Rain Energy Harvester

Evan Mayne, Alexander Weatherford, Rayan Baig, and Carlos Molina

Dept. of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450

Abstract — **An innovative system that generates electric power through a renewable source that is easily accessible. The Rain Energy Harvester is a compact hydroelectric system that is designed to use the rainwater flowing through the gutters or downspouts of a building and generate electric power that can be used for simple applications. It will constantly generate power as long as there is a suitable amount of water flowing through its pipes. Built into the casing is a system that displays statistics such as the amount of power generated and used over time with high accuracy. The casing is designed to securely separate the turbine chamber where the water will flow through and the electronics section. Making the Rain Energy Harvester a safe, reliable, and sustainable option for a renewable source of energy.**

Index Terms — **Hydroelectric Power Generation, Switching Regulator, Full-Wave Rectifier, Current Measurement, Power Measurement, TFT Display**

I. INTRODUCTION

The constant increase of energy demand is pushing businesses and the whole energy industry to develop new innovative ways to significantly enhance our rate of energy generation. This demand is due to the development of new technologies, population growth, economic expansion, etc. All of these factors contribute to an energy consumption that becomes greater every year. Not matching this demand with a sufficient or greater supply of energy would have serious implications for the economy. Additionally, with the shift towards renewable energy sources to slowly reduce the use of fossil foil as our primary source of energy, the goal of reaching that growing energy demand becomes more challenging. This was our main motivation to design a system that would help in the collective objective of generating more energy to meet that demand. One of our objectives for this system was to take advantage of a natural source of energy that is not being utilized or it is currently overlooked. The Rain Energy Harvester fulfills this objective by using the rainwater to effectively generate power, where otherwise it would just be dispersed on the ground and letting this energy to be wasted. While there are different options for having a renewable source of energy like, for example, solar panels for homeowners as well as business owners. The Rain Energy Harvester serves as a great addition in helping satisfy their energy needs. This system is designed for low-power applications, therefore, it is not meant to be a replacement for other systems that produce significantly more power. One example would be to use this system to constantly charge a backup emergency battery for a house in case of an outage or disconnection from the power grid. The output of this system can be modified to meet almost any application the user wants, but for our project we will use an USB Outlet to show the capability of the usable power.

II. SYSTEM COMPONENTS

To better understand the way our system operates, the description of each of the main individual components will be given as well as its function within the whole design. There were different component types that could have also worked for an appropriate design, however, the components that were ultimately used in this system meet our design objectives, specifications, and our estimated budget. All of these components were chosen after considering the level of power the system was going to supply, the approximate water flow rate, the ability to effectively communicate with peripheral devices, the accuracy in the power measurements, the overall safety of the design, as well as other factors. Each of the following components were tested individually and connected together to verify the system performance was matching our expectations using the selected components.

A. Hydro Turbine

The Pelton turbine is an impulse type hydropower turbine that absorbs the force of the water flowing into its unique paddles which split the stream of water, sending it along the grooves of the paddle. This change in momentum moves the paddles and causes the turbine to rotate a connected shaft. The jet nozzle will be positioned to hit the paddles at the bottom of the turbine to reduce the amount of water splashing into the backs of the other paddles. This turbine type and model was found to be optimal for the expected water head levels and flow rates. This model has 32 highly durable plastic paddles each with a diameter of 37mm and a depth of 16 mm. These paddles allow for a high degree of adjustability and ensure a lower total weight of 1.56 lbs.

B. Microcontroller Unit

The ATMEGA328P-PU is the microcontroller used to control and communicate with peripheral devices such as the LCD screen and the shunt sensors. The MCU allows for numerous communication types such as SPI, I2C, and UART, all of which will be utilized. The RAM, clock speed, and bit count all met the minimal requirements for the prototype design. The Arduino IDE was chosen due to its available libraries and was used to write code in C++ and then was used to program the MCU.

