Off-Grid Electrical Cabinet Dehumidifier

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ECE 445 Design Document - Fall 2020
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1. Introduction

1.1 Problem and Solution Overview:

The utility Ameren Illinois is interested in reducing corrosion, specifically on spare electrical cabinets in isolated areas. These cabinets are not in climate controlled environments, and they do not have access to a low voltage power supply. The central need is to have an off grid, autonomous system that regulates the environment of these cabinets to prevent corrosion on exposed electrical terminals. Ameren has begun acquiring parts for this project: two solar panels, a micro wind turbine, a 12 V lithium iron phosphate battery pack, an electrical heater, and a hygrometer. The system setup needs efficiency and system control optimization.

Our goal is to improve the system in three ways: efficiency, reliability, and transparency. For efficiency, we plan to incorporate a better charging process, specifically switching from Pulse Width Modulation (PWM) to a Maximum Power Point Tracking (MPPT) on the solar charge controller. The idea is to adjust the input voltage (from the solar panels) to the DC-DC converter to match the battery's charging capability (which in turn increases current) to maximize the wattage. This has the potential to increase efficiency of the solar input power by 5-25%.
For the reliability of the system, we propose adding three extra sensors-an exterior hygrometer and an interior and exterior thermometer- to more accurately identify when corrosion prevention is necessary. Additionally, we will add a dehumidifier and the necessary control logic to have it trade off with the heater to best regulate the relative humidity.
Finally, with regard to transparency, we plan to take the locally available data from all three sensors and periodically record humidity and temperature onto a microSD card. This should be periodically collected and checked by an Ameren coworker.

1.2 Background

Electrical cabinets are an inherent part of any substation, and they are prone to corrosion. Specifically, oxide corrosion, or rust, is an electrochemical reaction that occurs when water is exposed to certain kinds of metal [1]. Most metals can experience surface corrosion at humidies above 80%[2]. This commonplace process puts a heavy financial burden on electrical utilities. A study done by the National Association of Corrosion Engineers estimated that in 2013, utilities spent nearly $27.7 billion to correct corrosion related maintenance [3]. The process of corrosion is accelerated by humid conditions, when water can more easily condense on electrical equipment. Preventing corrosion is important from both financial and reliability standpoints, as the Electrical Power Research Institute of the United States estimates that "more than half of all unplanned power outages are due to corrosion" [3]. Therefore, preventing corrosion is a worthwhile endeavor, even on these spares.

Electric heaters prevent corrosion by decreasing the relative humidity, meaning that the air can hold more moisture without condensing. However, their ability to do this is hampered at higher temperatures in the summer when hot, humid air cannot be effectively made hotter. Therefore, the incorporation of a dehumidifying system that exchanges control with the heater is necessary to be able to take moisture out of the air at higher temperatures.

The PWM process is a standard way to charge batteries. However, the efficiency at higher wattage is not nearly as high as the MPPT. The Assam Don Bosco University found that for a higher wattage system above 200 W, the MPPT was 30% more efficient than PWM [4]. The setup that Ameren proposes will have a 600 W capacity, making the switch to MPPT to conserve power even more desirable. This is especially relevant during the winter months when the average solar panel wattage over a day is much lower.

1.3 Visual Aid

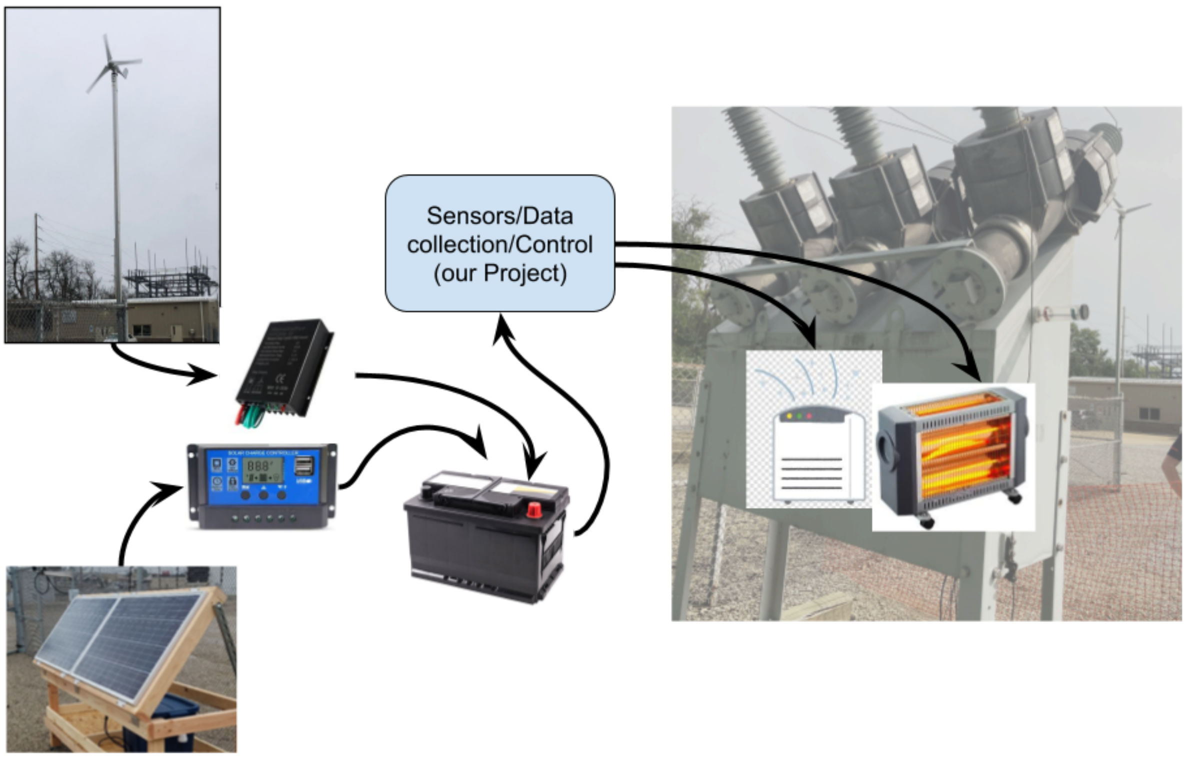

Figure 1: Project in pictorial representation

The visual aid in Figure 1 shows our solution in context. On the left, we have the Ameren provided wind turbine and solar panels which feed through their respective charge controllers to a 12 V li-ion battery. The battery powers our solution, the dehumidifier, and electric heater. Our project encompasses the sensors, control, and data collection in the blue box.

1.3 High-Level Requirements List

- The electric heater must keep all condensation off of exposed electrical terminals for at least a five-day period (ideally indefinitely), keeping humidity below 80%.
- The battery must have the capacity to run the dehumidifier and electric heater each for three hours a day for two days to account for a hypothetical situation of no wind and no sun for two days. This is 1350 Wh or 112.5 Ah on a 12 V battery.

- The data collection process must obtain and store temperature and humidity data both inside and outside of the cabinet to the precision of the tenths place once per hour (to be viewed by an Ameren worker at a later time).

