High Level Design Report:

Microgrid Team

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1 Introduction

As our world transitions to cleaner energy in response to climate change, innovative technologies must arise to provide affordable and practical solutions for communities. Solar microgrids are one such emergent technology, and offer clean, resilient energy to a community. Additionally, microgrids can keep money within a community by allowing units that generate a surplus of power to sell it off to other units that need more. However, microgrids (especially solar ones), require a robust energy management and storage system to operate effectively, and microgrid technology and support must be improved to make microgrids more practical to implement.

2 Problem Statement and Proposed Solution

Problem Description

Main Problem: *microgrids need to be simpler and more practical to implement.*

Solar cells provide transient energy, but an energy storage device is needed to provide energy when solar cells are inactive. Additionally, a solar microgrid needs to provide enough power to meet community demands that change throughout the day, especially responding to peak loads. The system must also monitor for faults or other errors that may occur and perform power switching to keep all of the loads operational. The power factor of each load/source must also be monitored to determine system efficiency, stay within operational ranges, and determine power cost.

Proposed Solution

The proposed solution is to develop a smart energy storage switching system that monitors and responds to varying power demand, transient power generation, and faults. To do this, we intend to create a model microgrid with multiple homes of varying loads and power generation capabilities. Each home will be modeled with solar panels for power generation. Power not consumed at the load will be sent to a battery storage system where the monitoring and switching will occur.

3 System Requirements

The overall system from generation to display involves a multitude of requirements including hardware, software and safety aspects.

Firstly, the project will be powered by rechargeable batteries and solar cells, and so for a smooth demonstration we will need a steady light source. To simulate real-world distribution, the DC voltage needs to be converted to AC and so inverters would allow for this change.

In terms of the embedded intelligence necessary, the power monitoring, communication and control of the system requires a specific setup for the intended purpose. The controls system will operate through logic statements, and the pcb processing this information will include a multiplexor to sample data and microprocessors to process it. The device will also need to be configured for power monitoring which includes tracking the power factor, the power demanded by the loads and the charge of the battery.

For the system to model different power demands, the loads will need to vary in power consumption, whether it be highly resistive or otherwise. Thus, we would need different types of components to consume varying amounts of energy such as LEDs, inductors etc.

Finally our system will need to have an interface displaying all of the monitoring and switching that will continually be in occurrence. This will give details about how much power is necessary where, as well as how efficient the system is.

This project will be on a small scale to minimize the current flow for safety reasons. Additionally the system should have a fault recovery process in place. Fuses and switches would meet these needs.

4 System Block Diagram

4.1 Overall System:

The high level block diagram of the overall system is shown below in Figure 1.

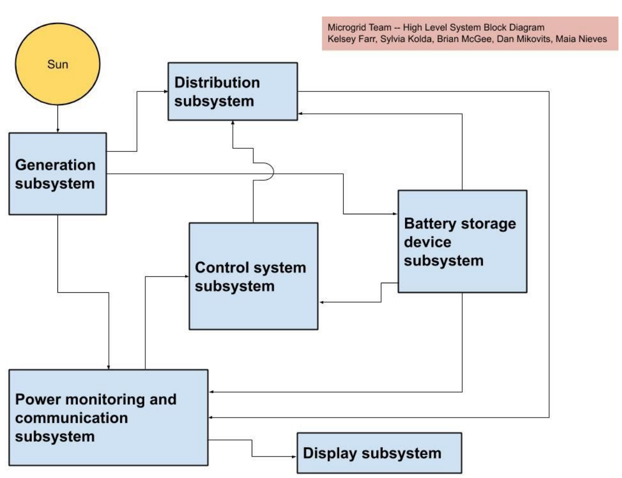

Figure 1. High Level Block Diagram of Overall System

Subsystems:

- Generation
- Distribution
- Storage
- Control System
- Monitoring
- Display

Block diagrams for each individual subsystem are shown in Figure 2 through Figure 7.

