Microgrid Optimization:

The Future of **Efficient**, **Reliable**, and **Autonomous Renewable** Energy

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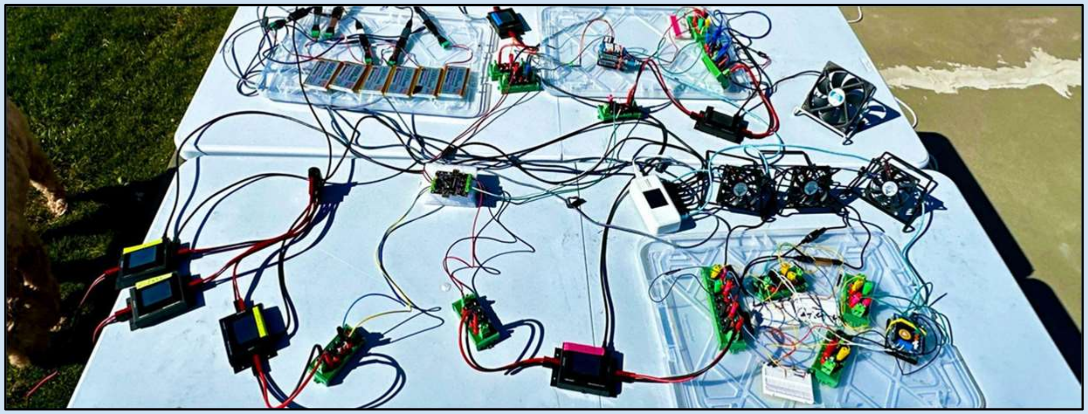


INTRODUCTION

- Microgrids are small power grids that generate their own electricity and supply a small local load
- Renewable microgrids must find a way to distribute energy generated throughout the day to the changing load and storage
- Microgrid optimization includes implementing strategies and codes to make this balance as energy efficient possible

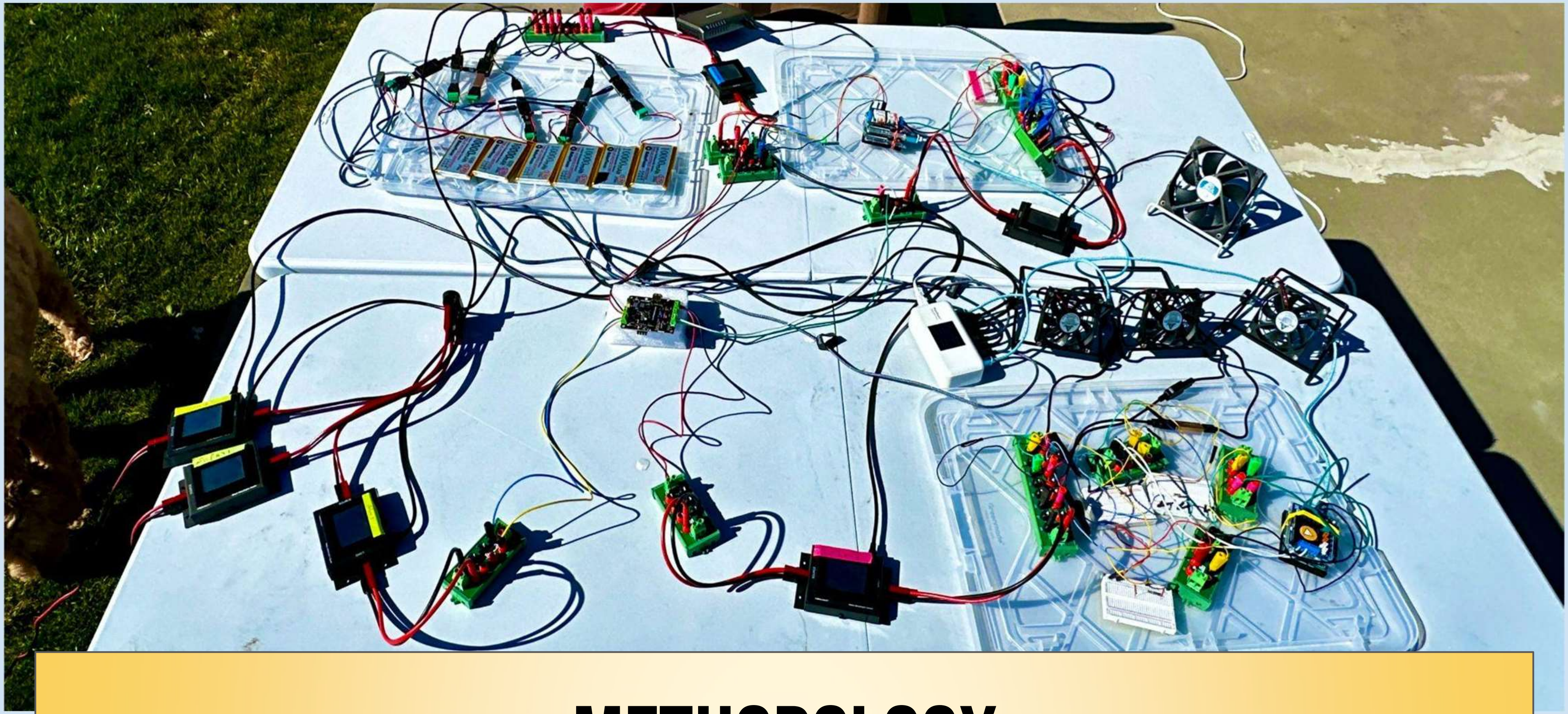
❖ My project models a microgrid at a small scale to observe the balance between generation, storage, and load when certain optimization strategies like maximum power point tracking, and a battery safety feedback loop are implemented to make an autonomous and efficient renewable microgrid

RATIONALE

- Microgrids are a versatile and customizable way to integrate renewable energy and achieve energy equity
- At its roots, a microgrid simply balances supply, demand, and storage with the natural clock of renewable energy.
- Microgrids will help us in reaching our sustainability goals and make energy more accessible and adaptable for the diversity of people's lifestyles

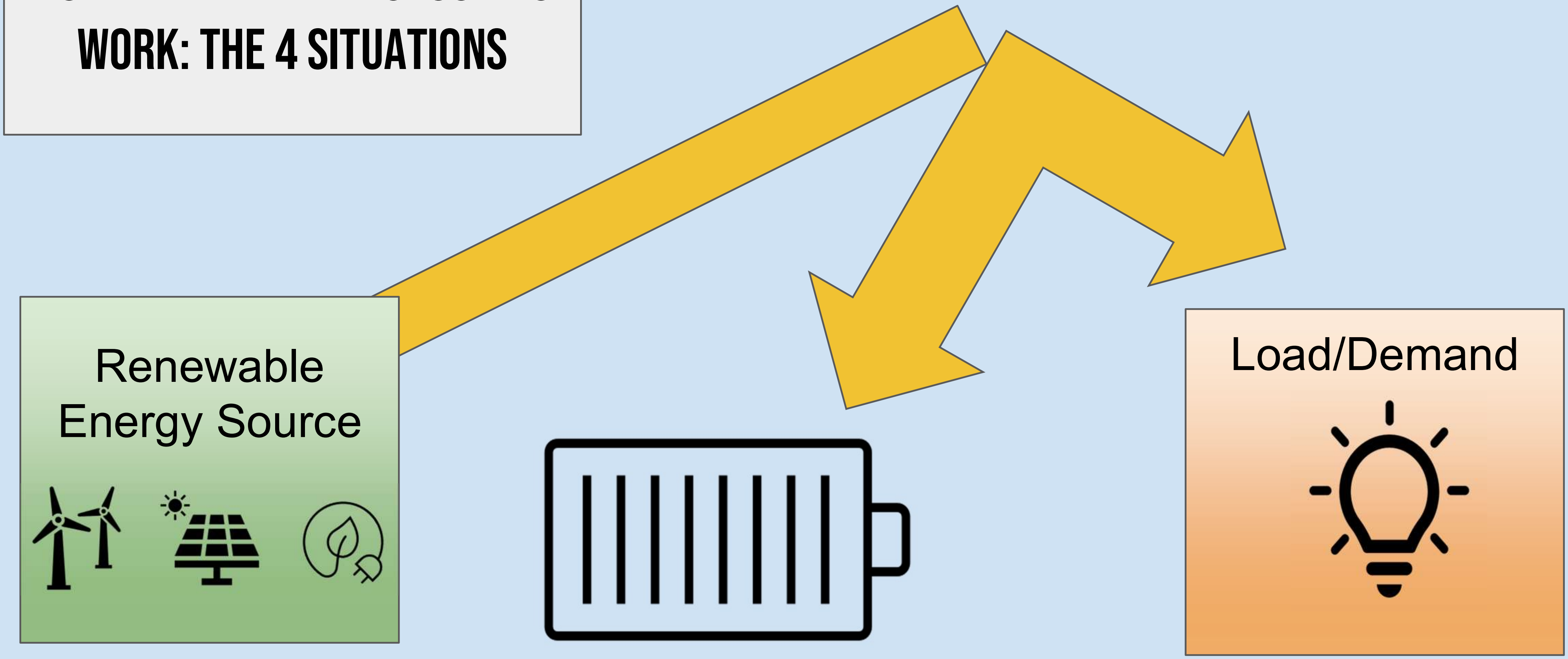
CURRENT USE

Currently, microgrids are used in isolated camps, islands, communities, military bases, and industry. The U.S. military has implemented microgrids in order to protect it from cyber-attacks and also to increase resilience