C. Motor

The Nema 17 - 17ME15-1504S stepper motor is used as an electrical generator for this project, converting mechanical energy to electrical energy. Stepper motors generate AC signals when rotated and typically do not have a gearbox, allowing the shaft to be easily rotatable even in low force operation. The specific Nema 17 motor has a step angle of 0.9 or 400 steps, rated for 1.5 amps, 12 volts, and max voltage being 73 volts. The values are for typical motor applications inputting electrical power however, may be applicable as the electrical output of the motor when mechanically spun.

D. LCD Screen

The Adafruit ILI9341 is used to display the statistics of power generation of the whole system. It is a 2.8 in display with 320 x 420 pixels of resolution which allows abundant display performance for the 2 modes of display for the measurement of data. Since it is a thin-film-transistor display it also has a high refresh rate which is ideal for showing graphs and fonts that update quickly in real time. Another factor we considered was the brightness and clarity of the display when exposed to sunlight. The Rain Energy Harvester is intended to be outside exposed to constant sunlight and rain, therefore, the screen needs to remain visible. The Adafruit ILI9341 also has this advantage over other models with similar characteristics.

E. Shunt Sensors

The INA226 sensors are used to measure the voltage and current that are flowing through the input of the system, that is the power generated from the motor, and the output which is the power supplied in the USB Outlet. These sensors use the shunt-based method for measuring voltage. This method consists of measuring the voltage that is parallel to the shunt. Shunts are resistors with very low resistance values that are close to zero. The INA226 comes with pre-built shunts connected in series with the current we want to measure as well. Both measurements are done at the same time with little to no impact to the signal being measured. From these values, we can easily calculate the power for the input and output signals of the system. Many of the other sensors that were considered could capture accurate measurements both for current only or voltage only. The INA226 simplified this process while providing accurate measurements with fewer components.

F. Pipe Structure

Two 5 ft long 2 inch diameter White PVC pipes are connected vertically with the bottom pipe being connected to a 3 way adapter. This adapter is connected to a flush screw on the bottom and a horizontal pipe of ¾ inch diameter that leads to a jet nozzle. These piping segments are connected and used to simulate the water that would flow through a gutter. These pipes are held by a custom made support structure that will allow for slight adjustments. For demonstration purposes the pipe will be connected to a garden hose and the water head level will be adjusted from 5 ft to 10 ft.

G. Casings

The Turbine and Electronics Casing was assembled using pressure treated pine wood and further waterproofed by applying clear coats to the surface. The dimensions of this component are 20 inches in length, 18.5 inches in width, and 24.5 inches in height. Acrylic was used for the doors into both sections of the casing as well as the front panel that holds the LCD screen, several buttons and switches, and the USB outlet. This part was made to house and separate the electronic components of the prototype from the water and the turbine while giving the user a clear view of both the turbine and the electronics.

H. Voltage Regulators

The LM2576 switching regulator is able to regulate an input voltage between 4 to 40 volts while outputting an adjustable output voltage of 3.3 to 37 volts. The wide range of input and output of the regulator allows the capability to use multiple of the same regulator in the project. When creating a buck converter with the LM2576 the efficiency can be as high as 83.4%, not dissipating too much of the energy loss as heat. [1].

I. Mechanical Parts

Multiple mechanical parts were needed to connect the Pelton turbine and the stepper motor. These parts consist of a custom made flange coupling with 5 evenly spaced 5 mm diameter bolt holes to connect the turbine to the flange and a single 5 mm diameter bolt hole to connect the flange to a custom made shaft. A wall mounted F205 model bearing is placed on both sides of the shared wall between the turbine and electronics casing. The custom shaft is held in place by set screws on the F205 bearings. Custom gears are attached to the end of the custom shaft and the end of the stepper motor with a teeth ratio of 1:2. This means that each time the turbine completes a single full rotation, the motor will complete 2 full rotations.

G. USB Outlet

The standard USB 2.0 female socket requires a constant 5 volt input and can draw current up to 0.5 amps. Any USB 2.0 devices will adhere to the socket standard, some devices requiring lower current than others to operate, giving flexibility to the device choices.