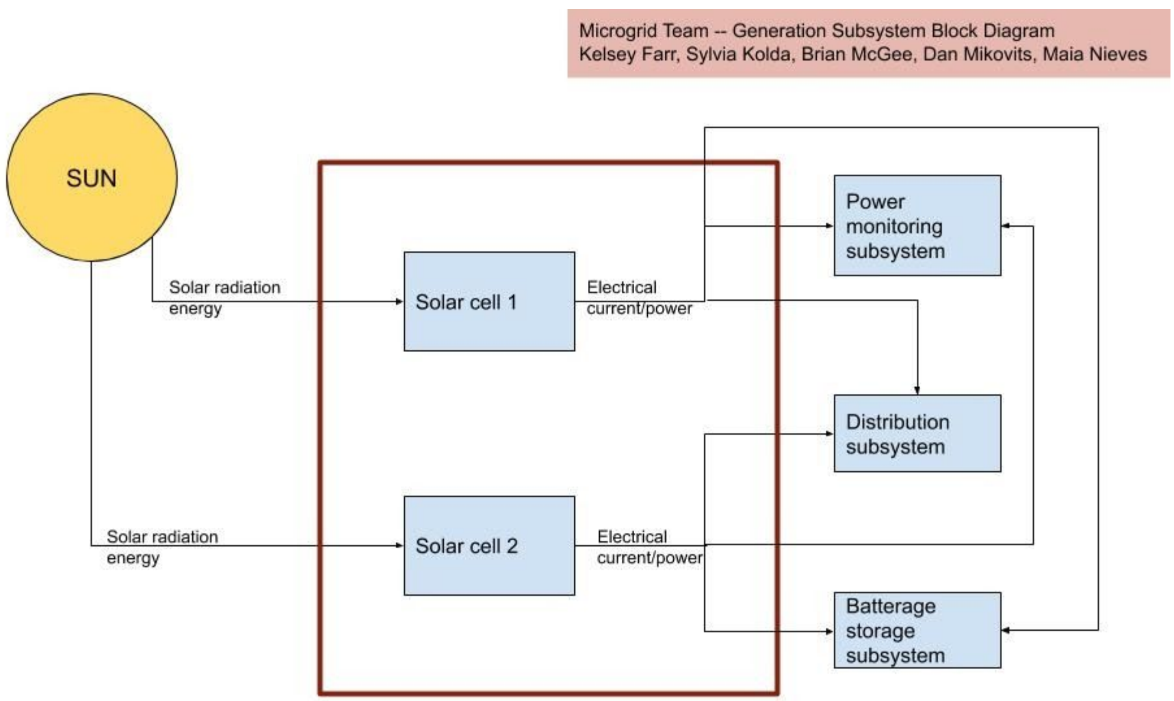

Figure 2. Block Diagram of Generation Subsystem

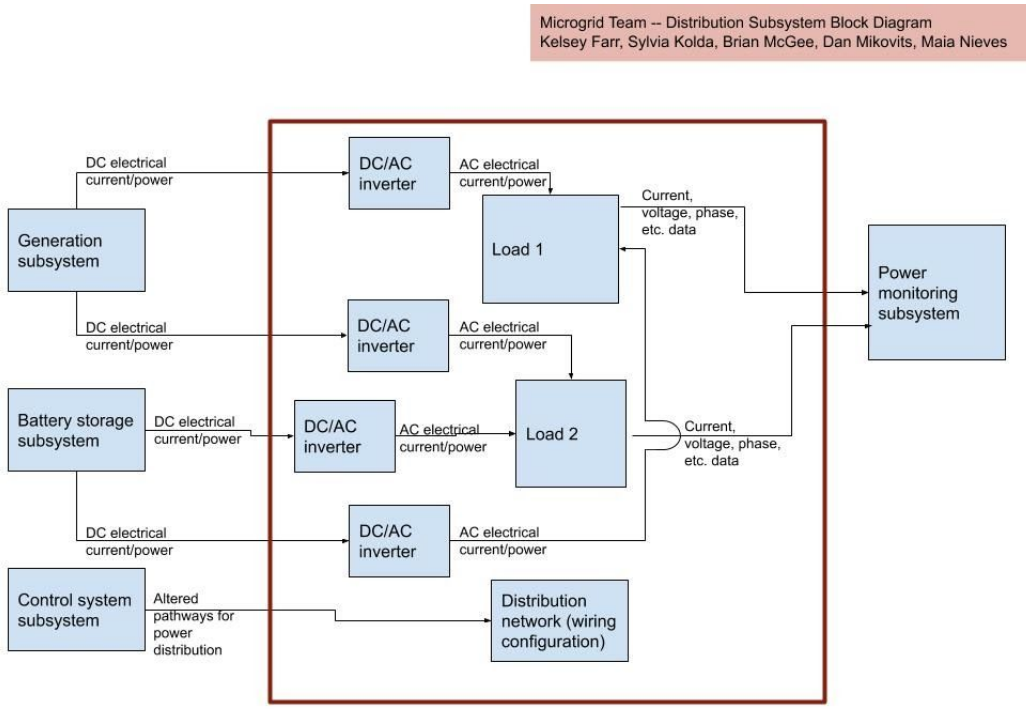

Figure 3. Block Diagram of Distribution Subsystem

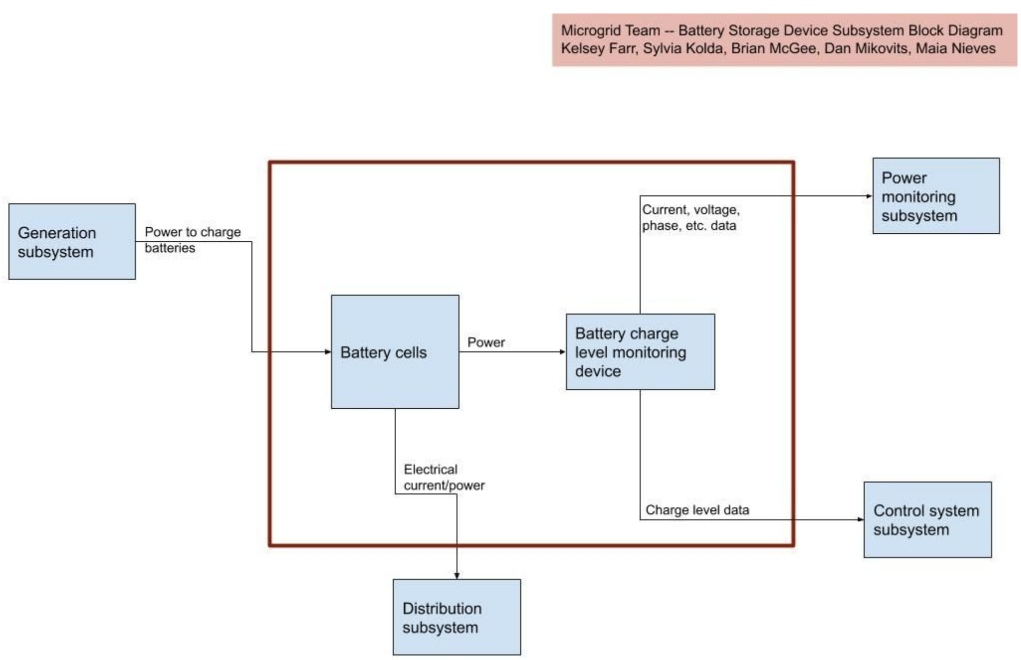

Figure 4. Block Diagram of Battery Storage Subsystem

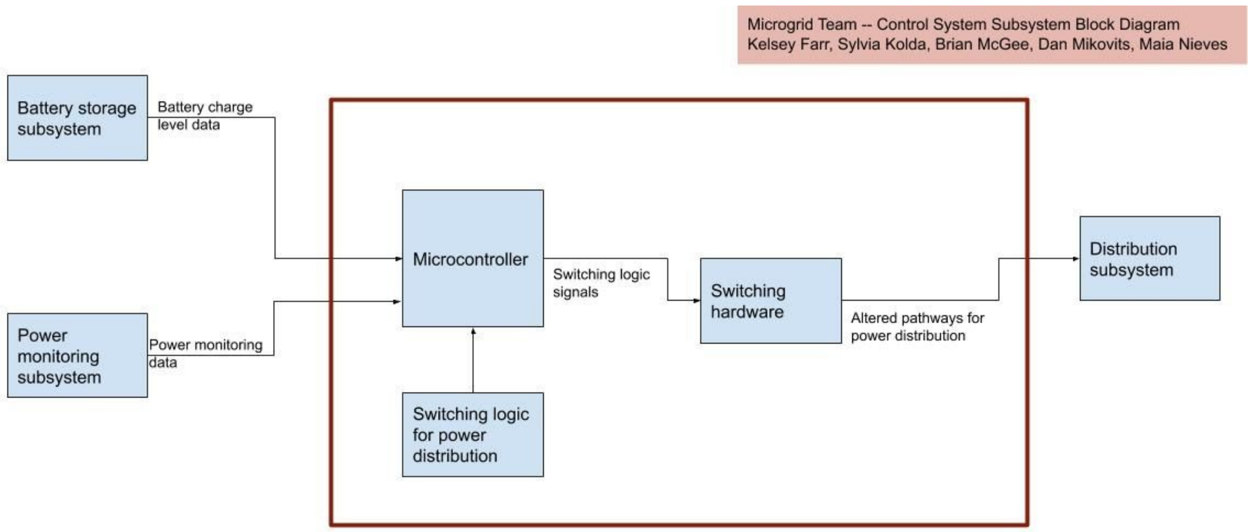

Figure 5. Block Diagram of Control System Subsystem

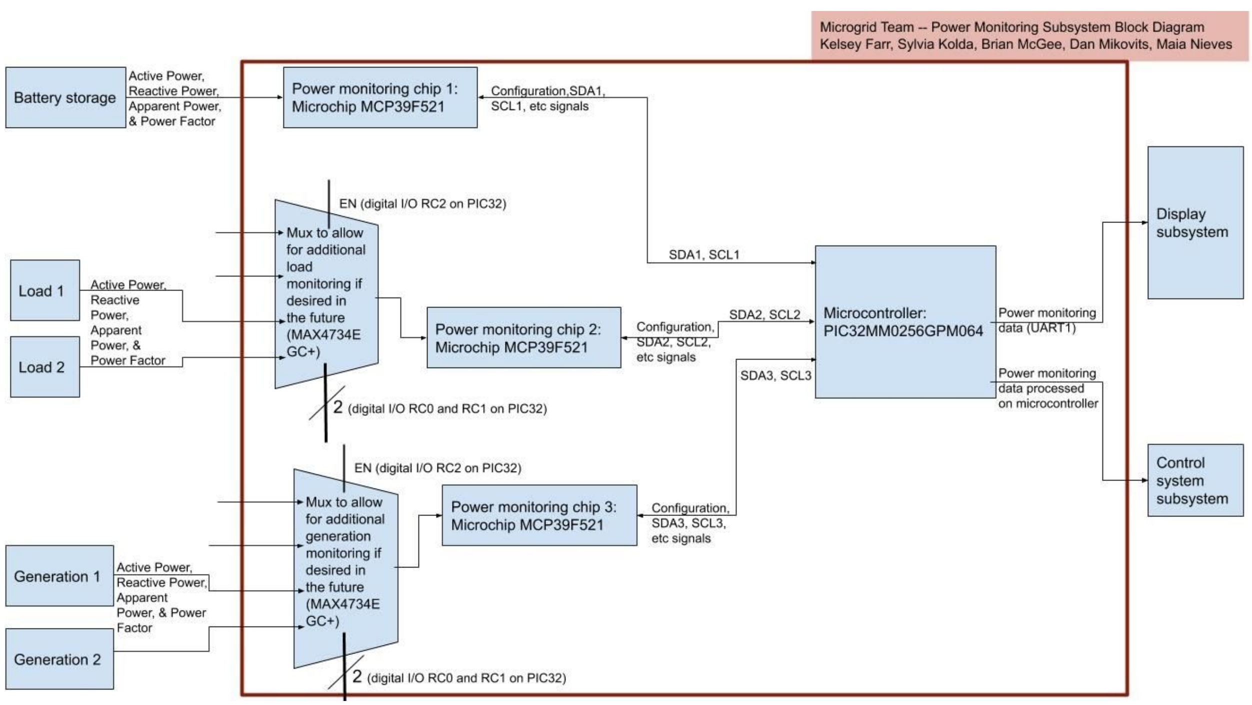

Figure 6. Detailed Block Diagram of Power Monitoring Subsystem

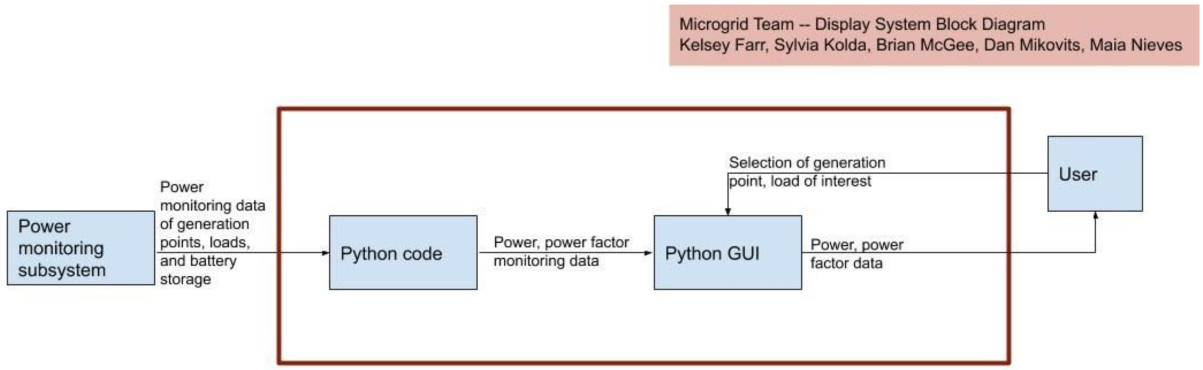

Figure 7. Block Diagram of Display Subsystem

4.2 Subsystem and Interface Requirements:

Subsystems:

- Generation
    - Solar Panels
- Distribution
    - Grid (distribution wires)
    - Inverters
    - Loads
- Storage
    - Battery system
        - Batteries
        - Fuses
        - Battery charge level monitoring device
- Control Systems
    - PCB