2. Design

2.1 Block Diagram

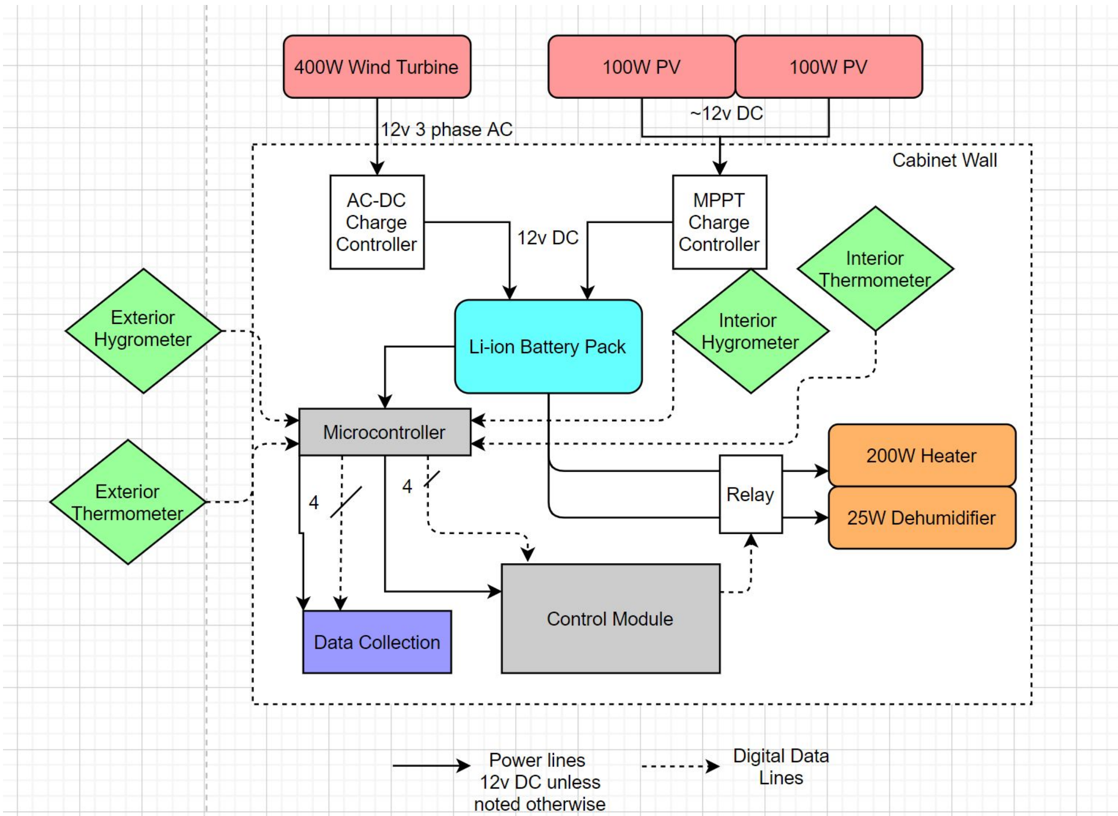

Figure 2: High-level block diagram

The high-level block diagram in Figure 2 shows an overview of our solution. Input power from the sources shaded in red will charge a Li-ion battery pack. This battery pack will power both the heater and dehumidifier as well as our microcontroller. The microcontroller takes in humidity and temperature sensor data from inside and outside the cabinet to send to our control module. The control module is a finite state machine that determines whether to run the dehumidifier, heater, or neither given the conditions. Finally, the data collection block in purple represents the microSD card which will be used to record sensor data periodically for an Ameren worker to be able to monitor the conditions over time.

2.2 Physical Design

There is no moving or mechanical part to our project, but we did take some consideration into the physical layout. Spacing can be tight in some of these cabinets, so the system should be as tightly contained as possible, without inhibiting any of the function of the project.

As depicted in Figure 3, the heating and dehumidifying element will be centered in the interior space as well as possible. A flexible hose will run from the water tray of the dehumidifier out through an access hole already in the bottom of these cabinets to drain excess water out to the ground. The battery pack will be located off to one side just far enough away from any important wiring or devices. The power lines from the solar panels and wind turbine will run through an access hole in the bottom of the cabinet to their respective charge controllers mounted or laid on the side of the battery. The exterior sensors will be fastened to a thermally insulating block of wood and their wires will run through the same access hole as the power lines into the control box. This block will be adhered to the bottom outside surface of the cabinet in order to best protect the sensors from harsh weather. The control box will contain all input, output, data collection and control circuitry. It will mount on top of the battery, secured with the bolts of the battery pack terminals. In this way the control modules have easy access to the battery terminals as well.

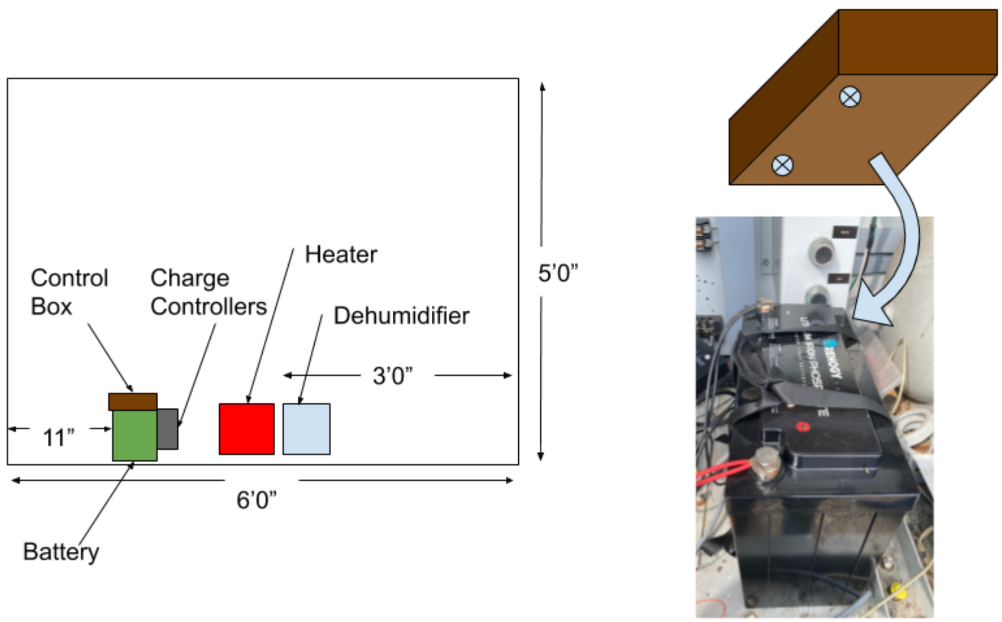

Figure 3: Physical layout of design

2.3: Renewable Energy Sources

2.3.1 Solar Panels

Table 1 shows the calculations done to determine the average input power from the solar panels in each season. The power is calculated considering a 20% capacity factor in the sun and 10% under the clouds [5]. We also assume that Illinois will have 56% of time during the day where sunshine reaches the ground [6].

$$\frac{100W\ rated}{panel} * 2\ panels * 20\%\ capacity\ factor * \frac{hours\ of\ daylight}{day} * 56\%\ sunlight\ = P_{sun}$$

$$100 * 2 * 10\%\ capacity\ factor * \frac{hours\ of\ daylight}{day} * 44\%\ clouds = P_{cloudy}$$

$$P_{avg} = P_{cloudy} + P_{sun}$$

Season	Fall	Winter	Spring	Summer
Approximate hours of Daylight in Champaign, IL [7]	10.2	10.3	13.8	13.6
Average Power per Day (Wh)	318	321	430	425