III. ENGINEERING SPECIFICATIONS

Specifications	
Power Generated:	Motor generates >= 2 W
Regulation Efficiency:	>= 50% power efficiency
Output Power:	0.1 W to 5.0 W
Turbine Speed:	150 RPM to 350 RPM
Temperature:	5℃ to 35℃
Turbine Efficiency	>= 45% Turbine Efficiency
Water Capacity:	2 GPM to 6 GPM
Power Transfer:	Voltage Losses <= 200 mV
Total Cost:	Estimated cost <=$400
Usability:	Takes a user 10 minutes to learn how to use
Dimensions:	<= 1.5 m x 1.5 m x 2.75 m

Fig. 1. Specifications Table with the four specifications that will be shown during the prototype's live demonstration.

The table above shows the engineering specifications that our project device should meet. The top four specifications are the ones which we will be proving in our final demonstration but we only need to show three so turbine efficiency will be our backup while these are the main demonstrations: turbine speed, regulation efficiency, and output power.

Under normal operation we expect our turbine to be spinning at a rate between 150 and 350 revolutions per minute (RPM). We want to maintain speeds in this range to ensure our device outputs the necessary power a USB device would require (5 Volts and 0.5 Amp). The way we will demonstrate this is by using a tachometer to measure the spin of the turbine. If the RPM is less than our minimum then USB devices will still operate but they will not run properly and if the RPM goes above our maximum then the parts on our PCB could overheat if the RPM is maintained for too long.

Another specification we will demonstrate is the generated DC power. This is the power of the signal that is generated by the motor after it has passed through the full bridge rectifier. We predict that this power will meet or exceed 2 Watts.

The last specification we will demonstrate is the output power which we predict to be between 0.1 Watts and 5 Watts because a USB 2.0 device can only output at most 5 Volts and 1 Amp which gives a power of 5 Watts. The minimum value of 0.1 Watts is how much a USB device requires of 5 Volts and 200 mA in order to still operate, albeit in a very weak state. So ultimately the reason the power will vary is due to the various loads we will be using to demonstrate functionality have currents varying between 0.5 Amps to 1 Amp but we have confirmed through testing that some can work with a minimum of 200 mA.

The backup specification is the regulation efficiency. Our output USB port has its input reduced with a voltage regulator to meet power requirements. We are going to demonstrate through voltage/current sensors on our PCB that the power which travels from the motor to the USB port has an efficiency greater than or equal to 50%. This value can vary depending on the load connected to the outlet.

IV. SYSTEM CONCEPT

When defining the structure of this system, there was a focus on the flexibility and safety for the user. The overall structure of the Rain Energy Harvester can be modified and scaled to the size of the building that is going to be installed on. It is also possible to have multiple of these on the same building whenever there are multiple gutters or several locations with constant water flowing through it. The printed circuit board as well as all other electrical components will remain unchanged if the user needs to modify the size of the casings. All electronic components need to remain as the current design that is being presented in this paper to maintain the functionality of the system. However, the user can install this system to add functionality to a gutter of the building that only was designed to transport water from the roof to the ground. Using the Rain Energy Harvester will also securely dispersed the water onto the ground or special container. The user can install an output pipe for the water to be dispersed into a different location, or separate container. One possible application of the dispersed water would be to connect it to a garden watering system. This system is not designed to disrupt the water flow of the gutters. While providing certain flexibility to the user, the main goal was to create a safe and reliable system. This is why extended research was done to make sure we select the appropriate materials for the casings. These enclosures are built for exterior usage where there is constant sunlight and rainwater exposure. All parts of the casings as well as the wall between the 2 sections were made waterproof by adding clear coats protecting all electronics components as well as the user. One major factor when selecting the proper electronic components for this design was the power consumption. The system is designed to be left outside regardless of the weather conditions, so the user is not expected to do frequent maintenance to the system. The system needs sufficient power to run by itself without constant interaction from the user. This power will come from a 9V battery that can easily be replaced inside the electronic casing. The figure below shows the connections between the physical components of the prototype.