        - Outputs to switches
        - Multiplexer so that we can designate which switch we are talking to without multiple pins
        - Switches
- Monitoring
    - PCB
        - Analog inputs
            - Multiplexer so that we can designate which switch we are talking to without multiple pins
        - I2C communication
- Display
    - Python GUI
        - Display power factor at each load

        - Demand at each load
        - Charge of battery
        - Percentage of current coming from generation vs storage
        - Curves at each load?

4.3 Future Enhancement Requirements

The main enhancement we would like to allow for is the addition of extra loads. We could increase the number of loads and vary the types of loads, such as resistive, capacitive, and inductive. To allow for this extra addition of loads, we would attach some of our power monitoring microchips to multiplexors. This would allow us to add extra loads (and generation sources) to the input side of the multiplexor. The select would then output one of the loads (or generation sources) to the chip, allowing it to still function properly with only one input.

Additionally, we would like to allow for expansion of our battery storage in the future by adding battery storage at each load. This should be able to be implemented with simply adding a couple more wires attaching the batteries to the solar panels, with the batteries being added between the solar panels and the inverters. We would then also need to connect the batteries to the power monitoring microchip.

5 High Level Design Decisions

- Generation
        - We will be generating power via solar panels at each load in order to model a neighborhood microgrid where power generation and consumption both occur at the building level.
- Distribution
    - Inverters
        - We will place inverters between the storage and the distribution grid and the generation and the distribution grid. The distribution is 12V AC while both storage and generation are 12V DC. We chose this instead of choosing one inverter after both the generation and storage, because that would require long transmission across the grid in 12V DC which is undesirable.
    - Loads
        - One load will be purely resistive with LEDs representing the load. The number of LEDs lit represents how much power is being consumed.
        - The other load will be a low power RL load. This will allow us to demonstrate how the microgrid responds to a reactive load as well as how it responds to a load that does not consume all of the power that its solar panels are generating. The amount of power will once again be