Table 1: Average input power from solar panels per day during different seasons

2.3.2 Wind Turbine

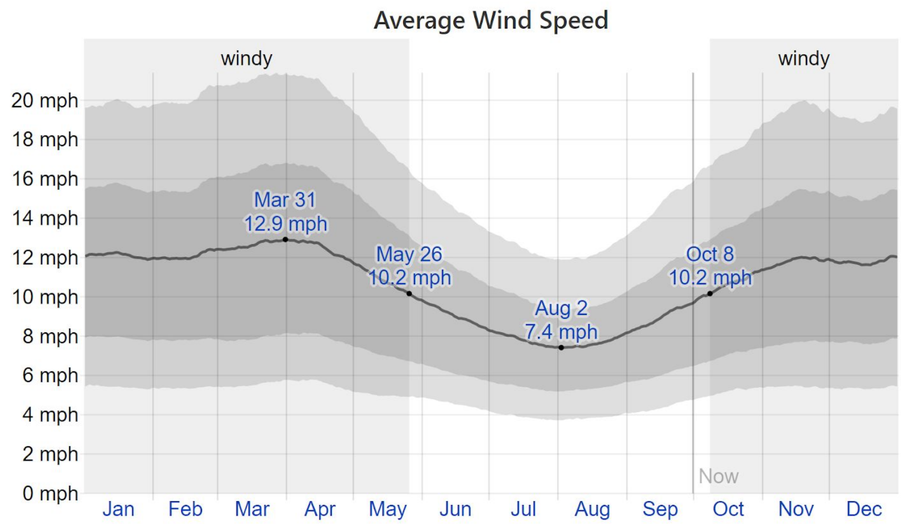

Figure 4: Average wind speed by season in Bloomington IL [8]

The rated wind speed of our wind turbine is 13 m/s, which means at 13 m/s wind velocity the turbine is at a saturated power level of 400 W. Knowing this and that power of a turbine is proportional to the wind velocity cubed [9], the following values for average power can be taken from average wind speed at different times of the year. As a general formula, $\left(\frac{V_{avg}}{13}\right)^3 * 400\ W * 24\ h = Total\ Wh/d.$

Season	Fall	Winter	Spring	Summer
Approximate average wind speed (mph)	10.2	12.0	10.2	7.6
Average Power per Day (Wh/d)	414.32	674.38	414.32	171.36
Total Power from solar and	732.32	995.38	844.32	596.36

wind (Wh)				

Table 2: Average power calculated from micro wind turbine

Requirements	Verification
1. The sources collectively produce enough energy to consistently power the system.	1. Total average input energy listed in table 2 is always significantly greater than our predicted energy needs listed in table 3.

2.4 Power Supply

2.4.1 Li-ion Battery Pack

We chose a battery pack with the following considerations in Table 3 to determine the estimated power needed daily for the system. The calculation of power consumption per day was done recalling that we are implementing a 25 W dehumidifier and 200 W heater.

Season	Fall	Winter	Spring	Summer
Approximate hours of Dehumidifying	6	1	7	12
Approximate hours of Heating	3	4	3	1
Approximate Power Consumption (Wh)	550	825	775	500

Table 3: Estimated power consumption per day during different seasons

Therefore, to be on the safe side of both keeping the cabinet in good condition and not wanting to deplete the battery entirely, which reduces the life cycle, we chose the Renogy 170 Ah 12 V Li-ion battery pack. Assuming an 80% efficiency of the battery and only desiring to use 85% of its capacity to preserve the life of the battery, we calculate the Wh available to use from the battery:

$$170\ Ah * 12\ V * 80\%\ efficiency * 85\%\ capacity = 1387.2\ Wh$$

For simplicity, we assumed that we have 1350 Wh of power available to use in the system with a full charge. Based on the data from Table 3, it is evident that our battery will be able to handle the daily load of running the heater and/or dehumidifier throughout the year. It should also be noted that the battery pack includes a Battery Management System (BMS), which has a charge cut-off voltage of 14.6 V and discharge cut-off of 10 V [10]. This range of voltage is acceptable for our system.

Requirements	Verification

1. Battery voltage must be between 10 and 15 V (depending on its charge percentage) for the system to operate [10]. 2. Battery must maintain 80% capacity for 6 years.	1. The control module stops the draw of power when under 11 V and the charge controller will not overcharge the battery. 2. The battery drops to 80% capacity after 2000 cycles. At 6 years this averages out to just under 1 cycle per day. Our control system and tolerance values are designed to minimize battery depletion; this should lead to well under the requirement.

2.4.2 Voltage Regulator

The voltage regulator is necessary to provide the ATMEGA328 microcontroller with power. The input to the regulator will come from the battery and its output to the VCC pin of the microcontroller. It can handle an input voltage between 10 V and 35 V, which is well within the bounds of our 12 V battery [11].

Requirements	Verification
1. Maintains an output voltage of 5 V +/- 0.2 V 2. Doesn't exceed temperature of 125 ℃, causing component to fail	1. Probe the voltage with battery at 100% charge and 50% charge with input power and without, making sure voltage stays within bounds 2. Temperature checked after 1 hour of normal operation in system and noting any signs of component failure (burning smell, smoke)

2.4.3 AC-DC Charge Controller

The AC-DC charge controller will take a 12 V 3 phase input from the wind turbine. An Awiterbine FW 12/24 charge controller is already provided by Ameren IL.

Requirements	Verification
1. Can convert power from a single 400 W capacity turbine into steady 12 V DC for charging battery.	1. Product already purchased goes in tandem with the turbine. Rated for 400 W at three phase 12 V AC input and 12 V DC output.

2.4.4 MPPT Charge Controller

An MPPT charge controller increases the efficiency of the charging to the battery from the solar panels. This is important to keep the system operating during periods of extended cloudy days. For our design, we are using two Renogy 100 W solar panels connected in parallel. Looking at the datasheet for the panels, we see that the optimum operating voltage is 17.9 V and the current is 5.72 A [5]. Therefore, our ideal input current to the battery is $5.72 * 2 = 11.44$ A. The short circuit current for each panel is 6.24 A, resulting in a total short circuit current of 12.48 A. To ensure safety of the system under non ideal conditions, we recommend a 30 A charge controller or greater. The MPPT charge controller that we incorporated into our project is the "Rover LI 30 A MPPT Solar Charge Controller." This decision was made instead of creating our own because of the safety concerns with improperly sized components, PCB trace width requirements, and the necessary cooling. Furthermore, the focus of our design is on controlling the dehumidifying process. The interface to the MPPT is shown in Figure 5.