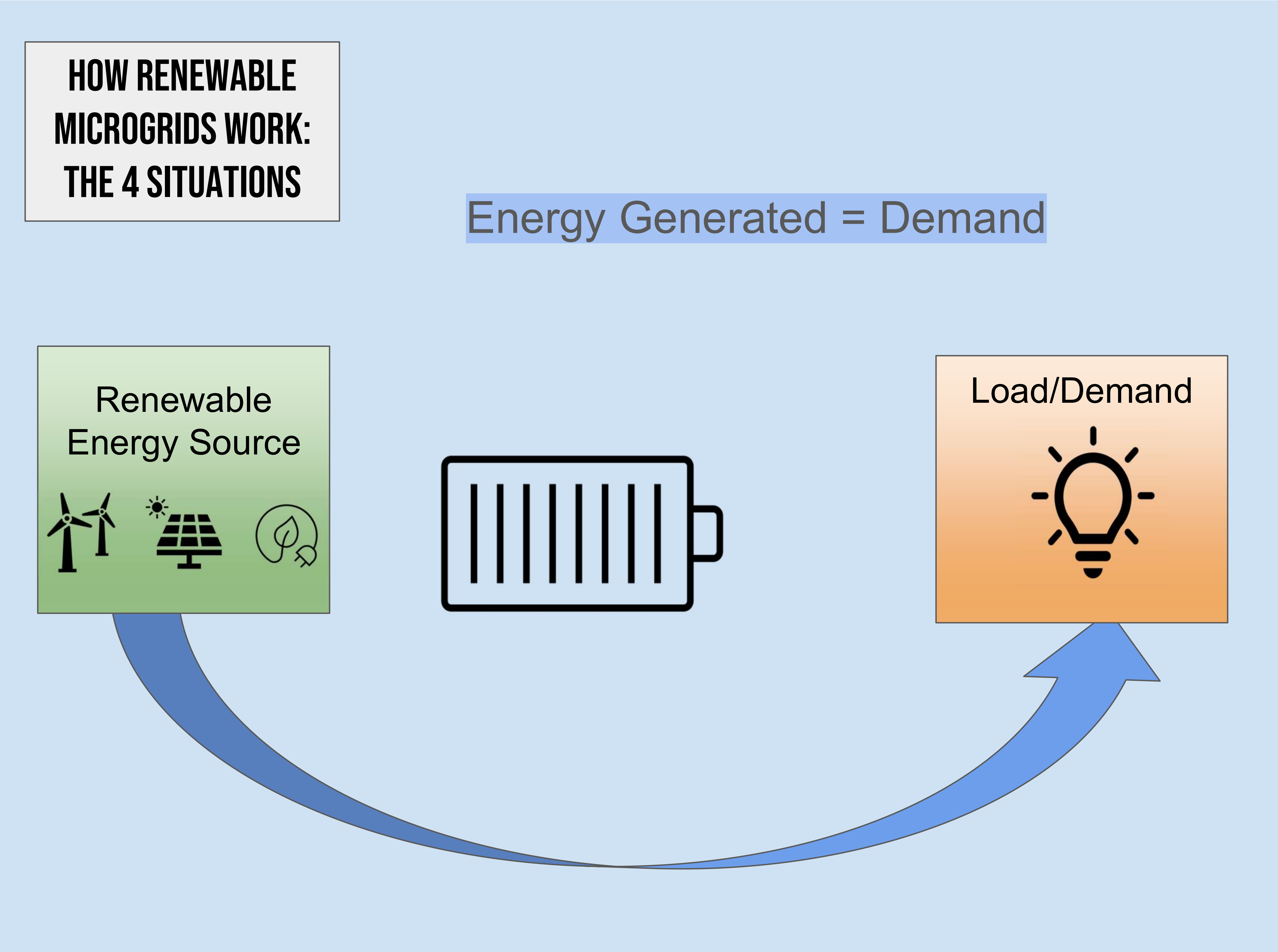


METHODOLOGY

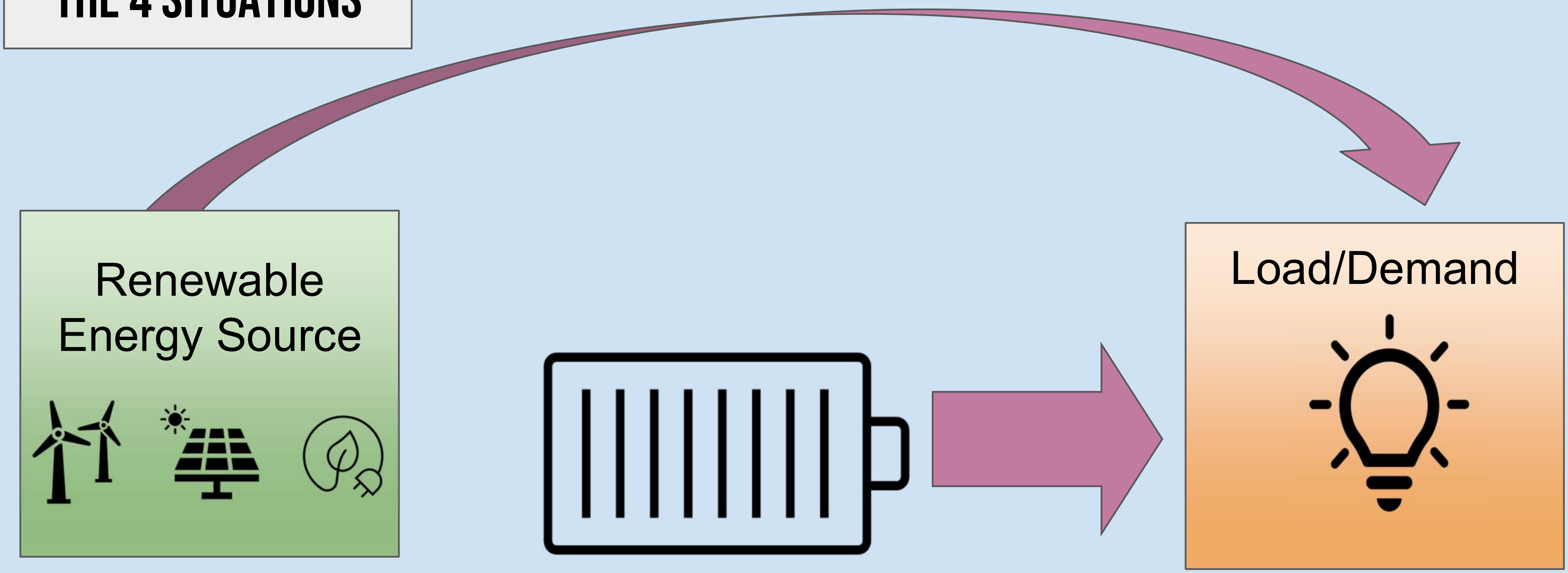
HOW RENEWABLE MICROGRIDS WORK: THE 4 SITUATIONS



Generation > Demand
Extra to Storage


HOW RENEWABLE MICROGRIDS WORK: THE 4 SITUATIONS
Energy Generated = Demand
Renewable Energy Source
Load/Demand

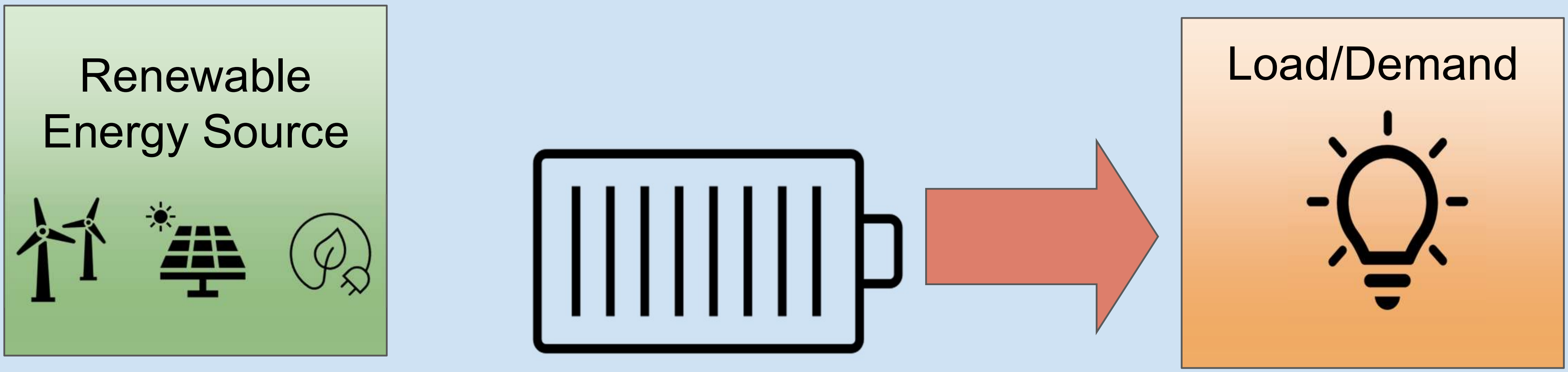
HOW RENEWABLE MICROGRIDS WORK: THE 4 SITUATIONS



