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Will Power Africa Final Project Report

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Executive Summary

This report outlines the final design for the Will Power Africa 2022-2023 senior design team and how testing proved that the design meets each determined project requirement and constraint. The Will Power Africa team was tasked with designing a reliable and durable off-grid energy generation source to power an electric fence to deter elephants and provide charging capabilities for portable devices intended to be implemented in Tsholotsho, Zimbabwe near Hwange National Park and along the routes of elephant herds. This design would allow the community to grow food protected from elephant raiding and increase general connectivity with easier access to device charging. The team's design consists of the following subsystems; energy generation, energy storage, system protection, fence, and USB charging device. These subsystems culminate in our final design; a protective waterproof case enclosing a solar panel and lithium battery system powering an electrified fence with an electric fence energizer, 4 external USB outlets for phone charging, and a fan to keep the case cool. The fence is to be constructed in the final location and will be 60'x60'x14' using wood poles and both high-tension offset electrified wires and spiraled hanging electrified wires.

Design choices were informed by similar design examples, research, and our project requirements and constraints. The project requirements included in this report reflect the final requirements as decided between the team, sponsor, and advisor. Especially in the initial stages of Fall 2022, these were fluid and changed in conversation and agreement with all parties as design plans progressed. Each requirement and constraint is addressed along with its associated test plan and results evaluated by acceptance criteria. Changes in test procedures and criteria and their reasoning are also noted with each requirement. The main changes from the Fall 2022 semester design plans and criteria include; a larger final battery, a greater energy-rated energizer, and a taller final fence planned.

Each project requirement and constraint is detailed further in the report but are as follows; Garden Protection/Elephant Deterrence, Phone charging capabilities, Autonomous overnight protection, Weather durability, Transport Durability, Commercial Flight Size Constraint, User Operation Ease, User Operation Safety, Solar Panel Adjustment and Efficiency, Academic Year Time Constraint, Remote Location Constraint, and Continuous Usage Operation. Testing concluded that our final design met all project requirements that we could test here in San Antonio. Some testing and requirements cannot be fulfilled until in the intended location including transport durability, final fence construction, and further user operation safety. User Operation Safety (or Instructions) Testing still needs to be done and will be included in the final presentation. The following section describes the design objectives, requirements, and subsystems in more detail.

Overall, the Will Power Africa team has created a functional prototype capable of fulfilling all of these requirements. Since all requirements and constraints were fulfilled, there are no immediate changes necessary. Future improvements to the design are expected with the new team beginning work on the project next semester, with specific focus on an alternative means of generating energy aside from solar power `. For the future team, we have provided manufacturing instructions as well as suggestions for improvements to future iterations of the Will Power Africa project.

1. Introduction

Tsholotsho, Zimbabwe, exists in a human-wildlife conflict region, where interactions between humans and the large animals nearby can be hostile. These interactions make it very hard for the locals to establish a safe livelihood for themselves as the animals are prone to raiding their crops, making it nearly impossible to grow food for themselves in large quantities. Most concerning of these animals are the elephants, as they can devastate a field of crops in a single night and prove quite stubborn when trying to keep them out of the local gardens. As a result, the locals often avoid growing crops on a large scale as it often results in the gardens being raided.

The most common method used to repel elephants and other animals away from gardens is an electric fence, however, prior implementations of electric fences in remote regions similar to Tsholotsho have consistently run into the same challenges. Due to the off-grid nature of rural Zimbabwe, any power generation system needs to be able to recharge itself and be extremely durable, as getting the tools to repair any systems out in the bush would likely take weeks if not longer. Additionally, elephants can adapt to electric fences rapidly and are smart enough to damage the infrastructure of a conventional electric fence to circumvent the system altogether.

The Will Power Africa team was tasked with creating an alternative energy generation device in addition to designing a unique electric fence that is capable of providing sufficient voltage to repel elephants and other wildlife from a 60’x60’ community garden. Additionally, the design must be capable of charging up to 4 USB devices simultaneously with a charge time that should not exceed 6 hours per device. Our project contains several working criteria assigned by our sponsors that were agreed upon by the team. The device must be intuitive to assemble and use for people who have limited knowledge of energy generation systems. An extension of this criteria includes the requirement that the system must be non-lethal to humans and animals when operated using recommended practices. The final location of our design will be in an off-grid location in Zimbabwe, which required weather and transport reliability criteria for the final design. This includes an internal operating temperature limit of 55 °C, protection against dust particles exceeding 0.45mm in diameter, and designing a system durable enough to withstand impacts and drops during air and land travel.

The two constraints imposed on the design were a dimensional constraint in addition to a time constraint. The majority of the design and implementation of subsystems for the project have been completed locally in San Antonio; however, the final design will be implemented in Tsholotsho, Zimbabwe which requires the design to be approved for international commercial air travel. The design also is constrained by time and must be completed by May 22nd, 2023, as two members of the Will Power Africa team will be traveling to Zimbabwe to oversee the final installation of the design. As previously mentioned, the final design location has limited access to construction and repair resources, and all subsystems must be fully operational before travel (with exception to the fence).

Through discussion with the project sponsors, the Will Power team has established several functional requirements that should be met to adequately meet the project objectives. Using literature from professionals experienced in designing electric fence systems specifically for deterring elephants, it was determined the fence must operate at a voltage level of at least 9 kV to sufficiently repel elephants and other wildlife (Fernando, 2020). The fence must also be capable of operating for 12 continuous hours without the need for energy generation. African elephants are primarily active during the night time and the village in which the final design will be implemented will require the fence to remain active overnight without human intervention.

While the project has 2 defined objectives, the ability to charge USB devices has been defined as a secondary objective due to the critical need for protection of the community garden. As a result, it is required that the design shall operate at a net energy gain when powering the fence alone.

The final design is divided into four subsystems that address the two project objectives outlined. The energy generation subsystem consists of a 50 watt solar panel, 20A MPPT solar charge controller, and will consist of a 100 Ah lithium battery when final construction begins in Zimbabwe. These items, in addition to a load center, are fastened inside the system protection subsystem, which consists of a Pelican 1640 transport case and electric fan capable of cooling the interior of the case. The energy generation subsystem is capable of charging the lithium battery by harnessing solar energy, which will then be used to supply power to both the USB device charging subsystem and fence subsystem. The fence subsystem is the only subsystem where a final prototype has not been created. The fence serves as the barrier which will repel elephants and other wildlife from the community gardens. Lastly, the USB device charging subsystem addresses the secondary objective of providing phone charging access and includes 4 USB ports installed to the exterior of the transport case.

2. Overview of the Final Design

As introduced above, the final design is a protective weatherproof case enclosing a solar panel and lithium battery system powering an electrified fence with an electric fence energizer, 4 external USB outlets for phone charging (Appendix C-6), and a fan to keep the case cool (Appendix C-7). The battery is charged by opening the case during sunlight hours (Appendix C-1) and can provide charge to all components while the case is open or closed (ie. they are all accessible externally through weatherproofed holes). A load center provides central access and control to each component powered by the battery (Appendix C-5). A circuit schematic and flowchart of the full system is available in Appendices B-1 and B-2. The fence is to be constructed in the final location and will be 60'x60'x14' using wood poles placed 10' apart, two high tension electrified wires (from 7kV-12kV) offset 4 feet from the posts on top and 5' above the ground, electrified spiraled hanging wires every foot from the top to one foot above the ground (Appendix C-2), and 9' ground rods every 10'. Changes from last semester's report include the height of the fence from 8' to 14', the size of the battery from 23Ah to 85-100Ah, and the electric fence energizer rating from 0.12J released to 4.3J released. The fence height change came from our sponsor's concern for the height and reach of African elephants (up to 12' at their shoulder) being larger than the other fence design sources intended for Indian elephants. The battery size change came from a better understanding of battery draw using the assumptions and calculations found in Table 1 in the following section. The change in energizer joule releasing ratings came from literature recommending a 3.5J minimum rating.

Part details can be found in the Bill of Materials in Appendix E. All pertinent materials were chosen based on pretesting and approval according to pertinent codes that our team identified (Appendix D).

The research and theory that led to the rest of our design choices largely came from similar design examples and project requirements, which will be discussed later in the report. The off-grid nature of our intended location guided our solar power decision for energy generation and other electric fences largely use electric fence energizers to step up battery voltage. The inclusion of a fan came from recommendations for our electronics operation to be under 55°C (Dakota Lithium, 2023), and with up to 49°C exterior temperature in the intended

location, we anticipated needing cooling for internal electronics. The protective case came from the portable nature of the system. Other elephant-intended electric fence testing recommends between 6kV and 9kV (Fernando, 2020). The hanging wiring choice came from our sponsor's recommendation and a similar design example intended to deter elephants from breaking traditional fences. The spacing of fence posts and ground rods came from other literature recommendations, namely "Ground rod installation: Grounding Electric Fence" (Zareba Systems, n.d).

For this design project, the team had two major items that required construction: the case and the fence. For the case, most of the subsystems and parts were acquired through purchase requisitions after careful research and consideration. Because of this, most of the construction for the case involved ways in which the team could reliably place all the subsystems in the case together. For items that needed to be mounted (USBs, charge controller, fan, and load center) the team used a reciprocating saw or hole-saw drill bits to precisely cut out pieces of the case for parts that needed to have an increased area exposed to the air (charge controller and fan) and small drill bits to make holes for screws and wires for the other parts of the case (USBs and load center). Additionally, a medium-sized hole was cut to give the energizer a place to plug into the load center. This hole was fitted with a PVC tube and cap to maintain the integrity of the case. Inside the case, all wiring is covered and protected with wiring conduit and taped with electrical tape to ensure the wiring in the case is organized and easy to understand. Each item is connected to its own breaker in the load center as well as a grounding terminal to provide a means to turn off any one system without disrupting the others. The solar panel was mounted on a removable wooden shelf (Appendix C-3) made by cutting wood scraps with the Makerspace's miter saw. Lastly, any holes or potential leakages were filled with caulk to ensure the case stays waterproof. The construction of the fence involved initially digging holes using a Skid Loader for the four posts for the small-scale prototype of our fence. The wiring of the fence was mostly done by hand only being assisted with equipment such as insulators and tensioners to achieve the final product. The hanging wires were coiled and wrapped individually by hand and held in space using a specialized screw and nut. Lastly, the post offset was created using 2x4s, and the Makerspace miter saw and mounted using wood screws.

Subsystem Designs

2.1 Energy Generation

The energy generation subsystem is our solar power system consisting of a 50W photovoltaic panel and a solar charge controller to regulate output between the panel and the battery. The largest constraint for the panel was the size of our system protection as our panel could not exceed the size of the case. We considered flexible or foldable panels but decided to go with a single standard panel to maintain durability. The panel we chose had one of the largest wattages available for its size. There were no sponsor-given project requirements for energy generation beyond the decided working criteria that the fence must operate without energy generation for 12 hours, meaning the source needs to generate enough power during daylight hours for the battery to sustain the energizer draw for 12 hours. This was confirmed in battery charge and discharge testing discussed in more detail in the following section. The other decided working criteria were that the panel can be removed from the case, adjustable, and performs at its optimal efficiency of 16.9% (Renogy, 2023). Adjustability came from testing that proved different angles are beneficial at different times of the day. Removability came from our

sponsor's recommendation to maintain low case temperature in the shade while having the panel separately in the sun.

2.2 Energy Storage

The energy storage system for our design was chosen to be a 12V lithium-ion battery. After deciding what solar panel and charge controller will be included in the system, research based on the Renogy performance parameters (current source and sink from the charge controller) informed our decision to get a 23 Amp hour battery that has a compatible current draw. However, this proved to be the backward way of evaluating the battery for our system. We realized that to size the battery we needed to do a load analysis. The load analysis can be seen in Table 1, which informed that the true size of the battery we need for our system needs to be 84.72 amp hours. Because of this new information and analysis along with flight restrictions, we decided that we will continue to use the 23 amp hour battery in San Antonio but we will be sourcing an 85-100 amp hour battery in Zimbabwe to be used in the final system in Africa.