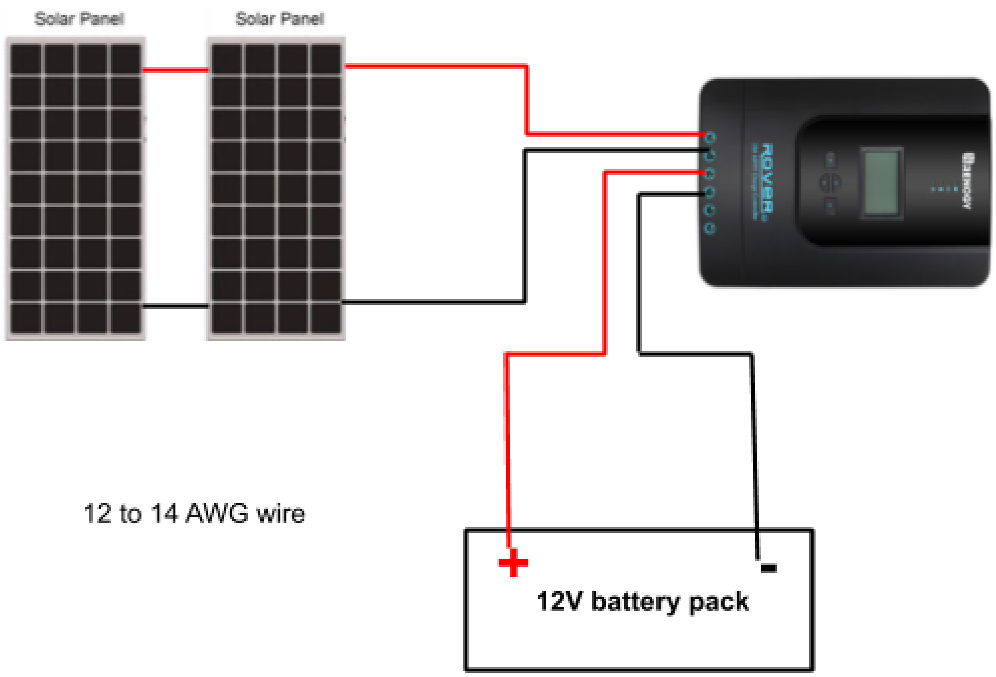

Figure 5: MPPT charge controller connection

Requirements	Verification
2. Can convert DC power from two 100 W panels into steady 12 V DC for battery charging.	2. A product designed for use specifically with PV arrays and DC battery packs would be purchased. Would be rated for 24 V and 8.33 A or 12 V and 16.67 A.

2.5: Sensor Inputs and Logic

Our design consists of five sensors. These sensors provide data that will be processed to act as control module inputs. Further information about the control module can be found in Section 2.7 — Control Module.

The five sensors and their function are as follows:

1) Voltage sensor — measures voltage of battery.
2) Thermometer (T_in) — measures ambient temperature inside of the electrical cabinet.
3) Thermometer (T_out) — measures ambient temperature outside of the electrical cabinet.
4) Hygrometer (H_in) — measures ambient relative humidity inside of the electrical cabinet.
5) Hygrometer (H_out) — measures ambient relative humidity outside of the electrical cabinet.

Data from these sensors will be fed into a microcontroller (ATMEGA328) where they will be processed to four digital output bits which will henceforth be represented as B, C, H, and T. These output bits B, C, H, and T will serve as the inputs for the finite state machine used as the control module. In order for our design to function properly, all sensors will need to function consistently. The sensor data processing will first be done on an Arduino UNO as a proof of concept before being ported onto a standalone microcontroller. For more information about the microcontroller, please refer to section 2.6 — Microcontroller. Note that the hygrometer for measuring humidity outside of the cabinet is used purely for data collection to show a difference between inside and outside humidity. It serves no purpose for input logic and processing.

The physical sensor used will be the AM2302 (also referred to as DHT22). This device contains both a thermometer and a hygrometer in one package. The AM2302 provides a digital output reading of ambient temperature and relative humidity. The device is able to read temperatures from -40 ℃ to 80 ℃ within 0.5 ℃ accuracy and relative humidity from 0% to 100% at 2% to 5% accuracy. Sensor data is sampled at a rate of 0.5 Hz. For this reason and to eliminate potential sources of error from any FSM clock cycle discrepancy, all digital output bits B, C, H, and T will be updated no faster than at a rate of once every two seconds.

The voltage sensor used will be the GR0430X10. This device will be able to measure DC voltage from 0.02445 V to 25 V. Figure 6 below depicts the thermometer and hygrometer. Figure 7 below depicts the voltage sensor.

Figure 6: DHT22/AM2302 temperature and humidity sensor

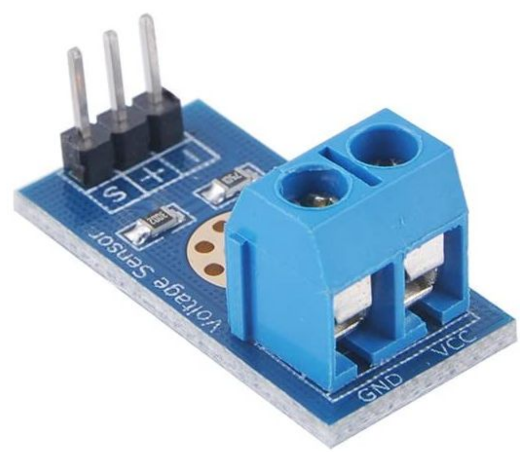

Figure 7: GR0430X10 *Voltage sensor*

Both devices are compatible with the ATMEGA328 microcontroller. The mappings for sensor input data to output bits B, C, H, and T can be found in Table 3 in Section 2.6 — Microcontroller.

Requirements	Verification

1. Voltage sensor accurately measures battery voltage to within 0.1 V. 2. Thermometers accurately measure ambient temperature to within one degree Fahrenheit at a rate no slower than once every two seconds. 3. Hygrometers accurately measure relative humidity to within 5% at a rate no slower than once every two seconds. 4. Code for data processing correctly produces desired digital outputs B, C, H, and T every two seconds.	1. Use an oscilloscope to apply voltage to the sensor and print readout to a computer screen. Check voltage of battery with separate voltmeter at 100% charge, 50% charge, and 5% charge. 2. Set data sampling rate to two seconds, and use a heating element and ice cube to change ambient temperature and print recording to screen. 3. Set data sampling rate to two seconds, and use a humidifier to change relative humidity and print recording to screen. 4. Use LED to verify the correct output of either 1 (high) or 0 (low) for each output bit.

2.6: Microcontroller

The microcontroller we chose for our design is the ATMEGA328 processor. Using a few components, including a 16 MHz Crystal, a 1k Ohm resistor, and two 20 pF capacitors, we can burn the Arduino bootloader onto it using an Arduino UNO. This diagram is in Figure 8. Next, we plan to flash our code that interprets the sensor data to it using the USB-to-serial converter (FTDI) chip [12]. This can be accomplished by the diagram in Figure 9.

