the components. A typical semiconductor factory produces 2 million integrate chips a month all the while consuming 20 million gallons of water, toxic chemicals, and energy which all is disposed as waste and be harmful to the environment.[7] It is ultimately unavoidable for the GSM Substation project, and many other electrical projects, to continue without electrical components, but an effort can be made to choose components that are made from minerals that are sourced naturally and are produced from less harmful processes. When sourcing parts, we will make sure to check where and how the manufacturer sources their components and what will be acceptable and what will not be acceptable. For example, if research finds that a certain component uses slave/child labor to source the minerals to make the component, we will find an alternative that is sourced more ethically.

One component that will be used on the PCB for the GSM Substation project will be capacitors, as they are necessary components to regulate voltage and current and produce viable output voltages; however, there are certain capacitors that are sourced and made from less ethical means. Tantalum capacitors are effective capacitors because they offer noise-free operation, high current-ripple handling, and low equivalent series resistance. These are all highly desirable traits to have in capacitors; however, the sourcing of tantalum ore is of great ethical concern. Tantalum ore is mined in the Democratic Republic of the Congo (DRC) where the money raised from selling the ore has aided in funding conflict and human rights abuses over the past two decades.[8] There are many other alternatives to tantalum capacitors that do not contain the same ethical quagmires such as ceramic, fusible tantalum, and electrolytic capacitors. These capacitors don't have the same efficient attributes that tantalum has, but they are close in their values and would be sufficient as replacements in order to not support DRC human rights abuses.

Despite the environmental negatives that are present within the project, that will be avoided with certain design considerations, there are also positives to the project that will help with the environment. By allowing workers to work from home and not have to travel to various work sites, gasoline is being saved and less carbon is being released into the atmosphere. Commuting to a work space is unnecessary while in a remote-work status and thus will lead to individuals contributing less to climate change.[9]

2.2.5 Economic Factors

Most technological projects are intended to be sold to consumers in the hopes of creating a profit or to assist in helping a company be more efficient in order to make more money. The GSM Substation project will fall into the second category, but there are certain negative aspects to being a tool to expedite processes. When a tool is designed to last for as long as possible, it can hurt the economy because not as many systems will have to be bought. When less of a product is consumed, the economy shrinks. Less components will have to be bought because less systems will be built; therefore, less money exchanges hands and the economy shrinks. Also, when components can be bought, the GSM Substation project will help to contribute to the global chip shortage occurring in 2021. This in turn leads to other companies, such as the automotive industry, to not be able to receive the chips they need to manufacture there product and will subsequently sell less products.[10] The spiraling nature of the global chip shortage has led to economies being damaged since goods and services cannot be produced and served at the rates they could pre-COVID19.[11] The GSM Substation project will factor these component shortages into the design to ensure that only the necessary components are acquired for the system to function properly.

2.2.6 Conclusion

The idea behind building a system that allows workers to remotely access, monitor, and control various equipment and settings within substations via GSM communication is one based upon aiding humanity and improving the quality of life of power systems employees; however, there are always avoidable and unavoidable negative impacts to various sectors either due to the project or contributed by the project's existence. Whether it be the public health, safety, and welfare of workers, the cultural and social impacts felt by society, the harm to the environment, or the economic price for our project, there are both positives and negatives. The GSM Substation project both gives employees choice and freedom to help aid their health and overall well-being at work, but also can cause job loss due to automation. It gives employees the ability to work in a better working environment, or allow for opportunities for employees to be less productive due to less work incentive. Pollution of the Earth can both be contributed to and negated by the GSM project, as well as the economy, either from buying up chip stocks or hurting economies by contributing to the global chip shortage. Various methods for negating the negative aspects of the project include adding more jobs to authenticate and monitor the employee that will be monitoring and operating the system, implementing PCBs that can work wirelessly through thick materials and long distances so the worker can work as close or far to the substation as they want, and conducting extensive research on component sourcing to understand if safe and ethical practices are used to mine and make the material. Overall, the project is in a state that it is worth pursuing and will be more of a benefit than a hindrance to society and the world as a whole.

2.3 Risks

Risk table is present on the next page.

Risk ID	Risk Description	Risk Category	Risk Probability	Risk Impact	Performance Indicator	Responsible Party	Action Plan
R1	Vendor Delay	Timeline	85%	High	Parts unavailable/on back order on vendor websites	Zach M.	Reduce delay by ordering components as early as possible.
R2	Teammate sickness	Team	50%	High	Team member becomes sick and is unable to do work/performs less work	Abdulla A.	Transfer partiality of sick member's work to another willing member to help & receivers
R3	User mishandles enclosure/components and breaks the system	User	20%	High	Components of project (GSM Module, Arduino, Power supply, Enclosure) fail to work as tested because of unintended damage	Yicheng X.	Group will ensure that there is a reduction in slick spots on components and will make sure surfaces are easy to handle
R4	Limited access to proper tools	Logistics	30%	High	Proper tools for tasks are not available	Zach M.	Solicit course instructors for equipment
R5	Schedule/timeline not followed or not defined well	Timeline	10%	Medium	Schedule overview during weekly meetings	Ali A	Ali will make sure to reference team schedule for the term during each meeting to ensure the team is on-track. If team is not on track, Ali will make sure to note on the schedule and let the team know so that the team can brainstorm ideas to fix the delayed schedule.
R6	Sensors aren't calibrated correctly	Technical	30%	High	Sensors display incorrect values because they are not calibrated before installation and use	Abdulla A.	Read sensor manual and ensure calibration tests are conducted before use
R7	Wires come loose/disconnect from components and short circuits	Technical	20%	Medium	Improper cable making and connecting cables to components.	Ali A.	Review electric boards and components to ensure proper connections and no faulty bodges/traces.
R8	GSM firmware issues	Technical	60%	High	Incorrect GSM behavior due to improper coding	Yicheng X.	Review code and compare with online resources

Table 1: Risk Assessment and Action Plans

2.4 References and File Links

2.4.1 References

[1]A. Sachan, Microcontroller Based Substation Monitoring and Control System with Gsm Modem. 2021.
[2]Supervision and Control of Substation by using GSM Module and Microcontroller, 8th ed. International Journal of Innovative Technology and Exploring Engineering (IJITEE), 2019.

2.4.2 File Links

Measering voltage/current
What is IP rating and how it works.

2.5 Revision Table

Revision Table		
Date	Revision Description	Revision done by
25 October 2021	All Subsections for section 2 have been included in the document All subsections for section 2	All team members
27 October 2021	risk table is complete in addition to the requirements and their verification method Section 2.1 Section 2.3	Abdulla Zach
9 November 2021	Requirements were updated to the specified format. addition of 2 more requirments where made.Section 2.1	Abdulla
9 November	Reference numbering, as well as indentation error for references and file links where fixed Section 2.4	Abdulla
11 November	Added new design requirements, engineering requirements and verification methods, as well as edited existing requirements. Added new Risk table items Section 2.2 and 2.4	Zach M.
19 November 2021	Updated the requirements section based on feedback. Section 2.1	Abdulla
2 December 2021	Updated requirements by adding appropriate heading, splitting GUI requirement into controlling and monitoring requirements and removing wall wart power supply requirement. Also reformatted and edited risks within the Risks section to better match feedback: Section 2.1-2.3	Zach M. Abdulla
6 May 2022	Included content for DIA portion of section. Added all sections including Public Health and Safety, Cultural and Social Impacts, Environmental Impacts, and Economic Factors.	Zach M.

3 Top-Level Architecture

3.1 Block Diagram

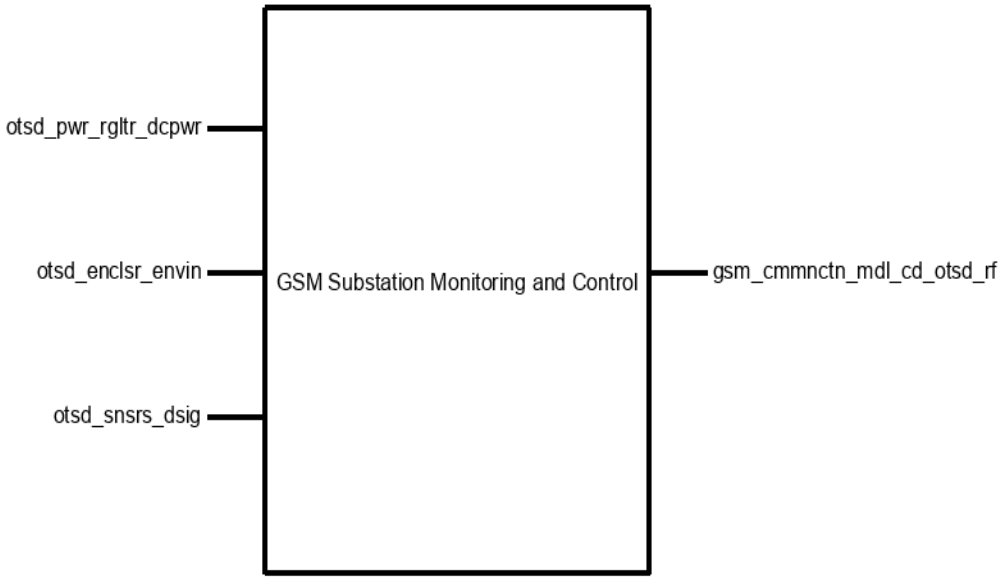

Figure 3: Black Box diagram for project

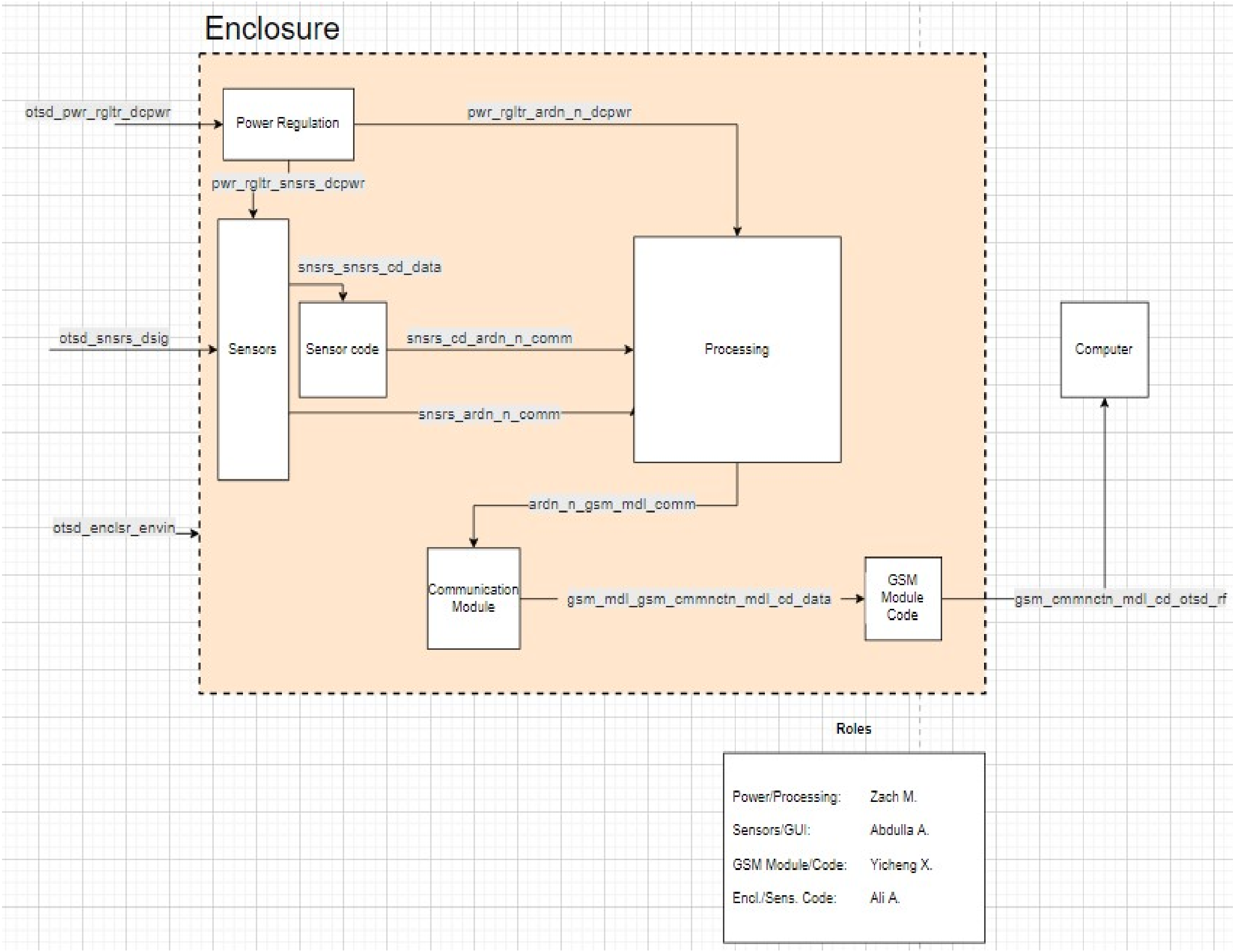

Figure 4: Block diagram for project

3.2 Block Descriptions

Block Descriptions	
Name	Descriptions
Power Regulator Champion: Zachery McLaughlin	Power regulator to take 12v from a 12v wall wart and convert it to 5v and 3.3v for sensors and PCBs. This regulator will provide constant power to these systems for optimal use[1].
GSM Module code Champion: Yicheng Xiong	The code that will process the data from the sensors and the Arduino UNO. This code will allow the messages to be sent over wireless communication to a remote user[2].
Enclosure Champion: Ali Alfadala	The enclosure will house all of the components of the project i.e. the power regulator, sensors, and GSM/Arduino combo. The enclosure will be IP65 rated to protect the components from splashes of water, dust, dirt, and impact.
Sensors Champion: Abdulla Al-Mannai	The sensors include one that detects voltage, one that detects current, and one that detects frequency. These sensors should be running at all times and will send data to the Arduino Uno through serial communication[3].
GSM Module Champion: Yicheng Xiong	The GSM Module (Adafruit FONA) will take the information processed through the Arduino UNO and prepare the data to sent over wireless communication to the user system. The GSM Module will allow for seamless remote work where a user will be able to remotely access the information from the overall system via the GSM Module.
Sensors Code Champion: Abdulla Al-Mannai	Code to process the sensor data received. Will be process through the Arduino Uno.
Arduino Uno Champion: Zachery McLaughlin	Arduino Uno that will process data from the sensors and send it to the GSM communication model for sending wirelessly. The Uno is directly compatible with the GSM module and hosts great tools to process signals.

3.3 Interface Definitions

Name	Properties
otsd_pwr_rgltr_dcpwr	• **Inominal:** 2 - 3 A • **Ipeak:** 3 A • **Vnominal:** 125 VAC
otsd_snsrs_acpwr	• **Inominal:** 2.5A • **Ipeak:** 2.53A • **Other:** Load: 300W lamp • **Vnominal:** 122V
otsd_gsm_mdl_dcpwr	• **Inominal:** 0.3mA • **Ipeak:** 0.48A • **Vmax:** 5.5V • **Vmin:** 4.5V
otsd_g_usrin	• **Usability:** Clickable button "Values" • **Usability:** Clickable button " ON" • **Usability:** Clickable button " OFF"
pwr_rgltr_ardn_n_dcpwr	• **Inominal:** 8 mA • **Ipeak:** 38 mA • **Vmax:** 5.10 V • **Vmin:** 4 V
pwr_rgltr_gsm_mdl_dcpwr	• **Inominal:** 20mA - 25mA • **Ipeak:** 30 mA • **Vmax:** 5.10 V • **Vmin:** 4 V
snsrs_snsrs_cd_asig	• **Other:** AC sine wave • **Vrange:** 0-5V (Current Sensor) • **Vrange:** 0-5V (Voltage Sensor)
snsrs_cd_ardn_n_comm	• **Messages:** Voltage • **Messages:** Frequency • **Messages:** Current
ardn_n_gsm_cmmnctn_mdl_cd_comm	• **Other:** Configures Arduino to send status SMS to user • **Other:** Configures Ardunio to turn relay off and on based on data from GSM hardware • **Protocol:** Ardunio Download
ardn_n_gsm_mdl_comm	• **Messages:** Voltage • **Messages:** Frequency • **Messages:** Current
gsm_mdl_ardn_n_comm	• **Messages:** Voltage • **Messages:** Frequency • **Messages:** Current
g_gsm_cmmnctn_mdl_cd_rf	• **Messages:** Sending an SMS "off" • **Messages:** Sending an SMS "get" • **Messages:** Sending an SMS "on"

Figure 5: Interface Definitions for the Block Diagram

3.4 References and File Links

3.4.1 References

[1]"DC/DC Switching Regulators | Overview | Power ICs | TI.com", Ti.com, 2021. [Online]. Available: Voltage converter/regulator. [Accessed: 20- Nov- 2021].
[2]A. Industries, "Adafruit FONA 800 Shield - Voice/Data Cellular GSM for Arduino", Adafruit.com, 2021. [Online].Available: Adafruit Fona [Accessed: 20- Nov- 2021].
[3]A. Industries, "Adafruit INA260 High or Low Side Voltage, Current, Power Sensor", Adafruit.com, 2021. [Online]. Available: INA260 [Accessed: 20- Nov- 2021].

3.4.2 File Links

Adafruit FONA:
- Library for Arduino
- Datasheet

INA 260 Voltage/current/power sensor:
- Library for Arduino
- Datasheet

How to use Solid Works

3.5 Revision Table

Revision Table		
Date	Revision Description	Revision done by
19 November 2021	subsection for section three were added to the document including the top level black box, block diagram and their descriptions,interface definitions, and references and links to documents used Seciton 3.1 - 3.3 Section 3.4 and 3.5	Zack M. Abdulla
2 December 2021	Sections 3.1 and 3.3: Interface definitions updated to include feedback from Section 3 Draft. Block diagrams updated as well to match desired format	Zach M.
6 May 2022	Updated Interface List to reflect current interfaces as of May 2022	Zach M.

4 Block Validations

4.1 Arduino UNO: Zachery McLaughlin

4.1.1 Description

Zachery McLaughlin will obtain an Arduino UNO for the GSM-Based Substation Monitoring and Control project. The Arduino UNO will interface with the system's sensors and the GSM module (Adafruit FONA) that will convert the sensor information to transmittable data for the GSM module to send to the user. The voltage, current, and frequency sensors will transmit their respective data to the input side of the Arduino UNO, where the UNO will parse the data. The data will be compressed into a readable format for the Adafruit FONA to send as transmittable information to the end-user's computer.

The Arduino UNO is a board houses the ATMega328P microcontroller with 14 input/output pins, of which 6 can be PWM outputs. A computer can be used to program the Arduino UNO to facilitate data transfer. The UNO will be powered via the custom power supply that will convert voltage and current from the monitored transmission line to a manageable voltage and current for the entire system to use.