Table 1. System Load Calculations and Analysis

Loads	Voltage (V)	Daily Use (hours)	Current (A)	Power (W)	Power needed per day (Wh)
Energizer	12	24	0.20	2.4	57.6
4 USB port	5	6	3.20	16	96
Fan	12	12	0.11	1.32	15.84
TOTAL			3.51	19.72	169.44
Safety Factor	2.00				
Days of Autonomy	3				
Required Power (Wh)	1016.64				
Required battery Capacity (Ah)	84.72				

2.3 System Protection

The energy generation, energy storage, and phone charging systems are all housed within the system protection subsystem, which exists primarily to prevent environmental hazards from damaging the more sensitive subsystems encased within, as well as regulate the temperature of the systems within. The subsystem consists of a modified Pelican case with holes drilled in specific locations to allow the system to properly ventilate, a computer fan capable of cooling the system by moving air out through one of the holes made in the case, and filters capable of

keeping out coarse sand placed over each hole. The primary constraint applied to this subsystem is the maximum allotted size for commercial flight; the total size of the case should not exceed 80 linear inches. As such, the pelican case selected for use was as close as possible to this maximum size. The main change for this subsystem from the Fall 2022 semester was the addition of a fan, which also meant creating holes in the case and covering them with filters to not compromise the system's environmental protectiveness. The fan runs at 2000 RPM and is capable of displacing a volume of air equal to the interior volume of the case in under a minute, and can be activated/deactivated at user discretion via the fuse box. This allows for the system to be adequately cooled when needed without complicating the system further through the use of an Arduino circuit and temperature sensor, although that option was considered.

2.4 Fence

The fence subsystem is designed to step up the voltage provided by the battery to the desired electric fence voltage of at least 6kV-9kV which will shock and deter animals ranging in size up to elephants. The fence subsystem consists of an electric fence energizer (Appendix C-5) as well as the fence itself, which consists of 14' tall fence posts spaced 10' apart around the perimeter of the protected space, with 9' grounding rods interspersed with the same spacing. Grounding rods are connected via 10 gauge insulated wire that is buried 12" deep. The posts have two main high-tension wires that run horizontally between each post. Additionally, there are 12" diameter coiled dangling wires that hang down off of the main wires. The main wires are placed on top of the post and around 5' off the ground, with the top wire offset from the posts by four feet and the lower wire offset by 2'. The positive terminal of the energizer is attached to the main fence wires and the negative terminal is attached to the nearest grounding rod using 10 gauge insulated wire. The energizer is powered using a barrel plug that is connected to the load center to draw power from the battery (Appendix C-4). The energizer has multiple variable settings to determine how often the system pulses, which in turn affects the energy draw of the energizer as well as the effectiveness of the fence as a deterrent. The design requirements that applied to the fence subsystem consisted of applying enough voltage to repel elephants, which is a minimum of 9,000 volts according to our research, while also ensuring that the fence would be as tamper-proof as possible to avoid elephants destroying the fence.

As the team began designing the fence subsystem this Spring 2023 semester, it has undergone significant design changes since the Fall 2022 semester. Primarily, the system now has two main wires running between the posts instead of one. This change was made to better protect the bottoms of the posts as our scale model showed that the single main wire risked leaving an approximately two-foot unprotected gap along the bottom. The bottom main wire also features a different offset length than the upper main wire, which provides the fence with multiple protective layers as opposed to a singular layer. This is to stop elephants from tampering with the fence using their feet as elephants have been documented using their toenails to damage electric fence posts.

2.5 USB Device Charging

The USB device charging subsystem's primary function is to provide access to charging for phones and other portable devices. While the objective of this project is centered around providing protection for a community garden, providing a means to charge people's phones will also greatly increase the ease of connectivity for the intended community. In the Tsholotsho region, there is no free access to electrical power or a battery so free charging access is in high

demand. The primary design requirement that applies to the design of this subsystem is the necessity to charge 4 USB devices simultaneously with a charge time that should not exceed 6 hours per device. Additionally, this subsystem affects the requirement for the design to continuously power the electric fence subsystem for 12 hours using the battery alone. The final design includes 4 prefabricated USB ports mounted to the outside of the Pelican transport case. The ports were then wired into the load center to provide a centralized location to turn the subsystem on and off. All wires were protected in the wiring conduit and fastened to the transport case.

3. Design Evaluation

This section outlines the design's determined project requirements and constraints and their associated test plans and evaluated results that prove their operation based on requirement working criteria. Any significant changes from the previous semester's design and criteria are also provided and explained with each test. Requirements are provided in chronological order as designed and tested this school year below.

3.1 Project Requirement #1: Solar Panel Adjustment and Efficiency

The system shall be capable of removing and placing the solar panel in an optimal position as well as be capable of adjusting the solar panel's angle to achieve the highest efficiency.

Associated Test Overview: PV System Efficiency

Objectives

1. Measure PV system efficiency and performance over extended periods in varying weather conditions and at different angles.

Features Evaluated

This test evaluated the solar panel at various angles and in various conditions to measure their effect on the solar panel's efficiency.

Test Scope

The test will be conducted on the roof of Trinity University's CSI building using a watt meter and Arduino to measure the output wattage of the solar panel. There will be long-term tests during different weather conditions as well as short-term tests to finalize the optimal angle for the solar panel.

Test Plan

Materials:

- Arduino Uno, Wattmeter, solar panel, charge controller, battery, PLX-DAQ

Tools, Techniques, Skills:

- Efficiency Calculations
- Power Calculations from voltage and current data
- Arduino coding to record data from wattmeter (available in Appendix F)

Assumptions:

- Consistent weather conditions during longer tests
- Longitudinal angle of the panel with respect to the sun will not be accounted for by target community or during testing

Data Collection:

- Wattmeter is connected to the panel while it charges the battery. Additionally, the Wattmeter is connected to an Arduino to automatically record the data over an extended period
    - Data recorded: voltage and current every 30 seconds
    - Trials: 4 under different weather conditions
- Solar panel efficiency is measured using data gathered from previous tests. Power flux and panel area are known constants.
    - Data recorded: efficiency
    - Trials: 4 under different weather conditions

Acceptance Criteria

The acceptance criteria of this test were that the solar panel performs at an efficiency of 16.9% (Renogy, 2023) however, we gave a 5% buffer to this efficiency rating as it was found in an optimal testing condition. Additionally, once we found whether or not the angle and weather conditions significantly affect the efficiency we provided a way to adjust/account for this.

Test Results and Evaluation

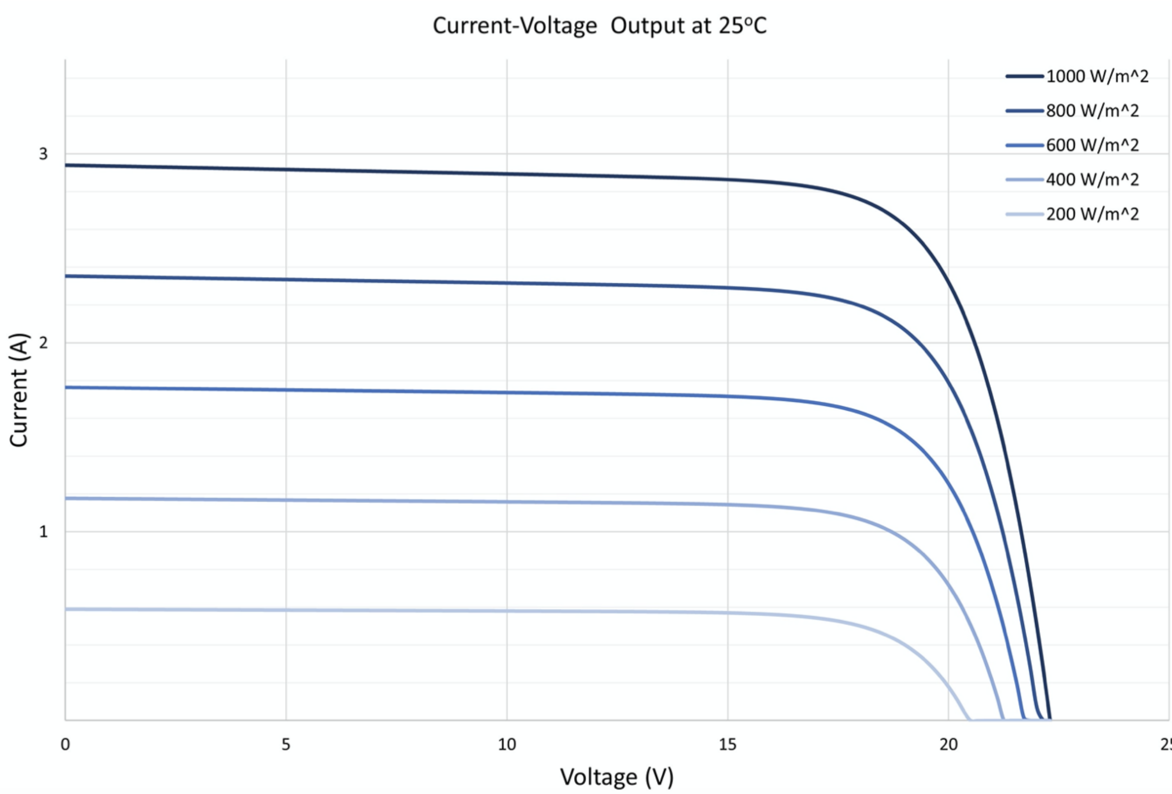

Figure 1. Solar Panel Voltage and Current Specifications at Different Solar Iridescences (Renogy, 2023)