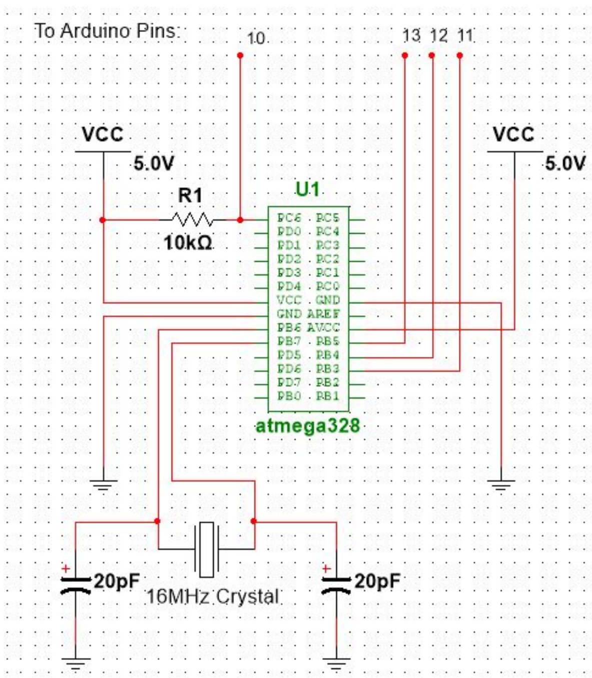

Figure 8: Burning bootloader to the ATMEGA328 using Arduino UNO

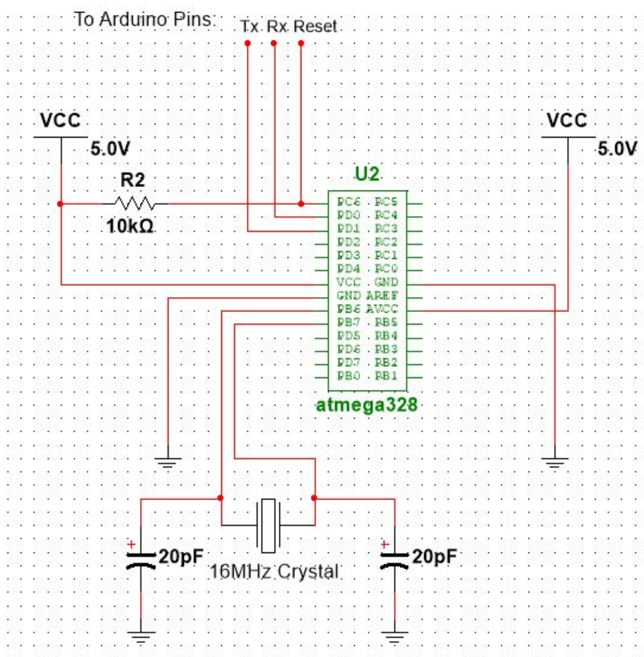

Figure 9: Flashing code to the ATMEGA328 using Arduino UNO

The microcontroller takes in raw sensor data and performs a couple tasks. It outputs the data to one significant figure past the decimal place as a comma separated string once per hour to a microSD card. It also discretizes the data to either a digital high or digital low, depending on the condition. The conditions are detailed in Table 3.

Sensor Data Condition	Resulting Variable Logic
Battery Voltage above 10.8 V	B = 1
Inside Temperature less than Outside Temperature	C = 1
Inside humidity greater than 80%	H = 1
Inside Temperature greater than 60 ℉	T = 1

Table 3: Input module legend

These resulting variables are digital outputs of the microcontroller to a 4:1 MUX, which is used by the finite state machine in the Control Module.

Requirements	Verification
1. Must be flashed with Arduino 2. Must have reset switch 3. Must pass through sensor data to SD card.	1. Test an LED blink sketch to see that program is flashed properly 2. Pressing reset switch momentarily should cause data to stop being written to the microSD card for 1-2 seconds. Reset never occurs otherwise.

	3. Use an ammeter on MOSI pin of ATMEGA328 to see if current (data) flows out to the microSD card module with sensor code on the microcontroller. Connect microSD card to computer to verify if data collection was successful.

2.7: Control Module

This block must take inputs from the input module and use them to “decide” what action to direct the output modules to take in a way that fulfills the high level requirements of our project as a hole.

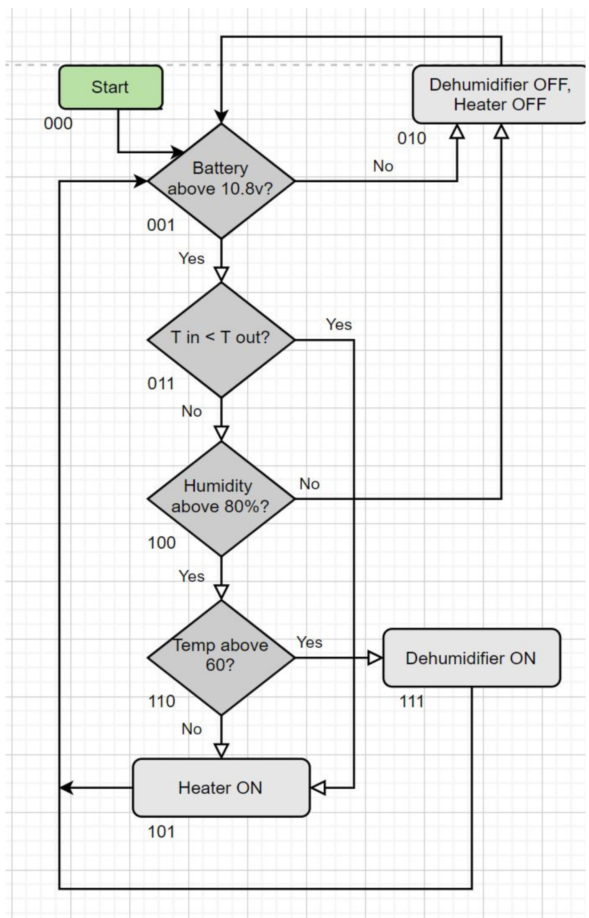

Figure 10: Control system flow chart

Using this flowchart as a state machine should fulfil all high level requirements. Numbering the states in this way allows for an input selector mux to filter the correct input our machine will need at the appropriate state. The first two figures of the state number are used in the mux to select from input signals B,C,H,T and leave a stand alone signal, I, in which a yes = 1 and a no = 0. The output signals Q_0 and Q_1 represent the dehumidifier and heater respectively.

From the above control flow diagram, and the assigning of states, we've created the truth table below in Table 5. It is necessary to note that the "x" in the input column is a traditional "don't care" variable, while the "xx" in the output column is instead a "don't change" where the current output state should not be changed from what it currently is.

Current State	Input	Out	Next State
x y z	I	Q_0 Q_1	x* y* z*
000	x	00	001
001	0	xx	010
001	1	xx	011
010	x	00	001
011	0	xx	100
011	1	xx	101
100	0	xx	010
100	1	xx	110
101	x	01	001
110	0	xx	101
110	1	xx	111
111	x	10	001

Table 5: FSM truth table

The machine will be carried out with three D flips flops, a 4:1 MUX for selecting the variable "I," and 12 three input NAND gates to account for our eight states. We chose to convert our logic to all NAND gates in order to save on the number of total chips needed and increase speed. The schematic in Figure 15 shows the layout of the control module more clearly.

Requirements	Verification
1. Follows the flow chart and properly maps all 8 states. 2. Properly responds to all inputs. 3. Can translate current state into output. 4. Has the availability of a manual reset.	1. 3 sets of D flip-flops can account for 8 states, 000 - 111, directed by input logic. 2. The input mux uses the first two bits of the state. The four different decision points have been numbered in such a way that these first two bits are unique between them (00 - 11). This mux will then pass through the proper input signal

	which is being asked for at the decision point. 3. Three states, each carrying a unique binomial, should have the ability to use and process by the output microcontroller to switch machines on and off. 4. A set of 3 gang switches which set all three flip-flops to ground would reset the FSM back into the start state.

2.8: Outputs

The "Out" bits Q_0 and Q_1, as indicated in Table 5, represent whether the dehumidifier and heater are turned on or off. In a typical finite state machine, "xx" represents "don't care bits" meaning these bits can be either a 1 or a 0 without affecting state machine functionality. However, in our design we need the "Out" states to remain consistent when switching to a state where the out bits are "xx." To accomplish this, the three bits representing the current state will be connected to the microcontroller that will provide a digital output to a relay turning the dehumidifier and heater on and off. Based on the current state, the microcontroller will be programmed to ignore the current states corresponding to "xx." This way, the state of the dehumidifier and heater will not change when changing states unless explicitly needed.

The relay we will be using is the HiLetgo SRD-05CDC-SL-C. A depiction of this relay can be found in Figure 11 below. This relay has a rating of DC 30 V at 10 A making it suitable for delivering power from the battery to the heater and dehumidifier. It is compatible with the 5 V Vcc from the microcontroller.