4.1.2 Design

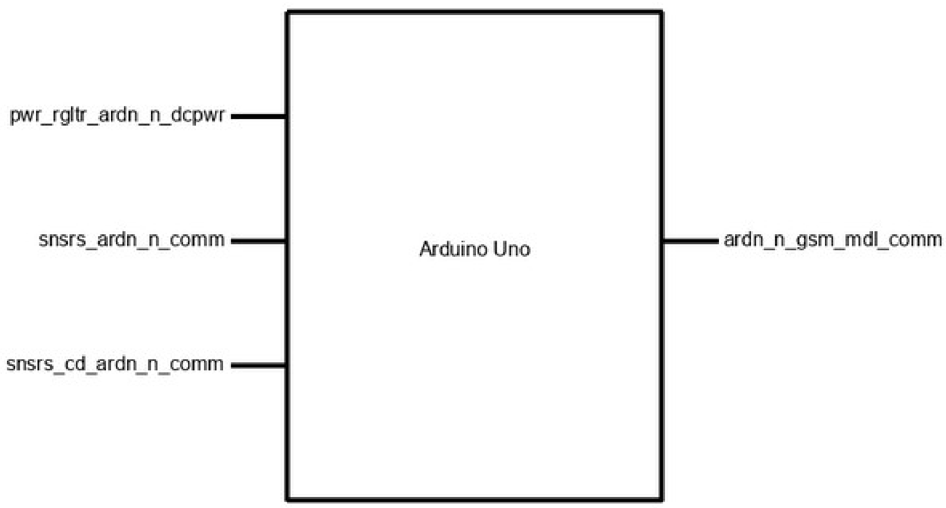

Figure 6: Black Box diagram for project

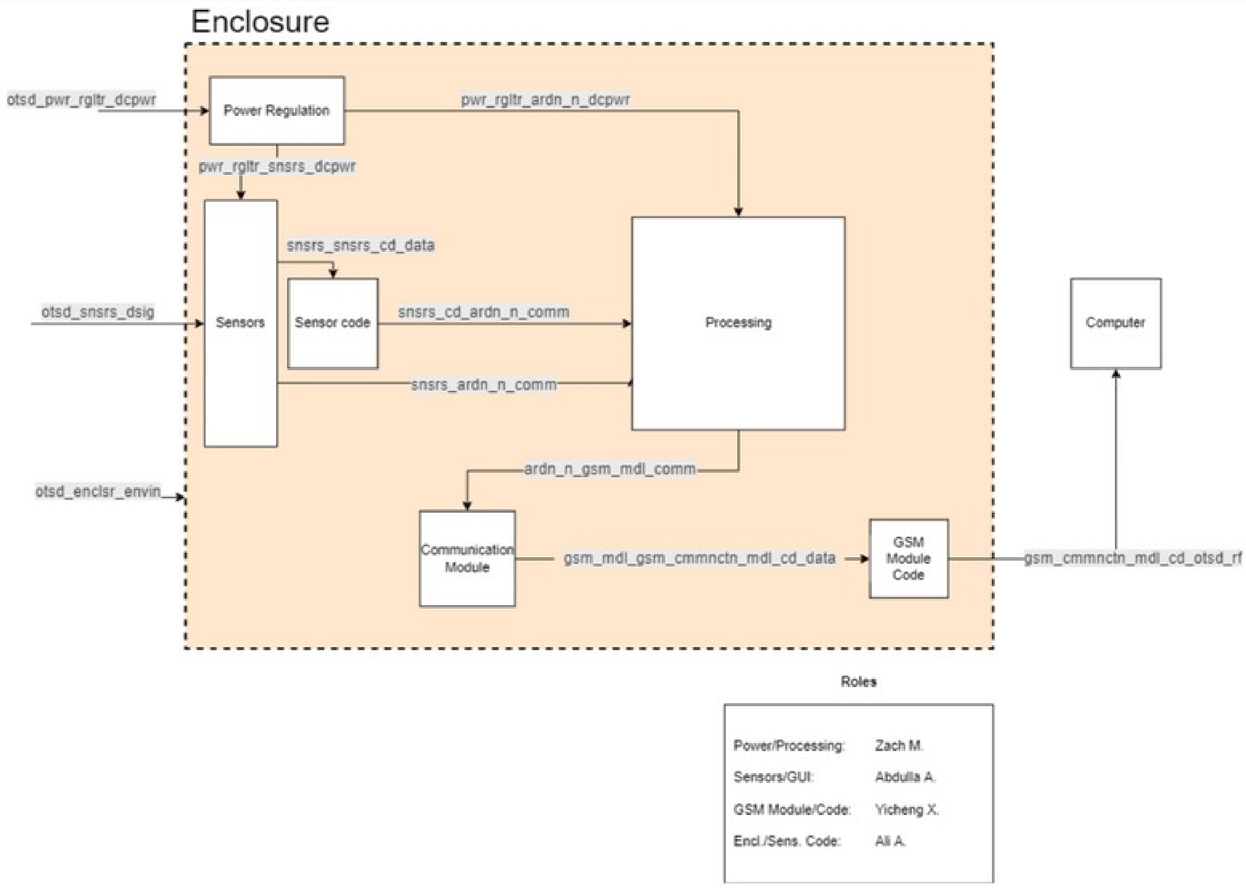

Figure 7: Block diagram for project

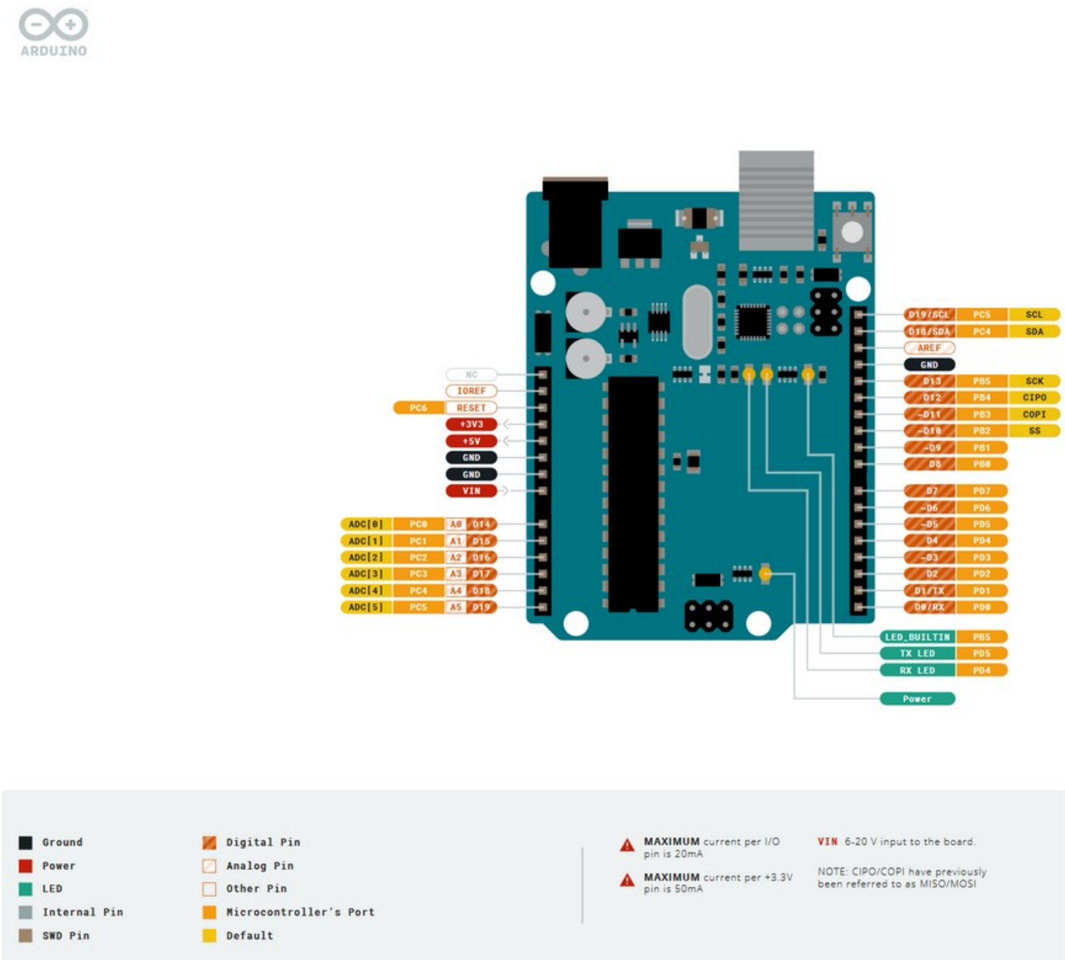

Figure 8: Black Box diagram for project

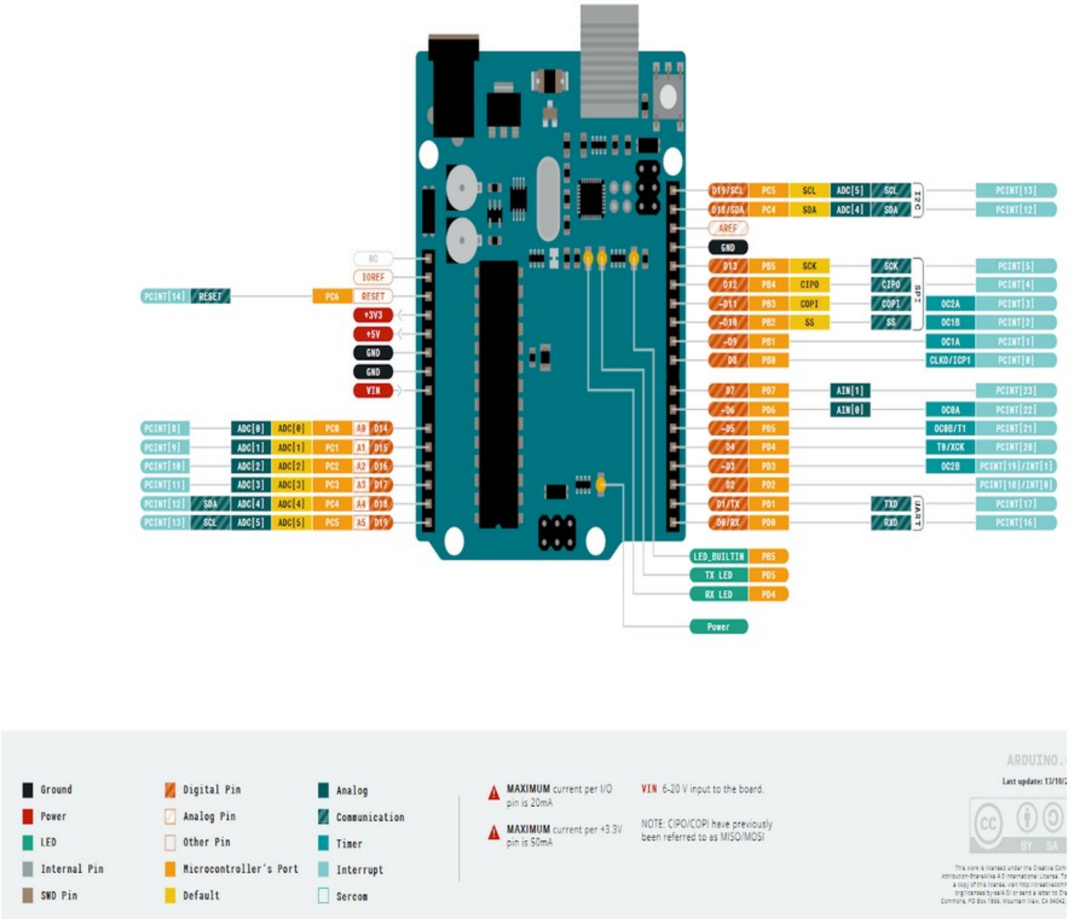

Figure 9: Block diagram for project

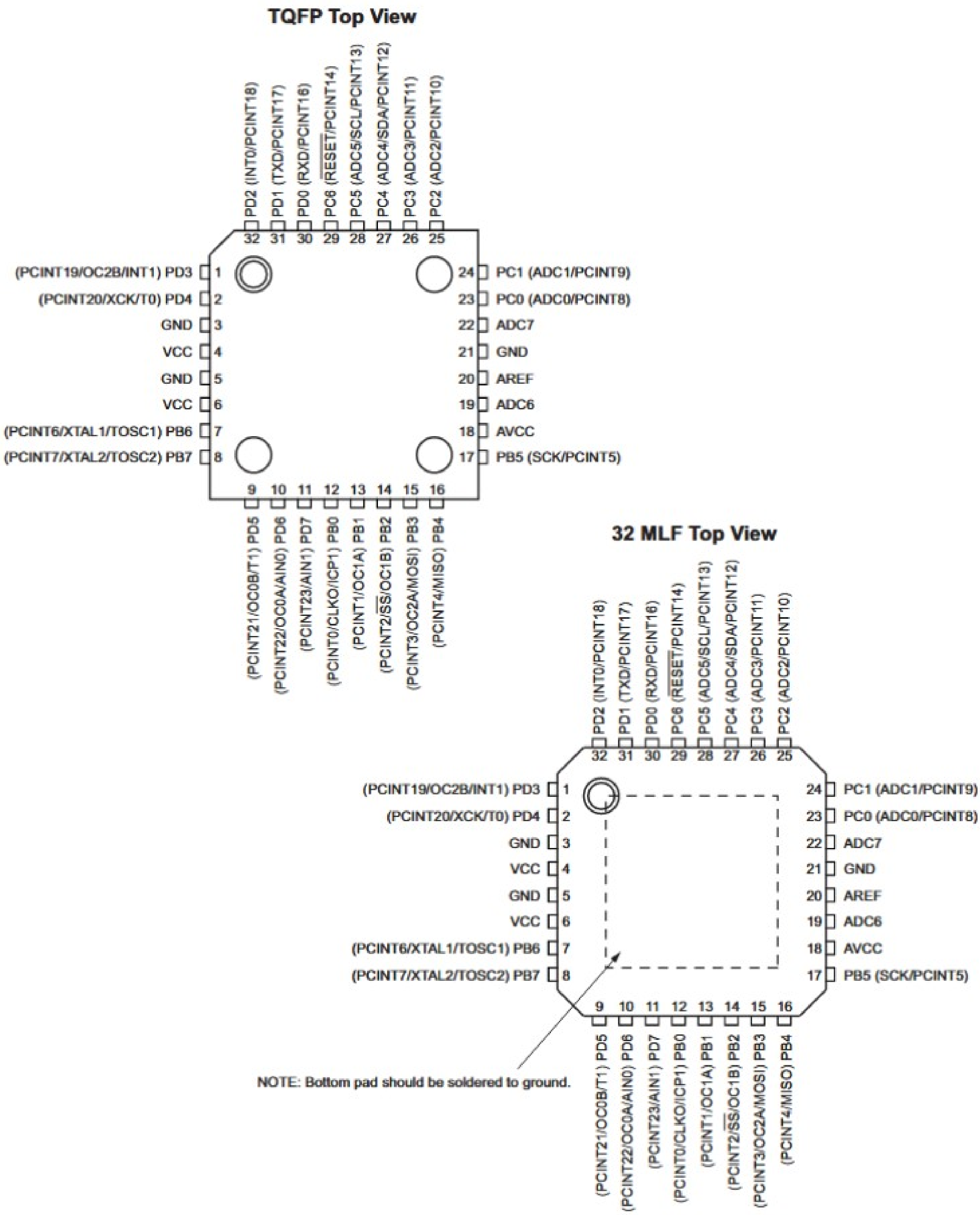

Figure 10: Black Box diagram for project

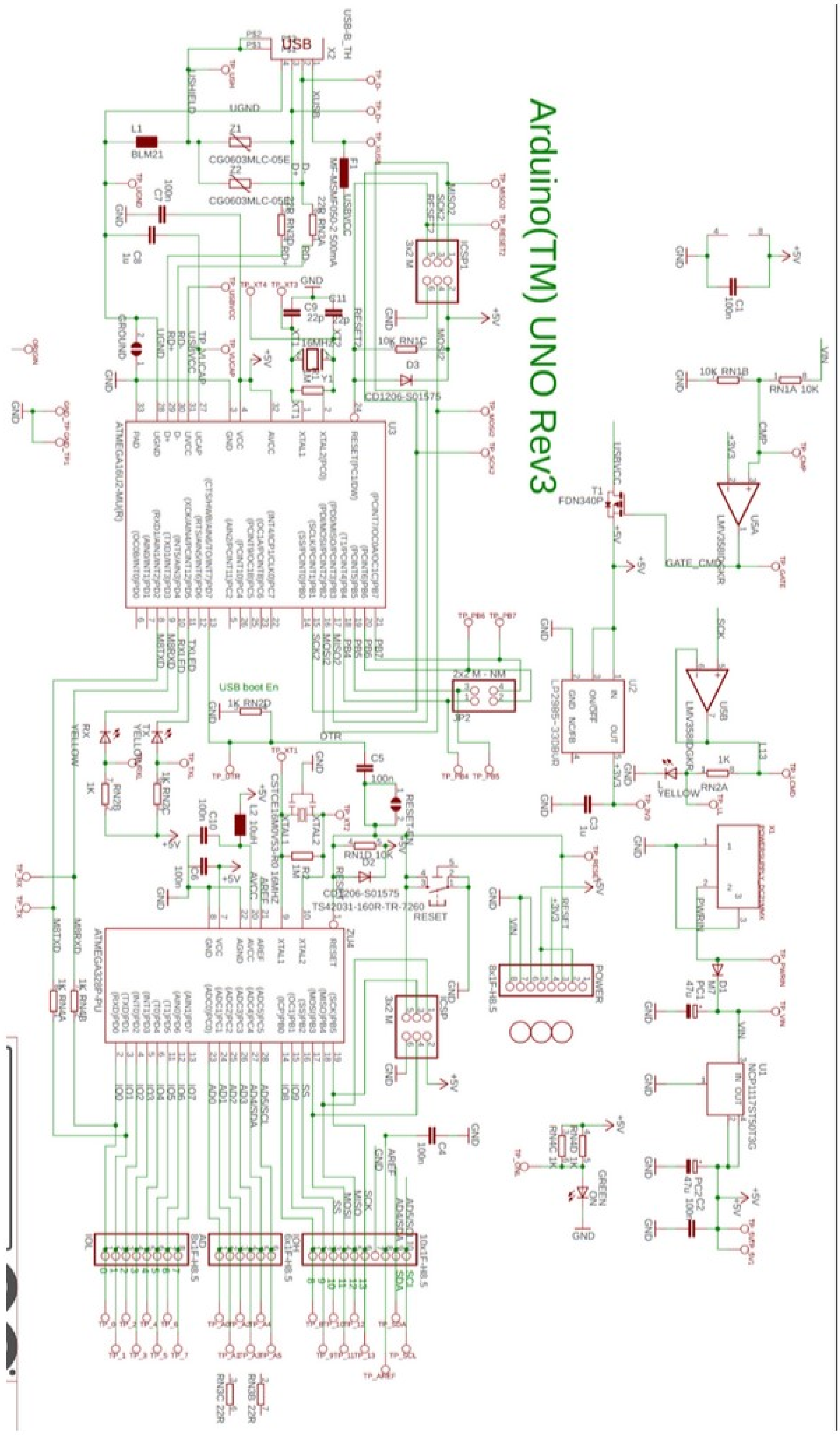

Figure 11: Block diagram for project

5.1 JANALOG

Pin	Function	Type	Description
1	NC	NC	Not connected
2	IOREF	IOREF	Reference for digital logic V - connected to 5V
3	Reset	Reset	Reset
4	+3V3	Power	+3V3 Power Rail
5	+5V	Power	+5V Power Rail
6	GND	Power	Ground
7	GND	Power	Ground
8	VIN	Power	Voltage Input
9	A0	Analog/GPIO	Analog input 0 /GPIO
10	A1	Analog/GPIO	Analog input 1 /GPIO
11	A2	Analog/GPIO	Analog input 2 /GPIO
12	A3	Analog/GPIO	Analog input 3 /GPIO
13	A4/SDA	Analog input/I2C	Analog input 4/I2C Data line
14	A5/SCL	Analog input/I2C	Analog input 5/I2C Clock line

5.2 JDIGITAL

Pin	Function	Type	Description
1	D0	Digital/GPIO	Digital pin 0/GPIO
2	D1	Digital/GPIO	Digital pin 1/GPIO
3	D2	Digital/GPIO	Digital pin 2/GPIO
4	D3	Digital/GPIO	Digital pin 3/GPIO
5	D4	Digital/GPIO	Digital pin 4/GPIO
6	D5	Digital/GPIO	Digital pin 5/GPIO
7	D6	Digital/GPIO	Digital pin 6/GPIO
8	D7	Digital/GPIO	Digital pin 7/GPIO
9	D8	Digital/GPIO	Digital pin 8/GPIO
10	D9	Digital/GPIO	Digital pin 9/GPIO
11	SS	Digital	SPI Chip Select
12	MOSI	Digital	SPI1 Main Out Secondary In
13	MISO	Digital	SPI Main In Secondary Out
14	SCK	Digital	SPI serial clock output
15	GND	Power	Ground
16	AREF	Digital	Analog reference voltage
17	A4/SD4	Digital	Analog input 4/I2C Data line (duplicated)
18	A5/SD5	Digital	Analog input 5/I2C Clock line (duplicated)

Figure 12: Block diagram for project

4.1.3 General Validation

The Arduino UNO is a good fit for this project as it is easy to use, easy to acquire, and has a plethora of documentation to reference. The Arduino UNO is also necessary to this project as it is the best board to pair with the Adafruit FONA GSM module. The team wanted to have a modular and easy-to-use system that would interface well with the Adafruit FONA and could be easily programmable. The Arduino UNO is relatively cheap, coming in around $23 on Arduino's main website. The system is also easily configurable via their Arduino software and code which is a set of libraries for the C++ programming language, including a preconfigured toolchain for compiling C++. programming language. Arduinos were also used during Junior Design, so members of the team have experience with this technology and have a better starting point than with other systems. Moreover, Arduino systems such as the UNO have a reasonable number of input and output pins to facilitate multiple data inputs.

4.1.4 Interface Validation

Block Descriptions		
Interface Property	Why is this interface this value?	Why do you know that your design details for this block above meet or exceed each property?
pwr-rgltr-ardn-n-dcpwr:		
Inominal: 8 mA	The nominal current was based on the Arduino UNO datasheet that details DC current per I/O pin.	For ATMega328P on UNO DC current per I/O pin is 8 mA (Arduino UNO Rev 3 website)
Ipeak: 38 mA	The peak current was based on the Arduino UNO datasheet that details DC current for 3.3V pin (40 mA) with some additional wiggle room	For ATMega328P on UNO DC current for 3.3V pin is 40 mA (Arduino UNO Rev 3 website)
Vmax: 5.10 V	The max voltage was based on the Arduino UNO datasheet that details the recommended input voltage maximum.	For ATMega328P on UNO Recommended maximum voltage value is 7V, but will only use 5.10 V as the input voltage will not vary. (Arduino UNO Rev 3 website)
Vmin: 4 V	The minimum voltage was based on the Arduino UNO datasheet that details the recommended input voltage minimum.	For ATMega328P on UNO Recommended minimum voltage value is 3.3V, but input will only provide 5V from power source. (Arduino UNO Rev 3 website)
snsrs-ardn-n-comm:		
Messages: Frequency	Sensors will collect Frequency information from the transmission line and send it to the Arduino.	Sensors will send string data of frequencies to the Arduino as raw information and will directly connect to the Arduino for connectivity (Judgement Call).
Messages: Voltage	Sensors will collect Voltage information from the transmission line and send it to the Arduino	Sensors will send string data of voltages to the Arduino as raw information and will directly connect to the Arduino for connectivity (Judgement Call)
Messages: Current	Sensors will collect Current information from the transmission line and send it to the Arduino	Sensors will send string data of currents to the Arduino as raw information and will directly connect to the Arduino for connectivity (Judgement Call)

ardn-n-gsm-cmmnctn-mdl-cd-comm:		
Other: Configures Arduino to send status SMS to user	We will use SMS to deliver messages to users	According to SIM7000-LTE-Shield datasheet, SIM7000a has SMS capability
Other: Configures Arduino to turn relay off and on based on data from GSM hardware	Users can control the Arduino to turn on or off through the mobile app	According to Arduino UNO datasheet, the Arduino UNO accepts pin state changes by external commands
Protocol: Arduino Download	This is the protocol provided by Arduino for using their libraries and boards	Testing the Arduino UNO will require the use of the Arduino IDE, and we will need to recompile it based on the Arduino libraries given by Botletics.
snsrs-cd-ardn-n-comm:		
Messages: Frequency	Collected frequency data will be parsed by code to be packaged and sent to the Arduino that will be readable	Sensors code will parse sensor information and send it to the Arduino and will directly connect to the Arduino for connectivity (Judgement Call)
Messages: Voltage	Collected voltage data will be parsed by code to be packaged and sent to the Arduino that will be readable	Sensors code will parse sensor information and send it to the Arduino and will directly connect to the Arduino for connectivity (Judgement Call)
Messages: Current	Collected current data will be parsed by code to be packaged and sent to the Arduino that will be readable	Sensors code will parse sensor information and send it to the Arduino and will directly connect to the Arduino for connectivity (Judgement Call)
ardn-n-gsm-mdl-comm:		
Messages: Frequency Value	Sending Frequency data for the Adafruit FONA to read and send to the user	Arduino will compress frequency data into GSM-readable message strings for the GSM to send to the User (Judgement Call)
Messages: Voltage Value	Sending Voltage data for the Adafruit FONA to read and send to the user	Arduino will compress Voltage data into GSM-readable message strings for the GSM to send to the User (Judgement Call)
Messages: Current Value	Sending Current data for the Adafruit FONA to read and send to the user	Arduino will compress Current data into GSM-readable message strings for the GSM to send to the User (Judgement Call)

4.1.5 Verification Process

1. Pwr_rgltr_ardn_n_dcpwr:

   - Build power regulator and test for functionality before plugging it into other devices (If power regulator is not built yet, use power brick with similar power specifications to ensure proper functionality when real system is used)
   - A DMM will be used to determine the voltage and current that is being produced by the power regulator to ensure proper values for use to power the Arduino UNO
   - Verify nominal currents and voltages to read 20 mA and 5 V respectively
   - Verify that Min/Max of current and voltage are 10mA - 60mA and 3.3v - 12V respectively

1. Snsrs_ardn_n_comm:

   - Arduino UNO will be connected to an Arduino NANO to show that the UNO can receive and send serial data. The UNO will serve as a MASTER and the NANO a SLAVE and the code will send data through the UNO to the NANO and then back to the UNO to show Transmit/Receive functionality. This data will be user-generated signal data to simulate sensor behavior.
   - Observe condition of sensors and make sure that certain ON/OFF and ERROR LEDs are lit or unlit depending on situation
   - Observe values obtained by Arduino from the sensors to ensure they match known frequency, voltage, and current values of the line at that moment
   - If incorrect, disable sensors and troubleshoot the issue.

1. Snsrs_cd_ardn_n_comm:

   - Arduino UNO will be connected to an Arduino NANO to show that the UNO can receive and send serial data. The UNO will serve as a MASTER and the NANO a SLAVE and the code will send data through the UNO to the NANO and then back to the UNO to show Transmit/Receive functionality. This data will be user-generated signal data to simulate sensor behavior.
   - Observe and ensure that data is being sent from the sensors that was parsed by the sensors code is being received by the Arduino
   - Make sure that the information received from the sensors is correct per the measurements from the transmission line itself.