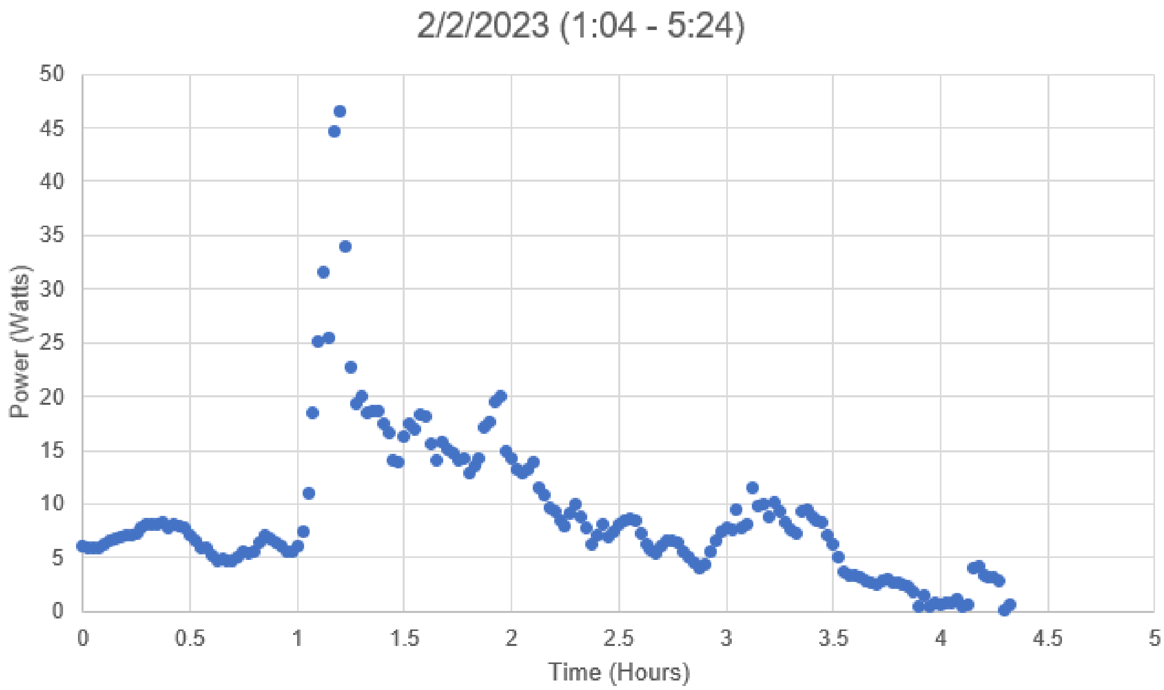

Figure 2. Solar Panel Power Over Time During Heavy Cloud Coverage

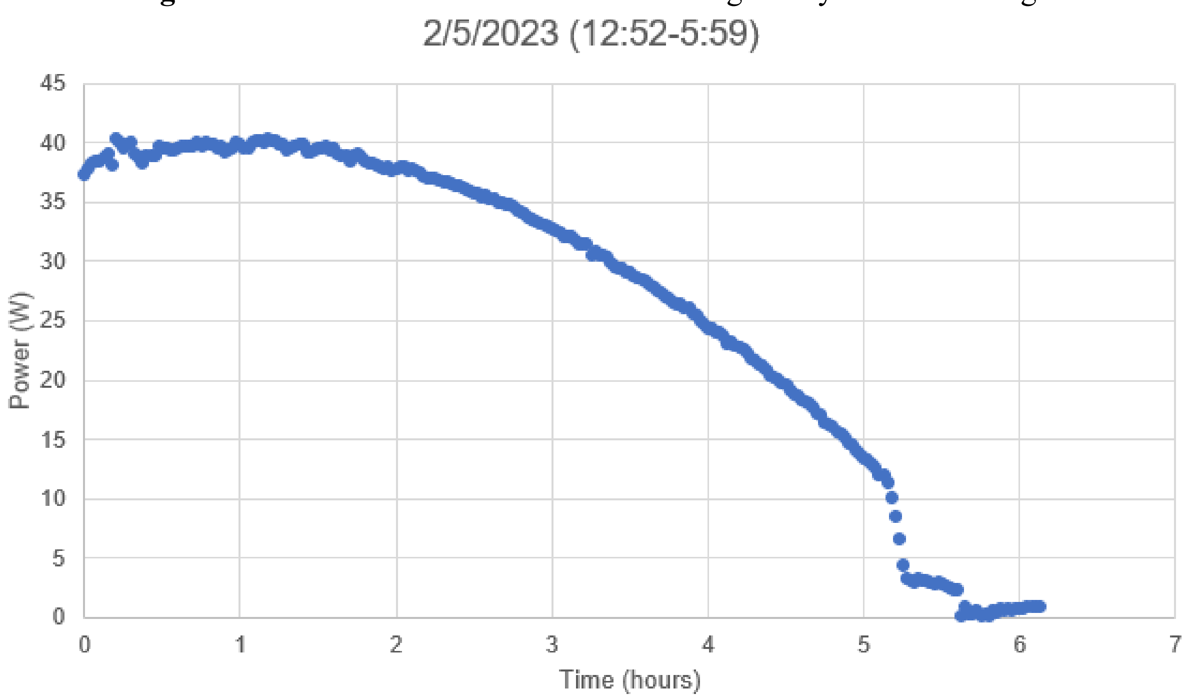

Figure 3. Solar Panel Power Over Time During Full Sun Conditions

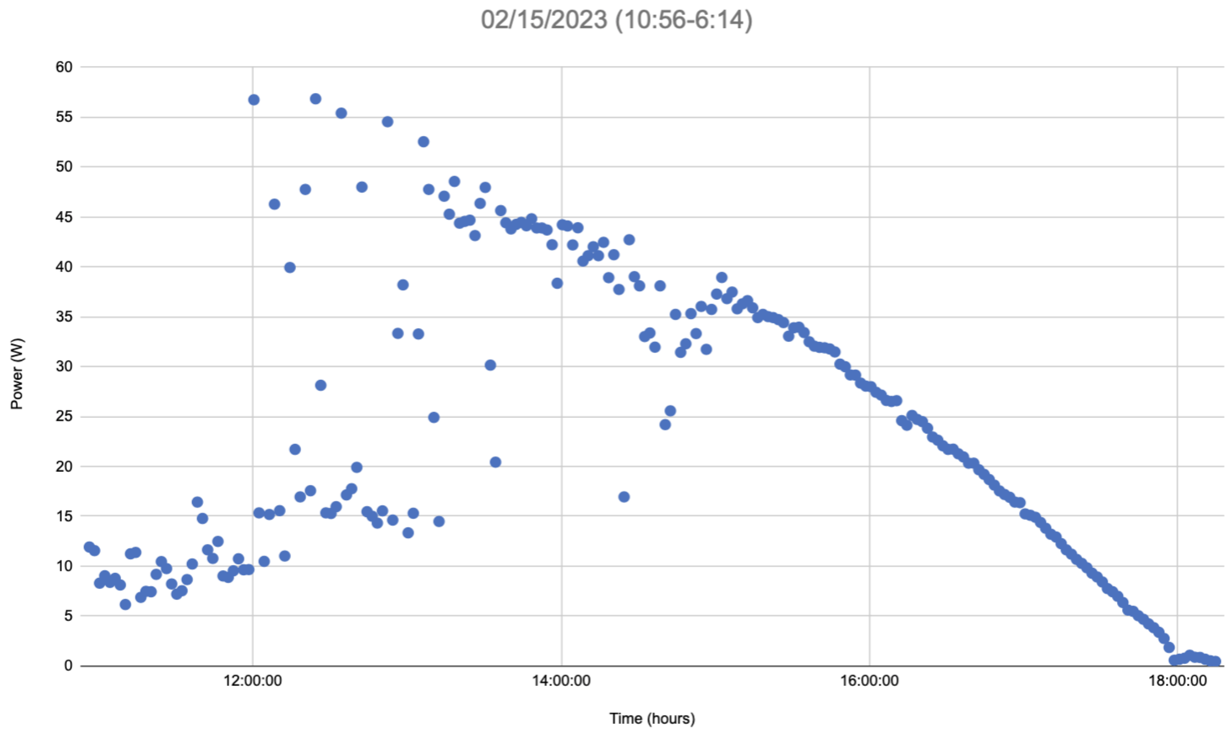

Figure 4. Solar Panel Power Over Time During Partial to No Cloud Coverage

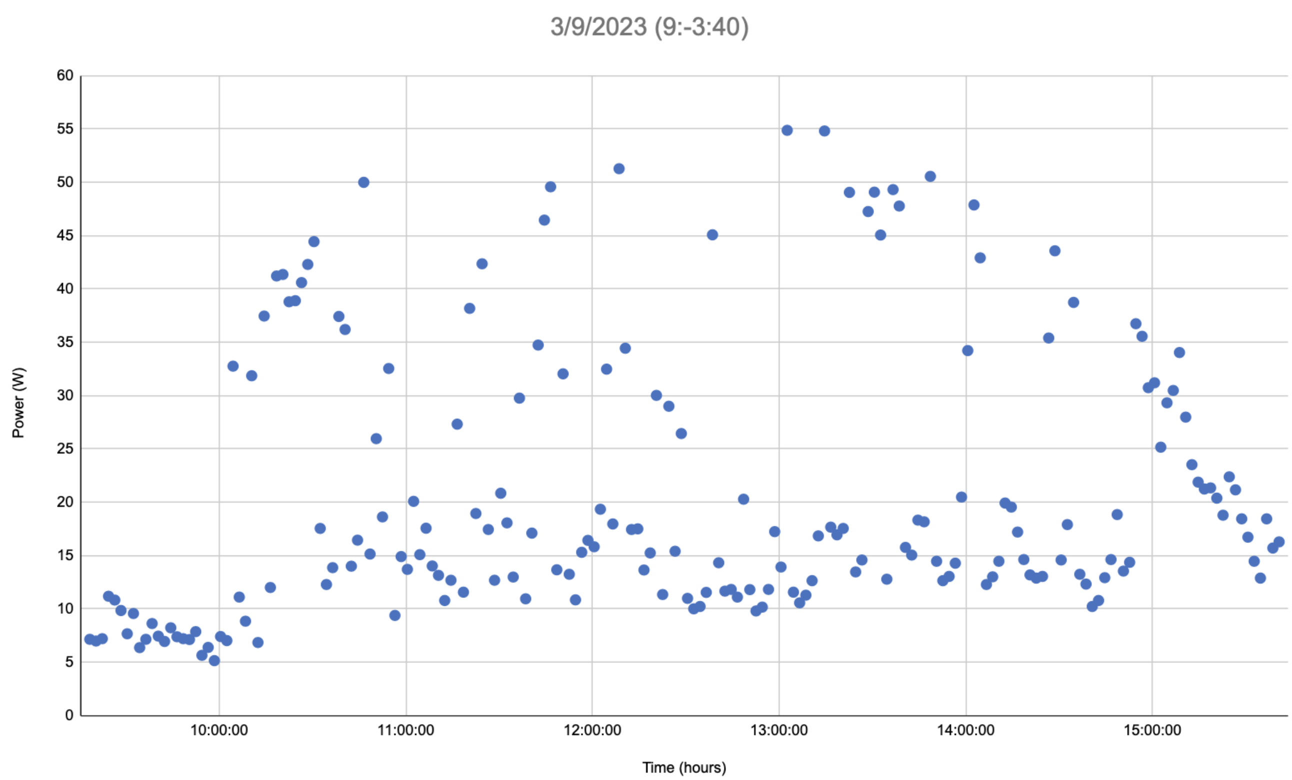

Figure 5. Solar Panel Power Over Time During a Sporadic Cloud Coverage

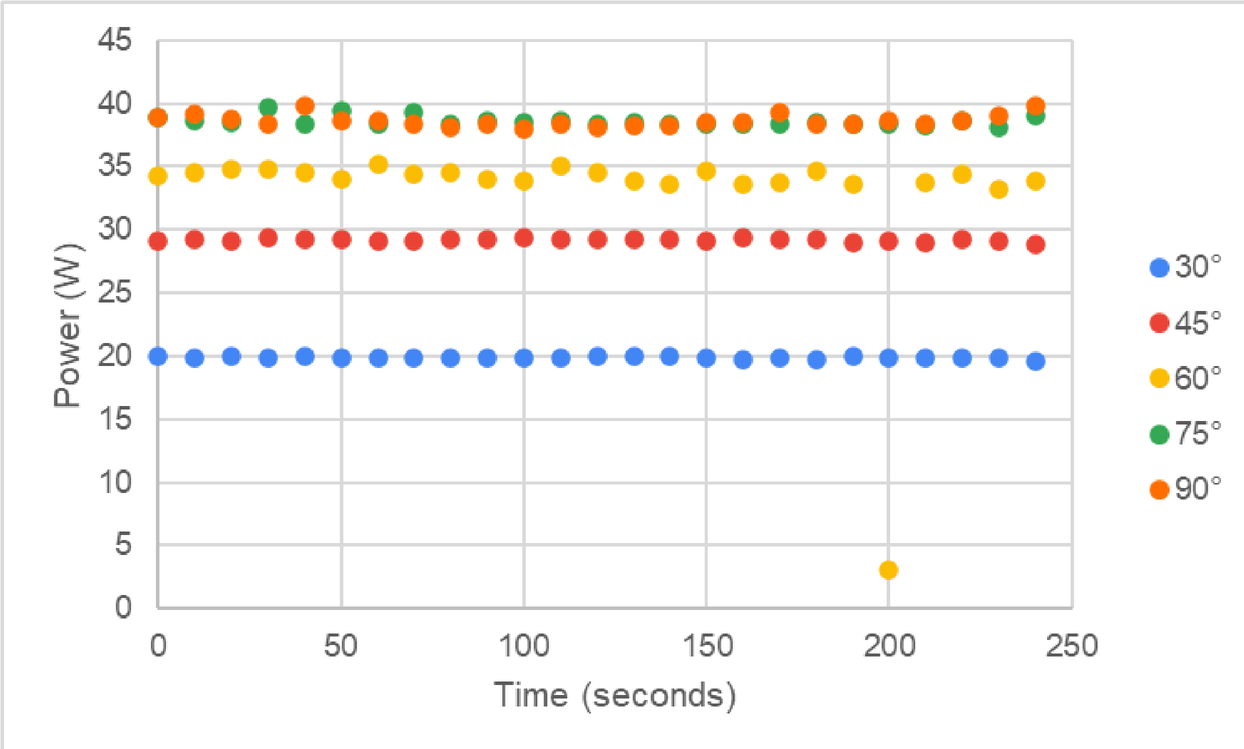

Figure 6. Solar Panel Power at Five Different Angles (Data Collected for 2 Minutes at 10 Second Intervals)

Figures 2-5 show that this solar panel was tested in various weather conditions and looking at any one figure can inform us about the weather condition during that test. Figures 2 and 5 show heavy cloud coverage where the panel is only producing higher wattages when the clouds reveal the sun for a short time. In contrast, Fig. 3 and 4 show a sunny day and the wattage maximizes and decreases as the sun gets lower in the sky (Figure 4 shows a cloudy start to the day). These figures indicate that the time of day and weather conditions play a large role in the efficiency of the solar panel.

The overall efficiency level of the panel was measured in a standard testing condition where the iridescence was maximized at an angle of 30° as determined optimal for San Antonio by “World Estimates of PV Optimal Tilt Angles and Ratios of Sunlight Incident upon Tilted and Tracked PV Panels Relative to Horizontal Panels”, this will be adjusted to about 22° for use in Zimbabwe (Jacobson and Vijaysinh, 2018), we evaluated our panel's performance at the most optimal points of its production against a standard value for the solar flux of the sun. On a sunny day, we achieve a maximum value of about 50 watts. When evaluated against the average solar irradiance on a sunny day (1000 W/m^2), we get an efficiency of 16.9%, exactly what the specifications of the panel stated. Additionally, on a cloudy day, the panel hovered around 15 watts. When evaluated against the average solar irradiance on a cloudy day (300 W/m^2), we get an efficiency of 16.9%, again exactly what the specifications of the panel stated. Overall, we can conclude that the solar panel we selected works has specified and produces power at a standardized efficiency level.

From Fig. 6, we can conclude that the best charge angle for the solar panel is 90°. Additionally, it is important to note that during the angle tests, we only accounted for the vertical position of the sun and neglected the horizontal position of the sun as it traveled across the sky. Because of this, we believe that the 60°, 75°, and 90° measurements did not have an equal

chance to show their greatest power output and as a result, we believe there would have been a greater difference in the average power produced by the solar panel. However, it is clear that the angle the solar panel is at has a large effect on the overall efficiency of the panel.