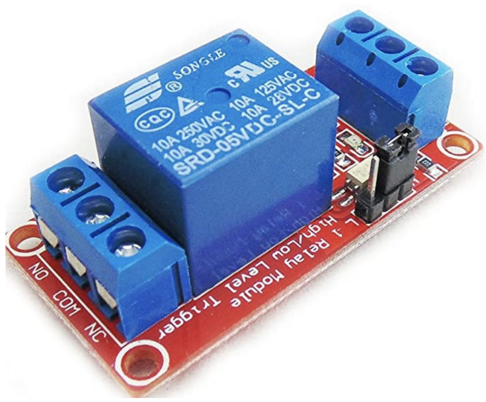

Figure 11: Electrical relay

Requirements	Verification
1. Microcontroller is able to detect the current state. 2. Microcontroller is able to control the on/off status of the heater and dehumidifier.	1. Print outputs to a computer screen to verify microchip is able to detect high/low signals. 2. Connect relays to microcontroller and heater and dehumidifier and verify that a high and low output signal from microcontroller turns on and off

	respectively the heater and dehumidifier.
3. Microcontroller turns on and off the heater and dehumidifier at states 000, 010, 101, and 111 based on Table 5.	3. Use switches or buttons to simulate different states. Use LEDs to represent digital outputs.
4. Microcontroller maintains previous status of the heater and dehumidifier in all other states with bits Q_0 Q_1 at xx.	4. Use switches or buttons to simulate different current states. Use LEDs to represent digital outputs.

2.9: Data storage (Miller)

The data storage element of our design serves to monitor the success of the system. We plan to record the exterior and interior humidity and temperature at a rate of once per hour and store that on a microSD card. Then, an Ameren worker who visits the electrical cabinet can retrieve the card and run a MATLAB script (which we will design as well) that will graphically display the data. The worker will be able to tell how the electrical cabinet was maintained during the time period and ensure that the sensors are working properly.

To interface the microSD with the microcontroller, we are using a 6 pin SD card module, namely because it has the necessary microSD slot and a 5 V to 3.3 V voltage converter that allows it to run off the ATMEGA328 microcontroller VCC.

Figure 12: 6 pin MicroSD card module [13]

Although the connection is shown in the schematic of the entire system in Figure 14 , we provide a closer look below in Figure 13.

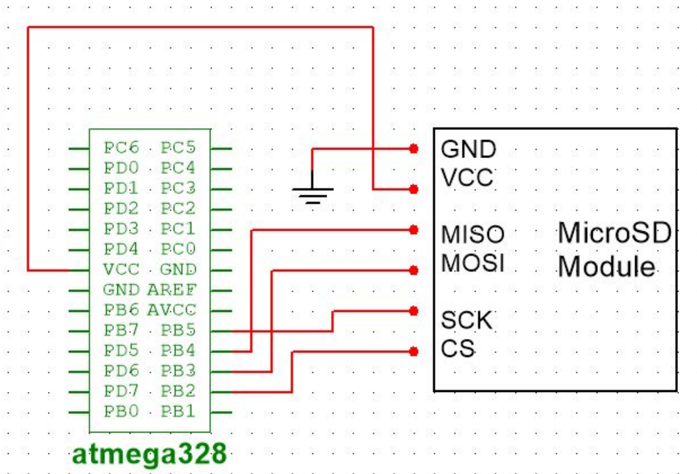

Figure 13: ATMEGA328 microcontroller to microSD card module connection

Finally, we plan to store the data from each sensor to the tenths place every hour. Each "capture" of data from the four sensors will have the following syntax as a comma separated line:

interior hygrometer, *interior thermometer*, *exterior hygrometer*, *exterior thermometer*

Requirements	Verification
1. Each sensor data "capture" is stored as a comma separated string. 2. Sensor data is correct to the tenths place at the time of writing to the microSD card.	1. Change frequency of "capture" from once per hour to once per ten seconds to verify the printing of new lines of comma separated strings. 2. a. Isolate the writing to the microSD card for one sensor. b. Change the frequency of "capture" from once per hour to once per ten seconds. c. As a side-by-side comparison, record what the sensor reads. Then, open the SD card text file to check that the value written matches. d. Repeat steps a.-c. for each sensor.