Generation < Demand

Storage + Generation will Supply Demand

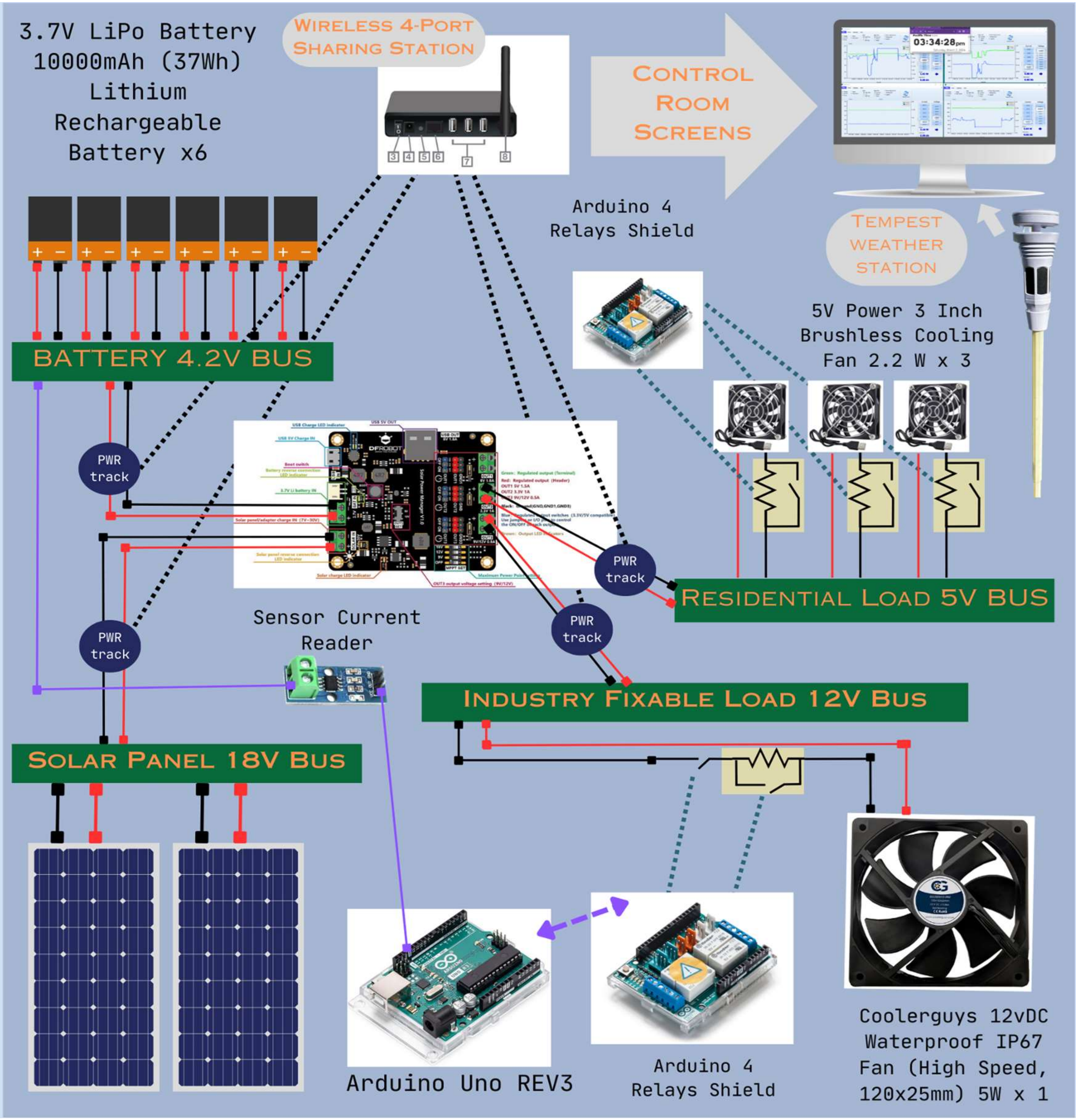
HOW RENEWABLE MICROGRIDS WORK: THE 4 SITUATIONS



No Generation

Storage supplies Demand

Complete Diagram of My Final Microgrid Model



COMPONENTS

- **Renewable Energy Source**
  - Two 30 W Solar Panels

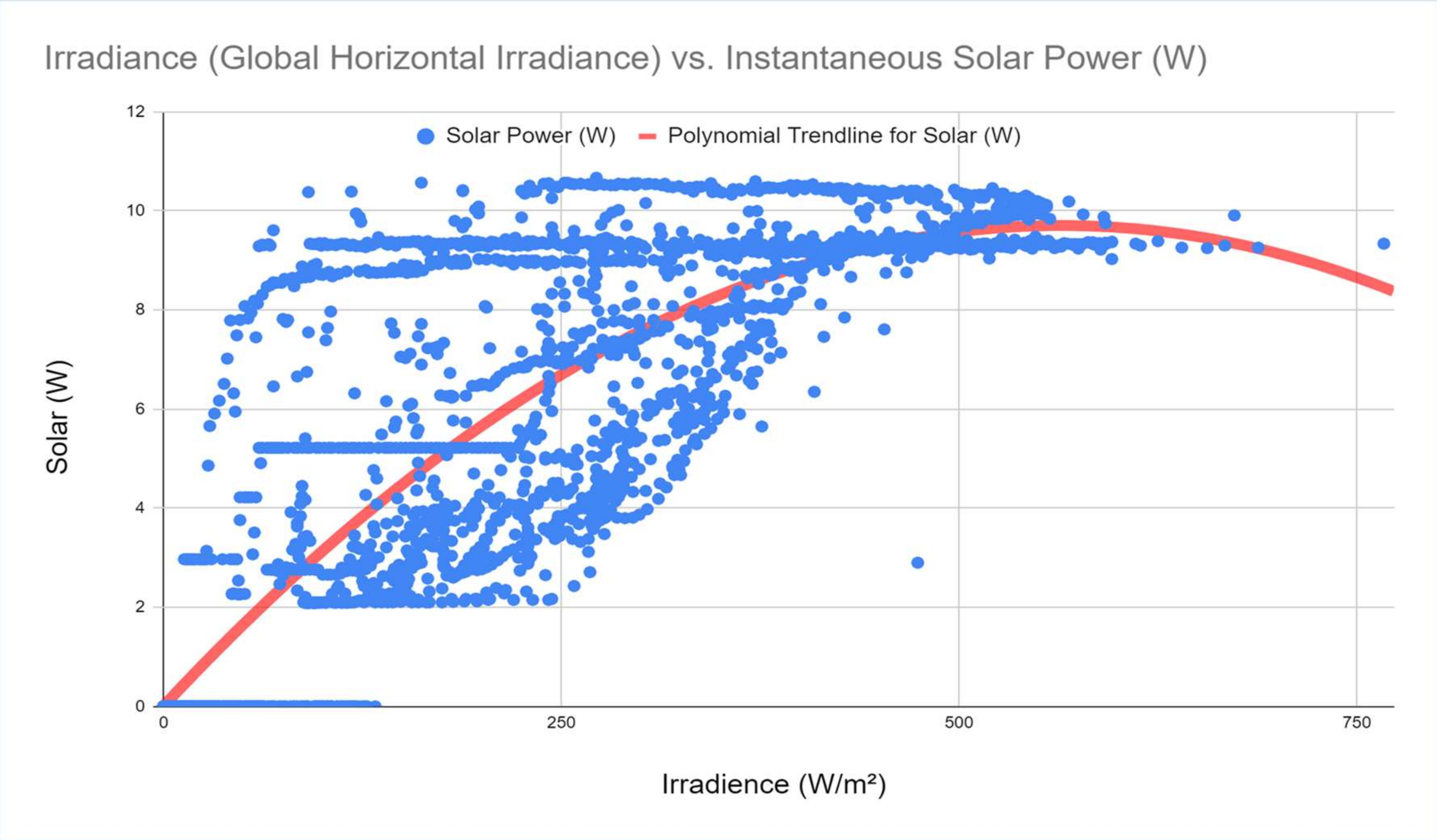
- **Storage**
  - Six 3.7 V Lithium Polymer Batteries

- **Loads → Controlled by Arduinos that turn the resistors on and off**
  - Three 5 V Fans
  - One 12 V Fan

- **Controls**
  - Solar Power Manager (from DFRobot)
  - Arduino Hardware
  - Current Reader Hardware

- **Data Collection**
  - Power Trackers
  - Weather Station

RENEWABLE ENERGY SOURCE: TWO 30 W SOLAR PANELS

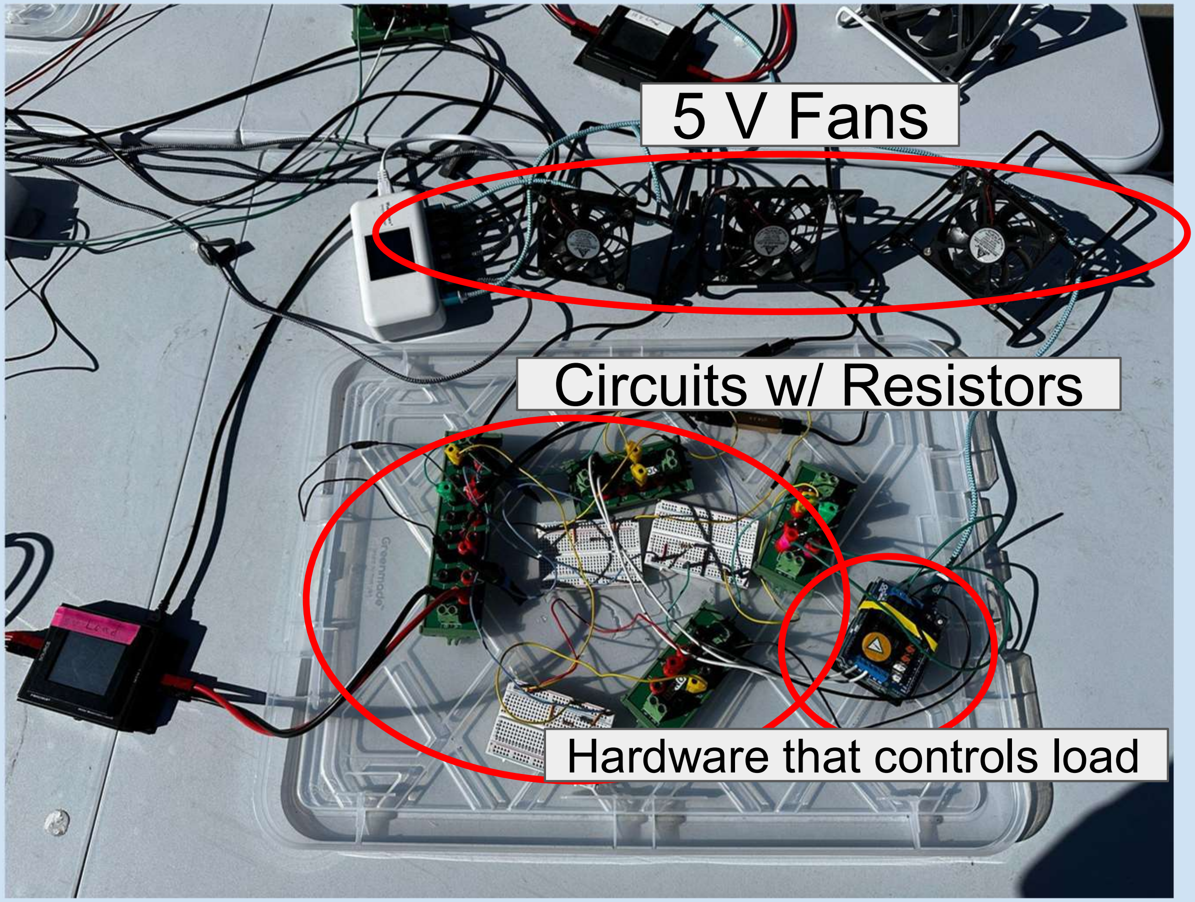


The data on the left, taken from one 30 W solar panel, shows the correlation between irradiance and energy generated

- One 30 W Solar Panel max energy yield approx. 10 W
- Two 30 W Solar Panel max energy yield approx. 15 W (this is less than expected because the solar power manager has a current threshold)

RESIDENTIAL LOAD: THREE 5 VOLT FANS

The 5 V fans were programed to create a residential load, having the highest demand in the morning and night, and the lowest demand in the afternoon hours.