From the results of this test, we determined that being able to adjust the solar panel's angle would be very important for the optimal operation of the final design. To ensure this was possible we purchased panel mounting brackets to be installed onto the solar panel that allows the solar panel's angle to be adjusted and for the panel to stay rigid at the chosen angle. Additionally, we determined that it would be necessary to include a way of removing the solar panel to ensure it is placed in the sunniest conditions. This was done by building a custom bench that the solar panel would be bolted to and could be easily removed and placed stably in the sunniest area (Appendix C-3).

3.2 Project Requirement #2: Phone Charging Capabilities

The system shall be capable of charging up to 4 mobile phones via USB port simultaneously with a charge time that should not exceed 6 hours per device.

Associated Test Overview: USB Device Charging Test

The Will Power team measured the charge time and average current and power draw from a variety of devices using the system's USB ports.

Objectives

1. Verify if our system is capable of charging up to 4 devices for 6 hours each and select an adequate-sized battery for the system.

Features evaluated

This test evaluated the functionality of the USB charging subsystem in addition to evaluating the lithium battery. The USB charging subsystem functionality was observed to ensure the system could support the charging of various devices.

Test scope

All testing was conducted in the Trinity University electronics shop. One micro-USB and one iPhone charging cord were used for all tests to reduce variations in testing conditions.

Test Plan

Materials:

- 12V 23Ah battery, 12V Automotive USB Port Panel Mount, Clamp Ammeter, Samsung Android phone, iPhone 12 Pro, iPad Pro, micro USB to USB power cord, Apple iPhone power cord, stopwatch

Assumptions:

- Voltage supplied to the USB chargers was assumed to be a constant 12V and was not recorded to make power draw calculations
- Linear charge curve assumption was used to calculate the estimated full charge time from the measured portion of the charge time, in reality, the charge curve tapers off at the end resulting in longer charging times

Data Collection:

- Charge time was measured using a stopwatch and the average current draw was calculated from the average of several current measurements using the clamp meter around the wire from the battery
  - Data recorded: Average current drawn, charge percentage, and time
  - Trials: 3 different portable devices

- Wh was calculated by multiplying the Amps drawn by the full charge time and the 12V from the battery

Acceptance Criteria

The results were accepted if the USB ports were functional and able to provide charge to the various devices. The results of this test are neither accepted nor denied based on the determined charge rate of the various devices; rather, this test was used to calculate the required battery size for the system to support the working criteria of charging 4 phones simultaneously where the full charge time should not exceed 6 hours per device

Test Results And Evaluation

Table 2. Phone Charging System Test Results

Device Used	Power Source Used	Charge Time [%, time]	Estimated Full Charge Time [hours]	Average Current Drawn [A]	Power Drawn [Wh]
Initial Circuit System Built Fall 2022					
Samsung Android Phone	Circuit with IPUSB-2JAPC Port	10%-80%, 5hr, 15 mins	7 hr, 30 mins	0.501	45.089
Existing Systems (for efficiency comparison)					
Samsung Android Phone	Wall Power	0%-50%, 0 hr 58 mins	1 hr, 59 mins	0.406	9.744
Samsung Android Phone	12V Lithium Ion Battery built-in USB Charging Port	0%-58%, 1hr 3 mins	1 hr, 47 mins	0.448	9.569
New Purchased System					
Samsung Android Phone	12V USB Outlet Automotive USB Port Panel Mount	0%-60%, 1 hr 26 mins	2 hr, 23 mins	0.600	17.136
iPhone 12 Pro	12V USB Outlet Automotive USB Port Panel Mount	0%-20%, 1 hr 0 mins	5 hr, 0 mins	0.800	48.000
iPad Pro	12V USB Outlet Automotive USB Port Panel Mount	0%-58%, 1 hr	1 hr 43 mins	0.9	18.576

This test showed that our initial system from last semester with a 7.5-hour full charge time had a large efficiency gap from other power sources (wall power and battery port) that had about a 2-hour full charge time for the same device. This test also showed that our new system was also more efficient than our original system with about a 2.5-hour full charge time for the same device. This new system is within our acceptance criteria of < 6 hours full charge time. Each of our tests this semester also showed a much lower energy consumption from the battery, increasing the total number of phones that could be charged from our system. The average power draw calculations helped us calculate the duration of our battery life cycle. Notably, the power drawn by one device for our new system is at a minimum of 12.672 Wh, which validates the need for a battery larger than the original 23Ah battery purchased. Lastly, our new system purchased and tested this semester includes 4 USB ports, fulfilling our team's decided guideline for the number of phones able to charge simultaneously.

3.3 Project Requirement #3: Continuous Usage Operation

The system shall operate at a net energy gain when powering the fence subsystem alone.

Associated Test Overview: Simultaneous Charge/Discharge Test

This test evaluates the performance of the system when energizing the fence and simultaneously collecting energy using the solar panel. This test was done to simulate true field operating conditions for the system and analyze the effectiveness of the solar panel in conjunction with the electric fence.

Objectives

1. Confirm the design will successfully energize the fence and collect solar power simultaneously.
2. Determine if power may be reclaimed at a net gain by the solar panel during simultaneous operation.

Features evaluated

This test evaluates the battery voltage, solar panel power, and fence energizer draw.

Test scope

This test was conducted at the site of the prototype fence design in Seguin, TX to best simulate the terrain and assembly of the final design. The test setup and operation were done using proper personal protective equipment, which included rubber-soled shoes, rubber gloves, and an AED device near the test site.

Test Plan

Materials:

- Solar panel, case, battery, charge controller, electric fence energizer, fence prototype, Arduino Uno, 2 wattmeters, voltmeter, clamping ammeter, rubber gloves, AED, PLX-DAQ

Data Collection:

- Solar panel was set to 30° with respect to the ground
- One Wattmeter took battery readings and one took solar panel readings
    - Data recorded: voltage and current every 30 seconds
    - Trials: 1 hour-long trial

Acceptance Criteria

The acceptance criteria of this test were the ability of the system to energize the fence while simultaneously charging the battery and achieving a net energy gain (power provided by the solar panel exceeds power consumed by the fence).

Test Results and Evaluation

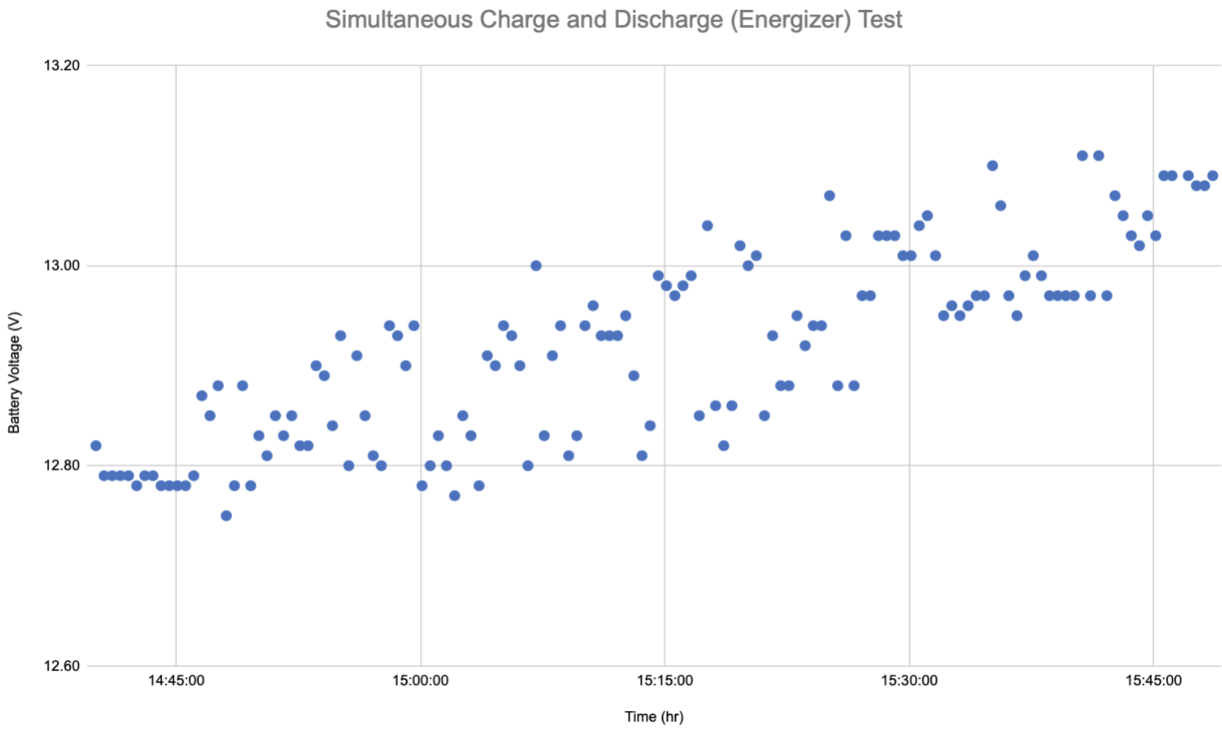

Figure 7. Battery Voltage overtime during Energizer Discharge and Panel Charge

Figure 7 shows the battery voltage over time while the energizer was drawing from the battery on its 12kV setting and the panel was charging the battery, during favorable sun conditions. The battery was able to charge from 12.8 V to 13.1 V which shows a net gain of battery charge during this time, in line with our acceptance criteria. Overall this test showed favorable fence-and-panel-use in conjunction, with a net gain in battery voltage, confirming our energizer's small draw on our battery. The use of our final larger battery will elongate the battery life cycle even further.

3.4 Project Requirement #4: Elephant Deterrence

The fence system provided by the Will Power Africa team must be able to repel wildlife of all sizes ranging up to the African elephant. Thus, the electric fence must maintain regular pulses of 9kV minimum to properly protect the garden from all wildlife. The pulse strength must not dip below 9kV anywhere on the fence to ensure there are no gaps in electric strength an elephant could use to move through the fence.

Associated Test Overview: Energizer, Fence, & Full System Operation test

The Will Power Africa team tested the voltage output of the fence and measured the voltage drop along the fence wires by constructing a scale model fence and testing the desired energizer/fence parameters on the scaled fence.

Objectives

1. Confirm that the energizer is outputting the voltage indicated on the energizer (12 kV).
2. Confirm that the energizer is pulsing at the correct intervals (< 1 cycle per second).

3. Visually confirm that the fence meets the working criteria to stop elephants; if not, reevaluate the system with knowledge of how the expected load (the fence and its length) affects the system.

Features Evaluated

The features evaluated in this test include the energizer and fence operation when implemented into the full system. The energizer must produce a voltage and current that will deter but not damage or kill elephants. Additionally, the entire length of the fence must be at the same value to ensure all parts of the fence are protected equally.

Test Scope

The scope of this test involves testing a small-scale fence prototype built in Seguin in similar conditions to the final location in Zimbabwe. A fence voltmeter measured the outputs of the energizer and fence when operating. The test will theoretically verify the non-lethal to elephants requirement however, we did not conduct animal testing due to complicated logistics.

Test Plan

Materials:

- Four 8' long fence posts, 10 gauge aluminum wire, fence insulators and springs, electric fence energizer, grounding rods, fence voltmeter, rubber gloves, battery (Set up can be seen in Fig. 8)

Assumptions:

- Location the prototype fence was constructed mimicked the environment of Tsholotsho, Zimbabwe

Tools, Techniques, Skills:

- Safety precautions and PPE was used

Data Collection:

- Recorded the voltage of the fence at multiple locations across the fence to look for any voltage drop in the wire
    - Data recorded: voltage of fence
    - Trials: 4 different fence locations

Acceptance Criteria

The acceptance criteria of this test were, for the entire full system operation, the energizer and fence both never produce a voltage or current that can cause harm to or kill an elephant - should not exceed 12.6 kV and to cause discomfort but not death for elephants. Lastly, the output must be the same all around the fence.

Test Results and Evaluation

Table 3. Fence Voltage Measurements

Location	High Tension Wire Voltage (kV)	Hanging Wire Voltage (kV)
First 10 ft fence section from energizer (5 ft total distance)	12.1	12.0
Second 10 ft fence section from energizer (15 ft total distance)	12.1	12.1
Corner Section (20 ft total distance)	12.0	12.0
10 ft fence section after corner (30 ft total distance)	12.0	12.0

Using the voltmeter, voltage measurements were recorded along the horizontal high-tension line at 4 locations; the midpoint between all 4 posts and between the two corner insulators. Table 3 confirms that our system is operating at a sufficient voltage level to deter elephants throughout the fence prototype, as outlined in the "Guide for Implementing Community-Based Electric Fences" (Fernando, 2020). However, there was a voltage drop of roughly 100 volts. This drop does not mean our fence system is ineffective, as recommended voltage to deter elephants is 9kV minimum and our fence is consistently over 11 kV; however, it is worth noting that increasing the length of the fence to the final 240 ft. perimeter will further reduce the voltage on the fence line.