Fig. 2. This hardware diagram shows the connections between the electrical components electrical and the water based mechanical components.

The general procedure that this system operates starts with the water coming from the roof, and goes through the PVC pipes. The water coming from the nozzle of the PVC pipes disperses the water directly into the Pelton Turbine. The Pelton Turbine spins and rotates the shaft that is connected to the motor shaft. The motor generates an AC signal that goes through a full-wave rectifier. Next, this signal passes through the INA226 sensor 1 that measures the current & voltage values and these are displayed into the TFT display as “Motor Voltage” or “M-Voltage” for example. The same signal continues through the circuit and goes through the switching regulator LM2576 that makes the voltage to be 5V. After the switching regulator, the signal will go through INA226 sensor 2 and power measurement values will be displayed into the TFT screen. The current, voltage, and power being calculated from sensor 2 will be displayed as “USB Voltage”. Next, the signal will go to the USB Outlet that will provide power to the external devices. The USB Outlet requires a constant DC signal of 5V to function properly and deliver the supplied power. Based on the power readings from sensors 1 & 2, the MCU will also calculate the regulator efficiency as a percentage, and display it into the screen. To get the most accurate readings we could get for this system, the INA226 sensors were calibrated and adjusted during testing.

V. HARDWARE DETAIL

A. Hydro Turbine

During testing the RPM range of the Pelton turbine without any load connected was found to be around 200 RPM with a water head level of 5 ft and 400 RPM at with a water head level of 10 ft. Using these RPM values the formula (1) was used to estimate the range of power generated by the turbine to be from 1.97 Watts to 3.67 Watts. Estimated losses of 10% to 50% were assumed for RPM in this equation. Torque for this formula was found using the radius of the turbine and the force applied from the pipe’s jet nozzle and the angle that the force is applied.

$$Power\ (W) = \frac{Torque(N \bullet m) \bullet RPM}{9550} \tag{1}$$

B. Microcontroller Unit

The ATMEGA328P-PU model has a relatively low pin count of 14 GPIO pins for programming and 6 PWM pins. This pincount is desirable as only 3 devices will communicate regularly with the MCU requiring 7 of these GPIO pins. This MCU model is dual inline package compatible and will allow for easier programming and replacement of this part on the PCB. A 16 MHz quartz crystal clock is needed to start the MCU before the internal clock can start. [1]

C. Motor (Alex)

The Nema 17 motor is a two phase motor that outputs AC signals. The AC output has to be changed to a DC output to run small scale devices and USB 2.0 devices. In order to convert from AC to DC a series full bridge rectifier was designed. Each full bridge rectifier was responsible for converting one phase of the motor and having it in series allowed for the most DC output without the rectifiers competing amongst each other.

The schematic below shows the two full bridge rectifiers which are placed in series to account for the 2 phases of our stepper motor and these output into the first sensor to measure the initial DC signal. The “X” connections which are labeled “M1” and “M2” are holes for wires which will connect to the motor externally. Also the component named "IN1+TP" is a test point which can be used to measure the raw DC voltage input.