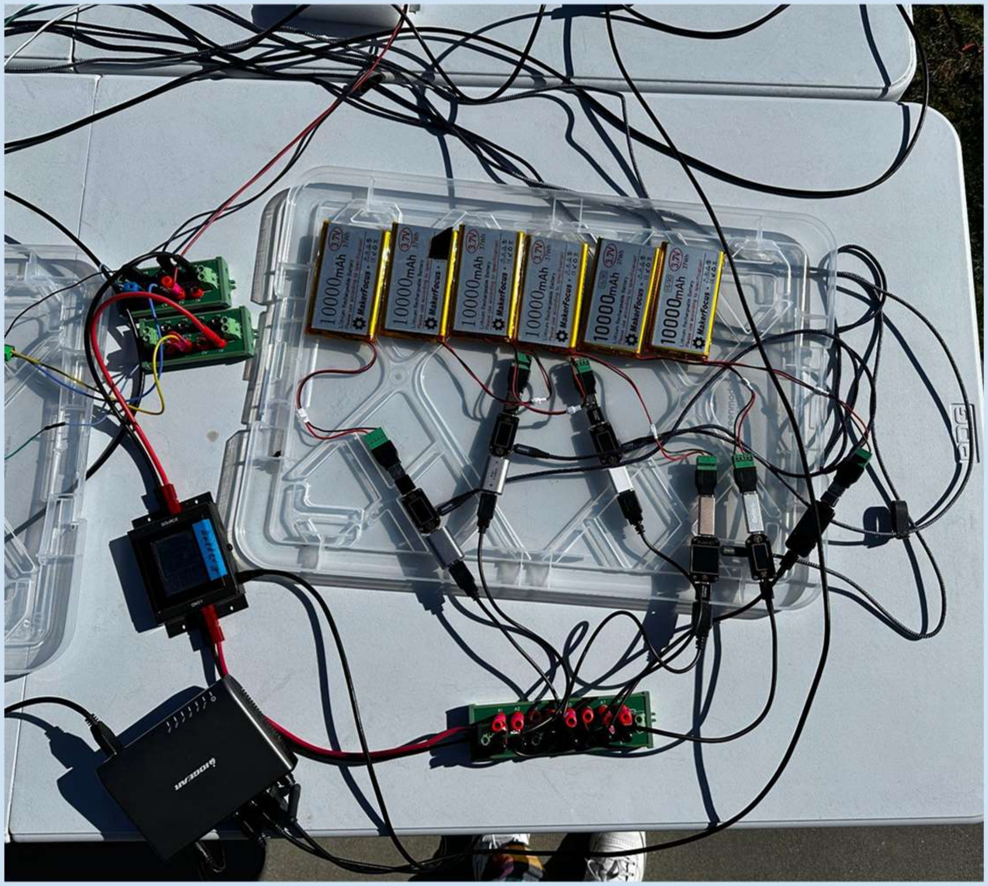
Hardware programmed to let current go through or bypass the resistors, allowing each fan to be at full or half power to create the residential load

STORAGE: SIX 3.7 V LITHIUM POLYMER BATTERIES

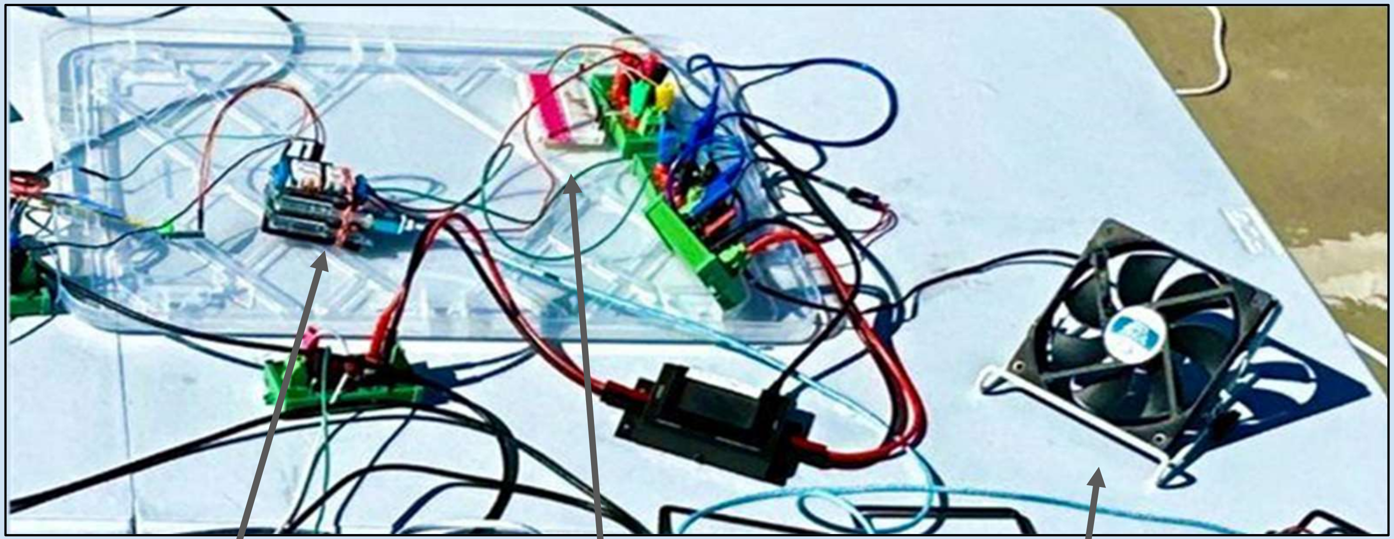
- Able to change between charging and discharging quickly

Battery Safety Feedback Loop:

- Keeps all the batteries in a safe range between 3.2 and 3.8 V by changing the 12 V demand in a feedback loop



12 V LOAD

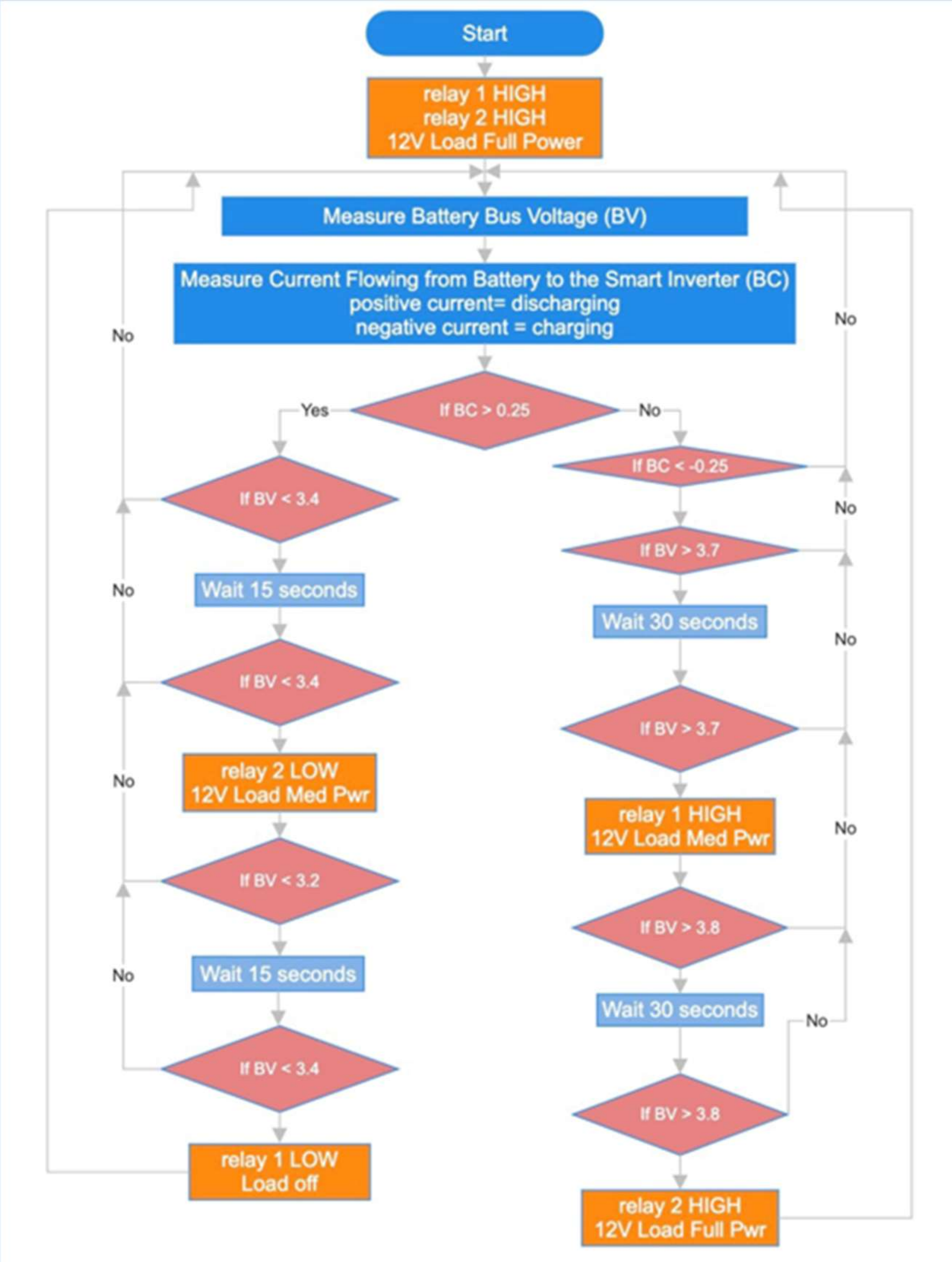


Arduino

Circuit w/ Resistors

12 V Fan

The voltage of the battery determines the demand of the 12 V load, which is supposed to represent an industrial load, and is second priority to the residential load