Figure 8. Fence Operation Testing Photo

3.5 Project Requirement #5: Weather Durability

The temperature inside the system protection case shall not exceed 55 °C and should protect against dust particles greater than 0.45mm in diameter

Associated Test Overview: System Housing - Weatherproof Case

The system housing, or weatherproof case, test will determine whether the case can properly protect the systems encased within and whether the temperature inside the case exceeds safe operating parameters for the electronics housed within.

Objectives

1. Determine the maximum temperature inside the case as the battery is both being charged by the solar panel and discharging electricity to the fence energizer.
2. Ensure that while the case is closed inclement elements such as dust/sand are unable to seep into the case. Acceptable amounts of elements being let in are subjective, but ideally, the amount of outside material entering the system is kept to a minimum.

Features Evaluated

The feature evaluated by this test was primarily the Pelican case's effectiveness at blocking out inclement weather and dust buildup, while also determining whether the case setup has sufficient airflow to prevent the electronics from overheating. To determine whether the system would overheat we needed all electronics running simultaneously inside the case.

Test Scope

The scope of the test included charging and discharging the battery simultaneously and discharging the battery while the case was closed. Additionally, it involved exposing the complete setup to a sandy outdoor environment while the case was closed to ensure that the system wouldn't become damaged through prolonged outdoor exposure. This test verified that the system did not risk either damaging itself or quickly degrading due to outdoor use and transport. It is also pertinent to note that our purchased protective case as well as the photovoltaic panel had already been tested and approved prior to purchase under the standard IEC 60529 for the degrees of protection for electrical equipment (IEC, 2013).

Test Plan

Materials:

- Pelican case, Arduino Uno, LM35C temperature sensor, battery, charge controller, solar panel, phone and charging cord, PLX-DAQ

Tools, Techniques, Skills:

- Temperature sensing Arduino testing code

Data Collection:

- Temperature data was collected outdoors in sunlight for 1.5 to 3 hours
    - Data recorded: Battery Temperature (°C and °F) every 30 seconds
    - Trials: Charging without the fan, discharging (phone charge) without the fan, discharging with the fan
- Sand/dust test conducted outdoors at fence prototype location in Seguin over 4 hours with the case open

Acceptance Criteria

The acceptance criteria were that the temperature within the case did not exceed 55℃, as regularly exposing the lithium-ion battery to such temperatures risks substantially lowering its lifespan or even breaking it (Dakota Lithium, 2023). Provided the case stays below this temperature, the remaining electronics housed within should not risk damage. The other

acceptance criterion was that the case shows a minimal buildup of dust. This evaluation was subjective based on the size of our fan mesh holes.

Test Results and Evaluation

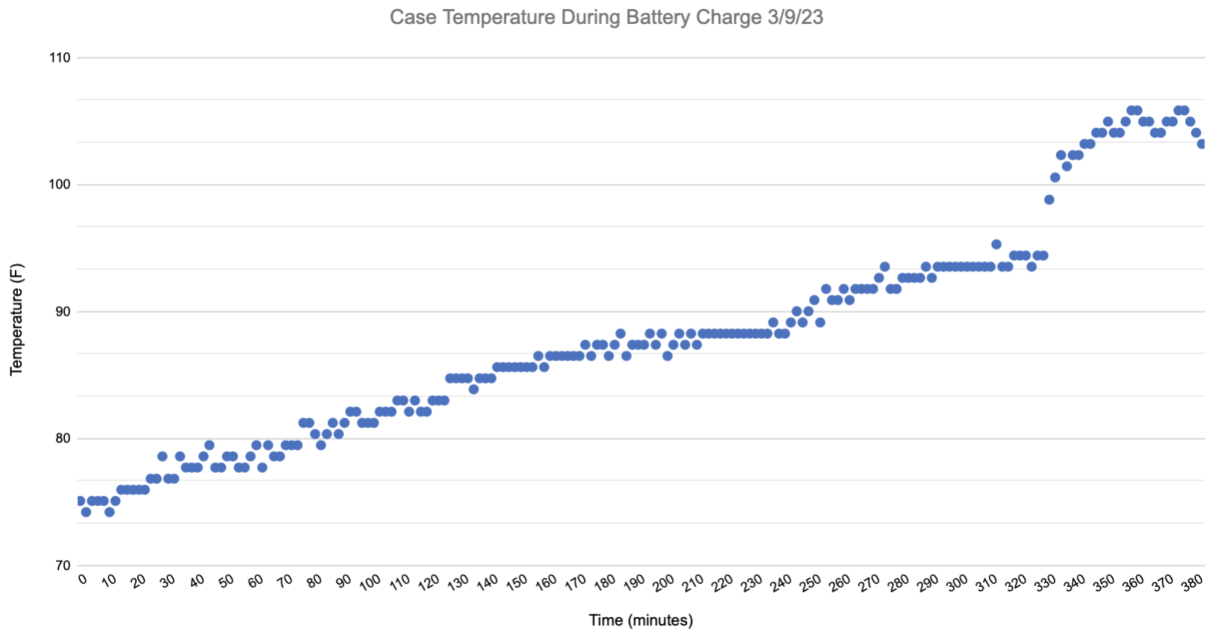

Figure 9. Internal Case Temperature during Charge

Figure 9 shows the battery temperature data during charging, so while the case was open. The data was taken between 9 a.m. and 3 p.m. on March 9th, with the ambient temperature increasing from 72℉ to 84°F during that period. From our temperature testing over 6 hours, we found that the system was able to stay under the 131°F requirement throughout the test. However, the system temperature was steadily climbing throughout the test as the ambient temperature rose, and when the temperature peaked at 84℉ the internal system temperature was 20 degrees above the ambient temperature. For the location in Zimbabwe, we plan on implementing this design, the temperatures peak well above 100℉ meaning the system could risk overheating under the worst potential heat conditions. The following figures show the temperature difference after implementing a fan for cooling.

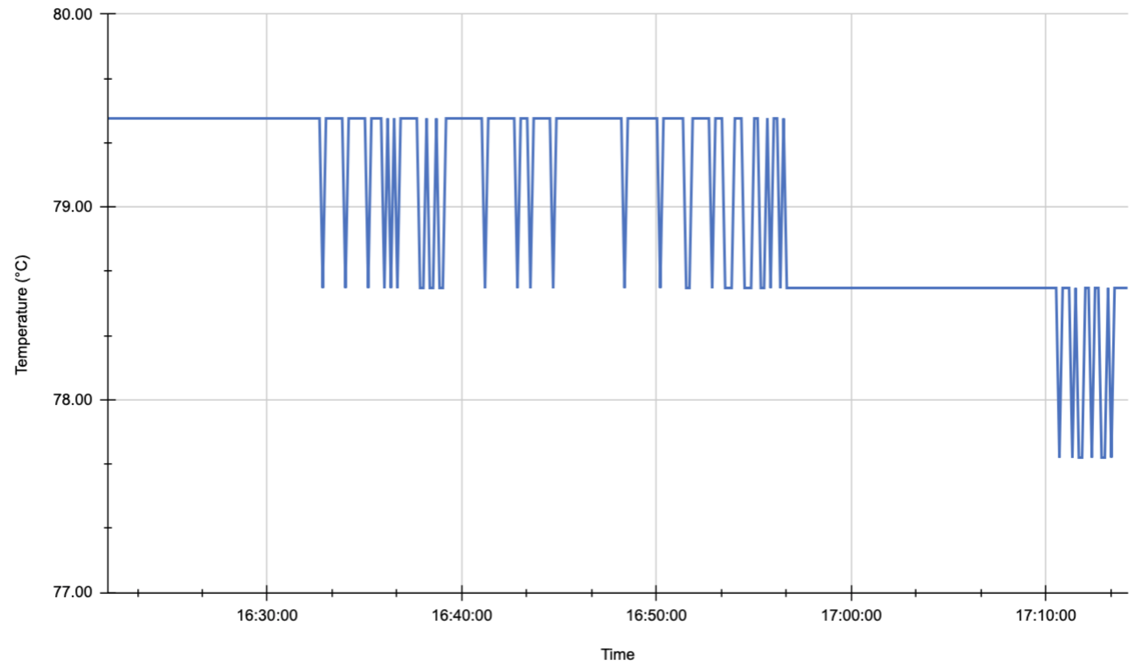

Figure 10. Internal Temperature in Case during Discharge (1 phone charging) with Fan

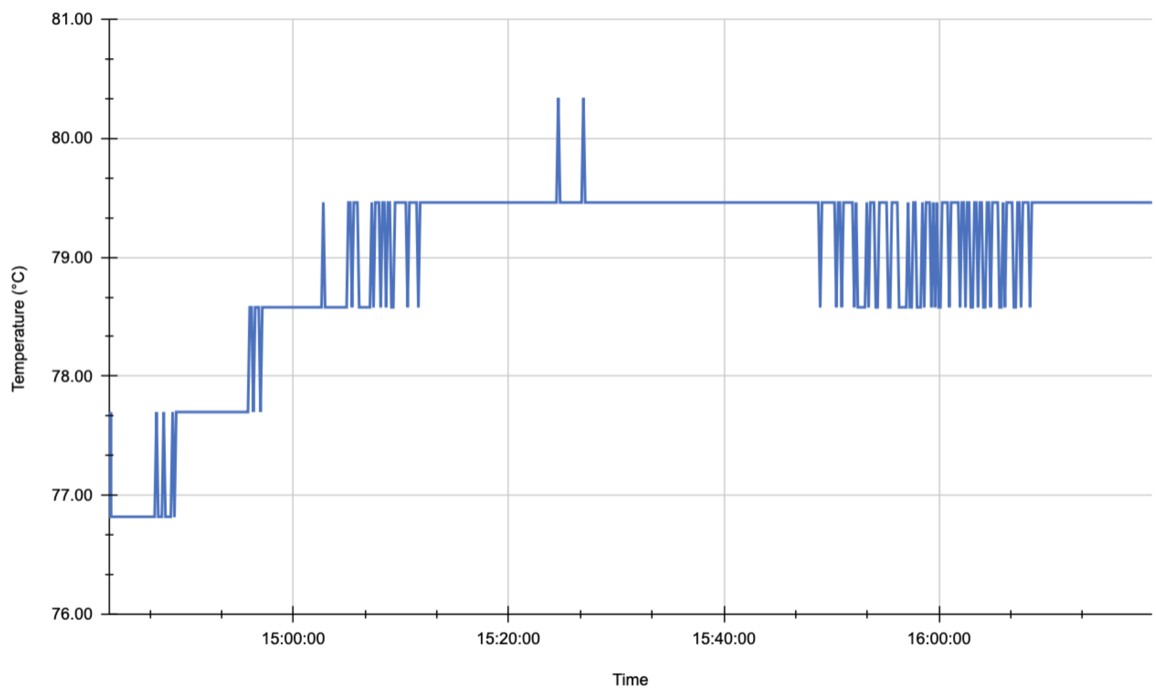

Figure 11. Internal Temperature in Case during Discharge (1 phone charging) without Fan

Figures 10 and 11 show the internal case battery temperature during battery discharge over 1.5 hours with and without the use of the fan respectively. The tests were conducted one after the other and the ambient temperature ranged from 79°F to 82°F during the span of testing. While the data doesn't span a long period or range of temperatures the general trend is an increase in temperature (76.75°F to 80.25°F) without the fan and a decrease in temperature (79.5°F to 77.75°F) with the fan. This shows that the fan

From our observational sandy environment exposure test, we qualitatively determined that dust buildup, though visually noticeable, was not large, being easily wiped away. The fan's mesh allows dust 0.45 mm large to enter the case. However, we have determined that this rating will protect from coarse sand and any fine sand particles will not interfere with the system and be easily wiped away as understood from the sand testing.

3.6 Project Requirement #6: Autonomous overnight protection

The fence must operate without energy generation for 12 continuous hours.

Associated Test Overview: Battery Discharge Testing

This test provided a charge/discharge curve and an estimated lifespan of our battery. This test was run by drawing from the battery equal to the expected operation load.

Objectives

1. Create a charge and discharge curve to determine behavior and time of 1 cycle during system operation
2. Using this cycle time, estimate the overall lifespan of the battery

Features Evaluated

The feature evaluated in this test was the battery. It was being evaluated against our sponsor's desired 5-year lifespan and overnight operation working criteria (discharge time of $\geq$ 12 hours) as this is the most vulnerable and necessary time for garden protection from elephants.

Test Scope

This test cycled between 25% and 85% battery charge, safer practice than the 0% and 100% assured in the Fall 2022 semester. Our battery's specifications also state that it has "a flat voltage curve, which means it has a steady power output as the battery discharges." (Dakota Lithium Batteries, 2023) While this is good, battery charge and discharge cycles are often nonlinear and this claim was investigated further with this test. It is also important to note that our battery has already been tested and confirmed before purchase under standard IEC62133 (Appendix D). It is important to note that the battery will have reduced efficiency with aging which we cannot test this semester, but providing best practices for use in the instructions will support battery longevity.