2.10: Schematics

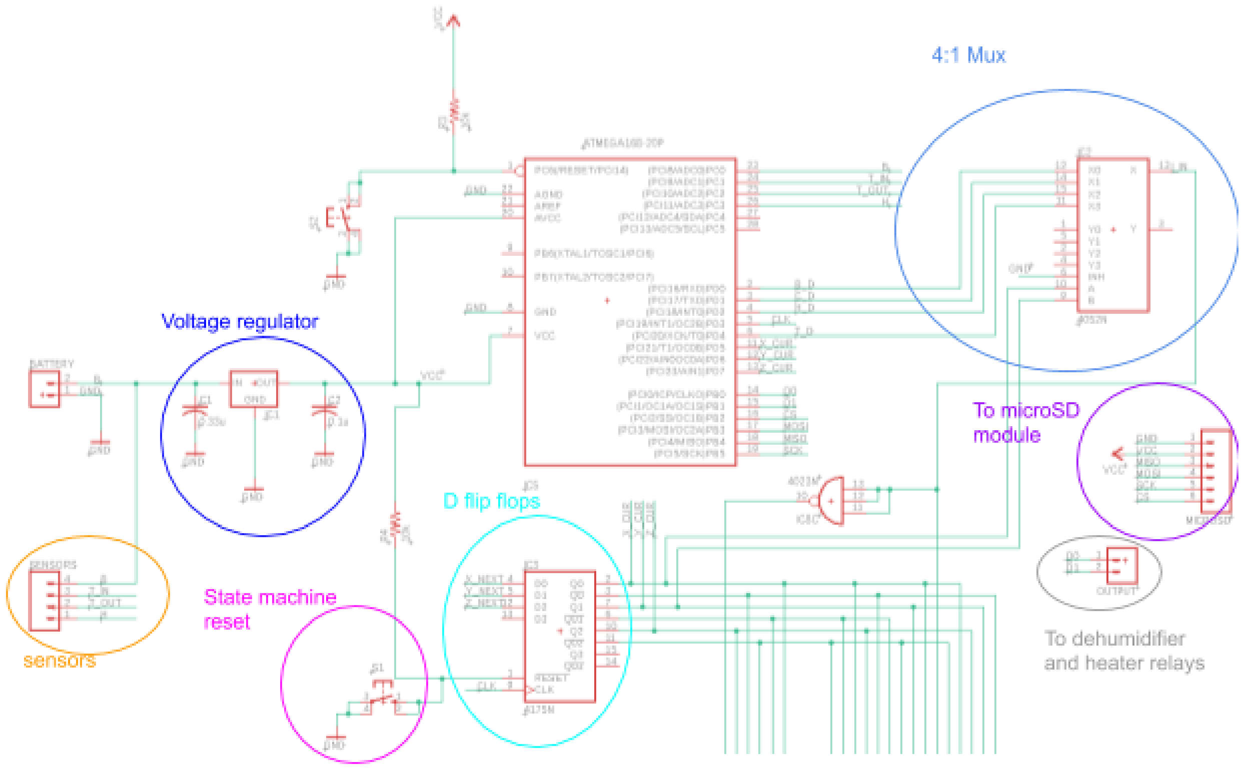

Figure 14: Schematic showing the inputs and outputs of the microcontroller

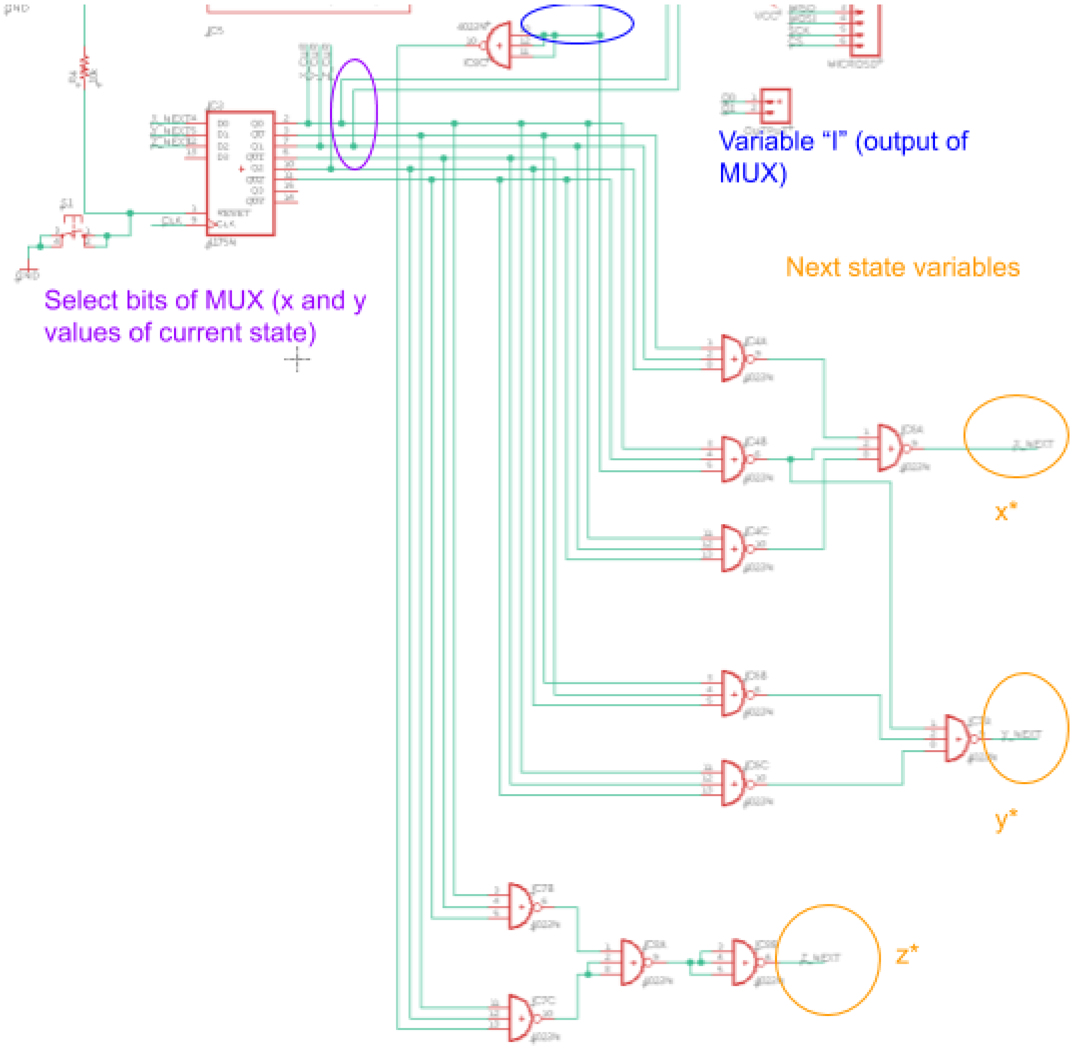

Figure 15: Schematic showing the control module state machine

2.11 COVID-19 Contingency Plan

A lack of lab access will not inhibit our project significantly. We can still complete the PCB revisions remotely and have the machine shop or a separate company, such as OSHPARK, create them for us. We also feel confident that we can assemble the physical system with all of the components we plan on ordering and the Ameren provided equipment. The main difficulty would be that a single person may have to do the physical build. However, this problem can be mitigated by redistributing the design and reporting work. Furthermore, the two people not doing the physical construction can work on PCB revisions, improving the code for the microcontroller, debugging the MicroSD card module, and/or starting to write the final report. As for the demonstration, we can still provide adequate photo and video evidence without an in-person demonstration to prove the functionality of our project.

2.12 Tolerance Analysis

The amount of power our sensors, control module and other digital logic equipment use may be of concern if it drains the battery for long periods without substantial solar or wind power. The specific concern is that if the battery voltage drops below 10 V, the internal Battery Management System (BMS) will shut off the power to our system. If this happens, human intervention is required to restart the system, which will prevent the system from being autonomous as desired.

The main concern then is what the tolerance can be for our variable "B" in our control module to be a digital "1." As mentioned previously, when B = 1, we allow the control module to determine if the heater or dehumidifier should run. When B = 0, we want the dehumidifier and heater off while the microcontroller can still be powered to log sensor data and wait until the battery voltage reaches an acceptable level. To determine this tolerance, we first need to estimate the power consumption of everything minus the dehumidifier and heater. We will first briefly examine the power consumption of our IC chips. The equations of importance to us for CMOS IC chips are:

$$P_{total} = P_{static} + P_{dynamic} \qquad \text{eq. 1 [14]}$$

$$P_{static} = I_{static} * V_{cc} \qquad \text{eq. 2 [14]}$$

$$P_{dynamic} = (C_L + C)V_{cc}^2 f N^3 \qquad \text{eq. 3 [15]}$$

In eq. 3, C_L is the assumed load capacitance (which we assume a high value of 70 pF), C is the internal capacitance, f is the switching frequency of 1 Hz for our design, and N is the number of switching bits (which we will assume is the number of transistors)

Using these equations and that $V_{cc} = 5\ V$, we can calculate the total power consumption of our three CD4023BE ICs using their known parameters on the datasheet [16]. .

Part	# of chips	I_{static}	C	N	P_{total}
CD4023BE (3 input NAND)	3	10^{-5} uA	50 pF	18	0.0525 mW

Table 6: CD4023BE power consumption calculation

We will spare the calculations for the 4:1 MUX and D flip flops and assume that in total the IC chips use a generous 0.5 mW. Looking at the datasheets for our other parts, we can find the total power consumption.

Part	Estimated Power Consumption
ATMEGA328 microcontroller	60 mW (running at 5 V, low clock speed, internal crystal oscillator frequency of 8MHz) [17]
MicroSD card module	$P_{dissipated} = 5\ V * 80\ mA$ = 400 mW [13]
L7805CV Voltage Regulator	$P_{dissipated} = (12 - 5)V * (\frac{.060}{5} + .080)\ A$ = 644 mW

Two DHT22/AM2302 Sensors	$P_{dissipated} = 2 * 5\ V * 0.0025\ A = 25$ mW [18]
All of the IC chips	0.5 mW

Table 7: Power consumption calculations for the system (excluding dehumidifier and heater)

After adding up all of the estimated values, we find our system power consumption to be approximately $P_{system} = 1.2\ W$. To be on the safe side and account for an unrealistic scenario that there is no sun or wind power for two days, we need a spare 57.6 Wh to keep the system alive (without running the dehumidifier or heater). If we round this up to 60 Wh, this is approximately 3.46% of our 85% capacity battery. Looking at an approximate discharge curve for a 12 V Lithium Iron Phosphate battery at 25 ℃ in Figure 16, we can determine a cut-off [19]. The quadratic dropoff begins roughly at 12.5 V at 20% capacity and goes down to 10 V at 1% capacity. This as a quadratic equation is:

$$y = -69.3(x - 0.2)^2 + 12.5 \qquad \text{eq. 4}$$

Therefore, at 4.46% percent capacity, we find the voltage to be 10.8 V, which should be the cut-off for which B = 1 as a tolerance for keeping the system autonomous.