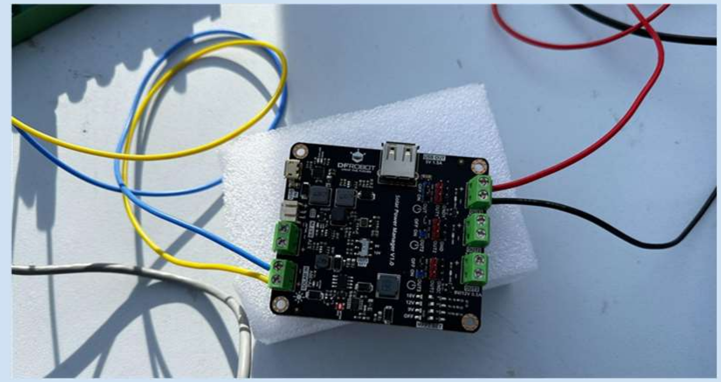


BATTERY SAFETY FEEDBACK LOOP FLOW CHART

By letting the voltage of the battery change the 12 V Industrial load, the battery is able to stay within a safe threshold and allow the microgrid to run longer

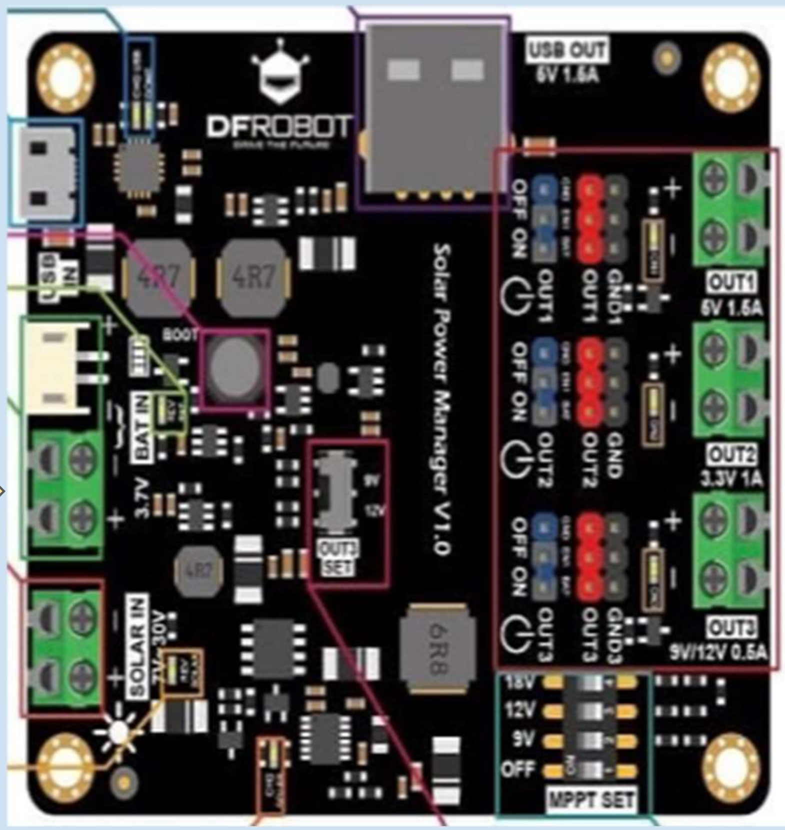
ENERGY DISTRIBUTION: SOLAR POWER MANAGER

Distributes energy depending on energy generated (as explained in the 4 Microgrid Situations



Battery Connection

Solar In

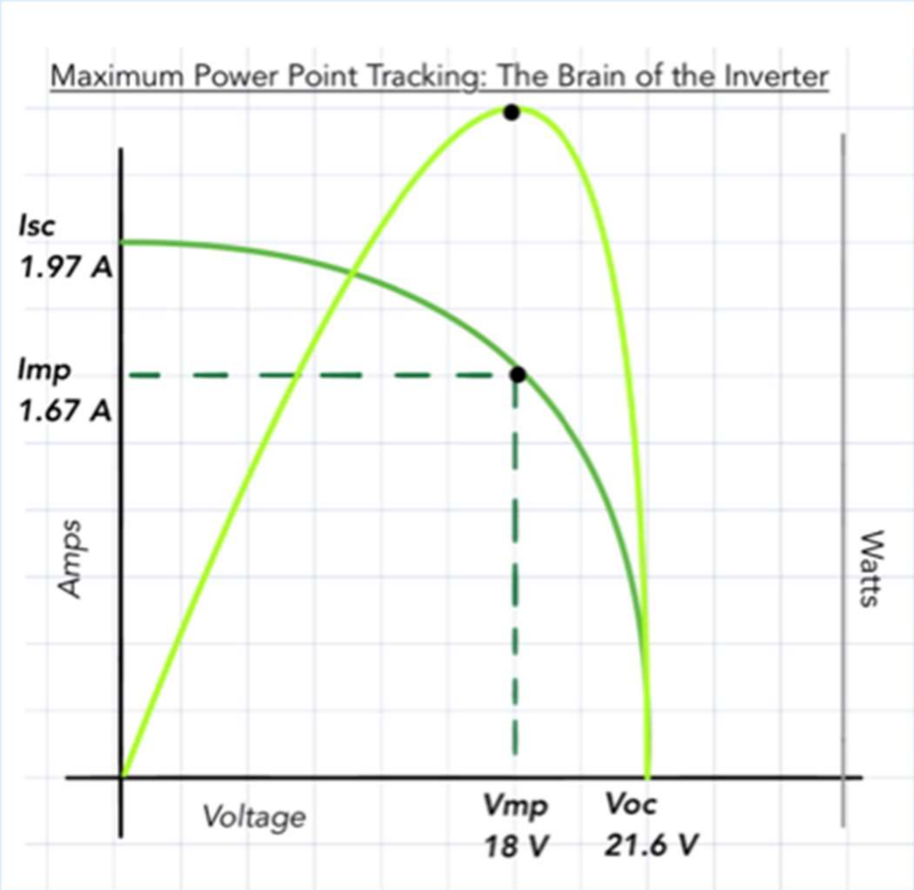


5 V Connection Output

12 V Connection Output

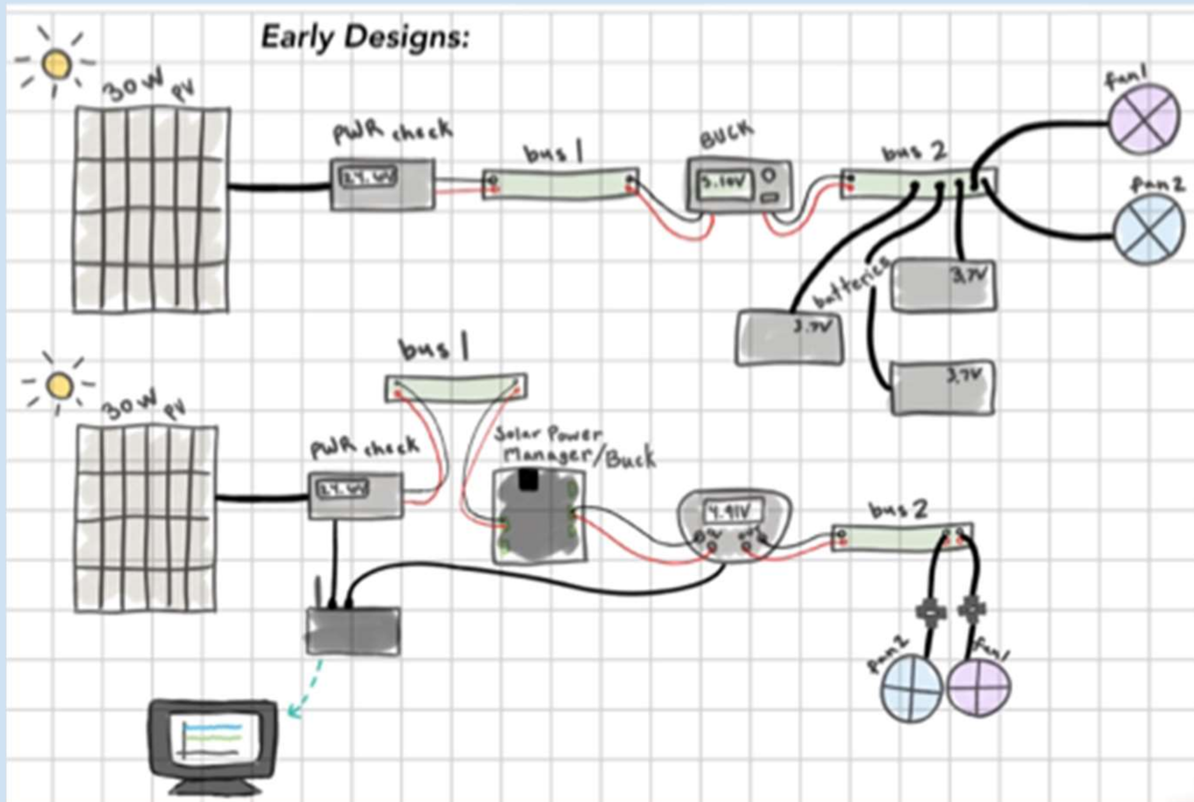
MAXIMUM POWER POINT TRACKING

Maximum Power Point Tracking, an algorithm built into the Solar Power Manager, balances the current and voltage of the energy source to yield maximum power during yielding times