Test Plan

Materials:

- Battery, Arduino Uno, wattmeter, PLX-DAQ, electronic load

Tools, Techniques, Skills:

-

Assumptions:

- Battery will last 3,000 cycles (this is based on our current battery and may change based on the model chosen in Zimbabwe)

Data Collection:

- Battery was connected to an electronic load that simulated the current drawn for each test
- A Wattmeter powered by an Arduino took data measurements and were recorded via the PLX-DAQ
    - Data recorded: Battery voltage and current every 30 seconds
    - Trials: 1) Energizer current draw, 2) Energizer and 4 phones charging current draw

Acceptance Criteria
The battery test was accepted if it has at least a 5-year lifespan and could support system operation overnight (discharge time of ≥ 12 hours). The battery subsystem is the most prone to needing replacement. Because of this, we are working off of 5-year aging conditions.
Test Results and Evaluation

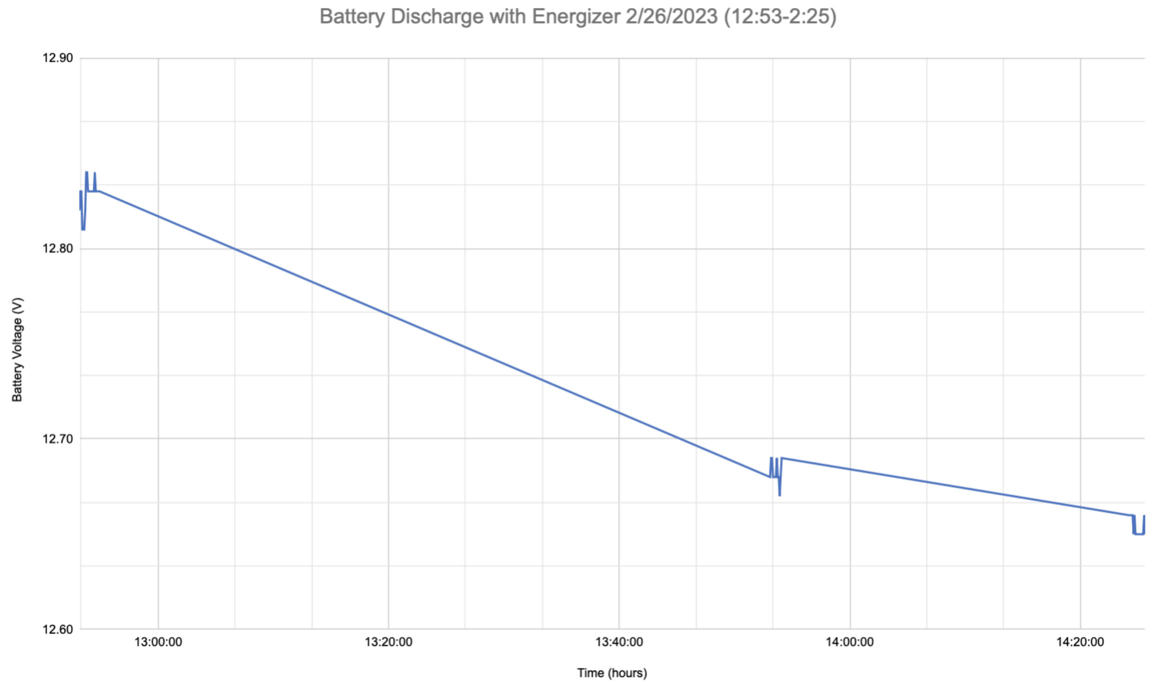

Figure 12. Battery Discharge with only Energizer (~0.2 A)

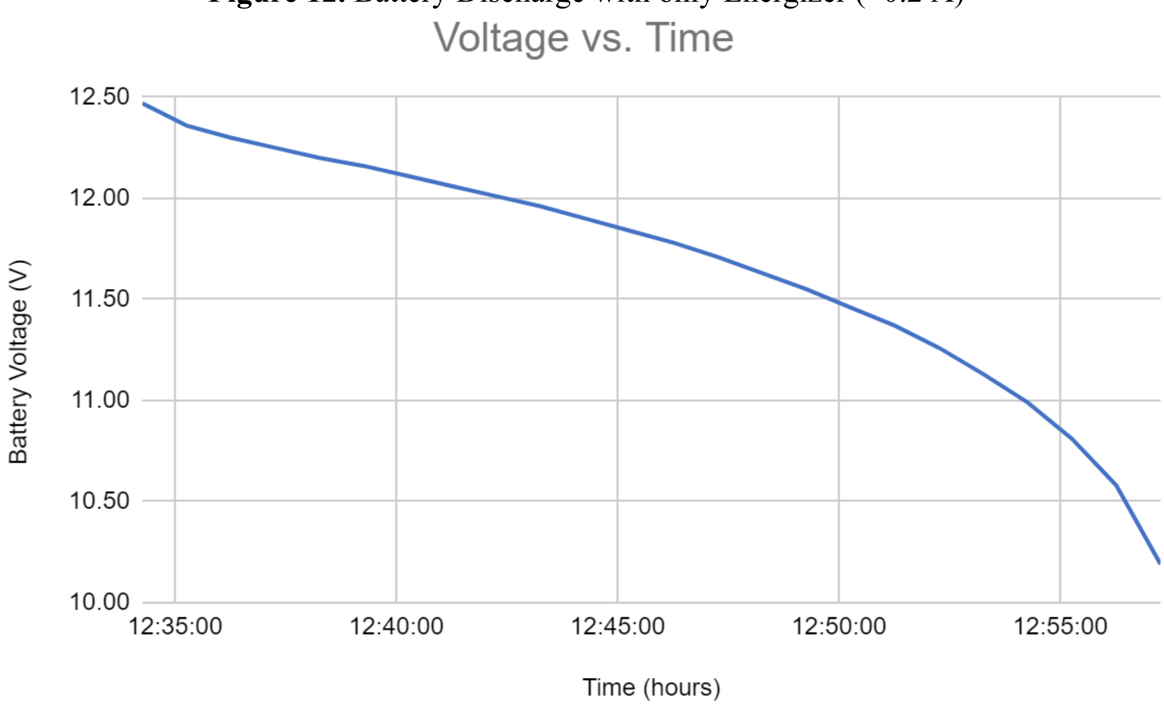

Figure 13. Battery Discharge Simulating Maximum Discharge Rate (Energizer and 4 phones charging) (~3.4 A)

The minimum current draw test, Fig. 12, features only the fence energizer attached to the battery during our field test day on our prototype fence. The theoretical maximum current draw test, Fig. 13, was done using an electronic load, with the current draw rate used stemming from our calculations and measurements of how much energy both the energizer and the four USBs would draw (Table 1).

From this data, it was determined that the battery will last significantly longer when only the energizer is used. From Fig. 12, the voltage loss follows a linear path downwards and at its steepest still takes approximately 40 minutes to lose 0.1 volts. Variations or jumps in data come from missing data due to a technical error during data collection so the linear portions are accurate. When considering discharging from maximum charge to completely drained at the rate in Fig. 12 the battery will have 80+ hours of continuous operation without the need for charge and an estimated life cycle of years up to 30 years at ideal conditions. This means that when solely running the energizer the battery falls within our acceptance criteria.

At the maximum discharge rate, simulating the energizer as well as phones charging with the electronic load, the battery drained at an extreme rate, with the battery losing 2.5 volts after only 23 minutes per Figure 13. Though the battery was not fully charged for this test, it can be safely deduced that when the system is running at maximum capacity the overall uptime of the battery falls significantly short of the desired 12-hour lifespan, about 2 hours, and a total estimated lifespan of about 3 years at ideal conditions. This greatly informed our decision to purchase a larger battery for the final operation, whose calculations can be found in Table 1. It is important to note that due to flight regulations our larger final battery will not be purchased in the U.S. so will not be tested here but we will scale up our lifetime calculations assuming the same discharge behavior.

3.7 Project Requirement #7: User Operation Ease

The system must be intuitive to set up and use for the intended community so must be straightforward and not require English.

Associated Test Overview: Instructions

This requirement was tested qualitatively rather than qualitatively using a research study iterative model.

Objectives

1. Produce refined instructions to ensure the ideal operation of our design in the target community

Features Evaluated

This test evaluated the Instructions feature (Appendix A) and was evaluated against the provided project requirement that "operation and troubleshooting need to be understood by the target community". The instructions include: parts included and their use, setup, operation, take down, best practices, and troubleshooting/FAQs through the use of pictures, built-in symbols, and some words.

Test Scope

This test encompassed implementing feedback from our sponsor and volunteers who used our instructions to set up and use the case. They were mainly measured on the "straightforward" criteria, not the "non-English" criteria. Participants were asked to rate the instructions from 1 to 5 on ease of set-up and clear communication.

Test Plan

After sponsor feedback, to get a third-party perspective, we had 3 non-engineer volunteers set up

our system for use using the instructions our team provided. Their qualitative feedback and any questions will be used to edit and improve the instructions. This test will also be repeated once in the target community for the best results.

Materials

- Instructions (Appendix A)
- Energy Generation and Case Subsystem
- Included Necessary Tools and Parts

Assumptions

- Target demographic is non-English speaking and does not have extensive engineering or electronics experience

Data Collection

- Ordinal Scale Data Collection (criteria rated 1-5)
    - Data recorded: Ease of Set-Up and Clear Communication
    - Trials: 3 non-engineering volunteers on separate occasions

Acceptance Criteria

The working criteria for this test are that the volunteers rate the ease of set-up and clear communication of instructions on average at least 4 out of 5.

Test Results and Evaluation

Due to scheduling delays, the results of this test are not yet available but will be provided during our final presentation.

3.8 Project Requirement #8: User Operation Safety

The fence must be non-lethal to humans and animals when operated under proper assembly conditions.

Evaluation

This requirement is of utmost importance as the fence voltage is a hazard capable of causing significant harm to humans if not handled correctly. That being said, this requirement did not have an associated test as safety practices were assumed and used for all fence testing. Correct fence safety practices were included in the instructions and will be communicated and stressed thoroughly to the intended community. The team also made sure that we were following all laws and standards local to the area in Zimbabwe as far as installing an electric fence. While our intended location is not in a highly populated area or even a federally enforced district - so we do not need certification - we still wanted to follow best practices as defined federally. We will use "THE LAW AND ELECTRIC FENCING: A Pocket Ready-Reference Guide to the Legal Dos And Don'ts of Electric Fencing In South Africa" which includes SANS 10335-76 and SANS 10222-3 - to inform and guide our installation (JVA, 2017) (IEC, 2002).

3.9 Project Requirement #9: Transport Durability

The system shall be secured and durable enough to handle impacts during air and rugged land transport.

Evaluation

We did not test this requirement because we are not able to simulate impacts during air travel or rugged land transport. Furthermore, if we were able to test these conditions and we were to fail this criterion because our pelican case broke, we would lose a significant portion of our budget and not be able to replace an essential portion of the design. However, there have been several instances where the case has been knocked or bumped around and the case as well as the

contents have remained undamaged. We fulfilled this constraint to the next of our ability by securing everything within the case. Overall, this criterion will have to be evaluated once the case is sent to Africa.

3.10 Constrain #1: Size

The energy generation subsystem must be under 70 pounds and 80 total linear inches to be approved for international commercial flight. This was changed from the original requirement of fewer than 50 pounds and 62 total linear inches to account for the larger battery needed.

Evaluation

This constraint informed much of our materials purchases and therefore is satisfied by our case measurements (71 total linear inches) and the current flight case weight of around 50 pounds.

3.11 Constraint #2: Time

The Will Power Africa team was tasked with completing the design and implementation of all subsystems as well as the design of a prototype fence by May 22nd, 2023, the date of travel to Zimbabwe.

Evaluation

The Will Power Africa team satisfied this constraint by finishing the design and implementation of all the required systems on schedule before the required date.

3.12 Constraint #3: Intended Location

The final design must operate in a scenario that is off-grid and remote, assuming no sources of energy, backup supplies, and maintenance.

Evaluation

This constraint informed all of our design choices and was fulfilled by the solar operation that only relies on sunlight and requires minimal intervention for operation and maintenance. This constraint cannot be tested locally before implementation and depends on many factors. The team will continue to be in communication with the target location community after implementation to determine the fulfillment of this constraint.

4. Conclusions

Of the 10 combined project requirements and project constraints, as well as the overall project objective, the system was able to successfully meet all requirements and constraints, with the completed instructions currently in progress and projected to be completed by May 4th. The time constraint was met as a result of satisfying all project requirements on schedule, however the size constraint was only barely missed due to the unexpected bulk of both the battery as well as the fuse box component.