1. Ardn_n_gsm_mdl_comm:

   - Arduino UNO will be connected to an Arduino NANO to show that the UNO can receive and send serial data. The UNO will serve as a MASTER and the NANO a SLAVE and the code will send data through the UNO to the NANO and then back to the UNO to show Transmit/Receive functionality. This data will be user-generated signal data to simulate sensor behavior.
   - Observe and ensure that data is being sent from the sensors that was parsed by the sensors code is being received by the Arduino
   - Make sure that the information received from the sensors is correct per the measurements from the transmission line itself.

4.1.6 References and File Links

[1]"Arduino Uno REV3," Arduino Online Shop. [Online]. Available: Arduino [Accessed: 07-Jan-2022].

[2]"Microchip technology," ATmega48A/PA/88A/PA/168A/PA/328/P megaAVR® Data Sheet. [Online]. Available: Microchip [Accessed: 07-Jan-2022].

1. File Links

   - Arduino UNO Rev3
   - ATmega48A/PA/88A/PA/168A/PA/328/P megaAVR® Data Sheet

4.1.7 Revision Table

Revision Table	
Date	Revision Description
20 January 2022	Zach M: Edited each section of the draft to incorporate peer review and instructor feedback.
06 January 2022	Zach M: Finished Block 1 Validation Draft document
05 January 2022	Zach M: Formatted draft to include all sections for Block Validation Draft. Included information for all sections, minimal information added for later subsections.

4.2 Power Regulator: Zachery McLaughlin

4.2.1 Description

The power regulator for the GSM-Based Substation Monitoring project will take 230V and step it down to 5V for the voltage and current sensors, Adafruit Fona GSM module, and the Arduino UNO. The power regulator will be a custom-made PCB that features a step-down transformer and a bridge rectifier to convert a high voltage down to a manageable voltage for other devices to use. Both voltage/current sensors and the Arduino operate efficiently with 5v; therefore, a step-down to 5v is necessary for optimal performance. The input for this block is also the same input that is being monitored by the sensors, that being the “transmission line”.

As the power delivery method for the overall system, there will need to be a constant and efficient 5V supplied to the other blocks in order to sustain overall operation. A winding transformer, coupled with a AC/DC bridge rectifier, will convert the AC transmission line value down to a 5V DC value for system use. The winding transformer will step-down 230V mains AC down to 12V AC. The bridge rectifier will convert AC voltage to DC voltage, then a voltage regulator will maintain the output voltage to be 5V despite changing conditions of the input.

4.2.2 Design

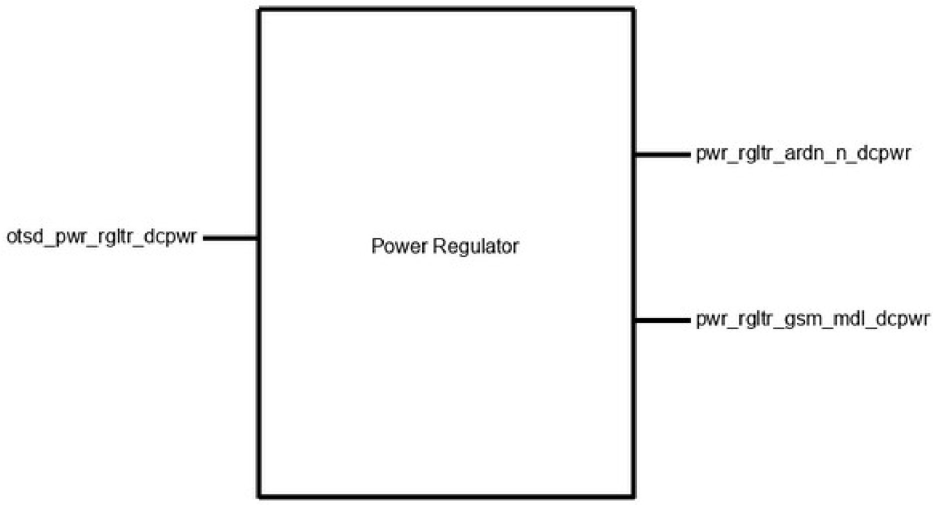

Figure 13: Black Box diagram for project

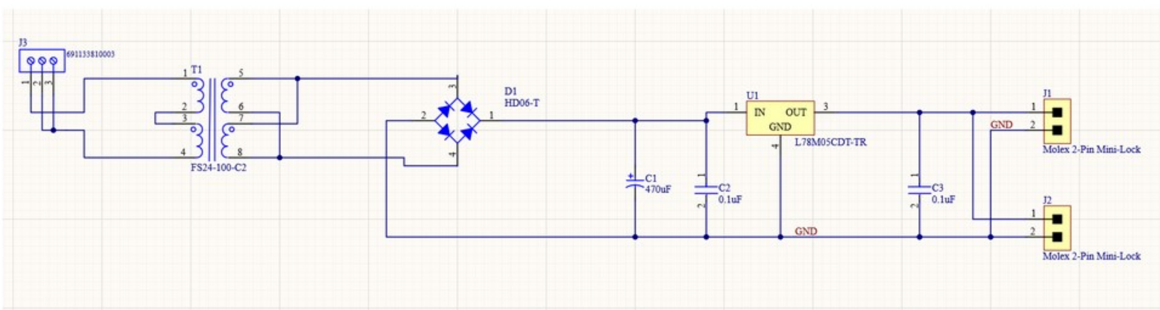

Figure 14: Block diagram for project

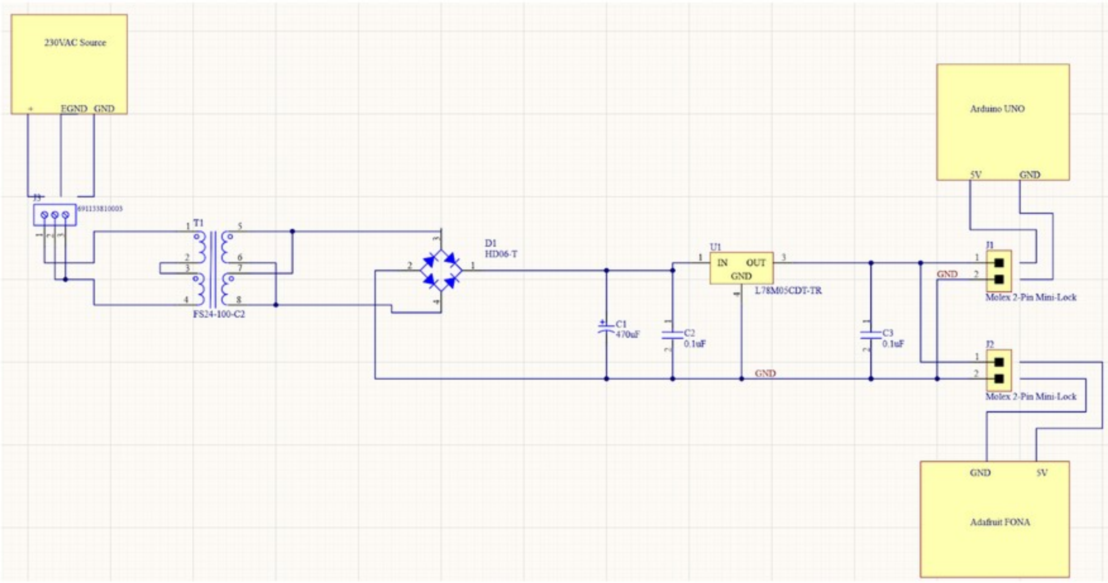

Figure 15: Black Box diagram for project

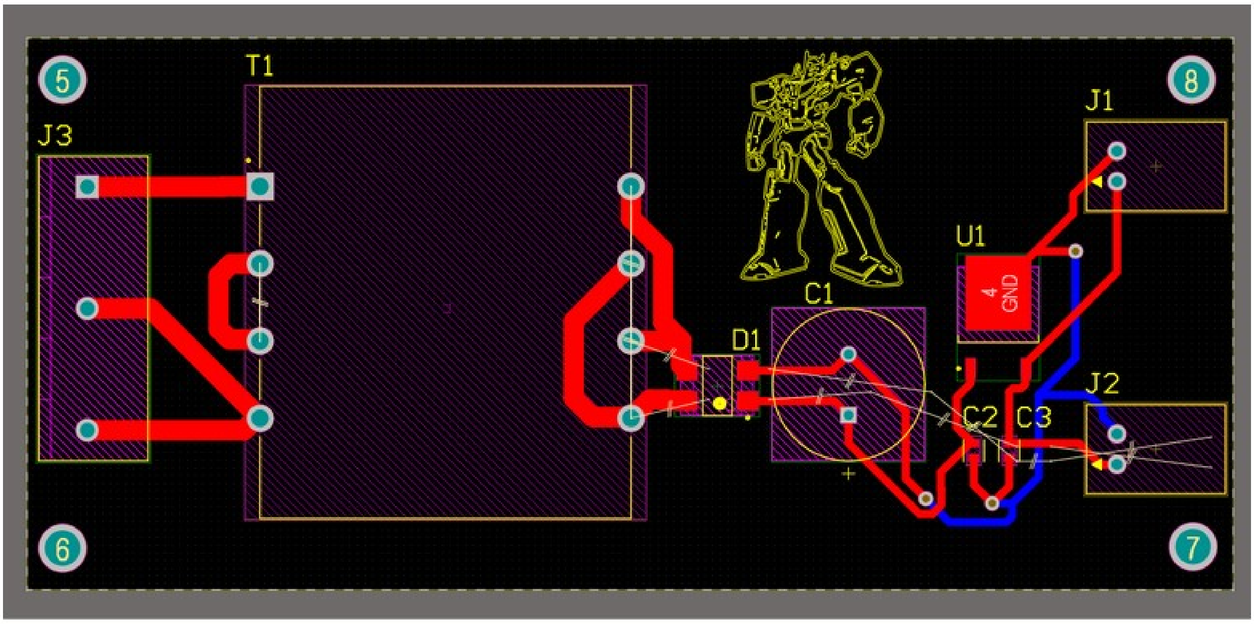

Figure 16: Block diagram for project

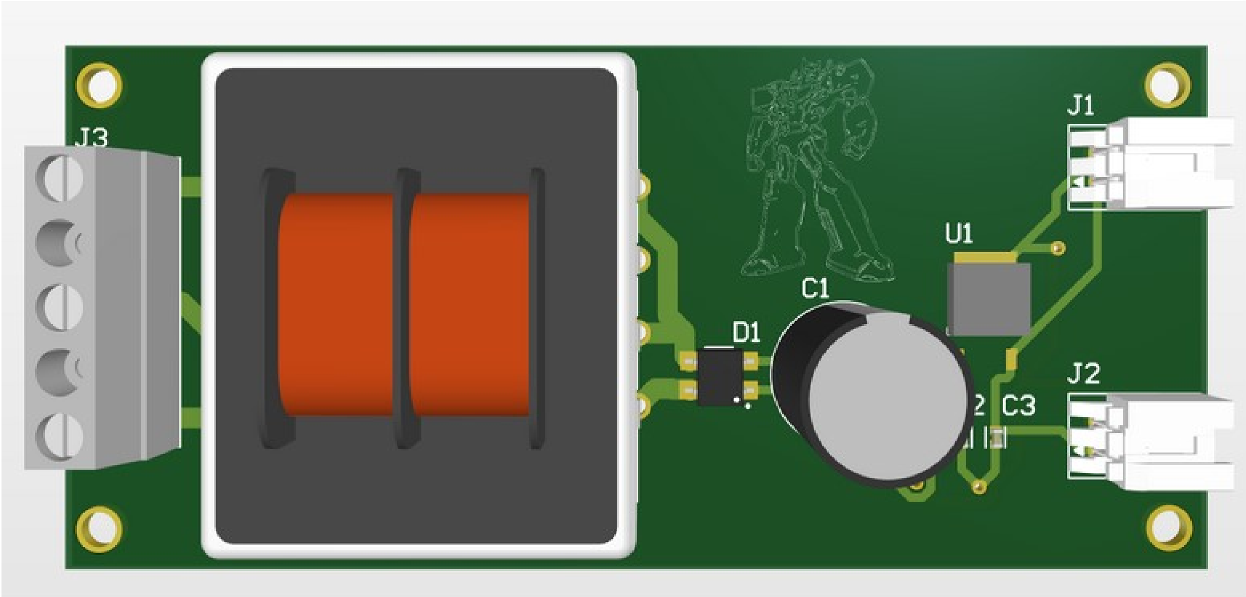

Figure 17: Block diagram for project

4.2.3 General Validation

The power regulator of this system is unique in the sense that it is not receiving power from a conventional power source. The regulator, and thus the entire system, will be receiving power from a “transmission line” that in this case will be 230V AC instead of a 12V wall-wart or conventional 120V AC outlet. Therefore, a specific type of conversion circuit will be necessary in order to convert the 230V AC down to 5V DC in order to power the entire rest of the system. A winding transformer, coupled with a AC/DC bridge rectifier, will convert the AC transmission line value down to a 5V DC value for system use. The winding transformer will step-down 230V mains AC down to 12V AC. The bridge rectifier will convert AC voltage to DC voltage, then a voltage regulator will maintain the output voltage to be 5V despite changing conditions of the input.

Other rectifiers can be used to step-down 230V to 5V; however, they are not ideal for the scenario in which the project exists. A type of rectifier called a Controlled Rectifier could be used to convert the voltage from AC to DC, but they are also used to vary the output voltage based on the input voltage. The project does not need a variable output voltage; therefore, the use of a controlled rectifier is unnecessary as an uncontrolled rectifier is mainly used for constant/fixed power supplies which is exactly what is needed.[1]

Certain considerations have to be made in regards to how the PCB will be made for this regulator such as trace widths and jumper/connector placements. For traces carrying 230VAC mains voltage, a minimum distance of 4mm is needed between traces; however, current is what ultimately decides the width of the traces themselves. The output current through the whole circuit will range from 5A-12A, so traces will need to be 2.5mm-7mm for the outer layers and 5mm-14mm for the inner layers[2].

There were considerations that had to be made when considering which components to order for the power regulator. The FS24-100-C2 Power transformer from Triad Magnetics was chosen to step the 230VAC down to 12VAC. This component can actually do either 115VAC parallel or 230VAC series for an input and either 12VAC parallel or 24VAC series. 230VAC to 12VAC is the desired setup for this transformer. [3] The HD06-T Bridge Rectifier by Diodes Incorporated was chosen to rectify the voltage from AC to DC voltage in order to power external blocks. This rectifier was chosen for its high thermal and current range, those being -55 to 150 C and 800 mA respectively. [4] Finally, the L78M05ACDT-TR Linear Regulator by STMicroelectronics was chosen to smooth drop the 12VDC to 5VDC and smooth the voltage for efficient operation. This linear regulator was chosen for its voltage range and thermal range, those being 5V - 35V and 0 - 125 C respectively. [5]

4.2.4 Interface Validation

Block Descriptions		
Interface Property	Why is this interface this value?	Why do you know that your design details for this block above meet or exceed each property?
otsd_pwr_rgltr_dcpwr : Input		
Inominal: 1-2A	Depending on the load (Arduino UNO, Adafruit FONA, sensors), the load current will vary. This will be the current drawn from the power source i.e. the transmission line.	Per McMaster-Carr Power supplies, 230V current ranges from 3A-12A [6]
Ipeak: 2A	Maximum current draw from the Power regulator. This will be the max amperage drawn to power the rest of the system. 12A will only be needed as a maximum since the Arduino UNO and GSM module will not need much current.	Per McMaster-Carr Power supplies, 230V current ranges from 3A-12A; therefore, max amperage is not to exceed 12A [6]
Vnominal: 125V	Power supply voltage high enough to simulate a minor transmission line. 230V is one of the highest voltages to test at without needing special equipment or sources.	Per McMaster-Carr power supplies that are offered, 230/240V are the highest available for single-phase. 230V is the one being chosen due to how standardized it is. [6]
Pwr_rgltr_gsm_mdl_dcpwr : Output		
Inominal: 0.2mA-0.25mA	The FONA operates at a low current to power all of its functions. The FONA operates on 0.2mA-0.25mA while it is running [4]	According to the FAQ section on the Adafruit FONA website, Adafruit states that 0.2mA-0.25mA is the operating current of the FONA.
Ipeak: 0.3mA	The FONA operates at a low current to power all of its functions. The FONA operates on 0.2mA-0.25mA while it is running. Therefore, the peak would be 0.25mA	For SIM800H on FONA DC peak current is 0.3mA
Vmax: 5.10V	The maximum voltage is 5.5V as any more could cause issues with the function of the FONA	For SIM800H on FONA DC max voltage is 5.5V
Vmin: 4V	The minimum voltage is 4.5V as any less could cause issues with the function of the FONA	For SIM800H on FONA DC minimum voltage is 4.5V
pwr_rgltr_ardn_n_dcpwr : Output		
Inominal: 8 mA	The nominal current was based on the Arduino UNO datasheet that details DC current per I/O pin.	For ATMega328P on UNO DC current per I/O pin is 8 mA (Arduino UNO Rev 3 website)

Ipeak: 38 mA	The peak current was based on the Arduino UNO datasheet that details DC current for 3.3V pin (40 mA) with some additional wiggle room	For ATMega328P on UNO DC current for 3.3V pin is 40 mA (Arduino UNO Rev 3 website)
Vmax: 5.10 V	The max voltage was based on the Arduino UNO datasheet that details the recommended input voltage maximum.	For ATMega328P on UNO Recommended maximum voltage value is 7V, but will only use 5.10 V as the input voltage will not vary. (Arduino UNO Rev 3 website)
Vmin: 4 V	The minimum voltage was based on the Arduino UNO datasheet that details the recommended input voltage minimum.	For ATMega328P on UNO Recommended minimum voltage value is 3.3V, but input will only provide 5V from power source. (Arduino UNO Rev 3 website)

4.2.5 Verification Process

1. otsd_pwr_rgltr_dcpwr : Input

- Using wall outlet to provide 120-125VAC.
- Plug in alligator clips to power supply and connect it to the input of the power regulator PCB
- Take DMM and measure voltage and current on the PCB traces prior to step-down transformer; ensure that 230V is being read. This will verify Vnominal.
- To test nominal output current, attach load (Arduino UNO and GSM) and measure current between the connections. The DMM has to be placed within the circuit in order to actually measure the current.

1. Pwr_rgltr_gsm_mdl_dcpwr : Output

- While being powered by 125V, measure output of J2 molex connectors with a DMM to ensure Vnominal is 5V.
- Repeat step 1 with Vmin and Vmax of input to ensure Vmin and Vmax of output at the molex connectors.
- To test nominal output current, attach load (Arduino UNO and GSM) and measure current between the connections. The DMM has to be placed within the circuit in order to actually measure the current.

1. pwr_rgltr_ardn_n_dcpwr : Output

- While being powered by 125V, measure output of J1 molex connectors with a DMM to ensure Vnominal is 5V.
- Repeat step 1 with Vmin and Vmax of input to ensure Vmin and Vmax of output at the molex connectors.
- To test nominal output current, attach load (Arduino UNO and GSM) and measure current between the connections. The DMM has to be placed within the circuit in order to actually measure the current.

4.2.6 References and File Links

[1]Anil Kumar, “Bridge rectifier : Circuit diagram, types, working & its applications,” ElProCus, 04-Dec-2020. [Online]. Available: Bridge Rectifier [Accessed: 05-Feb-2022].

[2] “Article: Motor driver PCB layout guidelines – part 1,” MPS. [Online]. Available: PCB Layout[Accessed: 05-Feb-2022].

[3] Triad Magnetics, “Class 2/3 Transformer”, FS24-100-C2 datasheet, May 30th, 2019 Transformer

[4] Diodes Incorporated, “0.8A SURFACE MOUNT GLASS PASSIVATED BRIDGE RECTIFIER”, HD01 - HD06 datasheet, January 2020, Diodes Incorporated

[5] STMicroelectronics, “Precision 500 mA regulators”, L78MxxAB/L78MxxAC datasheet, July 2009, Regulators

[6] “Ultra-Low-Noise Power Supplies,” McMaster-Carr. [Online]. Available: Power Supplies [Accessed: 05-Feb-2022].

[7] L. Ada, “Adafruit FONA FAQ,” Adafruit Learning System. [Online]. Available: FONA [Accessed: 05-Feb-2022].

[8] “Arduino Uno REV3,” Arduino Online Shop. [Online]. Available: Arduino [Accessed: 07-Jan-2022].

4.2.7 Revision Table

Revision Table	
Date	Revision Description
17 February 2022	Zach M: Added components used and descriptions/reasons for used, as per requested by reviewer Michael Crockett Changed location of Black Box diagram, now first image, as per request by peer reviewer Michael Crockett. Added images of 2D trace layout of PCB, final 3D board layout with components, updated schematic photos, and new wiring diagram. Added new references that pertain to datasheets of components used.
04 February 2022	Zach M: Finished Draft Finished Interface Verification Finished File Links and References Finished Design
03 February 2022	Zach M: Created Draft document and wrote up portions of Description and General Validation
6 May 2022	Zach M: Updated Interface definition and testing values to reflect new numbers of the current system.

4.3 Sensors: Abdulla AlMannai

4.3.1 Description

The Sensor block will have one of the most important roles in the system as whole where this block will be responsible for reading the voltage and current using two sensors to send that raw data to the Arduino for processing and storage of that data to a real time data base.

Abdulla will be responsible the wiring of the sensor for proper functionality of this block. The sensor will read the voltage/current values on a given point of the substation and analyse the values read from the sensor to detect if there was a risk during the operation of the substation to ensure the safety of the system and operation of the substation.