shown through the use of LEDS, but this load will also include inductors, which will be wires we coil ourselves.
    - We are choosing to model two loads in order to simulate the difference between loads that are present in a real microgrid and show that our power switching can maintain the power delivery needed at each load.
- Storage
  - Battery system
    - The battery banks will be set up in a configuration that minimizes the internal resistance while matching the voltage level and maintaining current levels less than the max rating.
    - These banks will all be located in an overall storage system where switching can occur to connect or disconnect battery banks.
    - We are planning to use rechargeable AA batteries as a cost-effective option to operate within our power monitoring voltage range.
    - The control systems subsystem switches will be internal to the battery to either switch in or switch out modules of batteries to match power demand.
  - Fuses
    - We are including fuses to operate as safety functionality for our project. If in some scenario the current exceeds our max ratings, the fuses will protect the system from damage.
- Control Systems
  - PCB
    - We plan to use the PIC32MM0256GPM064 family of microcontrollers, which is the same one used to create our PCB earlier this semester. The main functionality the group needs from the microcontroller is analog pins, which the PIC32MM0256GPM064 provides. The PIC32MM also has UART functionality, which will be useful for debugging purposes when needed. Choosing this chip will also be helpful because the group is familiar with the spec sheet of this particular microchip.

    - We will use digital output from the microcontroller in order to control our power switching and set switches on or off to determine how many battery banks are currently connected.
- Monitoring
  - PCB
    - Analog inputs - why?
      - The group is using AC to model a scaled down version of a real power grid, so analog inputs should be used to monitor this. Analog gives a better depiction of the real-time occurrences of the grid and allows for more accurate monitoring of power and load conditions.
    - Why are we choosing to monitor:
      - Display power factor at each load

                - This will show the efficiency of both the grid and the storage system. The only power that can do work is actual power, so the power factor is a measure of that.
            - Demand at each load
                - More so because the chip allows us to easily. Plus, this will allow us to show which scenario we are in (high demand vs low demand).
            - Charge of battery
                - Allows us to demonstrate the charging of the battery as well as its usage (depletion) over time
            - Current coming from generation vs storage
                - An exact percentage of contribution from each generation and storage is not needed, but we need to know if both generation and storage are contributing. If it ends up being easy to calculate percentage, then it could be done if desired. This shows the ability of the battery to meet power demand.
        - Class of microcontroller?
            - MCP39F521 -- 24-Bit Single Phase Power Monitoring IC
                - https://www.microchip.com/wwwproducts/en/MCP39F521
                - Monitors active, reactive, and apparent power, active and reactive energy, RMS current and voltage, power factor and line frequency, and line crossing detection.
        - I2C communication - why?
            - The monitoring chip we plan to use includes I2C communication functionality.
- Display
    - Python GUI - why python?
        - Python has built in serial functionality that is relatively easy to use. It can be used to configure a system that will organize and represent data as it comes in.

6 Open Questions

One of our questions about how to implement this project is centered around measuring state of charge in the batteries. At first we were not sure how to do this at all. Then we found a product online, an amp hour meter, that we thought could be helpful. We're not quite sure how we will implement it yet, but we think it should be rather self-explanatory.

Additionally, we are still not sure how we are going to scale the voltage. We know we are going to reduce the voltage from its real-life value, since that value is lethal. However, we are not sure how much to reduce it by. We have considered scaling it down by a factor of 10, but we are not sure how easily that will interact with the rest of our components, specifically what effect that would have on our required battery size. So, this question remains open.

Finally, we found it necessary to address the question of how we will demonstrate the project in the spring. We plan to build a scaled-down model of a microgrid, with solar cells as the generation, batteries as the storage, and LEDs and inductors as the loads. The solar panels will be powered by the artificial sun lamp that has been used to power solar in previous senior design projects. The LEDs will allow us to view how much power is being consumed at the load, and we will have a display showing other stats of our microgrid, such as power factor. Finally, we will pre-program some different scenarios into the software to show how the microgrid acts in certain situations.

7 Major Component Costs

The following components are necessary to our project but are available in 205 Stinson-Remick and therefore do not need to be included in our budget: wires, pin headers, resistors, capacitors, LEDs, materials to make inductors, mini USB power supply port, reset button, and LD1117SOT233 voltage regulator.

The following components will require a purchase by our group. Each component is listed, followed by its cost, quantity, and total cost in parentheses. Underneath each component is the link to the specific component we will purchase, as well as any additional notes.