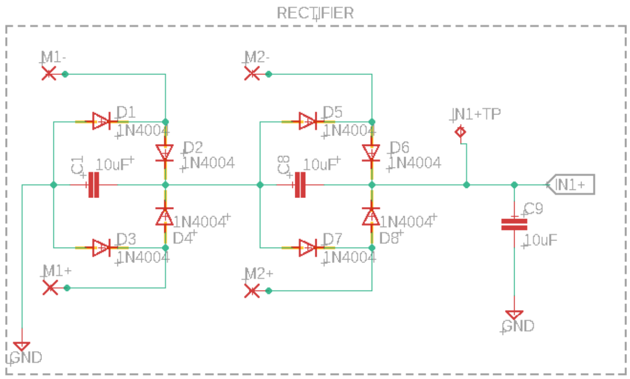


Fig. 3. Series Full Bridge Rectifier Schematic

D. LCD Screen

The Adafruit ILI9341 has a 2.8 in of diagonal display, and due to the thin film transistor technology the refresh rate and image quality is more than adequate for the design. Other TFT models were also considered, but the Adafruit version of this display had better resolution and response times. It has 2 main interface compatibility modes, the common SPI with 5 pins for data transmission, and the 8-bit parallel mode [2]. The 8-bit parallel mode was the recommended mode for applications that involved readings and measurements at high speeds. This mode was considered for the final design of this system, but the speed for the display to update using the SPI with 5 pins was sufficient to show the power statistics. For the 8-bit parallel mode, the display needed 8 pins for digital data lines, and 5 pins for digital control lines for a total of 13 connections. The SPI of 5 Pins requires 5 pins for data transmission, and 2 more pins for analog and digital values for the touch screen capability of the TFT ILI9341 making a total of 7 connections. The difference in speed for each update in the screen with the 8-bit parallel interface was not significant enough to justify the higher number of connections to the printed circuit board. This is the reason why the design of this system uses the SPI interface mode with 7 connections.

One major factor when selecting the proper display for this design was the actual screen size. Several of the other models that were considered for this design were smaller than the 2.8 in display. These smaller displays were good for displaying the power measurements and graphs. The only issue for these displays was the screen size. The user was not going to be able to see the data from the display without being extremely close to the electronic casing. The objective was to have a sufficiently large screen size so it was easy for the user to see the power statistics. This is why the minimum display size that seemed sufficient was 2.8 in. However, most of the larger screens did not meet the other requirements for the proper display of our system. After testing the TFT ILI9341, the 2.8 in size was enough to meet this requirement.

E. Shunt Sensors

The INA226 shunt sensors both have the negative terminal used for measuring current tied to the voltage reading terminal as well. This allows the sensors to measure the current, voltage, and power at a particular node. The first sensor measures the input signal after the full bridge rectifier but before the outlet switching regulator. This sensor is used to measure the usable DC signal that is generated by the motor. The second sensor measures the signal after the outlet switch regulator but before the USB outlet. This sensor is used to measure how much power is actually being supplied to the USB outlet.

The INA226 shunt sensor's I2C addressing was handled by connecting the two address pins A0 and A1 to SDA, SCL, Vcc, or GND. The first sensor has both address pins tied to ground which corresponds to the hex address of 0x40 while the second sensor has address pin A1 tied to a 5 volt source which corresponds to the hex address of 0x44. During testing the first sensor was found to be accurate but the second sensor was found to give inaccurate voltage measurements. The measured voltage was consistently 50 mV under what the actual voltage was. This sensor was calibrated manually by using a linear approximation.

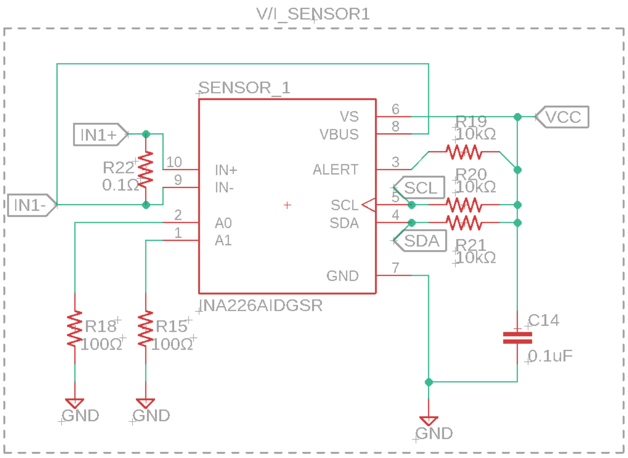


Fig. 4. INA226 Shunt Sensor 1 Schematic

The schematic above shows the connections for how sensor 1 will be implemented on the PCB and sensor 2 is similar with the only difference between them being the A1 pin's connection to VCC. "IN1+" is the input voltage from the full bridge rectifier and "IN-" is the output of the sensor which will go into the output voltage regulator. [3]