4.3.2 Design

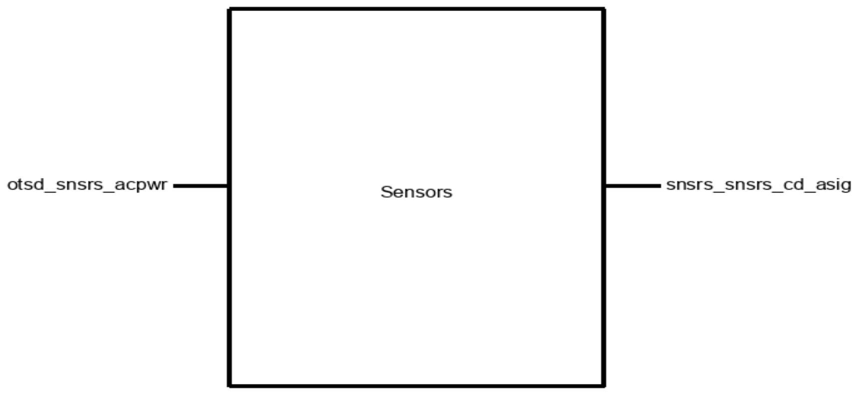

Figure 18: Block Diagram

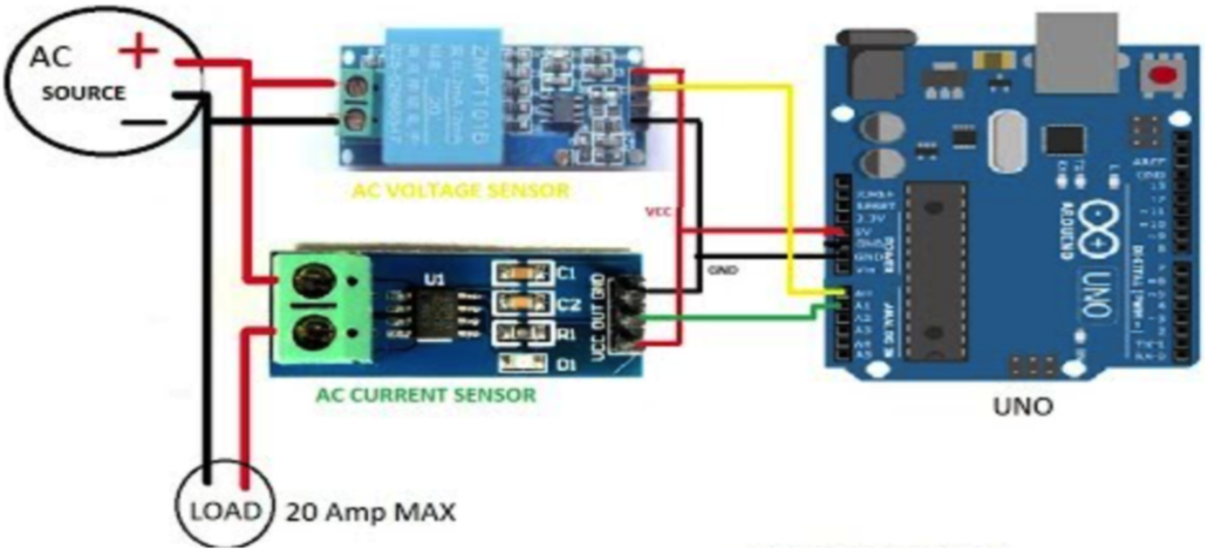

Figure 19: Wiring Diagram

4.3.3 General Validation

The ZMPT101B [1] single phase voltage sensor will be the sensor of choice for the system to sense the AC voltage and the ACS712 AC and DC current sensor [2]will be the choice for measuring the Ac current of the substation. The team has agreed on these sensors due to its capability of measuring AC voltage up to 250V as we will be monitoring an AC voltage from 240V AC source, and current sensor capabilities of measuring up to 30 amps AC or DC. Wiring diagrams are provided all around the internet so that someone with no experience at all can wire the sensor and start using it. This sensor has many open-source Libraries to use with the Arduino which is the microcontroller of choice for the team's project. This library has pre-built functions and commands to write the code necessary for operation depending on the application. ZMPT101B single phase voltage sensor and ACS712 Current sensor are also widely available either on AMAZON or multiple online websites and are relatively cheap with a price of almost $7 each for the voltage sensor and $10 for the current sensor.

4.3.4 Interface Validation

Block Descriptions		
Interface Property	Why is this interface this value?	Why do you know that your design details for this block above meet or exceed each property?
ardn_n_snsrs_dcpwr		
Voltage sensor : VCC input pin is: 5V DC	This property is 5 volts because the Arduino has an output Pin that provides 5V and the sensor will be powered by the Arduino.	For The ZMPT101B single phase voltage sensor: • The operating values of the sensor as to its specifications are 5-30V.
Current Sensor: VCC input pin: 5V DC	This property is 5 volts because the Arduino has an output Pin that provides 5V and the sensor will be powered by the Arduino.	For the ACS712 Module: · The operating values are between 4.5 and 5.5 V. and so 5v would be the ideal voltage supply.
Otsd_snsrs_acpwr		
Voltage sensor: L and N measuring probs: 0-250 Volts AC	This property will be between 0-250 AC volts because we are measuring the voltage from a substation's power line where the project's substation model will be transmitting ideally 230 AC volts	For The ZMPT101B single phase voltage sensor: · The sensor can measure up to 250 volts AC as per sensor specifications and design.
Current sensor: L and N measuring probs: 0-30 Amps.	This property will be between 0-30 amps as we are reading the current transmitted from the substation	For the ACS712 Module: · The range of measuring capability is between 0-30 V as per sensor specification and design.
Snsrs_ardn_n_asig		
Voltage sensor: OUT pin: between 0-5 volts Analogue signal.	This property will transmit between 0-5V Analogue signal to the Arduino because of sensor design of analogue data transmission.	For The ZMPT101B single phase voltage sensor: · The sensor transmits the data via analog signal between 0-5 volts
Current Sensor: OUT pin: between 0-5 volts Analogue signal.	This property will transmit between 0-5V Analogue signal to the Arduino because of sensor design of analogue data transmission.	For the ACS712 Module: · The sensor transmits the data via analog signal between 0-5 volts

4.3.5 Verification Process

1. General
   - Order the specified Sensors online or pick them up at a local shop.
   - Have the power supply plugged in and ready to use.
   - Plug the Arduino to the laptop and download the code intended to use for the sensors.
2. ardn_n_snsrs_dcpwr
   - Using a multimeter, measure the 5V output pin from the Arduino to verify that it is 5V

- Use the 5v pin from the Arduino to wire to the VCC to power the voltage sensor
- Repeat the same process to power the current sensor.

3. Otsd_snsrs_acpwr

- Connect the L prop of the sensor to the load of power.
- Connect the N prob to the negative Side of the load.
- Turn on the power supply.
- Using a multimeter, measure the voltage using the KV setting from the multimeter and place the probe on the top side of the screws where the L and N connections are.
- Verify that the voltage is equal to the supplied voltage.
- Repeat the same process for the current sensor using an additional load between the N prob and the negative pin of the power supply as shown in Figure2 in section 4.1.2.

4. Snsrs_ardn_n_asig

- Wire the OUT pin to the chosen digital pin on the Arduino for module/Arduino communication
- Wire the GND to the ground of the Arduino.
- While the sensor is transmitting data, using a multimeter, place the probes on the OUT pin and GND and read the voltage using.
- Verify that the voltage is between 0-5V as analog signal specification of the design.

4.3.6 References and File Links

[1]"Interfacing ZMPT101B AC Voltage Sensor Module w/ Arduino", Electropeak, 2022. [Online]. Available: https://electropeak.com/learn/interfacing-zmpt101b-voltage-sensor-with-arduino/. [Accessed: 22- Jan- 2022].

[2]Sparkfun.com, 2022. [Online]. Available: https://www.sparkfun.com/datasheets/BreakoutBoards/0712.pdf. [Accessed: 22- Jan- 2022].

How to connect and use the voltage sensor
How to connect and use the current sensor

4.3.7 Revision Table

Date	Revision description	Revision Done by
January 6, 2022	First draft was created, and sections of the document were filled.	Abdulla
January 21, 2022	Design changed as sensors where changed and all supporting section.Added black box diagram of the block and the wiring diagram for the sensors.	Abdulla

4.4 GUI: Abdulla AlMannai

4.4.1 Description

The graphical user interface will serve the purpose of accessing and controlling the system by either turning on or off the relays within the system to shut off the power or to request the parameter's values that are being monitored to be sent via sms to the registered number. The interface will have 3 different buttons on it: An ON button to turn on the system An OFF button to turn off the system A GET VALUES button to send the monitored values to the registered phone number. These buttons will be accessible from an interface created in Python and in combination with Twilio [1].Twilio is a platform that allows the communication between the GUI and sending the actual SMS through their dedicated servers using a specific number, account, and an authentication code that is assigned to us when we register.

4.4.2 Design

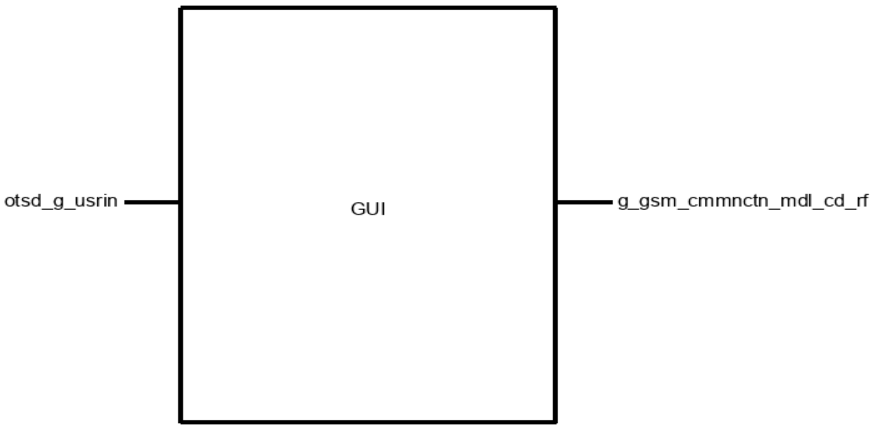

Figure 20: Block Diagram

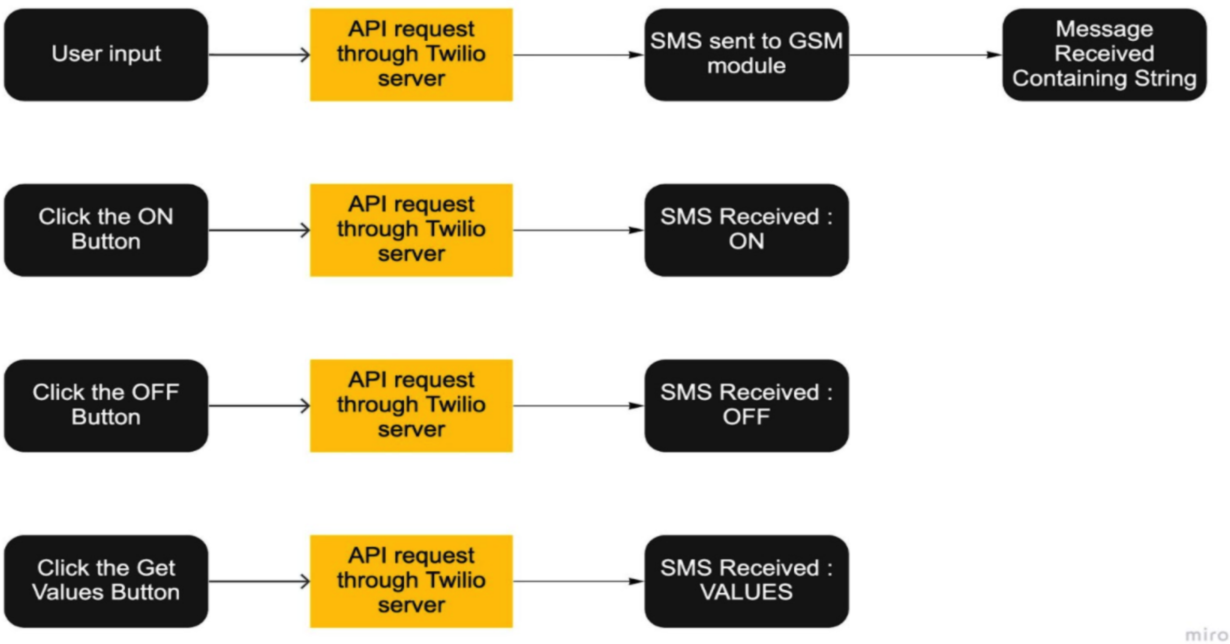

Figure 21: Flow Chart

4.4.3 General Validation

I chose this design because our project is GSM based and by implementing a GUI that sends SMS with every click from the GUI, this will base all the operation of the system via SMS through the communication module. Having commands sent via SMS that requires the system to respond also in SMS to a registered number will achieve the purpose of Cellular communication for the system. This will be done through a combination of Python to create the GUI and Twilio Which is a platform that allows API channels for communication such as SMS, Voice, Video and Whatsapp. FOr our design we will be using the SMS API to request an SMS to be sent from their servers using a specific number that is registered to us. This number is assigned by creating an account with a specific authentication code that is used during the request via a client that is compatible with python. This function allows us to send a message by stating (from, to, string) where "from" is the phone number assigned to us, to is the registered number we want to send to, and string is the message to be sent. We chose this process because most importantly is all SMS based for the communication, and is easy to map these functions with the difference in the message to be sent for each clickable button on the GUI.

4.4.4 Interface Validation

Block Descriptions		
Interface Property	Why is this interface this value?	Why do you know that your design details for this block above meet or exceed each property?
otsd_g_usrin : Input		
Usability: Clickable button " ON"	This interface is a clickable button because we want the user's input to turn on the relays within the system	As to the design of the GUI and the platform used, This option is supported with specifying the destination and content of the message.
Usability: Clickable button " OFF"	This interface is a clickable button because we want the user's input to turn off the relays within the system	As to the design of the GUI and the platform used, This option is supported with specifying the destination and content of the message.
Usability: Clickable button "Values"	This interface is a clickable button because we want the user's input to request for the monitored values to be sent via SMS	As to the design of the GUI and the platform used, This option is supported with specifying the destination and content of the message.
g_gsm_cmmnctn_mdl_cd_rf : Output		
Messages: Values	This Message will be "values" because it will execute a function based on that string that will send out the values monitored by the system to the registered number via SMS	As to the main code for the Arduino, functions will be ready to execute based on the string input sent from the GUI therefor sending this message will result in the right operation
Messages: ON	This Message will be "ON" because it will execute a function based on that string that will Turn on the rely to transmit power through the system	As to the main code for the Arduino, functions will be ready to execute based on the string input sent from the GUI therefor sending this message will result in the right operation
Messages: OFF	This Message will be "OFF" because it will execute a function based on that string that will Turn off the rely to transmit power through the system	As to the main code for the Arduino, functions will be ready to execute based on the string input sent from the GUI therefor sending this message will result in the right operation

4.4.5 Verification Process

1. Access the GUI intended for use.
2. Have the test phone ready to receive messages with good cellular reception
3. Click on the On button
4. You should receive an SMS to the test phone saying "ON"
5. Click on the Off button
6. You should receive an SMS to the test phone saying "OFF"
7. Click on the values button
8. You should receive an SMS to the test phone saying with three values being Voltage, frequency, and current.

4.4.6 References and File Links

[1]"The Twilio Python Helper Library", Twilio.com, 2022. [Online]. Available: https://www.twilio.com/docs/libraries/pyt
[Accessed: 19- Feb- 2022].

FLowchart

4.4.7 Revision Table

4 February 2022	Initial Draft was completed and all sections were added. Abdulla
18 February 2022	Additional information was added based on the feedback received such as adding what the GUI will be and what software is used. In addition to a general flowchart of how the system will act in general and based on each input.

4.5 SensorCode: Ali Alfadala

4.5.1 Block Overview

Ali is responsible for the Sensor Code block. The Sensor Code block will run on the Arduino Uno and input the voltage and current values output from the Sensors block. It outputs voltage, current, and frequency values to the Processing block, which is also running on the Arduino. Some processing will be necessary to produce these output values. The voltage and current values read by this block will be read from analog pins on the Arduino as 10-bit binary values. These values will have to be remapped to get the actual voltage and current values of the substation. The values are also varying as a sine function, and since we want to report peak or rms voltage and current, the inputs must be sampled at a high enough frequency to find the maximum values. The frequency to be output by the block will be determined by monitoring the voltage values and counting cycles. Then this value can be sent to the Processing block with the voltage and current outputs.

4.5.2 Design

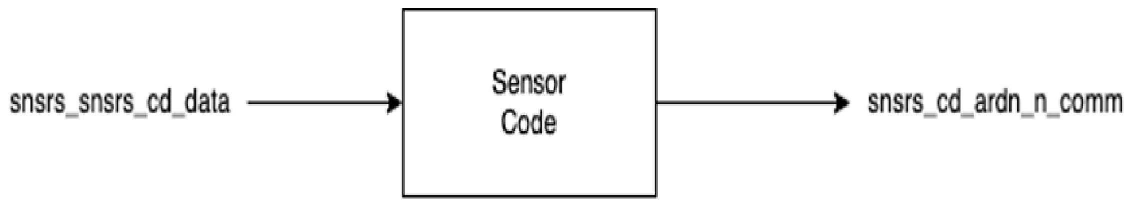

Figure 22: Block design

Function initFrequency()
Allocate array for recent voltage values
Allocate array for recent current values
Allocate array for cycle completion times
Initialize vi index to 0
Initialize cycle index to 0
Initialize last voltage value

Function monitorSensorInput()
Read voltage and current from analog pins
Map voltage and current 10-bit values to actual values
Save actual V and I values to arrays using vi index
Increment vi index
Compare new voltage with last voltage
If voltage comparison results in a cycle completion
Save current time to cycle array at cycle index
Increment cycle index

Last voltage = new voltage

Function getFrequency()

Calculate frequency from array of cycle times
Return frequency

Function getVoltage()

Find maximum voltage from array of recent voltage values
Return peak or rms voltage

Function getCurrent()

Find maximum current from array of recent current values
Return peak or rms current

4.5.3 Block General Validation

The purpose of this block is to produce accurate values of the substation's voltage, current, and frequency. The voltage and current have been read by the Sensor block with a known sensor, which maps these values to 0-5 volt values. These values are then mapped again to 10-bit values by the Arduino's ADC as they are read from the analog pins of the Arduino in the Sensor Code block. Because these mappings are known, it is straightforward to reverse these mappings to get the original voltage and current values of the substation. Since the voltage and current are varying as sine functions, the block needs to sample these inputs at a high rate to make sure a sample near the peak is found. With a sine frequency of 60 Hz, for example, a sampling rate of about 1000 Hz should give a good peak value, and the Arduino Uno, with an 8 MHz clock, is capable of reading sensors at this rate. Keeping arrays of recent voltage and current values over a period of a couple of cycles should give good peak values. When the substation's voltage or current is requested, an array can be searched for the maximum value, which can be returned. The frequency of the substation can be found by monitoring its voltage[1] and finding the times when a voltage cycle completes. Finding the exact time that a cycle completes is not necessary, since we will keep an array of many of these times and average them to get an accurate frequency. The important thing is not to miss a cycle, which won't be a problem at the sampling rate mentioned in the previous paragraph. The Sensor Code block will save the cycle completion times in an array. When the array fills up, indexing starts over from the start of the array, overwriting old values. This way the array always holds the most recent time values. The data in this array is all that is needed to calculate the frequency. Whenever the Processing block needs the current value of the frequency, it can request it from the Sensor Code block. Knowing the times of the oldest and newest cycles in the array and the number of cycles, an average frequency is returned.

4.5.4 Interface Validation

Block Descriptions		
Interface Property	Why is this interface this value?	Why do you know that your design details for this block above meet or exceed each property?
snsrs_snsrs_cd_data: Input		
Voltage: 0-1023	Range for Arduino Uno analog pin ADC.	Substation voltage value has been mapped to this range.
Current: 0-1023	Range for Arduino Uno analog pin ADC.	Substation current value has been mapped to this range.
monitorSensorInput (): Reads voltage and current values on analog pins from Sensor Block.	The function names are chosen to be informative.	This function is listed in the Block Design section pseudocode above. It monitors and stores recent voltage, current, and time values.
snsrs_cd_ardn_n_comm: Output		
getFrequency(): calculates and returns the returns the substation frequency	the function names are chosen to be informative.	This function is listed in the Block Design section pseudocode above.
getVoltage(): calculates and returns the substation voltage.	The function names are chosen to be informative.	This function is listed in the Block Design section pseudocode above.
getCurrent(): calculates and returns the substation current.	The function names are chosen to be informative.	This function is listed in the Block Design section pseudocode above.

4.5.5 Block Testing Process

1. General

- Download code from computer to Arduino.
- Apply specific voltage and current inputs (snsrs_snsrs_cd_data), both mapped to the 0-5V range for the Arduino analog inputs. For example, 2.5V for voltage (representing 110V source) and 2.0 V for current(representing a 20 mA source).
- Open the Serial Monitor on the computer and observe the printing of the voltage andcurrent values. These should match with 110 V and 20 mA.

4.5.6 References and File Links

1. References (IEEE)

1 "How to measure AC Frequency with Arduino? – A blog about DIY solar and arduino projects", A blog about DIY solar and arduino projects, 2022. [Online]. Available: https://solarduino.com/how-to-measure-ac-frequency-with-arduino/. [Accessed: 08- Jan- 2022].

1. File Links

- https://docs.google.com/document/d/1n3aKbVh5dfigeRI-RAGluHbpFHDnnquq/edit?usp=sharing&ouid=103175477404091625501&rtpof=true&sd=true

4.5.7 Revision Table

Revision Table	
Date	Revision Description
1/20/2022	Ali Alfadala: changed the interface properties and block testing process.
1/17/2022	Ali Alfadala: Added fixes for calculating voltage and current outputs.
1/8/2022	Ali Alfadala: Created the first draft.

4.6 GSM Communication Module: Yicheng Xiong

4.6.1 Description

The Botletics SIM7000A is an all-in-one communication module loaded with voice, text, SMS and data functions, and at its core is a GSM cellular module SIM7000A. on its own, this module can't do anything. It needs a microcontroller to drive it, and we chose the Arduino UNO as the microprocessor for it. The Arduino UNO, acting as a microprocessor, sends the collected data to the SIM7000A, a communications module, which uploads the data to the network.