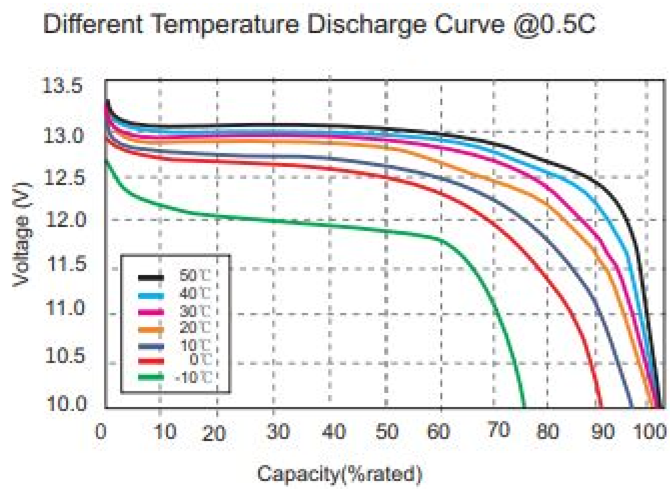

Figure 16: Discharge curve for a 12 V lithium iron phosphate battery [19]

3. Cost and Schedule

3.1 Cost Analysis

For calculating our labor cost, we assume an hourly rate of \$35/hr per engineer. This project involved three engineers working around 10 hours per week for 10 weeks from when the project was proposed to its demonstration. Therefore, we calculate:

$$\frac{\$35}{hour} * \frac{8\ hours}{week} * 10\ weeks * 3\ engineers = \$8,400$$

Additionally, we anticipate the machine shop taking 10 hours to create the two revisions of our PCB.

$$\frac{\$35}{hour} * 10\ hours = \$350$$

Part #	Description	Manufacturer	Quantity	Cost
ATMEGA328-PU-ND	ATMEGA328 Microcontroller	Microchip Technology	1	$1.90
DHT22/AM2302	Temperature + Humidity Sensor	HiLetgo	2	$11.99
GR0430X10	Voltage Sensor	Geekstory	1	$0.86
SRD-05CDC-SL-C	Relay	HiLetgo	2	$5.97
887-2015-ND	16MHz Crystal	TXC CORPORATION	1	$0.30
COM-15539	20pF Capacitor	Sparkfun	2	$0.20
10k Ohm Resistor	N/A	Sparkfun	2	$0.10
6 Pin MicroSD Card Module	MicroSD breakout board with 5V to 3.3V converter included	HiLetgo	1	$2.00
CD4023BE	3 input NAND	Texas Instruments	3	$2.00
CD40175B	quad D flip flop	Texas Instruments	1	$0.50
CD4052BC	dual 4:1 MUX	Texas Instruments	1	$0.50
Tact Button	Momentary tact button	FUNMANY	2	$0.20
COM-15515	0.33uF Ceramic Capacitor	Sparkfun	1	$0.10
COM-15507	0.1uF Ceramic Capacitor	Sparkfun	1	$0.10
L7805CV Linear Voltage Regulator	511-L7805CV	STMicroelectronics	1	$0.50
Hauture 600ml	Mini Dehumidifier	Hauture	1	$31.99
Rover Elite 20A MPPT	Solar Charge Controller	Renogy *note: may not actually buy	1	$99.99
SANDISK 4GB Micro SDHC Memory Card	MicroSD card	SANDISK	1	$8.37

PARTS TOTAL:	Electronics: $34.37 Whole: $175.09

GRAND TOTAL (parts and labor):	$8,925.09

Table 8: Parts and total cost

3.2 Schedule

Week	Drew	Kevin	Andrew
9/28	Design document	Design document	Design document
10/5	Control module FSM on breadboard made	Input module system (arduino)	Data to microSD card design
10/12	Control module FSM debugged and PCB design	Input module system PCB design	ATMega PCB design
10/19	Combine system blocks	Output module system PCB design	SD Card to Matlab configuration
10/26	Version 2 PCB design	Field test sensors and debug	Data logging test
11/2	Field test and debug	Field test and debug	Field test and debug
11/9	Prepare demo	Prepare demo	Prepare demo
11/16	Debug final demo	Debug final demo	Debug final demo
11/23	Presentation prep	Presentation prep	Presentation prep
11/30	Write final report	Write final report	Write final report
12/7	Finalize report	Finalize report	Finalize report

Table 9: Project timeline

4. Discussion of Ethics and Safety

One of the principal ethical considerations in our project is the necessity to remain transparent with Ameren of the product that is being developed and delivered. This product is to be used on spare electrical cabinets that may serve as a backup for maintaining components vital to the operation of critical infrastructure related to public safety. As such, the need to communicate the product clearly becomes relevant to section 7.8.1 and section 7.8.9 of the IEEE Code of Ethics where “the safety, health, and welfare of the public” becomes “paramount” [20] as well as section 1.2 of the ACM code of ethics [21]. Therefore, misrepresentation of the product due to poor communication and presentation may present a public safety risk. To be in accordance with section 1.3 of the ACM Code of Ethics [21] as well as section 7.8.3 of the IEEE Code of Ethics [20], the specifications and capabilities of our project must be accurately stated.

A lithium ion battery pack was chosen as it is generally the safest, most reliable, and widely available source of energy storage that meets the energy density requirements needed for our project [22]. However, any usage of battery powered electronics presents a possibility for water damage. Especially considering the remote conditions of the intended usage of our product, maintenance and repair may not be feasible in an expeditious manner given the event of unexpected failure in the lithium ion battery. Fortunately, the express purpose of our product is to prevent water induced corrosion and damage. All devices inside the cabinet will be kept dry. Any device and sensors outside the cabinet will be made waterproof to a minimum of IPX4 standard [23].

In accordance with section 7.8.9 of the IEEE Code of Ethics [20], we intend to mitigate any risk from working with high powered electrical devices by employing the one hand rule in which one hand is kept in the pocket at all times when working on electrical equipment. Further, when possible, all sources of power will be disconnected when working and assembling components. Circuitry and wiring will be checked by at least two persons as a safety verification before any testing is done. At least two persons will be present at all times such that at least one person can respond to any safety issues that unexpectedly occur during development and testing. In relevance to section 7.8.6 of the IEEE Code of Ethics [20], when working on-site at the Ameren substation, an Ameren employee will be present monitoring all work being carried out to ensure compliance with all safety requirements and legal regulations.

The usage of remote transmission of data may serve as a serious source of ethical concern. Any computing device that transmits data wirelessly may be subject to malicious cyber attacks. In the event of this product being used to maintain spare equipment for critical infrastructure, a malicious cyber attack may have catastrophic consequences. In accordance with section 7.8.1 and 7.8.9 of the IEEE Code of Ethics [20] and section 2.9 of the ACM Code of Ethics [21], our flash storage system is only stored locally and is read only in relation to the control module. Data storage has zero effect on the intended functionality of our device. Thus, there is minimal risk of remote malicious cyber attacks.

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