The most crucial requirements that we resolved first in the design process were the requirements that the system be durable enough to withstand both transport and inclement weather, as well as the system requirement that it be able to operate at a net energy gain while still powering the electric fence. The design of the case system allows it to be opened or closed depending on weather conditions. When open, the system contains a solar panel to recharge the battery housed inside the case, and when closed the system contains filters to keep out dust particulates while not restricting airflow. The case used is a modified pelican case, with holes drilled into it for mounting parts inside as well as ventilation holes being drilled to keep temperatures inside low, while the solar panel used is a purchased 50 W Renogy solar panel.

Through the use of the case and filters, all of our durability requirements were handily met, while the solar panel allows our system to recharge itself and fulfill the requirement for net energy gain during fence operation.

After completing these requirements, we took the case and began working towards satisfying the phone charging constraint, which consisted of adding USB ports to the case that would connect back to the battery. The USB ports we ended up implementing were weatherproof and flush with the case, allowing the USBs to connect to the side of the case without compromising on our weatherproofing requirement. At the same time, we worked towards satisfying the temperature control requirement for the system, which involved adding a fan to increase air circulation throughout the system. The implementation of a fan involved cutting a hole into the case, which initially went against our weatherproofing requirement. However, through the use of a filter, we were able to re-satisfy the weatherproofing requirement while allowing continual operation of the fan, allowing our system to satisfy the temperature control requirement.

The last set of requirements we focused on were continuous usage operation, overnight autonomous protection, and user safety constraints. All requirements were tested on a small-scale fence prototype, in an outdoor environment selected to closely mirror Tsholotsho, Zimbabwe, where the final prototype will be implemented. The results from all tests performed on the fence prototype satisfied all three of the listed requirements and showed that the system would be capable of functioning properly in the environment where it will be implemented. These final requirements were also satisfied before May 22nd, satisfying the time constraint for the project.

Overall, the Will Power Africa team created a successful prototype capable of generating energy for itself, providing said energy to both an electric fence as well as USB ports for charging phones, while all being encased in a temperature-regulated system that blocks dust particles from entering the system.

4.1 Potential Pitfalls and Alternatives

Our final design was able to meet all constraints, however there is still much room for improvement, especially in regards to the size constraint on the prototype. The current design only slightly exceeds the criteria for standard shipping and is still capable of being shipped internationally as an oversize item. However, future iterations of the design should fall within the 62 linear inches and 70 pound requirements to ensure the system can be checked as luggage onto an airplane without requiring extra fares. An additional pitfall we encountered when determining the transportability of the system was the lithium-ion battery used. Lithium-ion battery transport, especially on airplanes, is heavily regulated and as such purchasing batteries of optimal size in the U.S. is problematic as they then cannot be taken via airplane to Zimbabwe. Our team's solution was to find a battery seller in Africa and purchase the full-size battery upon the prototype arriving in Africa, using our smaller battery for testing here in the U.S. Future teams must carefully consider FAA regulations when determining new energy systems to implement as depending on FAA regulations certain system designs cannot be flown to Zimbabwe.

4.2 Next Steps and Recommendations

For future iterations of the design, we recommend using filters capable of blocking particles 250 μm in size compared to the current filter which is capable of blocking particles 450 μm. The current filter is capable of preventing coarse sand and other particles from entering, but a 250 μm filter would be capable of blocking smooth sand from entering. Blocking out smooth

sand would be a nice convenience as it means the inside of the system wouldn't need to be cleaned as often. The next Will Power Africa team is expected to add another energy generation system to the case to supplement the solar panel (details in Appendix G). The current load center leaves 4 open slots for additional fuses. Depending on the number of devices added, more fuses or a larger load center could be necessary to have all systems connected to a unified load center.

To facilitate the construction of a new prototype by the incoming Will Power Africa team, a list of materials, system instructions, a general flowchart of system operation and photos of the system in operation are provided in appendices of this document. The current Will Power Africa team recommends constructing a prototype using the same parts from the parts list provided while following the encompassed instructions before creating new subsystems to add to the design. Note that some of the parts used could be replaced with others, see section 4.1 for recommendations on parts to replace.

Appendices

Appendix A. System Instructions

The following instructions are a preliminary draft made for the understanding and use of the design by the project sponsor and next year's team. Instructions to be provided to the intended community will be informed by these instructions but with more pictures, built-in symbols, and less words. These final instructions will be completed and included in the final presentation.

System Constructions Steps

Case Construction

1. Calculate the total load that the system will be required to power
    a. This project included the electric fence, fan and USBs
2. Choose and purchase battery that can support the calculated load
    a. This project required a 85-100 amp hour battery
3. Choose and purchase solar panel (and aluminum mount) and solar charge controller that is compatible with the chosen battery
4. Choose and purchase a Pelican (or other strong weather proof case) to house all the subsystems of the design
5. Choose and purchase a load center (breaker box) and compatible breakers for each load in the system
6. Using a reciprocating saw or hole-saw drill bits create holes for the various subsystems of the design in the pelican case
    a. This project needed a large circular hole for the fan, a large square hole for the solar charge controller and 3 smaller holes for the USB and energizer wires
7. Install all parts using correctly sized nuts and bolts ensuring all parts are stable
    a. This project included the solar charge controller, USBs, fan, and load center
8. Using 2x4s create small support table able to attach solar panel aluminum mount and that would fit snugly into the protective case
9. Install the aluminum solar panel mount onto the solar panel and secure it to the support table
10. Using Velcro attach the battery to a central part of the case making sure the battery is secure
11. Wire the battery to the load center (should be connected to the large wiring bolts
12. Wire each load's positive terminal to a breaker and negative terminal to the ground bar of the load center
    a. This project also requires a PVC tube and cap to be installed into the hole for the energizer when not plugged into the system
13. Connect all breakers to the load center
14. Place solar panel table inside the case and ensure the case can close completely
15. Wire the solar panel to the solar charge controller
16. Using caulk fill in any holes or gaps that could compromise the integrity of the case

Fence construction

1. Measure the perimeter of your enclosed area. Place stakes at 10 ft. intervals to mark the location of your posts. Determine which corner post will serve as the mounting location for the energizer.
2. Drive grounding rods into the ground at ~20 foot intervals along the interior perimeter staked out. Drive ground rods down until they are ~12” out of the ground.
3. Using a post hole digger or similar tool, dig the post holes for the fence. Depth should be at least ⅓ the desired height of the fence (5 ft. hole for a 15 ft. fence)
4. Place the post in their holes and fill with cement. fill in holes and allow fence posts to set for at least 24 hours or until they are stable and upright.
5. Fasten upper and lower L angle wood extenders to the outer face of all fence posts.
6. Determine the desired location for the upper high tension wire, which should be a minimum of 13 ft. above ground level. Place a fence staple on the corner post and slide a length of fencing wire through the staple.
7. Beginning at the corner post, tie a simple fence termination knot, leaving about 24” of offset wire to slide the fence insulator on. Slide the insulator on and repeat the fence termination knot to secure.
8. attach a P spring to the opposite end of the insulator. Tie the beginning length of your fencing wire to the spring using a fence termination knot. spool out your fencing wire, being sure to slide wire through the insulators on the attached L angles.
9. Repeat step 7 once the fence wire has been looped around the perimeter of the fence, terminating the fence line on the main corner post.
10. Repeat steps 5-8 for the lower tension wire.
11. Using electric fence wire splices, attach vertical hanging wires every 12” along the entire length of fence. Wire should be coiled to ~12” diameters and should extend to ~12” above the ground. Fasten fishing weights as needed to the bottom of the vertical wires to stabilize.

System Setup and Usage Steps

1. Open protective case and remove solar panel table
2. Check to make sure all breakers are off
3. Place the solar panel in the sunniest spot in the area where the case is and set the panel to the most optimal angle for that area
4. Unscrew PVC cap and pull through the energizer plug
5. Plug the energizer into the specified plug
6. Ensure that the energizer is also connected to any required ground rods and electric fences
7. Flip solar charge controller breaker to the ON position
    a. WARNING do not operate system with the solar charge controller breaker in the OFF position, as it could risk over discharging the battery
8. Determine what you would like to do with the system
    a. USB charging: flip USB breaker to the ON position and plug in any device to the female USBs on the outside of the case
    b. Energize the electric fence: flip energizer breaker to the ON position and select the voltage directly on the energizer
    c. Cool the case: flip the fan breaker to the ON position

            i. It is recommended that the fan is always in use during day time operation
    d. All items above can be used simultaneously
9. When finished with the system, turn off all breakers
    a. WARNING turn off the solar charge controller breaker LAST
10. Place solar panel table back into the case and completely close the protective case

System Maintenance and Troubleshooting Steps

To maintain and troubleshoot the system follow these few steps:

1. Always have solar charge controller breaker ON when using the battery
2. Become familiar with solar charge controller error messages
    a. the most likely error will be that the battery is over discharged, in this case turn off all other breakers and allow battery to charge without any power being drained
3. Check for any dust within the case and wipe away any build up with a towel.
4. Be mindful of the temperature in the case
    a. the charge controller has a built in temperature sensor that can be checked very easily, be sure to turn the fan on if the case is too hot (above 100°F), and it it is not cooling fast enough stop using the case and place it in a shaded environment
5. If a subsystem breaks down or stops working
    a. replace the breaker it is associated with
    b. if this does not fix the issue contact engineering associated with the project
6. If the fence is does not have a voltage that you are expecting
    a. ensure you have enough ground rods in the fence system and that no shrubs or other obstructions are grounding the fence
    b. Confirm the insulated connecting wires are securely fastened to both terminals of the energizer as well as to the nearest grounding rod and fence line.
    c. Confirm all grounding rods are securely connected in series
    d. If soil conditions near ground rods are very dry, soak the nearby soil with water to improve conductivity. A simple solution is to drill a small hole in a 5 gallon bucket, fill with water, and place adjacent to ground rods

System Safety and Best Practices Instructions

When using this system be sure to be mindful of the following safety instructions:

1. If battery is hot to the touch turn off system immediately and let battery cool off
    a. this should be prevented by using the installed fan
2. only maintain the fence when energizer is unplugged from the case
    a. if testing voltages make sure to have protective rubber gloves
3. Avoid leaving the solar panel in the open environment for prolonged periods of time to reduce risk of scratches or damage
4. Always audibly alert those nearby when turning the fence ON/OFF