4.6.2 Design

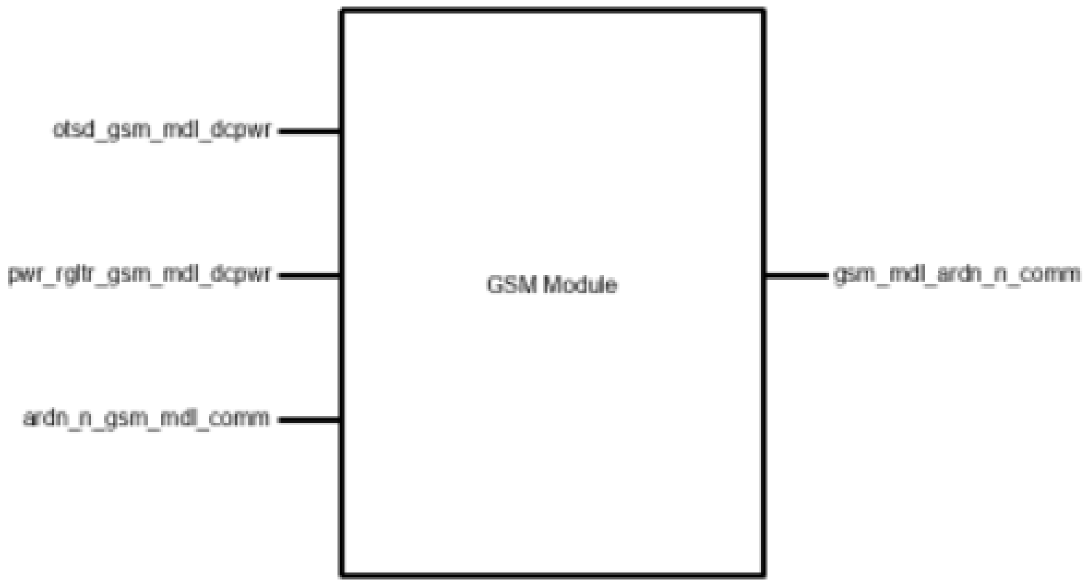

Figure 23: Block Diagram for GSM Module

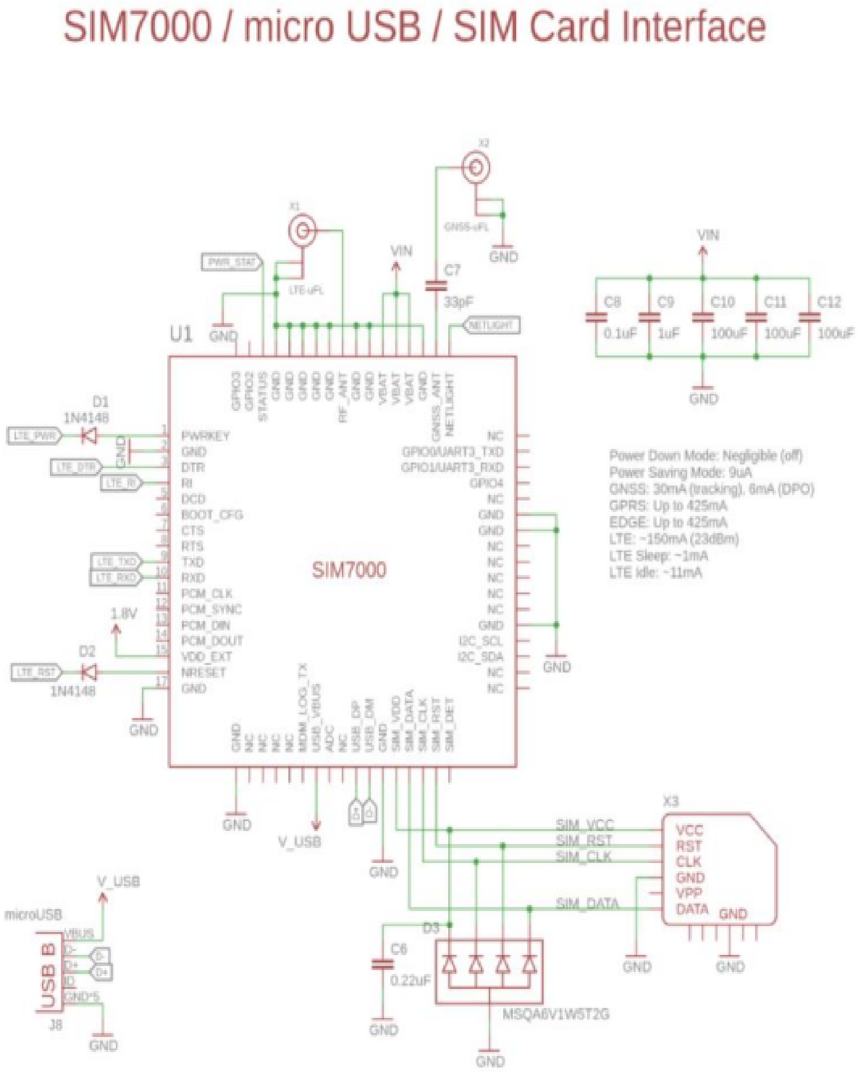

Figure 24: SIM7000A Interface

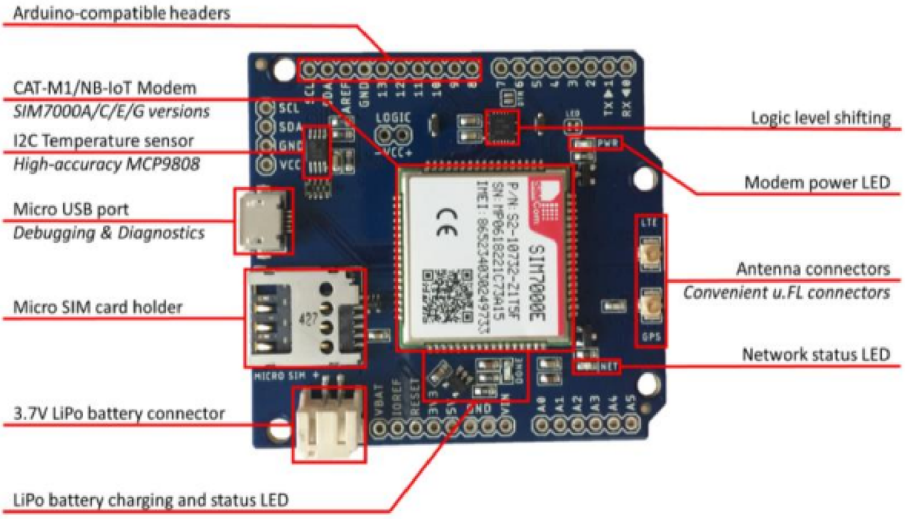

Figure 25: SIM7000-LTE-Sheild feature overview

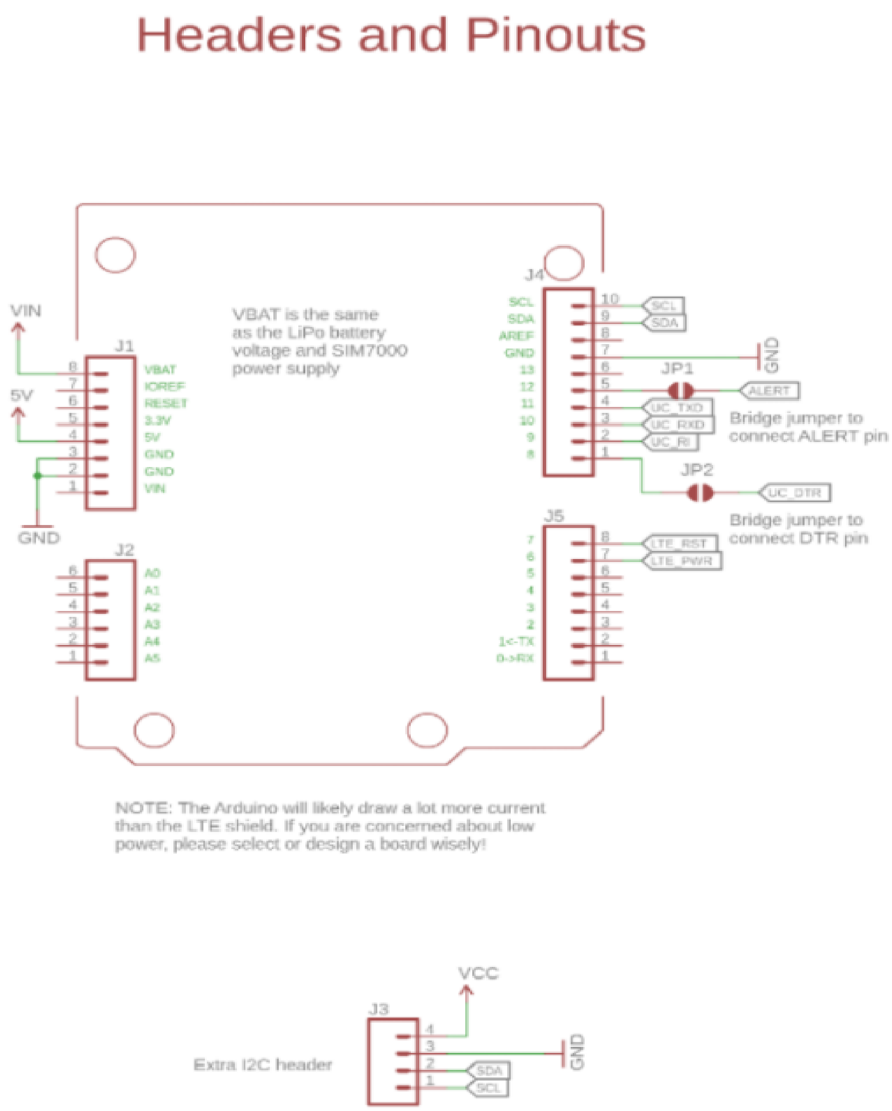

Figure 26: SIM7000-LTE-Sheild Headers and Pinouts

4.6.3 General Validation

SIM7000A is available from Amazon with 65 dollar. This is a good communication module to interact with Arduino, with a full library available to interact with Arduino UNO, and the features of SIM7000A are perfectly suited to our needs, also be able to use GSM network for data upload. That is the reason why we chose SIM7000A.

4.6.4 Interface Validation

Block Descriptions		
Interface Property	Why is this interface this value?	Why do you know that your design details for this block above meet or exceed each property?
otsd_gsm_mdl_dcpwr;		

Inominal:1000mA	We will be using external power here, so maintaining sufficient power to keep the device performing is what we want to see.	A minimum of 500mA is required for activation, and it is recommended to keep it at 1000mA. According to SIM7000-LTE-Sheild datasheet.
Ipeak: 2A	Since this is a large current for the PCB, we want to make sure that its flow across the PCB is as unrestricted as possible	Up to 2A and with peak performance,According to SIM7000-LTE-Sheild datasheet.
Vmax: 5V	This is the highest voltage we can expect.	The range of Vin is 3-5 V. According to SIM7000-LTE-Sheild datasheet
ardn_n_gsm_mdl_comm;		
Logic level: 3.3V	We chose 3.3V logic for our entire system. The main reason is that the processor we're going to use is designed for 3.3V logic.	Pins are started from at least 1.5V up to 5.5V, so 3.3V is feasible.
Other: active low	This depends on the characteristics of the boost converter chosen.	When SHDN TH is lower than 1.5V, the system is in off state; when SHDN TH is higher than 1.5V, the system is in on state.
gsm_mdl_ardn_n_comm;		
Logic level: 3.3V	We chose 3.3V logic for our entire system. The main reason is that the processor we're going to use is designed for 3.3V logic.	Pins are started from at least 1.5V up to 5.5V, so 3.3V is feasible.
Other: active low	This depends on the characteristics of the boost converter chosen.	When SHDN TH is lower than 1.5V, the system is in off state; when SHDN TH is higher than 1.5V, the system is in on state.

4.6.5 Verification Process

1. Process Step:

   Botlerics provides a complete Arduino library to test the SIM7000A for AT commands, which is one of the reasons we chose it for our project, and we can complete our verification by rewriting the equations given in the library. During the verification process, various steps are required to avoid unnecessary waste of time and resources.

   - After the wiring is completed, first turn on the power to check whether the power supply is successful, by observing the lights on the Arduino UNO and SIM7000A boards to determine whether the power is connected.
   - We will use the test code to observe the current and voltage by displaying it on the Arduino serial communication screen.
   - We will use a sliding resistor and oscilloscope to test the current and voltage values.

4.6.6 References and File Links

1. References (IEEE)

   - A. Sachan, Microcontroller Based Substation Monitoring and Control System with Gsm Modem. 2021.
   - Supervision and Control of Substation by using GSM Module and Microcontroller, 8th ed. International Journal of Innovative Technology and Exploring Engineering (IJITEE), 2019.

1. File Links

   - https://github.com/botletics/SIM7000-LTEShield/blob/master/SIM7000%20Documentation/Spec%20Overview%20Docs/SIM7000A_SPEC_2017-9-21.pdf SIM7000-LTE-Sheild Datasheet
   - https://www.farnell.com/datasheets/1682209.pdf Arduino UNO Datasheet

4.6.7 Revision Table

Revision Table	
Date	Revision Description
1/21/2022	Yicheng Xiong: Update interface properties.
1/18/2022	Yicheng Xiong: Edited each section of the draft to incorporate peer review and instructor feedback.
1/7/2022	Yicheng Xiong: Complete text preparation and basic proofreading.

4.7 GSM Communication Module Code: Yicheng Xiong

4.7.1 Description

Yicheng Xiong will be responsible for the wiring between Arduino UNO and SIM7000-LTE Sheild for the GSM-based substation monitoring and control project. The Arduino UNO, acting as a microprocessor, sends the collected data to the SIM7000-LTE-Sheild, a 4G-LTE communications module, which send data to user through SMS.

The Arduino UNO is a board with an ATMega328P microcontroller with 14 input/output pins, six of which can be PWM outputs. A computer can be used to program the Arduino UNO to facilitate data transfer. the UNO will be powered by a custom power supply that will convert the monitored voltage and current of the transmission line into manageable voltage and current for the entire system.

The SIM7000-LTE-Sheild is an all-in-one communication module loaded with voice, SMS, and data functions. At its core is a GSM cellular module SIM7000A. This module needs a microcontroller to drive it, and we chose the Arduino UNO as the microprocessor for it.

4.7.2 Design

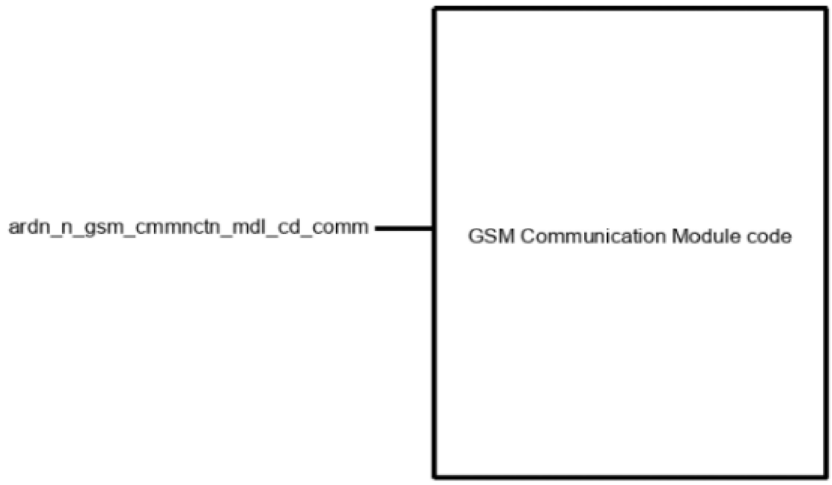

Figure 27: Block Diagram for GSM-Code Module

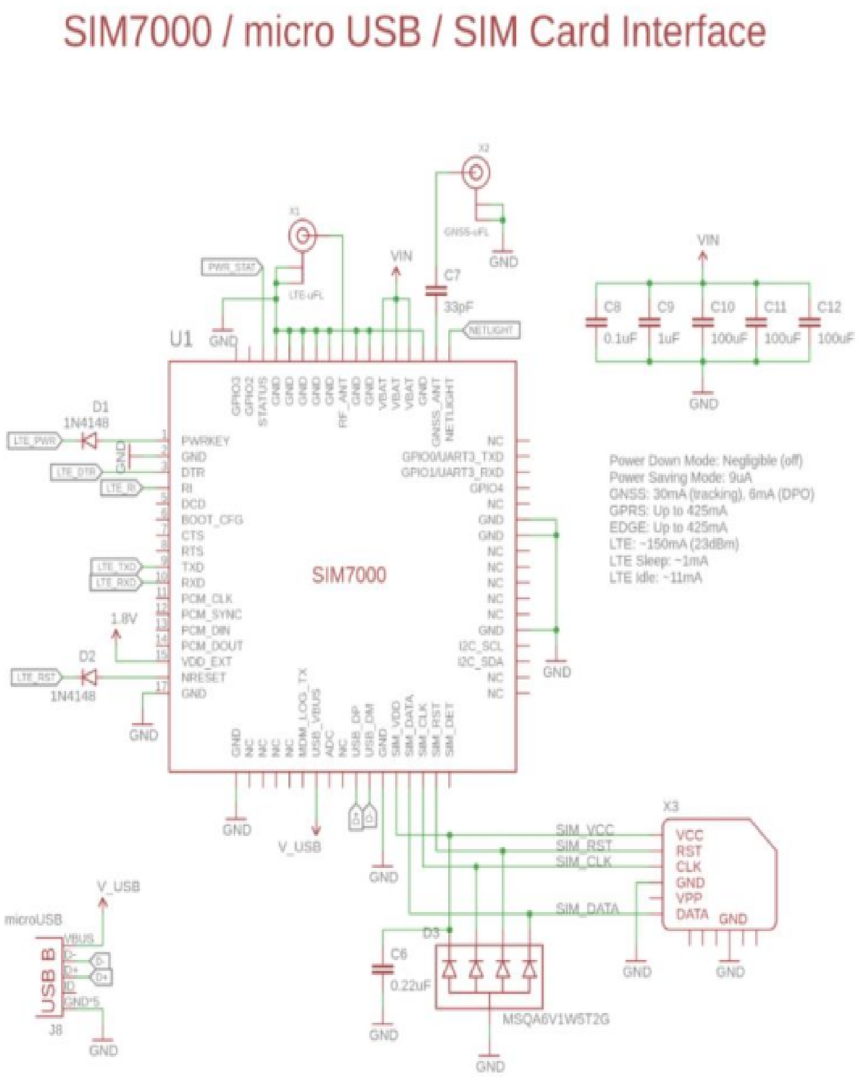

Figure 28: SIM7000A Interface

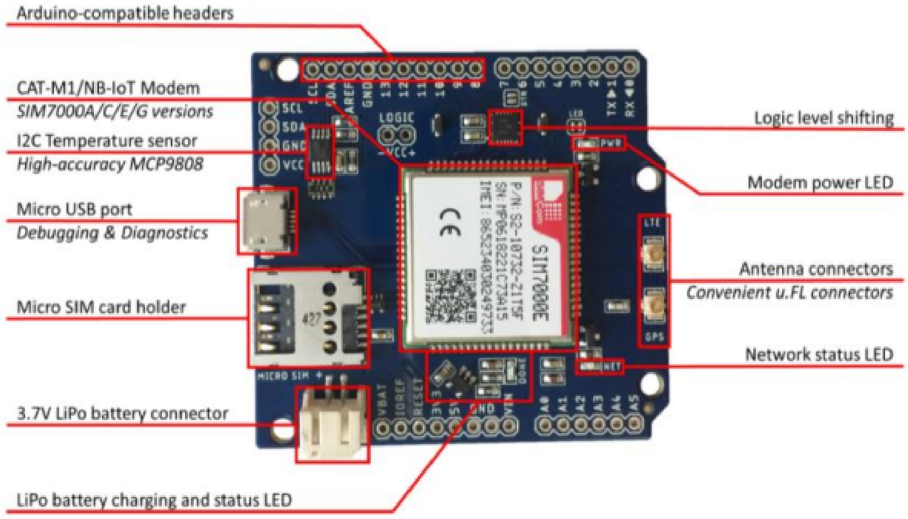

Figure 29: SIM7000-LTE-Sheild feature overview

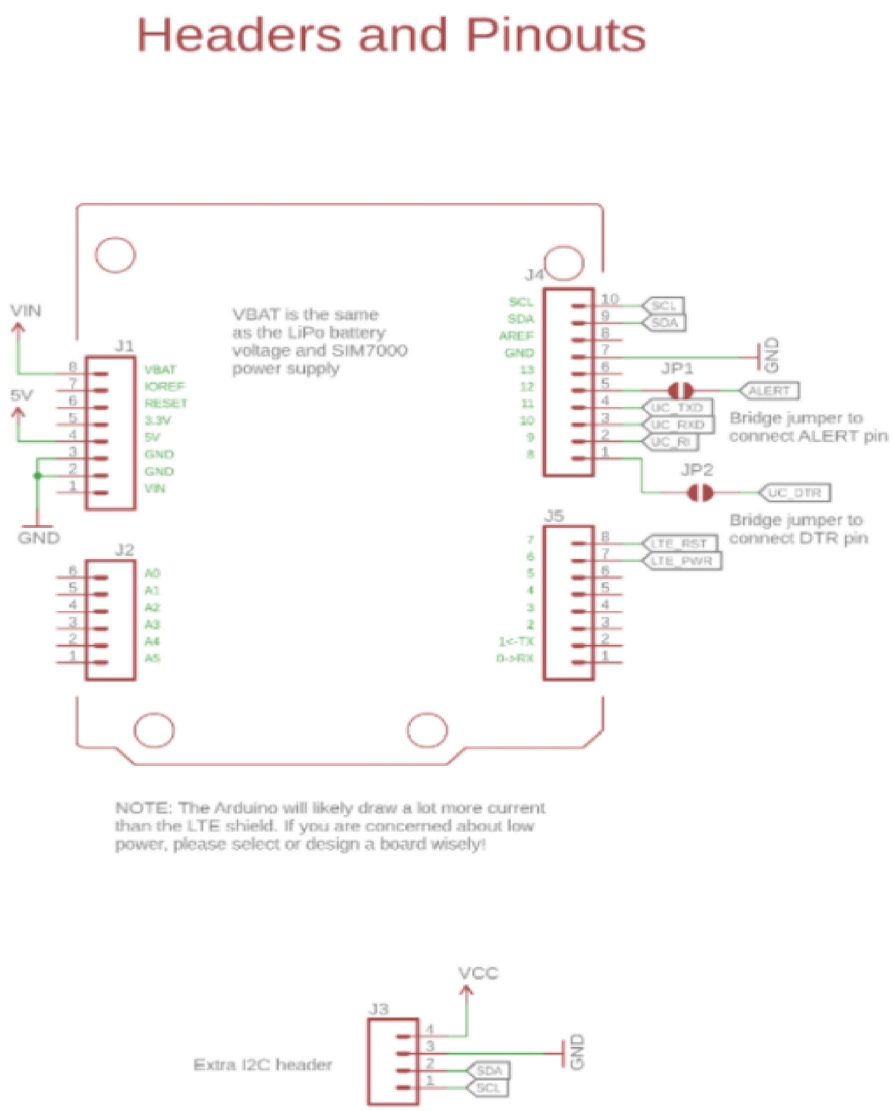

Figure 30: SIM7000-LTE-Sheild Headers and Pinouts

4.7.3 General Validation

Our previous choice of communication module, the Adafruit FONA, was forced to be replaced with the SIM7000-LTE-Sheild, a 4G LTE-enabled communication module, because 2g and 3g networks are no longer available in the US. SIM7000-LTE-Sheild is available on Amazon for 65 dollar. This is the easiest 4G communication module to interact with Arduino, there is a complete library to interact with Arduino UNO, SIM7000-LTE-Sheild is able to send SMS text messages and connect to 4G communication network, these features are perfectly suited to our needs.

4.7.4 Interface Validation

Block Descriptions		
Interface Property	Why is this interface this value?	Why do you know that your design details for this block above meet or exceed each property?
ardn_n_gsm_cmmnctn_mdl_cd_com:		
Other: Configures Arduino to send status SMS to user	We will use SMS to deliver messages to users	According to SIM7000-LTE-Sheild datasheet, SIM7000a has SMS capability
Other: Configures Arduino to turn relay off and on based on data from GSM hardware	Users can control the Arduino to turn on or off through the mobile app	According to Arduino UNO datasheet, the Arduino UNO accepts pin state changes by external commands
Protocol: Arduino Download	This is the protocol provided by Arduino for using their libraries and boards	Testing the Arduino UNO will require the use of the Arduino IDE, and we will need to recompile it based on the Arduino libraries given by Botletics

4.7.5 Verification Process

1. ardn_n_gsm_cmmnctn_mdl_cd_com:

   Botlerics provides a complete Arduino library to test the SIM7000A for AT commands, which is one of the reasons we chose it for our project, and we can complete our verification by rewriting the equations given in the library. During the verification process, various steps are required to avoid unnecessary waste of time and resources.

   - Since Arduino UNO is not connected to the sensor at present, we will input text data to replace the data collected by the sensor and use Arduino UNO to send the data to the designated mobile phone by SMS, which can prove that users can obtain information through SMS.
   - To test that the user can switch the substation in the network user interface, as this is a separate block test, we decided to adjust the state of the PIN of the Arduino UNO by receiving the ON/OFF command at the same time. This can prove that we are able to control the Arduino UNO by receiving commands.
   - All code debugging, and compilation is done in the Arduino IDE and uploaded into Arduino UNO, which also validates the Arduino download.

4.7.6 References and File Links

1. References (IEEE)

   - A. Sachan, Microcontroller Based Substation Monitoring and Control System with Gsm Modem. 2021.
   - Supervision and Control of Substation by using GSM Module and Microcontroller, 8th ed. International Journal of Innovative Technology and Exploring Engineering (IJITEE), 2019.