F. Pipe Structure

The power available from the piping structure was estimated using the equations below in series (2,3,4,5). The force from the nozzle was found to be roughly 0.9 Newtons and the estimated power from the piping was found to be 8.5 Watts. During testing the flow rate of pipes was found to be 3.205 gallons per minute at 5 ft and 4.539 gallons per minute at 10 ft, this gave the new estimated power range of 3 Watts to 8.5 Watts.

$$Pressure\ (Pa)\ =\ \rho(\frac{kg}{m^3})\ \bullet\ Gravity(\frac{m}{s^2})\ \bullet\ Height(m) \quad (2)$$

$$Area\ (m^2)\ =\ \frac{1}{4}\pi\ \bullet\ diameter(m)^2 \quad (3)$$

$$Force\ (N)\ =\ Pressure(\frac{N}{m^2})\ \bullet\ Area(m^2) \quad (4)$$

$$Power\ (W)\ =\ Flow\ Rate(\frac{L}{s})\ \bullet\ Pressure(\frac{kg\bullet m^2}{L\bullet s^2}) \quad (5)$$

G.. Voltage Regulator

The LM2576 voltage regulator is used to regulate both the MCU supply voltage and the project output voltage. The MCU supply is run by a 9 volt battery being regulated to a 5 volt output. However, the output voltage regulator is more centered in our PCB design, where the current flows from the full bridge rectifier, to sensor 1, then into the output regulator which then steps the voltage down to 5 volts and outputs to sensor 2, and that sensor outputs to the USB port. The output value for the regulator portions are the same, which resulted in using the same buck converter circuit design for each section.

The feedback pin of the voltage regulator determines the value for the regulated voltage output. Two resistors R1 and R2 are placed in between the feedback pin as dividers to set the Vout value. By using equation (6) and (7) the resistor value R1 was chosen to be 1K and R2 as 3k for a regulated five volt output [4].

$$Vout\ =\ Vref\ (1\ +\ \frac{R2}{R1}) \quad (6)$$

$$Vref\ =\ 1.23V \quad (7)$$

The inductor is a vital portion for a buck converter circuit to operate and a 100 uH inductor was chosen using equation (8) and relating the obtained value with max load current using figure 8.8 of the datasheet [4]. The Vin (IN1-) varies by the full bridge rectifier output and the max load current will be 2.5 amps for the USB port but is expected to be lower. The 100 uH inductor covered a wide range of the field with the varying voltage input and max load current, hence it was chosen.

$$E\ *\ T\ =\ (Vin\ -\ Vout)\ \frac{Vout}{Vin}\ *\ \frac{1000}{F(in\ kHz)}\ (V\ *\ us) \quad (8)$$

Cinx load current and 1.25 times the max input voltage [4] is a bypass capacitor that maintains the stability of the voltage regulator, 100 uF was chosen. Cout is used to filter the output voltage and to stabilize the output: 1000 uH is the ideal choice.. The diode of the circuit is used to guide the current in the system. A Schottky diode 1N5822 with a current rating of 3A and 40 Volts is used since the recommended rating for the current is greater than the max.

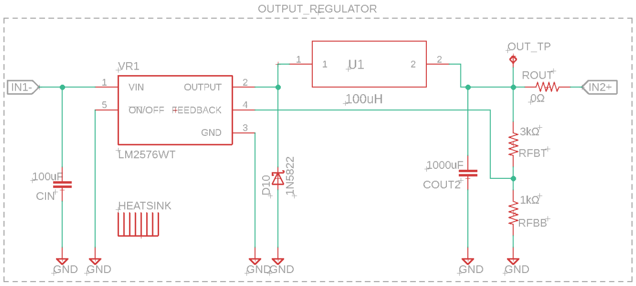


Fig. 5. LM2576 Output Switching Regulator Schematic

The schematic above shows the output regulator circuit which has an input essentially from the two full bridge rectifiers that leads ultimately to the USB port. We have another regulator circuit used as a supply which is exactly the same as this one but the input and output connections are different. For this supply regulator the input instead connects to the battery and the output connects to the peripherals. We have a test point which can be used to verify the 5 V output named "OUT_TP". Also, you can note from the schematic that we have a heat sink as well, and this is made to fit the TO-220 model of LM2576-adj regulators and both regulators will utilize one to help with heat dissipation.