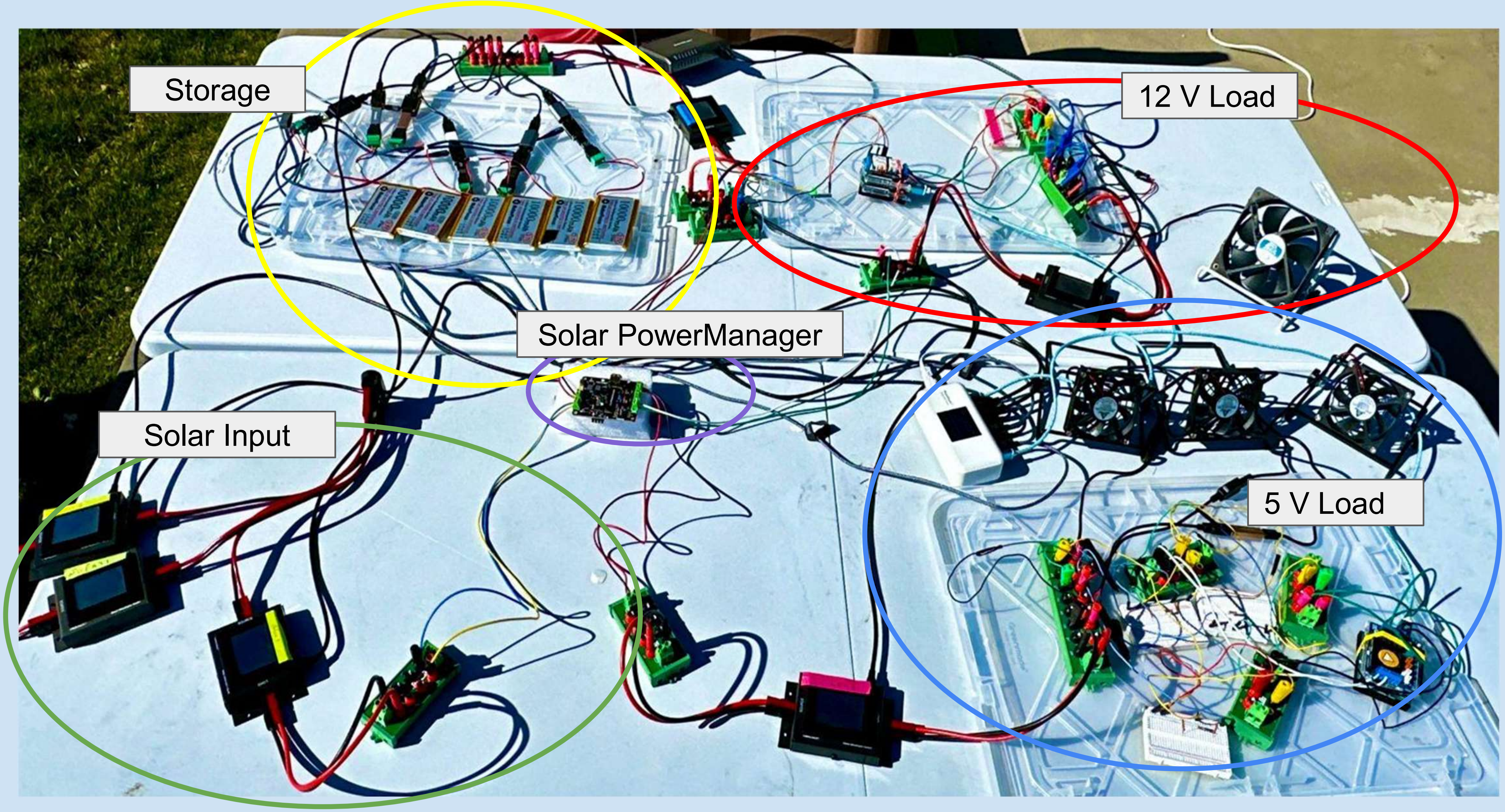
EARLY STAGES & CHANGES

Initially I wanted to use a miniature fuel cell for energy storage, but this became problematic as the miniature fuel cell I had would not be able to charge and discharge without human assistance, and couldn't yield much energy to begin with.

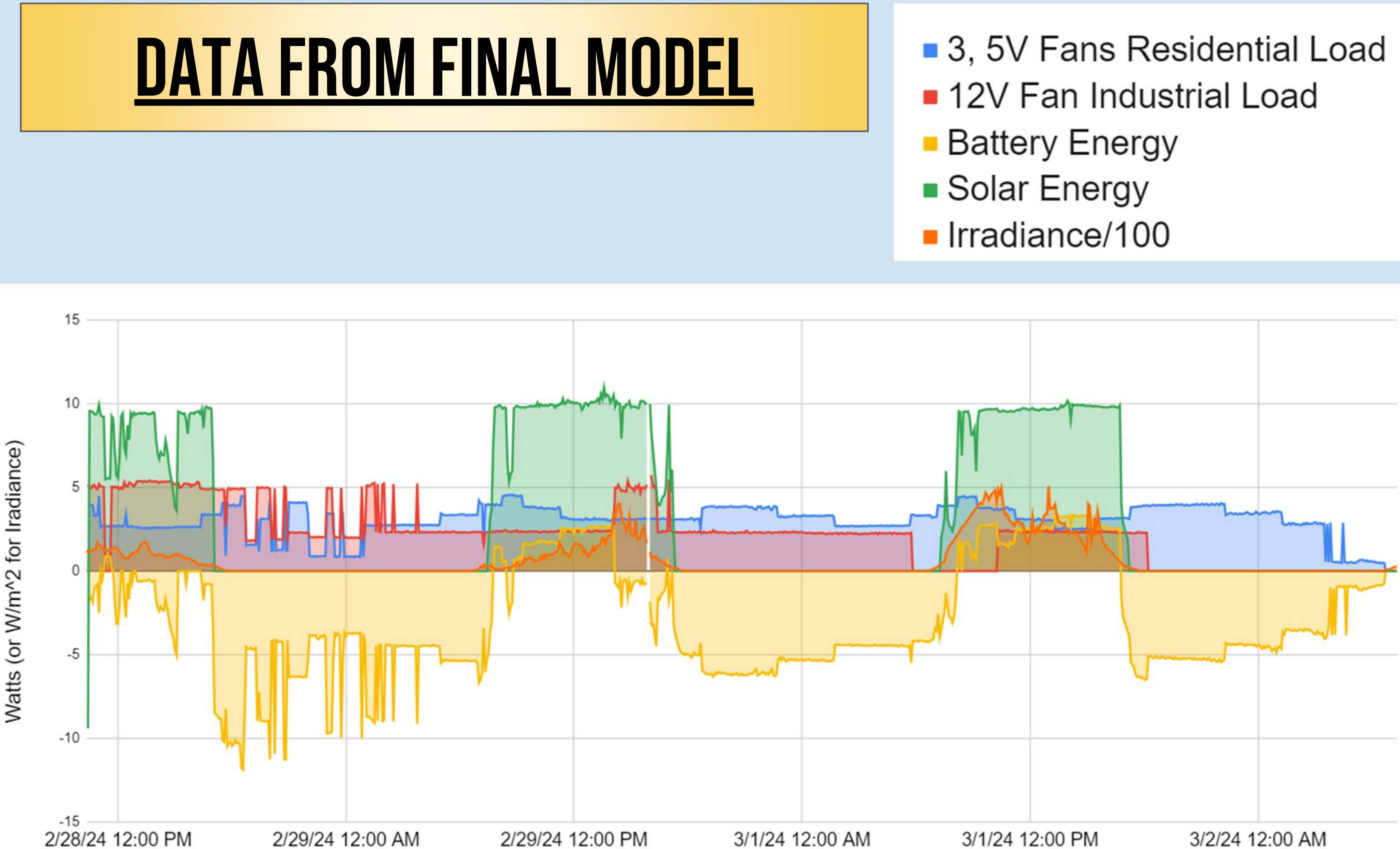


To be more resilient, it is best for microgrids to diversify their renewable energy sources. I wanted to do a have wind and solar energy together in my model, but struggled to find one that was appropriate scale and unproblematic