1. File Links

- https://github.com/botletics/SIM7000-LTEShield/blob/master/SIM7000%20Documentation/Spec%20Overview%20Docs/SIM7000A_SPEC_2017-9-21.pdf SIM7000-LTE-Sheild Datasheet
- https://www.farnell.com/datasheets/1682209.pdf Arduino UNO Datasheet

4.7.7 Revision Table

Revision Table	
Date	Revision Description
2/18/2022	Yicheng Xiong: Update interface properties to sections 4.1.4 after talking to Mr. Heer.
2/13/2022	Yicheng Xiong: Edited each section of the draft to incorporate peer review and instructor feedback.
2/9/2022	Yicheng Xiong: Added content to sections 4.1.2, 4.1.3 and 4.1.4, added functional diagram of GSM module and annotated interface properties.
2/3/2022	Yicheng Xiong: Complete text preparation and basic proofreading.

4.8 Enclosure: Ali Alfadala

4.8.1 Block Overview

Ali will be responsible for making the Enclosure for the project. The enclosure is going to be a box that has a dimension of 9" X 9" X 5" and the cover for the box being 9" X 9" X 4.6". It should protect all components when the lid is screwed and sealed from water as it will have 1.5 gallons water sprayed on it from all 6 faces. The enclosure will house all of the components of the project i.e. the power regulator, sensors, and GSM/Arduino combo. The enclosure will be IP65 rated to protect the components from splashes of water, dust, dirt, and impact. There will be a slot around the cover to insert a rubber seal around it so it can secure it tight and prevent anything coming inside the box and damaging parts inside the enclosure. All Parts inside the enclosure will be screwed to a plexiglass sitting 1" away from the bottom of the box; this leaves room for nuts and bolts that might be hanging down. All of the components will be screwed to the plexiglass before putting the plexiglass in as the plexiglass will be sitting on tabs coming out from the inner walls of the box so this will make it easier to take in and out with all components attached. Then when you close the cover for the box the cover has two poles opposite each other coming down and will sit just by the plexiglass to make sure when the box is flipped the plexiglass doesn't just smash the components onto the lid and damage the components or cause and loose connection and fail the system. The enclosure will be designed using solid works and then 3D printed. In addition, it will have 2 holes drilled for:

- C13 Socket

4.8.2 Design

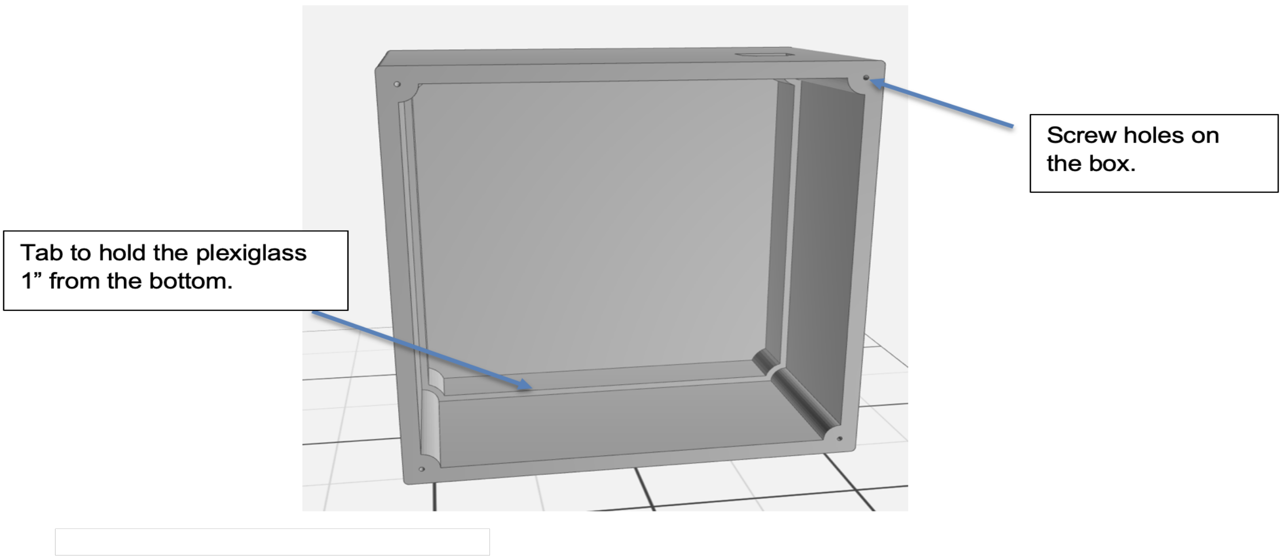

Figure 31: BoxTopView

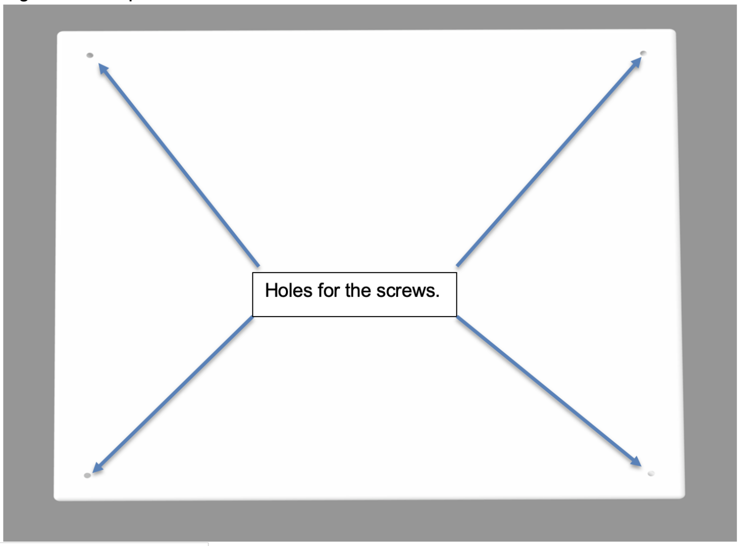

Figure 32: CoverTopView

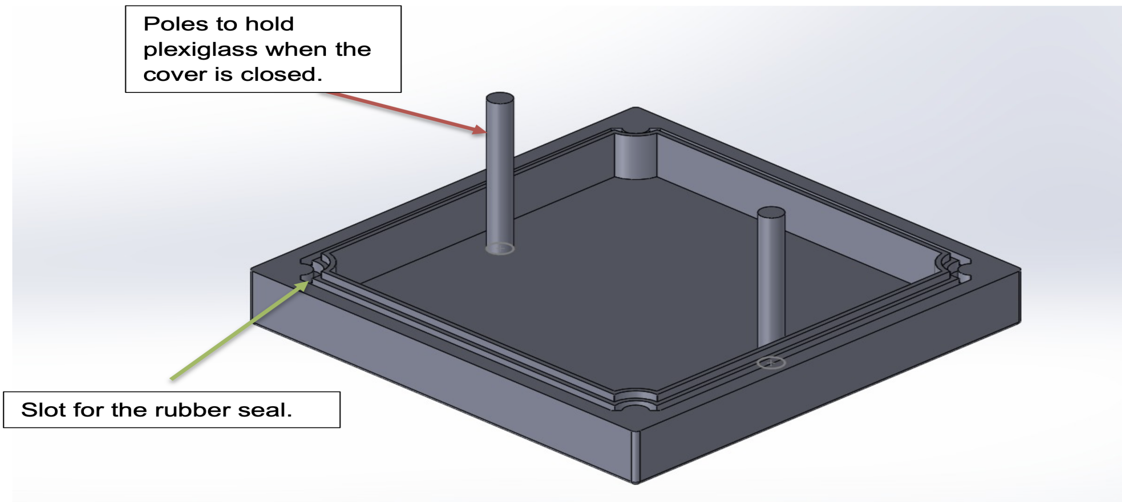

Figure 33: CoverBottomView

These will be the components that will be inside the enclosure:

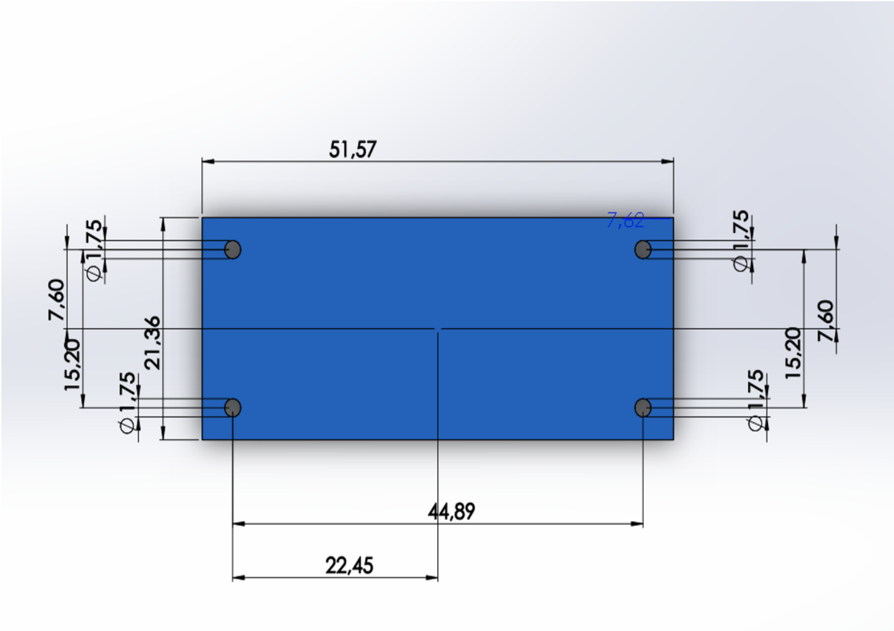

Figure 34: VoltageSensor

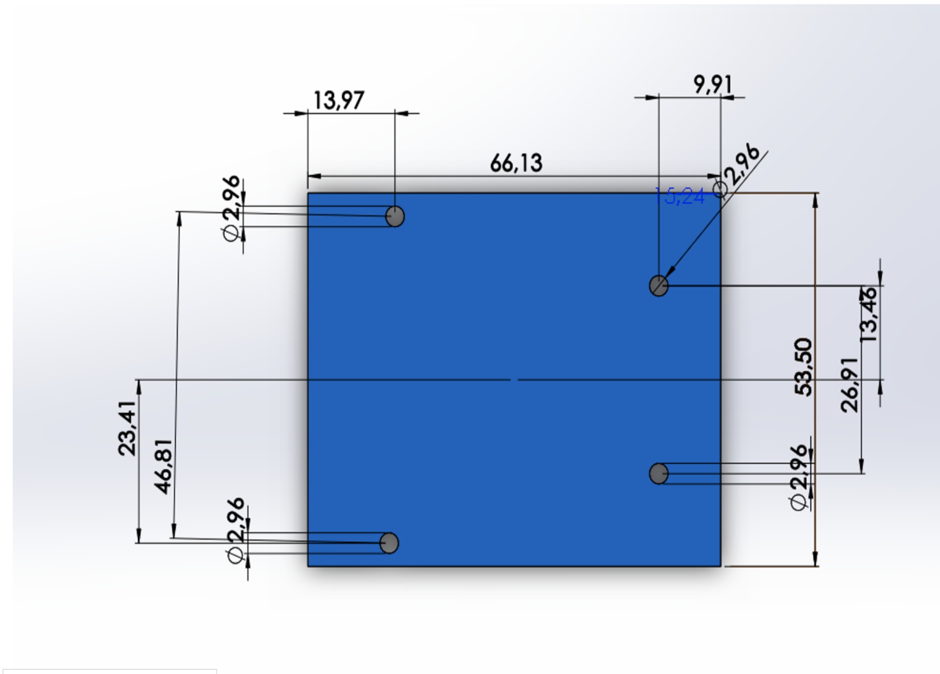

Figure 35: Arduino

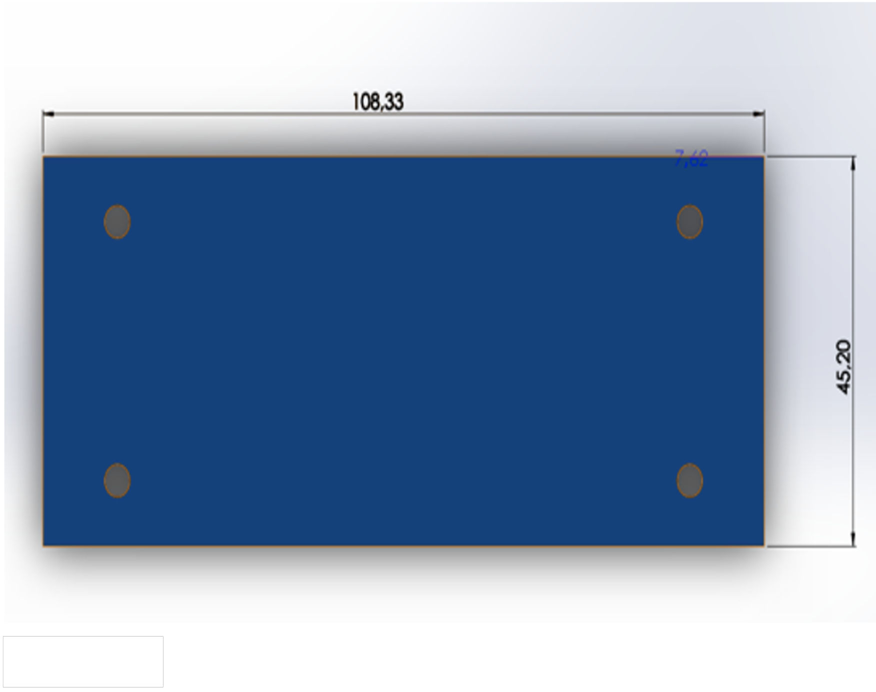

Figure 36: PCB

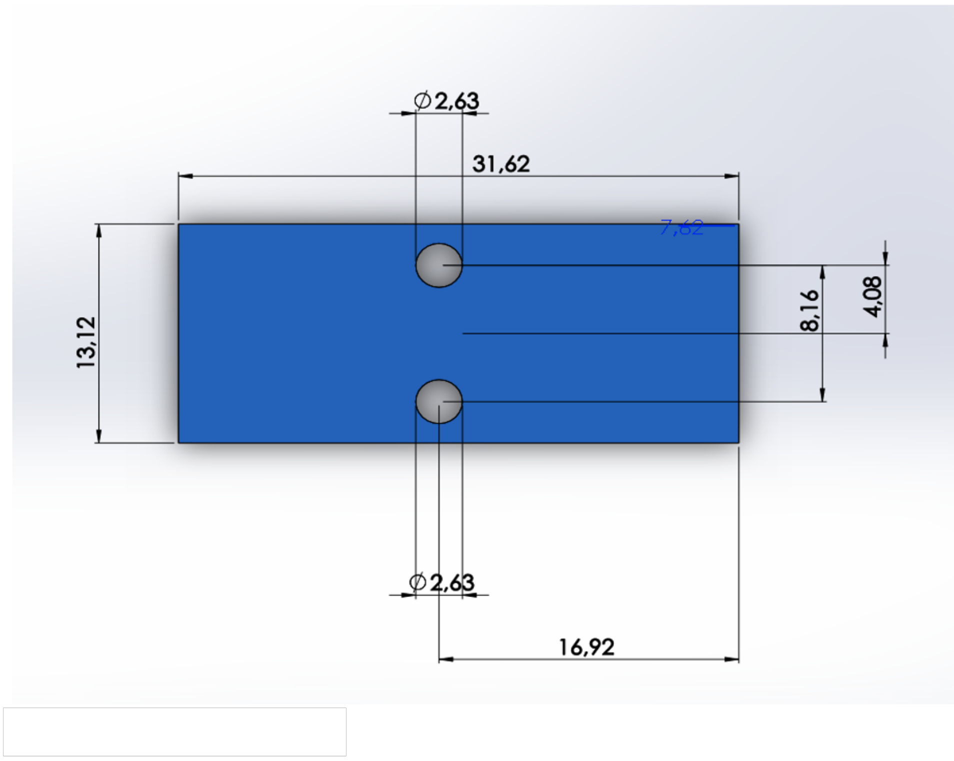

Figure 37: CurrentSensor

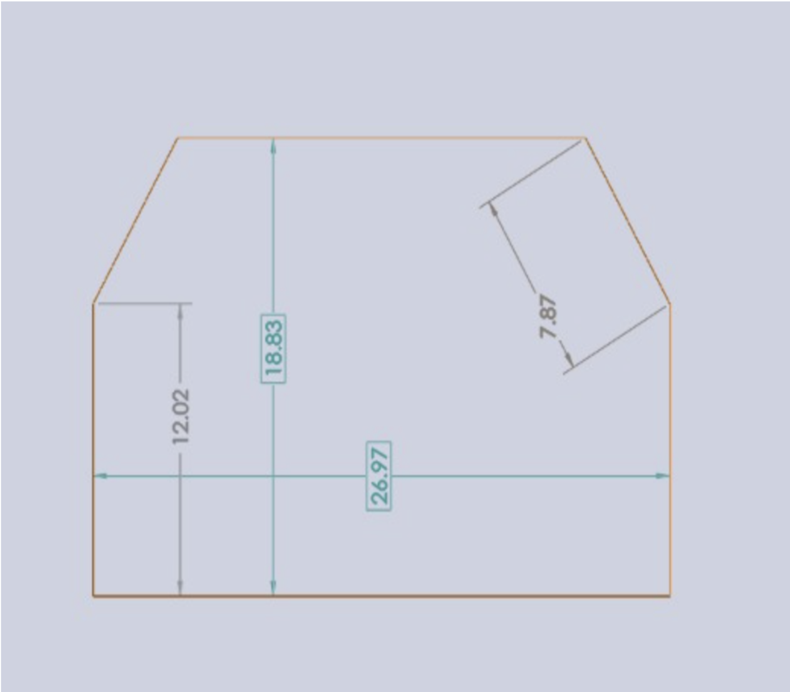

Figure 38: C13Measurement

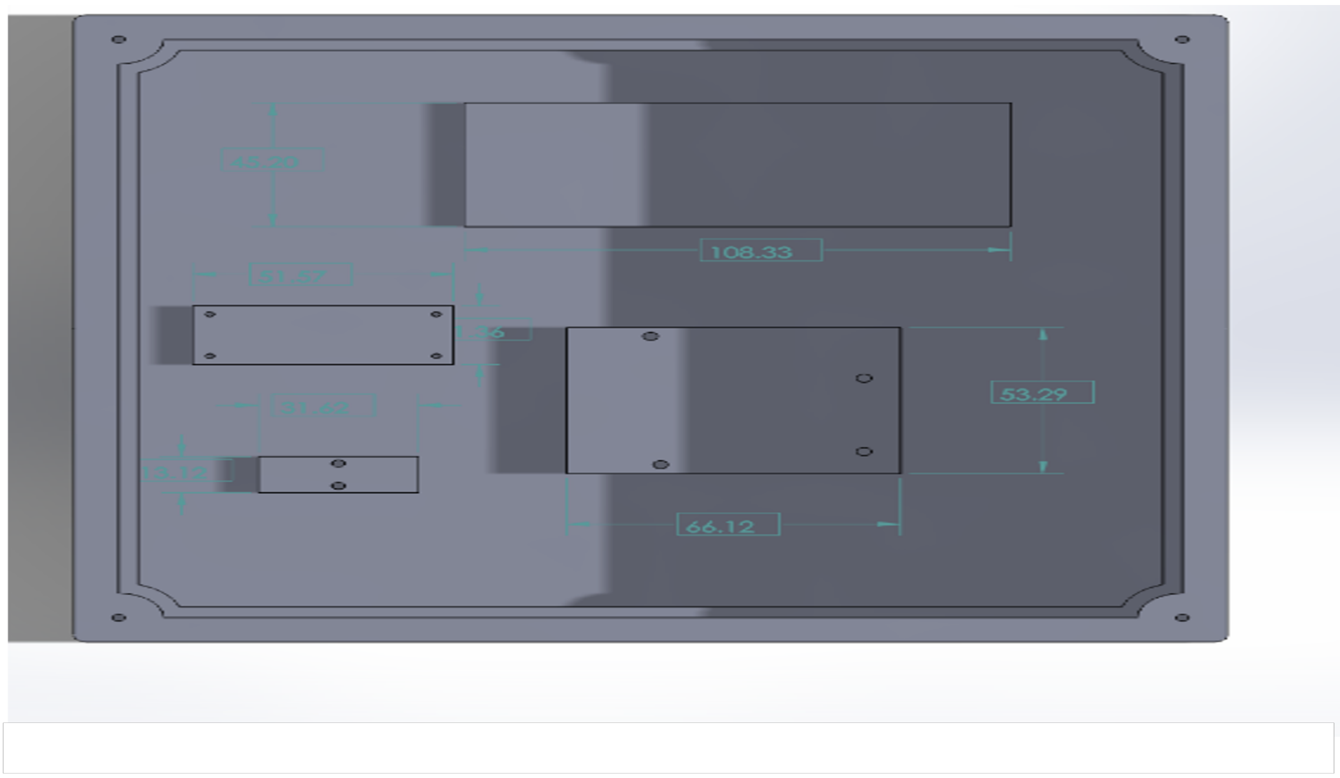

Figure 39: MeasurementsOfComponentsInside

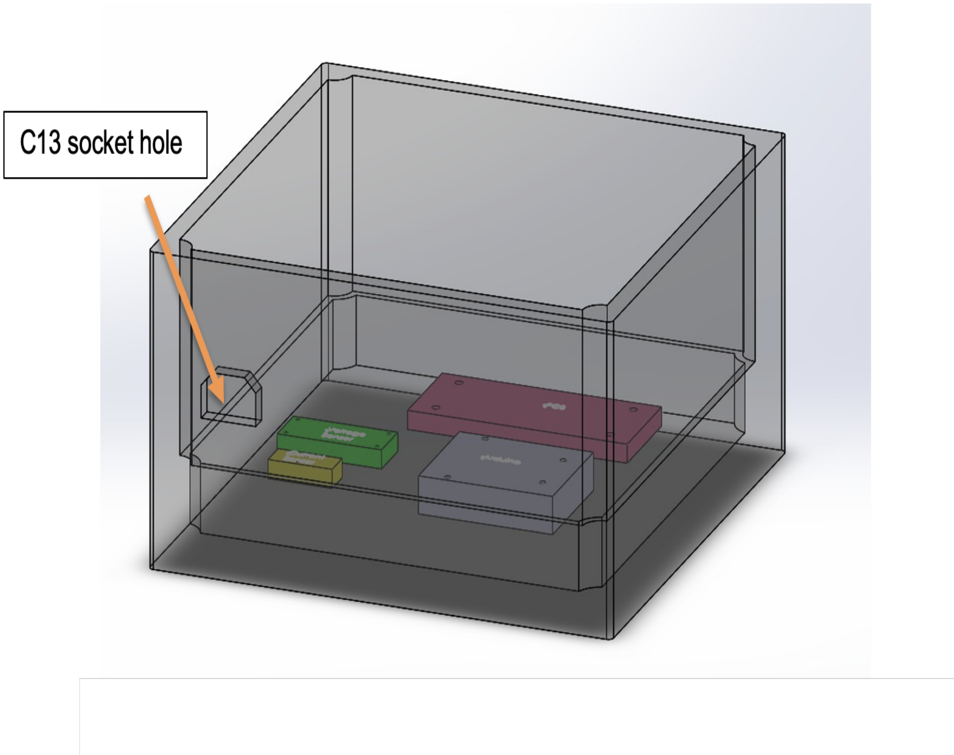

Figure 40: XrayVision

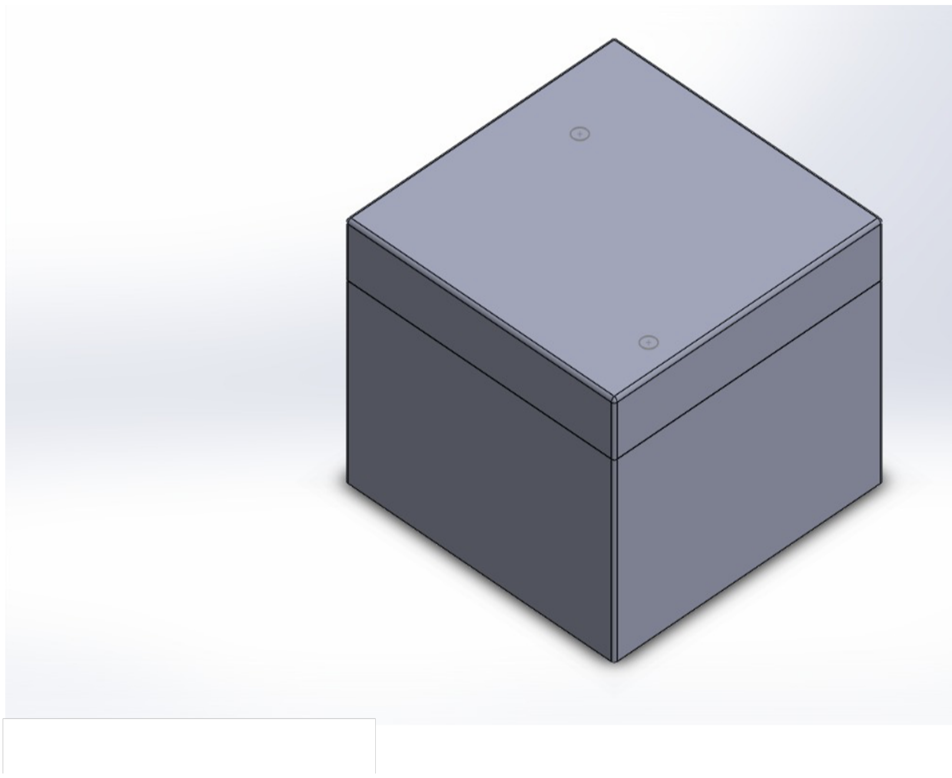

Figure 41: EnclosureClosed

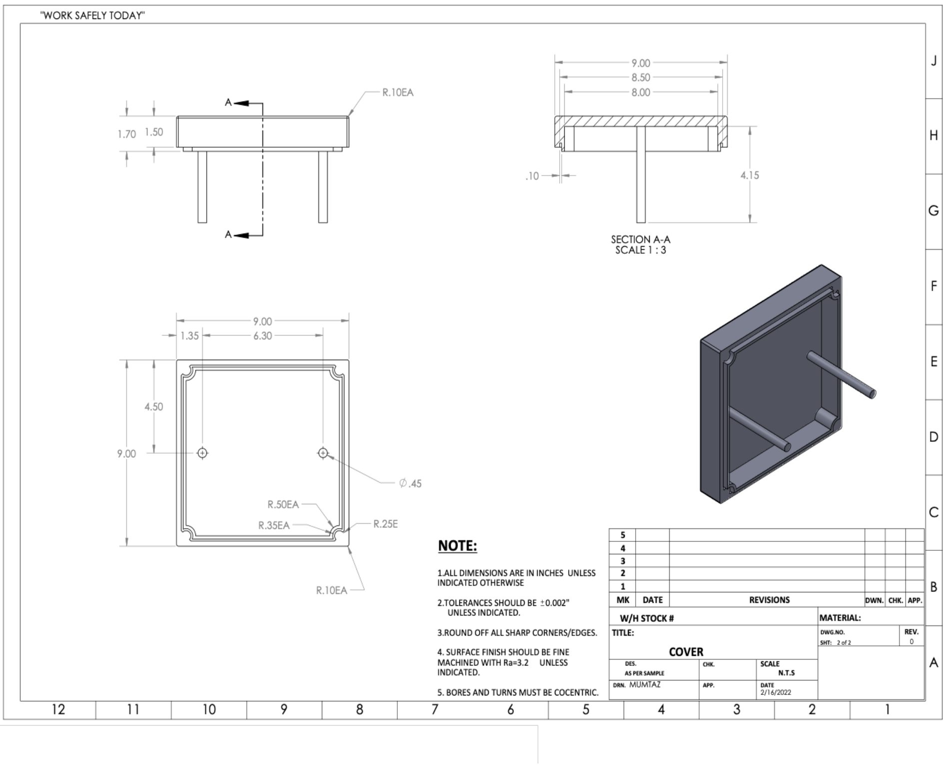

Figure 42: DetailedMeasurementsOfCover

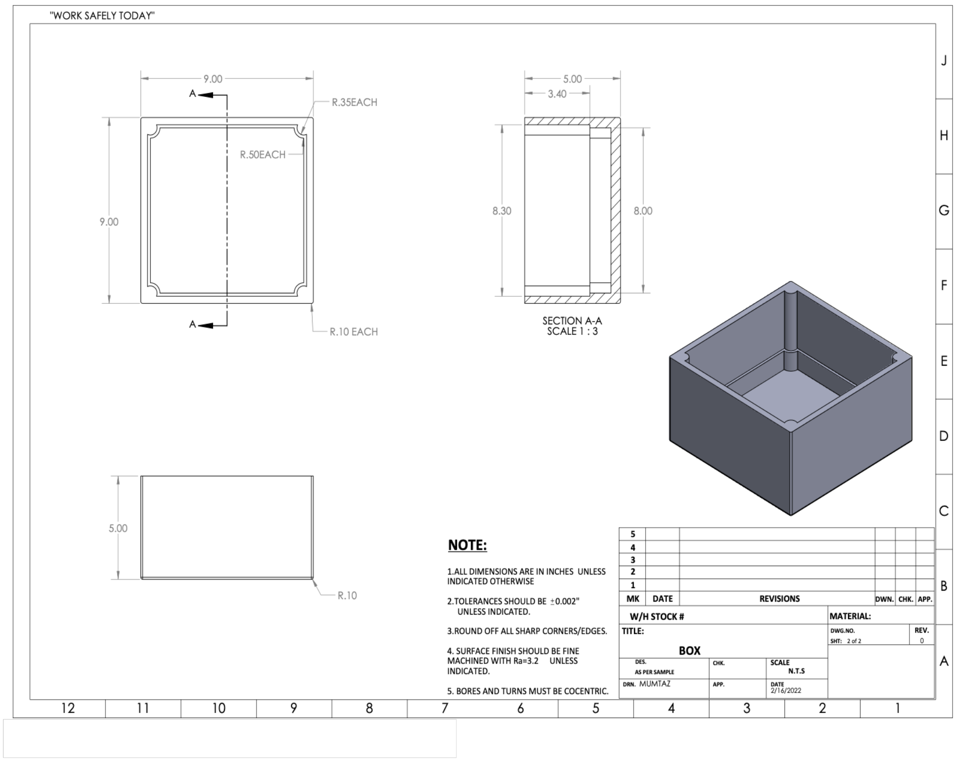

Figure 43: DetailedMeasOfBox

Figure 44: ScrewsAndNutsToHoldComponentsOnPlexiglass

4.8.3 General Validation

The chosen material for the enclosure is going to be PLA plastic as it is easy to find, and we can use it in the 3D printer. Another reason why we chose PLA is because it has no fumes when it is being melted like ABS which can contain harmful inhalants. The screws we will be using are steel thread rolling screw this will be the best choice to match the PLA plastic as this screw forms the thread and whilst it is forming it, it presses the material to the walls and forms the threads instead of creating material chips down and clogging it. To make sure all of our components inside are not going to be moving we will use a sheet of plexiglass and screw all the components on it by brass heating it that way we don't have to do any measurements or risk breaking the plexiglass if we were going to take measurements then drilling as plexiglass is very fragile it can crack.

4.8.4 Interface Validation

No direct interface with other components

4.8.5 Verification Plan

1. Fully close enclosure.
2. make sure lid is facing up towards the ceiling/sky
3. Turn system on via power supply
4. Flip box over 180 degrees
5. Test by sending commands from the GUI to control the system by turning on and off the output of the system
6. Check for light bulb if it is turning on and off.
7. Flip box over 180 degrees to its original position.
8. Remove lid to inspect components within the enclosure and verify that they are not damaged and continue to function properly by controlling the system from the GUI.

4.8.6 References and File Links

[1]2022. [Online]. Available: https://www.solidworks.com/sw/docs/student_wb_2011_eng.pdf. [Accessed: 07- Mar- 2022].

video of box

where to find screws to screw components to plexiglass except arduino and GSM module

screws for arduino and GSM module

power cord

C14 Panel Mount Plug Adapter Power Connector Socket with Spring Cover

Power Socket Plug Panel 15A 125V AC Panel Mount Outlet

4.8.7 Revision Table

Revision Table	
Date	Revision Description
2/18/2022	Ali Alfadala: changed the verification plan and added more pictures about the parts inside the box and c13 socket also added labels for the screws.
2/16/2022	Ali Alfadala: Added solidworks screenshots and labeled parts.
2/4/2022	Ali Alfadala: Draft for Block2 is created.

5 System Verification Evidence

5.1 Universal Constraints

The project has a list of constraints that it must meet in order to be considered quality work.

1. **The system may not include a breadboard**
   The system includes no breadboards throughout its design and does not need any in order to function properly. A custom PCB was created for the power regulator to step down voltage to usable levels, and a SIM7000 module is used to handle SMS messaging. Breadboards are only used for testing the components of the system when they are separate from the other components.

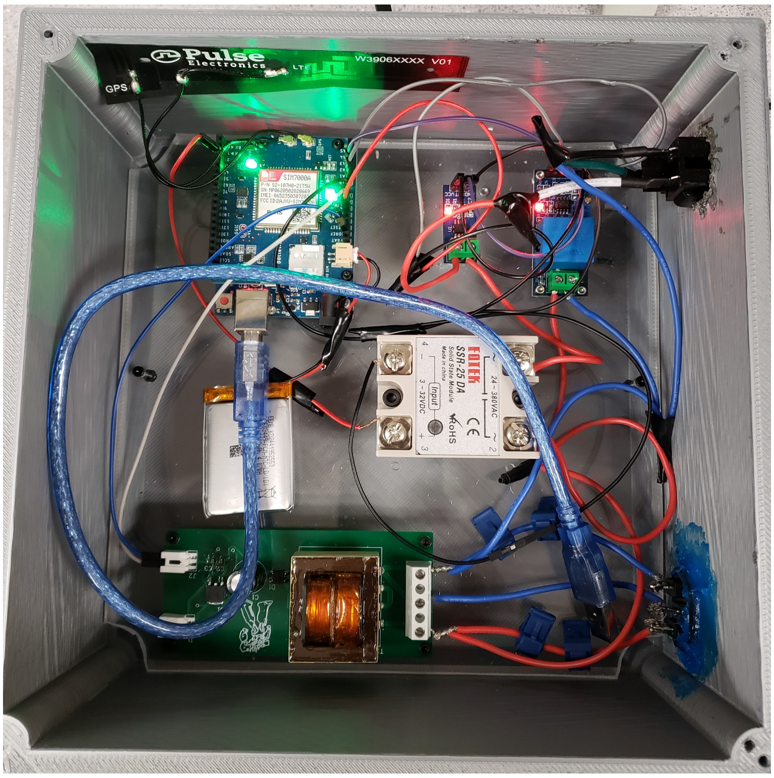

Figure 45: Full system to show no breadboard being used

2. **The final system must contain both of the following: a student designed PCB and a custom Android/PC/Cloud application.**
   The system contains both a student-designed PCB and a custom application. The 230VAC/5VDC Power regulator board was built by Zachery McLaughlin using Altium and ordered through JLCPCB, and Abdulla Al-Mannai developed a custom Python GUI application that can turn the system ON/OFF and receive sensor values.

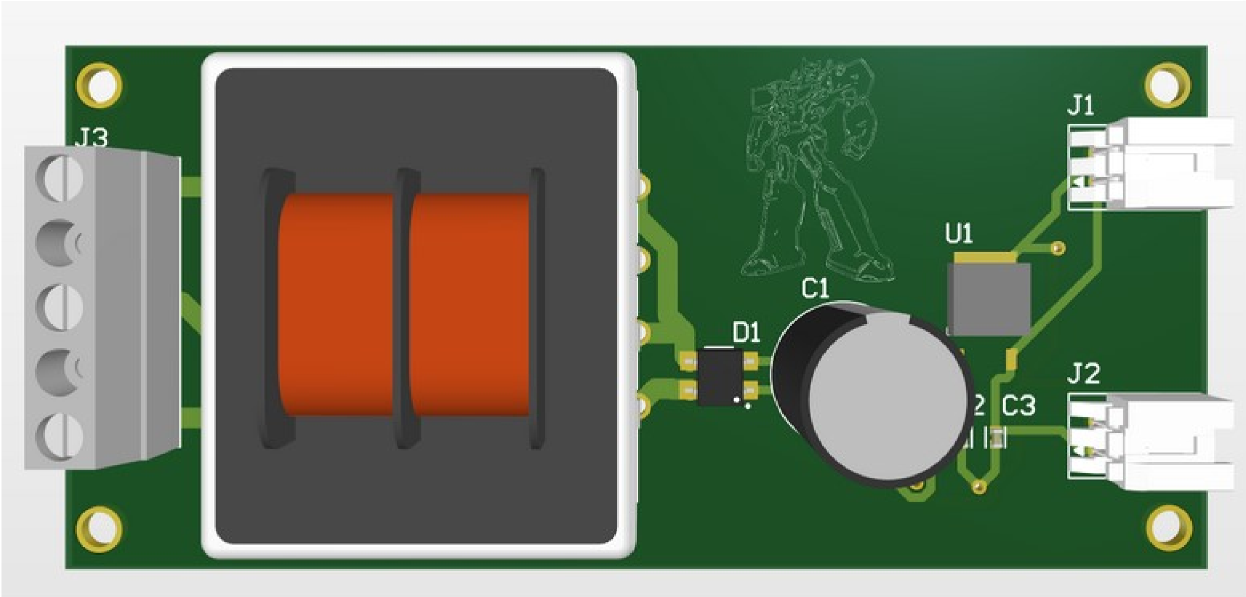

Figure 46: Custom PCB

Figure 47: Custom GUI for user to interact with

3. **If an enclosure is present, the contents must be ruggedly enclosed/mounted as evaluated by the course instructor.**
   A plexiglass floor is securely mounted within the enclosure in order to hold all of the project's components. Each components is screwed into the plexiglass to give them rigid support within the enclosure to prevent damage to both the enclosure and the components.

Figure 48: Enclosure with lid on

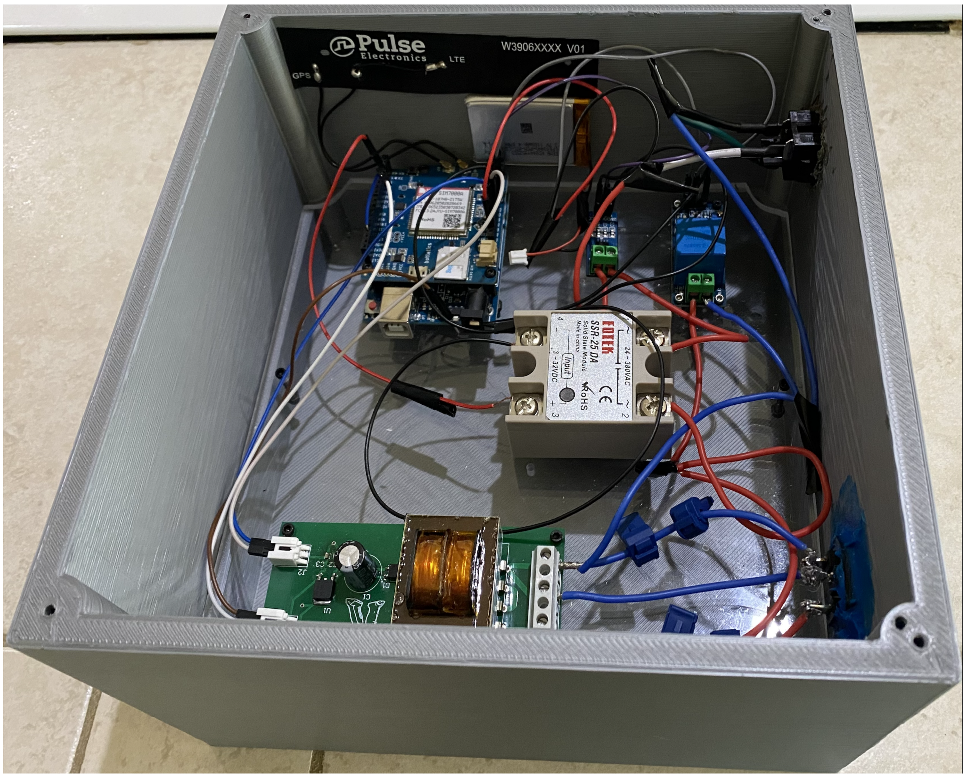

Figure 49: Full system to show that all components are mounted

4. **All power supplies in the system must be at least 65% efficient**
   Testing was conducted on the Power supply of the system to see that the ratio of PIN/POUT is >= 65%. Calculations are also made to ensure that the theoretical efficiency is >= 65%

```
+CMGR: "REC UNREAD","+18449073238",,"22/05/04,10:20:18-28",145,36,0,0,"+12063130056",145,3
get
***** SMS *****
 (3) bytes *****
Message Was:get
*****
        ---> AT+CMGF=1
        <--- OK
        ---> AT+CMGD=001
        <--- OK
Delete SMS OK!
Send to #15417404041
message is: voltage=124.88,current=1.69,freq=62.89
```

Figure 50: Current, Voltage, and Frequency measurements read from the sensors and sent via SMS

Figure 51: Meter showing current within 5% error

Figure 52: Meter showing voltage and frequency within 5% error

5. **If present, all wire connections to PCBs and going through an enclosure (entering or leaving) must use connectors**
   There will be two wires connecting from outside to the enclosure which are the 120VAC power cable which connects to a plug that then is connected to the power supply and there will also be a outlet that will be the output of the system to draw load. Only connectors are used within between the boards.

6. **The system may be no more than 50% built from purchased modules**
   The system Consists of Eight main Blocks. Three of which are bought and Five are built. This results in 37.5% bought modules from the full systems. These blocks are classified as:
   Bought blocks:

   - Sensors
   - GSM module
   - Relays

   Built blocks:

   - Sensors's Code
   - GSM communication module code
   - Power Regulator
   - GUI.
   - Enclousre

5.2 Fitment

5.2.1 Requirement

Power Regulator, GSM module, sensors, and Arduino UNO must all fit within 15" X 13" X 7" 3D-printed enclosure.

5.2.2 Testing Processes

Fit components, sensors, and boards within enclosure.

1. Place all components within enclosure
2. Attach all cables and wires to boards

5.2.3 Testing Evidence

On 03/02/2022, Ali Alfadala verified that all components fit within the enclosure.

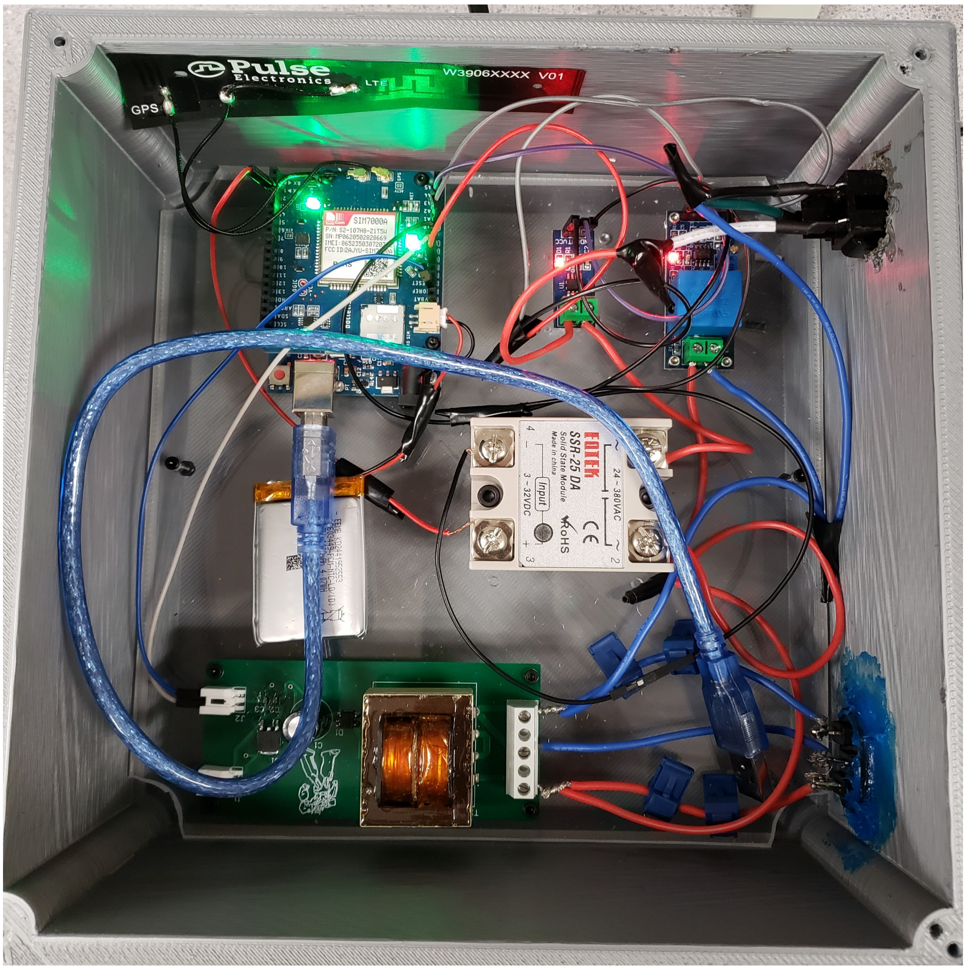

Figure 53: Enclosure with all components fully connected

5.3 Power

5.3.1 Requirement

The system will be powered by a step-down converter that will convert 120VAC to 5VDC so that it can power an Arduino UNO and charge the battery for a SIM7000 communication module. The power will also be used to power voltage and current sensors through the Arduino UNO. The range of voltage will be between 4-5V.

5.3.2 Testing Process:

Verification Method: Connecting the outputs of the power regulator to a programmable load and plugging the input plug into both the input side of the board and into a 120VAC wall outlet. The programmable load will read the output voltage and the currents that the system is drawing.

1. Connect wires on output side of power regulator to positive and negative leads of programmable load
2. plug 120VAC input into the input side of the board.
3. set current values for range of expected currents that will be drawn from Arduino UNO, sensors, and SIM7000.
4. test for various currents to test for ranges of voltages that are to be expected.
5. repeat process above for all parameters.

5.3.3 Testing Evidence:

The Power regulator was tested and evaluated during the block 2 checkoff conducted on 03/02/2022. The testing was comprised of the same testing parameters mentioned in the testing process section above. The outputs were connected to a programmable load and the input was supplied with 120VAC. The output read 5VDC and various current ranges were tested that were in line with what was to be expected from the Arduino UNO, sensors, and the SIM7000.

https://drive.google.com/file/d/1_e0E398FYZwF2xNZ71PCs47XRNYBtlPt/view?usp=sharing
Time stamp 0:30 to 1:15

5.4 Enclosure

5.4.1 Requirement

The enclosure that the electrical devices reside in must be able to withstand being flipped over 180 degrees from start position. All components must remain functional and not be damaged.