- PCB ($50)
- Digi-Key MAX4734EGC+ 4x1 multiplexer ($2.59x2 = $7.77)
    - https://www.digikey.com/en/products/detail/maxim-integrated/MAX4734EGC-/1779880
- 12 Vdc to 12 Vac Inverters - doesn't exist - we need to build our own
    - 1 for each generation and 1 for each battery bank
    - 12 Vdc to 110 Vac inverter ($16.99x3 = $50.97)
        - https://www.amazon.com/DEPZOL-Power-Inverter-Converter-Charger/dp/B08FRFP2DQ/ref=sr_1_31?dchild=1&keywords=dc+to+ac+converter&qid=1605460975&refinements=p_85%3A2470955011&rnid=2470954011&rps=1&sr=8-31
    - 120 Vac to 12 Vac step-down transformer ($19.30x3 = $57.90)
        - https://www.1000bulbs.com/product/208018/CL-55307599.html?gclid=Cj0KCQiAwMP9BRCzARIsAPWTJ_FpqV24Ppcl_mevQbH-XitlcguZ8iuZUWTkDQ2aiSRt6T2fYpNo2QwaAscrEALw_wcB
- MCP39F521 Power monitoring microchip ($2.52x3 = $7.56)
    - https://www.microchip.com/wwwproducts/en/MCP39F521
- PIC32MM0256GPM064 microcontroller ($2.23)
    - https://www.microchip.com/wwwproducts/en/PIC32MM0256GPM064
- UCS2113 switch for fault recovery power switching ($2.42x5 = $12.10)

        - 1 for each load plus 3 estimated for battery storage (1 for each battery array)
        - https://www.microchip.com/wwwproducts/en/UCS2113
- Solar cells ($26.25x4 = $105)
    - The price is for a pack of 4 which we could then connect in series
    - https://www.amazon.com/AMX3d-Micro-Mini-Solar-Cells/dp/B01N38GZFD/ref=asc_df_B01N38GZFD/?tag=hyprod-20&linkCode=df0&hvadid=167157220945&hvpos=&hvnetw=g&hvrand=3614752947271761703&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9016280&hvtargid=pla-314689476883&psc=1
- Sun-simulating lamp (borrow from EE department)
    - We believe the EE department has one of these. If not, we can buy a full spectrum lightbulb for approximately $15.
- Fuses ($0.43x2 = $0.86)
    - 1 for each generation
    - https://www.digikey.com/en/products/detail/eaton---electronics-division/BK%2FAGC-1-R/954154?utm_adgroup=Fuses&utm_source=google&utm_medium=cpc&utm_campaign=Shopping_Product_Circuit%20Protection_NEW&utm_term=&utm_content=Fuses&gclid=Cj0KCQiAwMP9BRCzARIsAPWTJ_HAS2sD3l9lPw8boL9OuVeU5VdBl4gALDDMRMm1vp7HC-6URRvUCOQaAmH6EALw_wcB
- Rechargeable batteries ($29.99)
    - A pack of 20 3V batteries
    - https://www.thebatterysupplier.com/products/20pcs-energizer-cr123-2-3a-3v-lithium-batteries.html?gclid=Cj0KCQiAnb79BRDgARIsAOVbhRrPuQ0f0zH2NaaUpq5AjuBjmEqRime9OE0gX4oYfFboqSIL1nFQuIgaAiHGEALw_wcB
- Amp hour meter ($17.99)
    - This is for a 200A meter, which is probably too much
    - https://shop.makerfire.com/products/200a-high-precision-power-analyzer-watt-meter-battery-consumption-performance-monitor?variant=18002447532083&currency=USD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&utm_campaign=gs-2020-06-16&utm_source=google&utm_medium=smart_campaign&gclid=Cj0KCQiA7qP9BRCLARIsABDaZzi8mXatV1LF3SB31OWoq3xoRBO8ikJ8Nsu5JDu1n3s1unVqyLRtTw8aAs_IEALw_wcB
- **Total: $342.37**

8 Conclusions

At this point we have a clearer vision of the direction our project is headed in. The block diagrams helped us define our requirements and decide on the necessary components to fulfill them. After having selected the microcontrollers and boards, we determined which pins will be mapped to the respective parts of our system and hence firmly believe our plan has the capability to run upon completion.