Appendix B: Circuit Diagrams

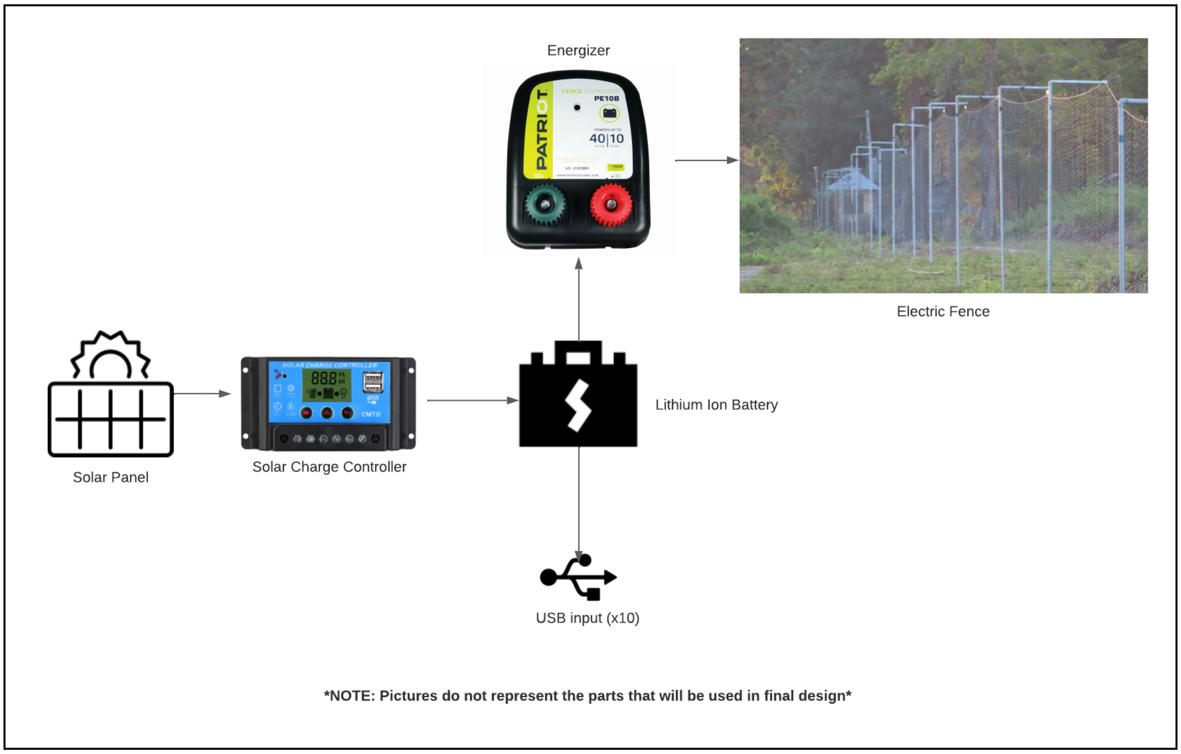

Figure B-1. Flowchart Diagram of Total System Components

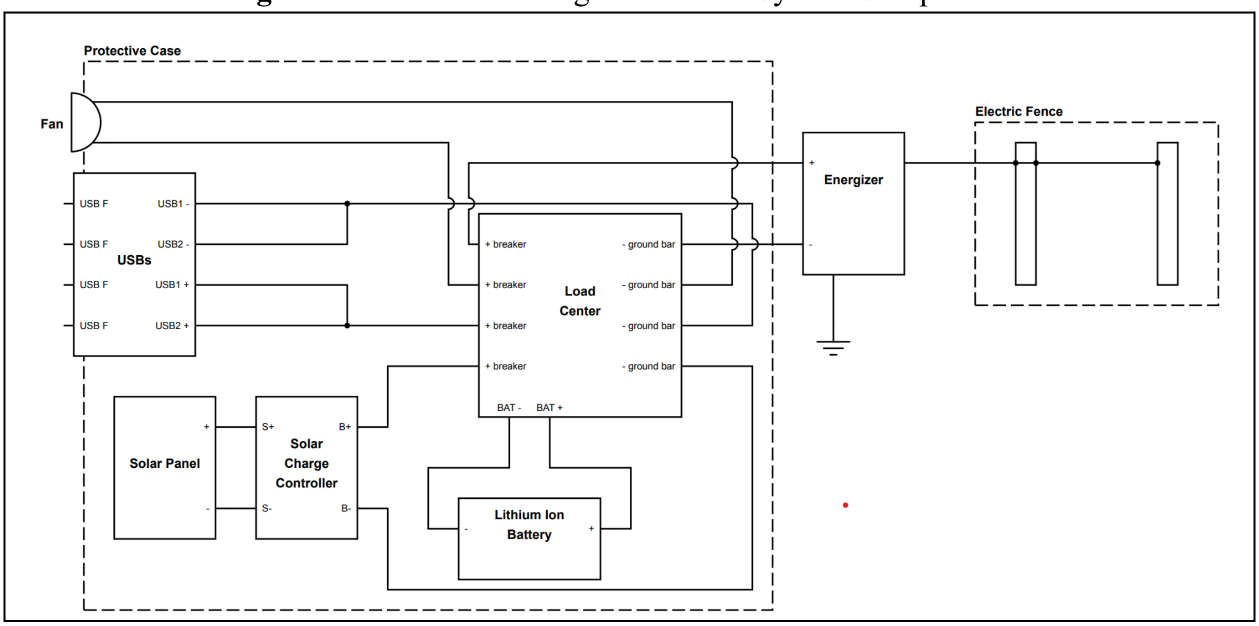

Figure B-2. Full Circuit Schematic

Appendix C. Final Design Photos

Figure C-1. Case and Panel Set-Up During Charging

Figure C-2. Fence Corner Offset and Hanging Wires

Figure C-3. Removable Panel Stand

Figure C-4. Electric Fence Energizer

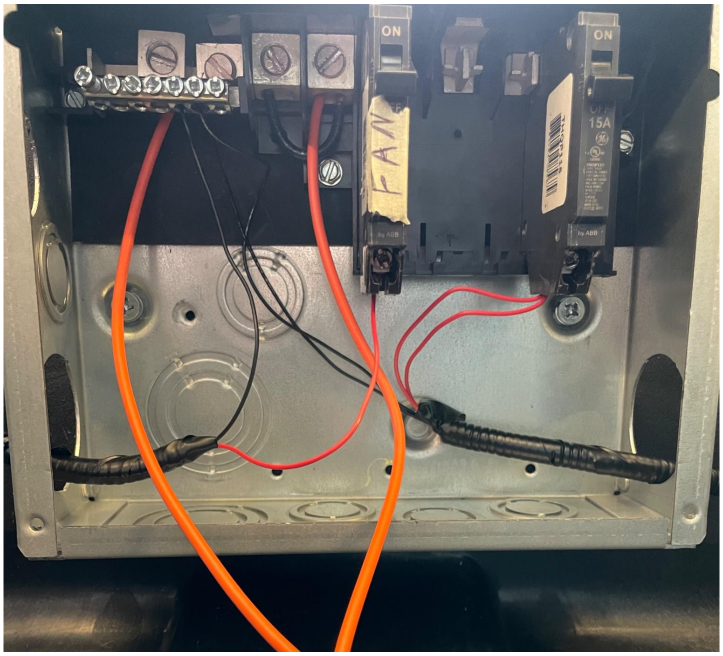

Figure C-5. Load Center

Figure C-6. External USB Outlets

Figure C-7. Case Fan

Appendix D. Codes, Standards, and Specifications

Applicable Part or Procedure	Code, Standard, or Specification
Battery	IEC62133: Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable application (IEC, 2012)
Protective Case	IP67: IEC 60529 Applies to the classification of degrees of protection provided by enclosures for electrical equipment with a rated voltage not exceeding 72.5 kV. (IEC, 2013)
Photovoltaic Panel	Junction Box: IP65 Solar Connectors: IP67 (IEC, 2013)
Installation in Intended Location	THE LAW AND ELECTRIC FENCING: A Pocket Ready-Reference Guide to the Legal Dos And Don'ts of Electric Fencing In South Africa (JVA, 2017)
Fence in Intended Location	SANS 10335-76 Particular requirements for electric fence energizers, SANS 10222-3 Electric fences (non-lethal) and manufactures requirements (IEC, 2022) (JVA, 2017)

Appendix E. Bill of Materials

Manufacturer	Source	Item Description	Cost
Renogy	Renogy	50 Watt 12 Volt Monocrystalline Solar Panel	$84.99
Renogy	Renogy	Rover Elite 20A MPPT Solar Charge Controller	$109.99
Dakota Lithium	Dakota Lithium	DAKOTA LITHIUM 12V 23AH BATTERY WITH DUAL USB PORTS & VOLTMETER	$229.00
Field Guardian	Tractor Supply Company	14 gauge aluminum wire (240')	$34.43
Pelican	Pelican	Pelican 1640 Transport Case	$405.88
Renogy	Renogy	Solar Panel to Controller Adaptor Cords	$38.59
Southwire	Home Depot	10 gauge insulated wire	$18.12
Frienda	Amazon	12V Automotive USB Outlet	$12.45
Link Solar	Link Solar	Panel mounting brackets	$49.99
Home Depot	Home Depot	Spray Paint	$14.57
Premier Supplies	Premier Supplies	JS Wood Post Claw Insulator	$4.80
Premier Supplies	Premier Supplies	JS High Strain End Insulator with P-spring	$24.44
Premier Supplies	Premier Supplies	Fence Staples	$6.15
Premier Supplies	Premier Supplies	Electric Wire Fence Taps	$75.78
Home Depot	Home Depot	Rubber Gloves	$7.27
Home Depot	Home Depot	Sealing Tape	$4.40
Home Depot	Home Depot	Caulk	$6.18
Premier Supplies	Premier Supplies	PrimaShock® 4 Fence Energizer	$221.60
Arctic	Amazon	ARCTIC F8-80 mm Standard Case Fan	$7.99
Maxmoral	Amazon	Maxmoral 5pcs 14cm PC Fan Dust Filter	$8.99
Premier Supplies	Premier Supplies	Rapid Fence Wire Tensioner for Fencing	$15.00
General Electric	Home Depot	GE subpanel 125A with 15A breakers	$82.70
	Amazon	Barrel Plug Extension Cord	$8.99
Premier Supplies	Premier Supplies	Shorter offset end insulators (8)	$4.80
Total Cost			**$1,477.10**

Appendix F: Arduino Code Used for Testing

```
//THE CODE BELOW IS BASED ON THE PROJECT DESCRIBED BELOW//
/***************************************************************************
****
         Aboubakr El Hammoumi
****************************************************************************
***/
/***************************************************************************
*****
   PROJECT :  Instrumentation of PV panel characteristics
   Function : Real-time data acquisition of solar panel using Arduino and
Excel

****************************************************************************

    Written by   :  Aboubakr El Hammoumi                  Date : 04/05/2018
    Email : aboubakr.elhammoumi@usmba.ac.ma

****************************************************************************
****
/*initialization function*/
#include <DFRobot_INA219.h>
/*!
   file getVoltageCurrentPower.ino
   SEN0291 Gravity: I2C Digital Wattmeter
   The module is connected in series between the power supply and the load
to read
the voltage, current and power
   The module has four I2C, these addresses are:
   INA219_I2C_ADDRESS1  0x40   A0 = 0  A1 = 0
   INA219_I2C_ADDRESS2  0x41   A0 = 1  A1 = 0
   INA219_I2C_ADDRESS3  0x44   A0 = 0  A1 = 1
   INA219_I2C_ADDRESS4  0x45   A0 = 1  A1 = 1

   Copyright    [DFRobot](http://www.dfrobot.com), 2016
   Copyright    GNU Lesser General Public License
   version  V0.1
   date  2019-2-27
*/
#include <Wire.h>
#include "DFRobot_INA219.h"
#define sensorPin A0

DFRobot_INA219_IIC     ina219(&Wire, INA219_I2C_ADDRESS4);
// Callibration
// for linearly calibration
float ina219Reading_mA = 1030;
```

```
float extMeterReading_mA = 1200;

void setup() {
 Serial.begin(9600);
    while(!Serial);

    Serial.println();
    while(ina219.begin() != true) {
        Serial.println("INA219 begin faild");
        delay(2000);
    }
//serial connection setup
//clear all data that's been place in already
Serial.println("CLEARDATA");
//define the column headings (PLX-DAQ command)
Serial.println("LABEL,t,voltage,current,power,tempf");
}
/*the main code*/
void loop() {
//measure voltage current and power from wattmeter
float voltage = ina219.getBusVoltage_V();      //PV panel voltage
float current = ina219.getCurrent_mA();      //PV panel current
float power = ina219.getPower_mW();            //PV panel power
  // Get the voltage reading from the LM35
  int reading = analogRead(sensorPin);

  // Convert that reading into voltage
  float tvoltage = reading * (5.0 / 1024.0);
  // Convert the voltage into the temperature in Celsius
  float temperatureC = tvoltage * 100;
  // Print the temperature in Fahrenheit
  float temperatureF = (temperatureC * 9.0 / 5.0) + 32.0;
//allows the serial port to send data to Excel in real-time
Serial.print("DATA,TIME,"); // PLX-DAQ command
Serial.print(voltage);    //send the voltage to serial port
Serial.print(",");
Serial.print(current);    //send the current to serial port
Serial.print(",");
Serial.print(power);  //send the power to serial port
Serial.print(",");
Serial.println(temperatureF);
delay(120000); //wait 120s before repeating
}
```

Figure F-1. Arduino Watt Meter and Temperature Data Test Code (Hammoumi and Motahhir, 2020)

Appendix G: Relevant Information for Future Design Group

As of April 19th, 2023, the will Power Africa project has been approved for year 2 of development. The following outlines the primary objectives for the 2023-2024 design team; however, final project objectives will be subject to change based on the requests of the sponsor.

Year 2 Objective

The final implemented design for the 2022-2023 Will Power team includes a functional electric fence that is powered using a lithium ion battery. While this year's design team chose to utilize a solar panel in order to recharge the battery, there are a few notable downsides to using solar technology for this specific project.

1. In remote locations across Zimbabwe, solar panels are a frequent target for robbers/thieves. Should the panel be tampered with or stolen, it would quickly render the system useless
2. Solar panels are heavily dependent on the amount of sun available at any given time. While the design has been constructed to operate overnight with no energy being collected by the panel, significant periods of heavy cloud coverage or high usage of the USB charger could result in the battery being depleted faster than energy can be recovered
3. Photovoltaic technology is unfamiliar to the community that the final design will serve. Should any repairs or maintenance be required, the community has little knowledge of how to repair the system

Considering these downsides, the year two team will be required to design a second source of energy generation in order to supplement the energy being supplied by the solar panel. The design must adhere to the following requirements; however, additional constraints or requirements will likely be included

Year 2 requirements:

1. The device must be capable of charging a 12V, 100Ah battery
2. The device must be able to fly internationally on a commercial flight
3. The device must be able to generate 385 Wh of power daily
4. The device must be intuitive to use for non-English speakers
5. The device should be non-lethal and cause no harm to users when operated under proper conditions

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