5.4.2 Testing Process:

Verification Method: After the enclosure is designed and printed, the enclosure must be sealed and placed upright and then flipped over 180 degrees. All components must remain functional and not be damaged.

1. Fully close enclosure.
2. make sure lid is facing up towards the ceiling/sky
3. Turn system on via power supply
4. Flip box over 180 degrees
5. Test by sending commands from the GUI to control the system by turning on and off the output of the system
6. Check for light bulb if it is turning on and off.
7. Flip box over 180 degrees to its original position.
8. Remove lid to inspect components within the enclosure and verify that they are not damaged and continue to function properly by controlling the system from the GUI.

5.4.3 Testing Evidence:

The Enclosure, once fully assembled with all screws in place and the top securely fastened, is flipped over 180 degrees where it will be upside down and then flipped back over to be upright. The top was removed in order to inspect the components inside and see that all components are functioning properly.

https://drive.google.com/file/d/1_e0E398FYZwF2xNZ71PCs47XRNYBt1Pt/view?usp=sharing
Time stamp 2:08 to 3:14

5.5 Alert

5.5.1 Requirement

The system must alert the user via text if there was a risk detected from an increase in the voltage/current safe operating levels (>2A).

5.5.2 Testing Process:

Verification Method: A commercial amp meter would be attached to the output of the system while connecting a load that requires more current than the safe level of operation. The system should automatically shut off and the user should receive an SMS saying that the system has detected a risk.

1. Connect the commercial amp meter to the output of the system.
2. connect the test load to the output of the system.
3. turn on the system from the GUI to enable power transmission.
4. Check for the reading on the amp meter.
5. Check phone for possible SMS sent form the system stating that the system was turned of for safety purposes.

5.5.3 Testing Evidence:

The Kill-O-Watt meter is attached to a wall outlet and the power cable attaching to the system will attach to the Kill-O-Watt meter. An external current load was also attached to the system to draw more current than what is safe which triggered the alert system. The relay automatically shut off to stop powering the system and the GSM module sent an alert to the user to indicate an overcurrent spike was detected.

https://drive.google.com/file/d/1_e0E398FYZwF2xNZ71PCs47XRNYBt1Pt/view?usp=sharing
Time stamp 1:21 to 2:08

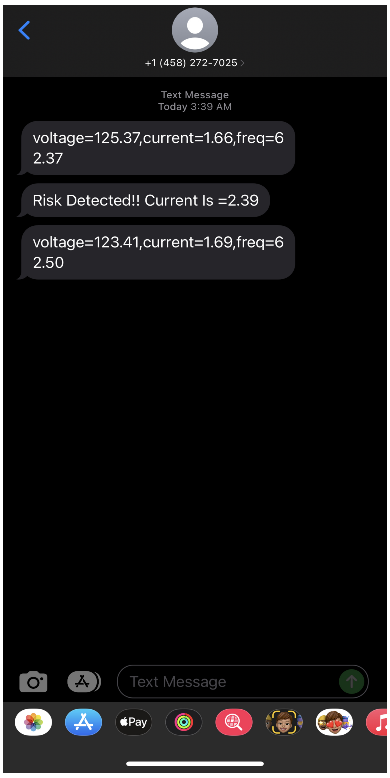

Figure 54: Middle text shows risk detection. Overcurrent spike >2A

In the image above we see that there is a text message sent when a risk is detected (overcurrent spike >2A) and automatically shuts the relay off for system protection.

5.6 Accuracy

5.6.1 Requirement

The voltage and current sensors must be able to read voltage, current, and frequency within an error percentage of 5%

5.6.2 Testing Process:

Verification Method: An Commercial amp/voltage meter should be connected to the output of the system while connecting a load that consumes power, check by sending the request to get values sent via GSM module as SMS and compare with the reading from the voltage/amp meter connected.

1. Connect the commercial voltage/amp meter to the output of the system.
2. Connect the load to the output of the system.
3. Turn on the power delivery form the system.
4. Request for the values being read from the sensors by pressing the proper button on the GUI to be sent via SMS to the registered phone.
5. Compare the value that was sent from the system with the value being displayed on the voltage/current meter.

5.6.3 Testing Evidence:

The Kill-O-Watt meter is attached to a wall outlet and the power cable attaching to the system will attach to the Kill-O-Watt meter. An external current load was also attached to the system to draw current for the system. The system values were requested by the user and the values were compared against the values being read by the Kill-O-Watt meter to ensure accuracy within 5%.

https://drive.google.com/file/d/1_eOE398FYZwF2xNZ71PCs47XRNYBtlPt/view?usp=sharing
Time stamp 0:30 to 1:15

```
+CMGR: "REC UNREAD","+18449073238",,"22/05/04,10:20:18-28",145,36,0,0,"+12063130056",145,3
get
***** SMS *****
 (3) bytes *****
Message Was:get
*****
        ---> AT+CMGF=1
        <--- OK
        ---> AT+CMGD=001
        <--- OK
Delete SMS OK!
Send to #15417404041
message is: voltage=124.88,current=1.69,freq=62.89
```

Figure 55: Current, Voltage, and Frequency measurements read from the sensors and sent via SMS

Figure 56: Meter showing current within 5% error

Figure 57: Meter showing voltage and frequency within 5% error

5.7 Shutoff

5.7.1 Requirement

The System must be able to automatically shut off the substation via relays when a risk (>2A). is detected to protect the substation components.

5.7.2 Testing Process:

Verification Method: An Commercial amp/voltage meter should be connected to the output of the system while connecting a load that consumes more than the operating levels.

1. Connect the commercial voltage/amp meter to the output of the system.
2. Connect the load to the output of the system.
3. Turn on the power delivery for the system.
4. check the displayed values on the voltage/amp meter.
5. Check the phone for SMS received from the System stating that the relay was turned off with the detected risk value

5.7.3 Testing Evidence:

The Kill-O-Watt meter is attached to a wall outlet and the power cable attaching to the system will attach to the Kill-O-Watt meter. An external current load was also attached to the system to draw more current than what is safe which triggered the alert system. The relay automatically shut off to stop powering the system and the GSM module sent an alert to the user to indicate an overcurrent spike was detected.

https://drive.google.com/file/d/1_eOE398FYZwF2xNZ71PCs47XRNYBtlPt/view?usp=sharing
Time stamp 1:21 to 2:08

```
+CMGR: "REC UNREAD","+18449073238",,"22/05/04,10:18:45-28",145,36,0,0,"+12063130056",145,3
off
***** SMS *****
 (3) bytes *****
Message Was:off
*****
        ---> AT+CMGF=1
        <--- OK
        ---> AT+CMGD=001
        <--- OK
Delete SMS OK!
Power off!
```

Figure 58: Power OFF case via Arduino Serial Monitor

```
***** SMS *****
 (2) bytes *****
Message Was:on
*****
        ---> AT+CMGF=1
        <--- OK
        ---> AT+CMGD=001
        <--- OK
Delete SMS OK!
Power on!
```

Figure 59: Power ON case via Arduino Serial Monitor

In the image above we see that the system is able to turn on and off via relay, whether it be manually from the user or from an overcurrent spike.

5.8 Analyze

5.8.1 Requirement

Build a system that analyzes voltage, current, and frequency data for 5 minutes and sends it to the GSM module. The sensors must sample for 2 minutes. This data will be transmitted serially between the GSM module and the users computer.

5.8.2 Testing Process:

Verification Method: Run the system for 2 minutes and ensuring that at least 1,000 data points are collected that are within an error % of +- 5%

1. Connect multi-meter to sensors to measure actual voltage, current, and frequency numbers.
2. Record voltage, current, and frequency values observed after transmission from GSM module.
3. Run system for 2 minutes.
4. Compare values to ensure accurate results as well as no errors occurred along the way.

5.8.3 Testing Evidence:

We plugged the power cord into the wall outlet to turn the system on. Once the system was turned on, the sensors started collecting data and sending it to the serial monitor of the Arduino IDE to see the data collection rate. Within 2 minutes, over 1,000 data samples were collected that displayed voltage, current, and frequency values at each time variation.

5.9 Controlling

5.9.1 Requirement

The user must be able to manually control (Turn ON/OFF) the relay in the substation via a GUI .

5.9.2 Testing Process:

Verification Method: An Commercial amp/voltage meter should be connected to the output of the system while connecting a load to the output of the system as well.

1. Connect the voltage/amp meter to the output of the system.
2. Connect a load such as an lamp to the output of the system.
3. Press the ON command form the GUI.
4. Check that the lamp has turned on.
5. Press the OFF command on the GUI.
6. Check that the lamp has turned off.

5.9.3 Testing Evidence:

Using the GUI, there is a button that says ON/OFF. When OFF is pressed with a mouse click, the relay shuts off and disconnects the power source to the sensors, GSM module, and the Arduino. When ON is pressed with a mouse click, the relay turns on and connects the power source to the sensors, GSM module, and the Arduino.

https://drive.google.com/file/d/1_e0E398FYZwF2xNZ71PCs47XRNYBtlPt/view?usp=sharing
Time stamp 0:23 to 0:31 and 1:13 to 1:19

```
+CMGR: "REC UNREAD","+18449073238",,"22/05/04,10:18:45-28",145,36,0,0,"+12063130056",145,3
off
***** SMS *****
 (3) bytes *****
Message Was:off
*****
        ---> AT+CMGF=1
        <--- OK
        ---> AT+CMGD=001
        <--- OK
Delete SMS OK!
Power off!
```

Figure 60: Power OFF case via Arduino Serial Monitor

```
***** SMS *****
 (2) bytes *****
Message Was:on
*****
        ---> AT+CMGF=1
        <--- OK
        ---> AT+CMGD=001
        <--- OK
Delete SMS OK!
Power on!
```

Figure 61: Power ON case via Arduino Serial Monitor

In the image above we see that the system is able to turn on and off via relay.

Figure 62: GUI for user to interact with

5.10 References and File Links

5.11 Revision Table

Revision Table		
Date	Revision Description	Revision done by
6 March 2022	Sections 4 and 5 have been filled with the block's details for the system	All Team members.
22 April 2022	Section 5 was updated to include all 8 Engineering Requirements with descriptions, verification methods, and testing evidence	Zach M.
1 May 2022	Section 5 Testing Evidence for each ER was updated to reflect their respective requirement.	Zach M.
3 May 2022	Edited Testing Evidence for various ERs to update current system.	Zach M.
6 May 2022	Added video links and time stamps as part of ER testing evidence.	Zach M.

6 Project Closing

6.1 Future Recommendations

6.1.1 Technical Recommendations

1. Voltage/Power limit: the system is supposed to be able to monitor a transmission line, which ranges in the kV's of voltage. The current system, as is, can only take a standard wall input of 120VAC. The first recommendation would be to expand on the input voltage capability and have it take a 230VAC input instead of 120VAC. The power supply was meant for a 230VAC input anyways, so this would be a logical next technical step before expanding to higher voltage supplies. [12]

2. Enclosure: The enclosure is rugged and securely fits all components, but is susceptible to outside conditions (i.e. rain, dirt, mud). A next step for the enclosure would be to create seals, or a brand new enclosure, that can better withstand harsher elements such as rain, wind, mud, and dirt. [13]

3. GSM module: There was issues with the service provider for the SMS system with the GSM module, some modules support 2G or 3G only where in the US, only 4G and LTE is supported for network communication. The next team should look into modules that support 4G and LTE for better system support and for more modularity within the grid. [14]

4. The platform that was used for the GUI to GSM module communication had server issues in converting API requests to send SMS through their servers, look for more stable platforms or a GUI implemented as an mobile phone app to send direct SMS from mobile phone. [14]

6.1.2 Global Impact Recommendations

1. Parts shortage: electrical components and systems have been in short supply since the beginning of the COVID-19 pandemic that began in early 2020. The current team had to redesign and order different components and parts based on what was available at the time and what could arrive within time for testing and checkoffs. The parts shortage and supply chain issues continue to persist as of May 2022, so the new team will need to be cautious as to what parts can be acquired in regards to what changes they will want to make. The recommendation for the next team will be to design and plan on creating systems based on components and parts that are actually available instead of choosing a component to base a system on without making sure they are actually can be acquired. [11]

2. Integration with the grid: The current system works in a very small-scale and controlled environment separate from its intended purpose. The current system is essentially a scaled down version of what the intended full system would actually be. Once the system is scaled up to handle the 10s to 100s of kV's of voltage from the grid by the next teams, the next issue would be how to include it into the current grid systems within North America and other markets such as Europe. The electrical grid systems in various countries tend to be very slow in regards to adoption of new technology simply because of how complicated it would be to replace old systems within a country-wide grid network. The new teams would have to work extensively with the governments of these countries and their energy departments to create testing and integration plans for the system within their grids. These plans would be multi-year plans due to the extensive prepping and work required to actually install these systems throughout a grid network. [15]

6.1.3 Teamwork Recommendations

1. Communication: Weekly meetings should always be stuck to and done every single week for the duration of the project at the very least. Continual conversation with teammates, even just to update on current progress, is better for the project and the team to progress. There can be moments where group members would be unaware of changes made to the project or to documentation because they had not met together for longer periods of time. The next team should be sure to meet at least once a week to discuss the project, their concerns, and to plan ahead for future project goals or challenges. [16]

2. Equal distribution of labor: There should be no one person doing more work than the rest. Each team member should work on a portion of the project that is equal to what their other group

members are doing. When there is an unequal distribution of work, team members can get frustrated with each other and/or under deliver on certain aspects of the project because they didn't have enough time to fully work on the parts of the project they were assigned. The next team should be sure to review each block of the project and judge the difficulty of each one in order to understand if it's a part that needs a team member only focusing on it or if it can be shared with another block for a team member to do. [17]

3. Conflict: If there are disagreements or misunderstandings between group members within the project, they should be dealt with immediately and head-on. All group members should work together to try and resolve the conflict or misunderstanding so that progress can be made on the project. For future teams, make sure to communicate between all team members in order to understand if there are any conflicts or misunderstandings so that they can be dealt with worked through. Working through these interpersonal challenges together will be more beneficial for the team than if they were left unattended. More work can be accomplished when the team is unified in understanding than divided. [16]

4. Project Partner/Supervisor/Manager communication: Weekly/biweekly meetings should be held with upper management of the project to ensure the project is making adequate progress as well as remaining within the scope that the management desires. Not keeping in communication with management can lead to misunderstandings and requirements not being met because information isn't being shared. Future teams should make sure to hold weekly/biweekly meetings with their management in order to ensure the project maintains proper progress. [17]

References

[1] "4. The internet will continue to make life better | Pew Research Center." [Online]. Available: https://www.pewresearch.org/internet/2019/10/28/4-the-internet-will-continue-to-make-life-better/

[2] "Remote working in research," *EMBO reports*, vol. 20, no. 1, p. e47435, Jan. 2019, publisher: John Wiley & Sons, Ltd. [Online]. Available: https://www.embopress.org/doi/full/10.15252/embr.201847435

[3] "Don't fear AI. The tech will lead to long-term job growth." [Online]. Available: https://www.weforum.org/agenda/2020/10/dont-fear-ai-it-will-lead-to-long-term-job-growth/

[4] "Infrastructure Cybersecurity: The U.S. Electric Grid." [Online]. Available: https://www.rpc.senate.gov/policy-papers/infrastructure-cybersecurity-the-us-electric-grid

[5] "The Negative Effects of Working From Home on Company Culture." [Online]. Available: https://www.coworkingresources.org/blog/the-negative-effects-of-working-from-home-on-company-culture

[6] E. L. Kelly, L. F. Berkman, L. D. Kubzansky, and M. Lovejoy, "7 Strategies to Improve Your Employees' Health and Well-Being," *Harvard Business Review*, Oct. 2021, section: Human resource management. [Online]. Available: https://hbr.org/2021/10/7-strategies-to-improve-your-employees-health-and-well-being

[7] "Can computer chip makers reduce environmental impact?" [Online]. Available: https://news.stanford.edu/pr/96/960605chipsenvir.html

[8] "There is now an alternative to solid tantalum capacitors," Mar. 2017, section: Capacitors. [Online]. Available: https://passive-components.eu/there-is-now-an-alternative-to-solid-tantalum-capacitors/

[9] A. Kylili, N. Afxentiou, L. Georgiou, C. Panteli, P.-Z. Morsink-Georgalli, A. Panayidou, C. Papouis, and P. A. Fokaides, "The role of Remote Working in smart cities: lessons learnt from COVID-19 pandemic," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 0, no. 0, pp. 1–16, Oct. 2020, publisher: Taylor & Francis _eprint: https://doi.org/10.1080/15567036.2020.1831108. [Online]. Available: https://doi.org/10.1080/15567036.2020.1831108

[10] B. Vakil and T. Linton, "Why We're in the Midst of a Global Semiconductor Shortage," *Harvard Business Review*, Feb. 2021, section: Supply chain management. [Online]. Available: https://hbr.org/2021/02/why-were-in-the-midst-of-a-global-semiconductor-shortage

[11] J. Cox, "A breakdown of the major chip shortage: How long it will last and the market and economic impact," May 2021, section: Pro: Pro Insight. [Online]. Available: https://www.cnbc.com/2021/05/03/a-breakdown-of-the-major-chip-shortage-how-long-it-will-last-and-the-market-and-economic-impact.html

[12] "Steps to convert the 230v to 5v dc to powerup the circuits," 2016, publisher: ElProCus. [Online]. Available: https://www.elprocus.com/steps-to-convert-the-230v-ac-to-5v-dc/

[13] A. Weiman, "Designing rugged, waterproof enclosures for electronic devices." [Online]. Available: https://www.bresslergroup.com/blog/designing-rugged-waterproof-enclosures-for-electronic-devices/

[14] "What is gsm and how does it work?" [Online]. Available: https://www.electricaltechnology.org/2018/01/gsm-global-system-mobile-communications.html

[15] "Overview of grid integration issues," publisher: Greening the Grid. [Online]. Available: https://greeningthegrid.org/quick-reads

[16] "Effective interpersonal and team communication skills for engineers," *IEEE Press*, publisher: John Wiley & Sons, Ltd. [Online]. Available: https://search.library.oregonstate.edu/primo-explore/fulldisplay?docid=CP51230865450001451&context=L&vid=OSU&search_scope=everything&tab=default_tab&lang=en_US

[17] "Project management for engineering design (1st ed.)," *IEEE Press*, publisher: Morgan Claypool. [Online]. Available: https://search.library.oregonstate.edu/primo-explore/fulldisplay?docid=CP71165148780001451&context=L&vid=OSU&search_scope=everything&tab=default_tab&lang=en_US

6.2 Project Artifact Summary with Links

Sensors Hardware Validation, wiring diagram, and Interface Definitions.

Arduino Block Validation and Interface Definitions.

Sensors Code Validation and Interface Definitions.

Power Regulator Validation, Schematics, and PCB design.

Graphical user interface design, command flow, and interface definitions.

Enclosure Design, 3D schematics in Solid works, and connector choices.

GSM Code Validation and Interface Definitions.

Full Wiring Diagram for all components within the system in the enclosure.

Folder containing the code for the Header files and Arduino file for the final system.

System's Block Diagram.

Demonstration Video of the system's functionality and individual requirments.

6.3 Presentation Materials

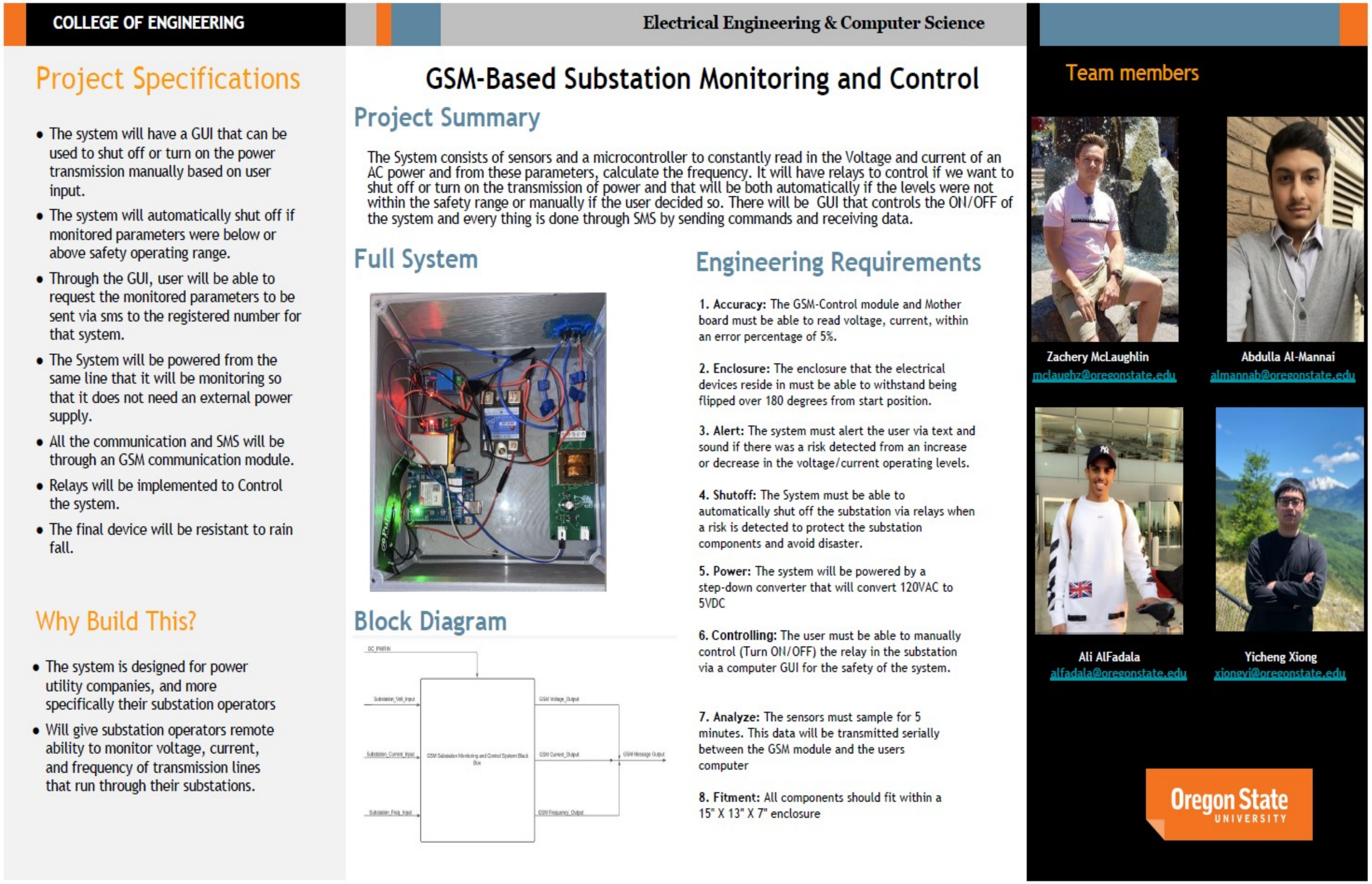

Figure 63: Presentation Poster for overall project