FINAL MICROGRID MODEL



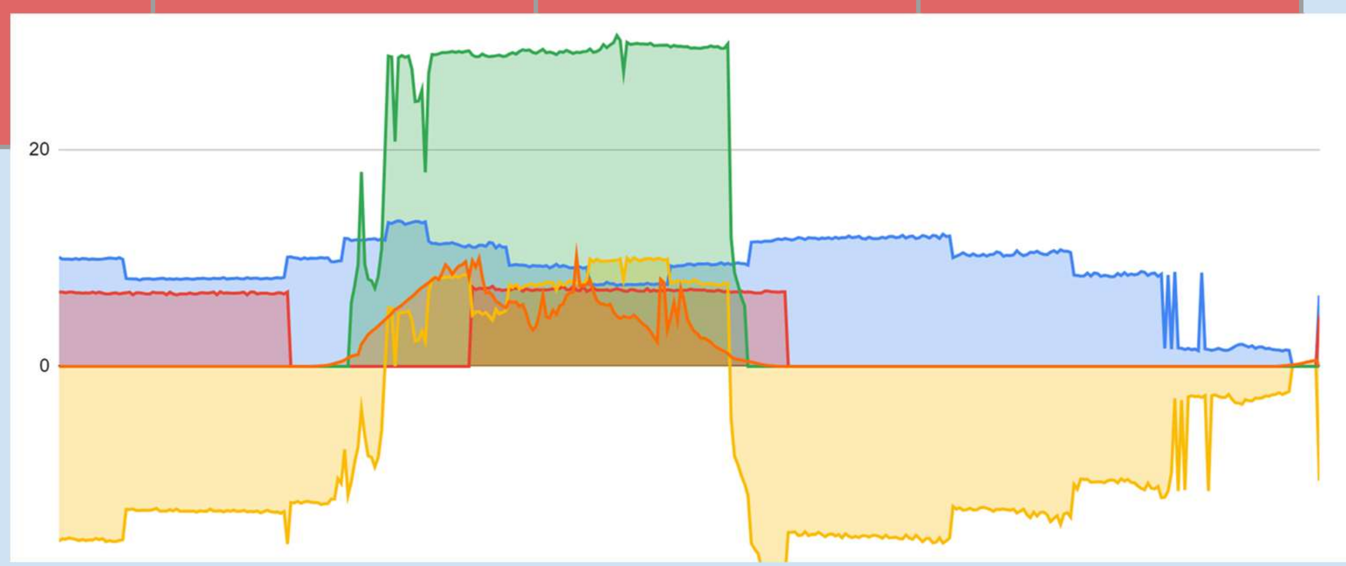
DATA FROM FINAL MODEL



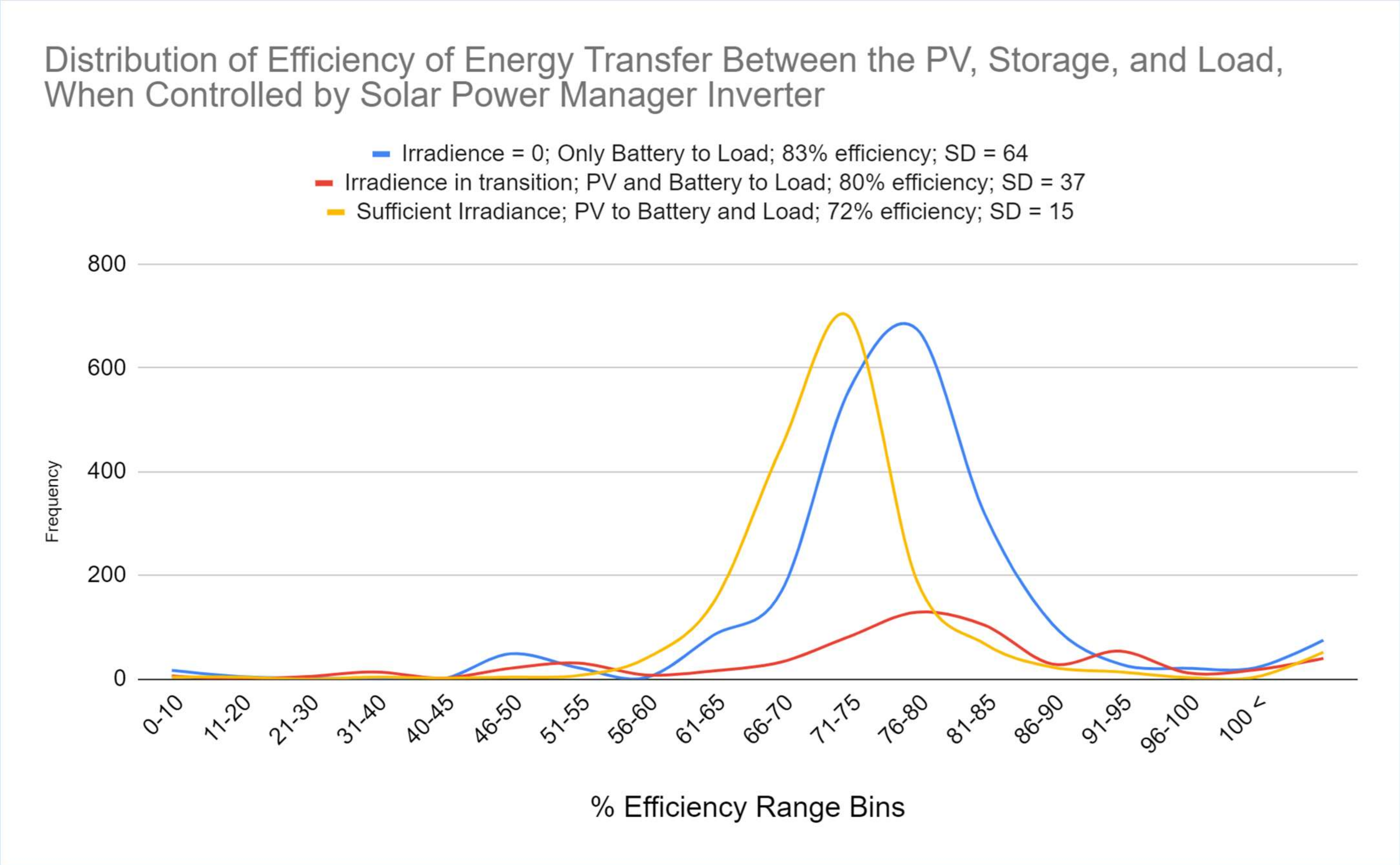
DATA

- 3, 5V Fans Residential Load
- 12V Fan Industrial Load
- Battery Energy
- Solar Energy
- Irradiance/100

	12 AM	**6 AM**	**12 PM**	**6 PM**
Solar/Irradiance	0	Increasing	Peak	Decreasing
Battery	Discharge to load	Charging and Discharging interchangeably	Charging	Charging and Discharging interchangeably
Residential (5 V)	Medium	High	Low	Very High
Industrial (12 V) * Not as consistent from trail to trial	Low	Low	Med/High	Low



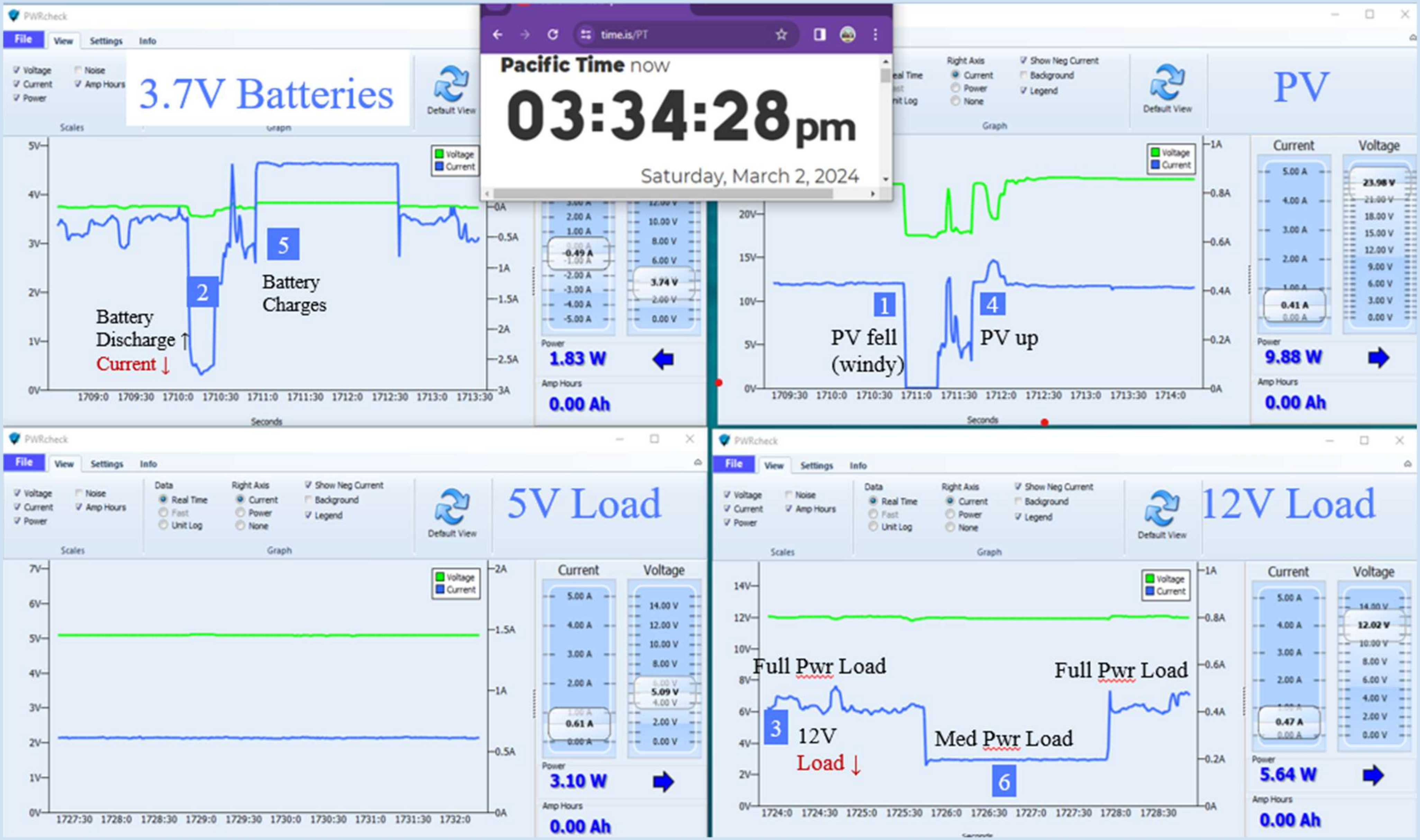
STATISTICS

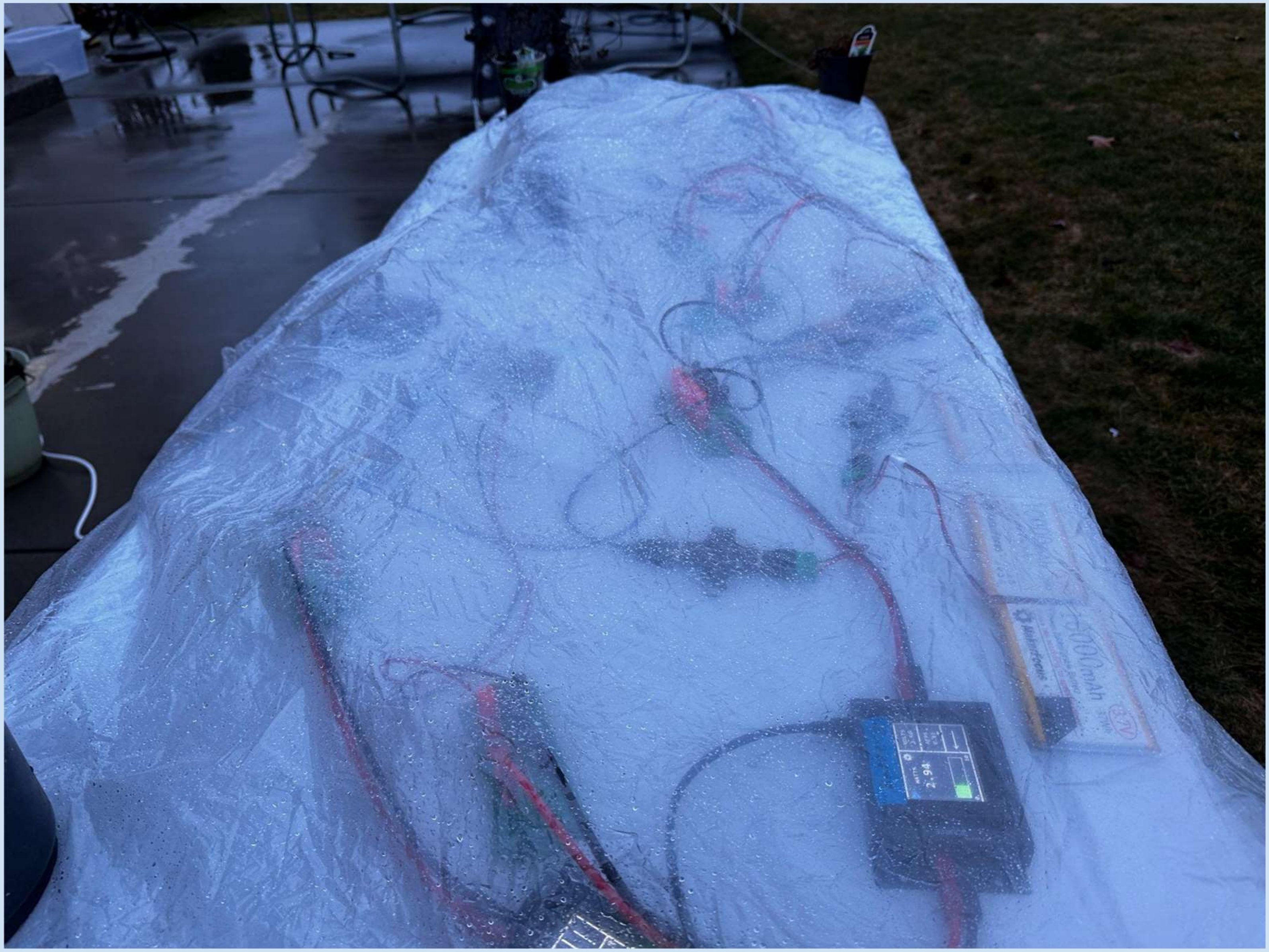


Distribution of Efficiency of Energy Transfer Between the PV, Storage, and Load, When Controlled by Solar Power Manager Inverter
Irradience = 0; Only Battery to Load; 83% efficiency; SD = 64
Irradience in transition; PV and Battery to Load; 80% efficiency; SD = 37
Sufficient Irradiance; PV to Battery and Load; 72% efficiency; SD = 15
800
600
400
200
0
Frequency
0-10
11-20
21-30
31-40
40-45
46-50
51-55
56-60
61-65
66-70
71-75
76-80
81-85
86-90
91-95
96-100
100 <
% Efficiency Range Bins

Snapshot from the “Control Room” where data from PWR checkers was displayed

- This snapshot shows how the microgrid is able to quickly respond to changes





Microgrids must run in the rain too…

CONCLUSION

The broad definition of a microgrid allows it to take different forms in order to fit the user's needs best. On another note, as users become more mindful of their environmental impact, many look to change the means by which they power their lives, with solar energy at the forefront. Renewable microgrids are genuinely the best of both worlds and are the future of how we will sustainably and reliably provide energy for the whole world, and power future societies.

The final model was a result of evolution and problem-solving. At first, the model was supposed to implement a solar panel, wind turbine, and fuel cell; the wind turbine and fuel cell weren’t appropriate to use at the scale of my project, so they were scrapped. It is wise for renewable microgrids to implement different types of renewable energy, but if this is not possible, creating reliable storage is a must. Six 3.7 V LiPo Batteries were used in the model. As the model evolved, the number of batteries kept increasing as more pressure was being put on the load, which was programmed to model real life. The heart of the operation was the Solar Power Manager Hardware from DFRobot. This hardware connected the solar energy to the loads and batteries; it intelligently distributed energy when appropriate in relation to the irradiance and solar energy yield. When Irradiance was high, there was enough energy to power all the loads and charge all the batteries. When irradiance is in a transitional state or weak, solar panel and battery energy powered the load. When it was dark, and there was no solar energy, seldom the batteries powered the loads. The overall efficiency of the Solar Power Manager was approx. 80%, which is very high. This project was immensely more challenging since it was done in the winter since irradiance was weak, days were, and the environment was more moist and rainy. On the other hand, the cold temperatures enhanced the hardware's efficiency by keeping it cool.

CONCLUSION CONT.

To test the model, it had to be stimulated by changing load. By adding resistors to the fans, each load was able to be off, at medium power, or at full power. The simulation for this model was a 5V residential load that peaked at 7 am, dipped from 12 pm to 4 pm, and rose till 12 am, then decreased again. In earlier stages of the project, where only the 5V load was implemented, on the first day (which was cloudy) the batteries were close to dying by 2 am the next day, and on the second day (fairly sunny) the batteries were close to dying by 6 am the next day.

To mitigate this issue, two solar panels and six batteries were the new conditions of the model. Also, to avoid the batteries dying, a new program was implemented to control the 12 V load. The 12 V load was to represent an Industrial load. Arduino Relay Hardware was used to model the loads, and Arduino Unos was used to read battery current and voltage. The demand for the 12 V load depended on the voltage and current of the batteries. When the battery voltage was less than 3.4 V, the 12 V load was decreased to half; when the battery voltage was less than 3.2 V, the 12 V load was fully turned off. On the contrary, when the voltage was greater than 3.7, the 12 V load increased by half; when the battery voltage was greater than 3.8, the 12 V load was increased to full power.

The beauty of the model is seeing how all the elements work together to keep everything in balance, providing reliable and clean energy for the user. Of course, this project is a very simple microgrid model. Renewable microgrids cover a wide range of definitions, and that is what makes them so versatile and useful. Their versatility allows them to thrive in different environments, and function well in all conditions. The future of our energy lies in renewable microgrids. For example, they serve poor rural villages because of their accessibility and long-term profit on investment. They also are implemented by the military to allow them to have reliable energy in isolated areas. In the future microgrids will be implemented more frequently and will reach many people and communities all over the world.

APPLICATION

Microgrids are best suited for certain purposes, that being said they shouldn't be going on the replace perfectly fine and dependable energy grids. Microgrids will best serve individuals or communities looking to have highly personalized energy (thus higher dependability). They are also the most realistic way to integrate renewable energy into the world, giving users an overall return on their investment.

Large power grids have some downfalls: they are complex, big, and susceptible to bad weather; once one thing goes wrong, everything else does as well, putting many people who depend on these grids in danger in some cases. Microgrids are less complex and small, if there is an issue, it won't effect as many people as a large power grid, and it will be easier and less time consuming to fix.

Places that are increasing in population and expanding at a fast rate like urban cities in Africa and Asia can implement microgrids to offer energy to everyone instead of having to spend more time into making a large microgrid. This allows cities to grow faster and gives more people access to energy.

Microgrids are also really well suited for rural isolated areas like islands, rural villages, or military bases. U.S. military bases employ microgrids because they are harder to cyber attack, and allow them to train in remote areas.

Goals of swithich all energy to renewables is hard to do by changing what already exists, and instead should be done by adding it to new developments in the world. This easiest and smoothest way the world will switch to clean energy is via microgrids.

ABSTRACT

Microgrids must be efficient, intelligent, accurate, and autonomous. This overall goal was to model a renewable microgrid. After months of trial and error the model evolved to be complex yet simple, with many different elements all working together. Two 30W Solar Panels, three 5V fans, one 12V fan, and six 3.7 V LiPo batteries were used. Solar energy went to the Solar Power Manager, connected to the batteries and loads. In high irradiance, solar energy powered the load and charged the batteries, and in darkness, the battery-powered the load. MPPT calculates the voltage and current the system should run at to yield the most power. Issues arose when the loads would shut off without sufficient power. To mitigate this, three Arduino cards were used. One programmed the 5V load to peak in the morning and night. Another analyzed the battery current and voltage to control the 12V load. The Solar Power Manager had an efficiency of approx. 80%, allowing much energy to be conserved despite shorter daylight hours. The most useful data shows how all the elements work together in different conditions over many days as the model evolves. Renewable microgrids shouldn't go on to replace excellent power grids but can be implemented in rural villages or military bases. Microgrids integrate renewable energy on a small scale, giving users more personalized and reliable energy.

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