VI. Software Detail

The MCU controls and communicates with the LCD screen through a 5 pin SPI communication protocol and the shunt sensors through I2C communication protocol. The functions used for the INA226 sensors were included in the "INA226_WE.h" library and include several setup functions such as setting the conversion time, the sampling rate, and the measurement mode of the sensor. Other basic functions in this library include those used to measure voltage, current, and power. The Adafruit TFT display uses functions from the "Adafruit_ILI9341.h" library and the "Adafruit_GFX.h" library. The "Adafruit_ILI9341.h" library was used for configuring pins on the MCU for SPI mode communication. These data pins are the CLK for clock, MOSI for master output slave input, MISO for master input slave output, CS for chip select, and DC for writing data and commands.

The “Adafruit_GFX.h” library was used for printing text to the LCD screen and drawing basic shapes such as lines and rectangles that will be used for creating line graphs. Several graphing functions created by Kris Kasprzak for the Adafruit HX8357 model were found on Github and were changed to work with the ILI9341 model that is used in this project. The changing of variable types, such as float to integer, and function parameters was necessary to implement this graphing functionality. [5]

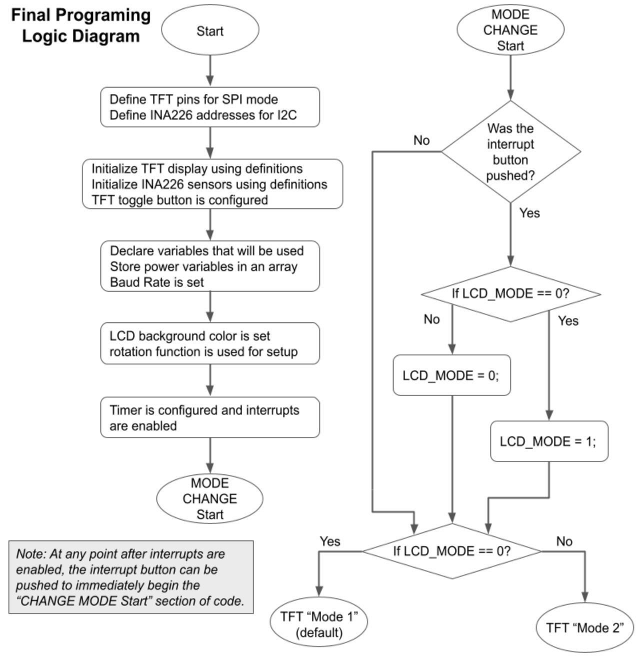


Fig. 6. General Programming Logic Diagram that shows the beginning of the program and the interrupt that is used to change between the two main modes in the program’s loop.

For the setup, variables are initialized and SPI functions and I2C addressing functions are executed first for the LCD screen and then for the shunt sensors. An LED is toggled ON to to signify that the initialization was successful. Then the watchdog timer is started, interrupts are enabled, sleep mode is enabled, and the ADC pins as well as unused digital pins are disabled to reduce power consumption. The shunt sensor setup functions are executed and the background color and orientation of the LCD screen are set.

At the start of each loop the previously raised flags for reading measurements from the shunt sensors are cleared and voltage and current measurements are taken from both sensors. From this point the code will vary depending on the mode that is active, both modes however sleep between each loop and toggle the LED at the end of each loop. This was implemented to reduce the overall power consumption of the MCU as a delay was needed for the display to be readable. The time spent sleeping is determined by the watchdog timer, which is set for an interval of 1 second. Modes can be changed between by using a digital button interrupt. Once this button is pressed, the current loop is finished and the screen is cleared for the new mode to begin.

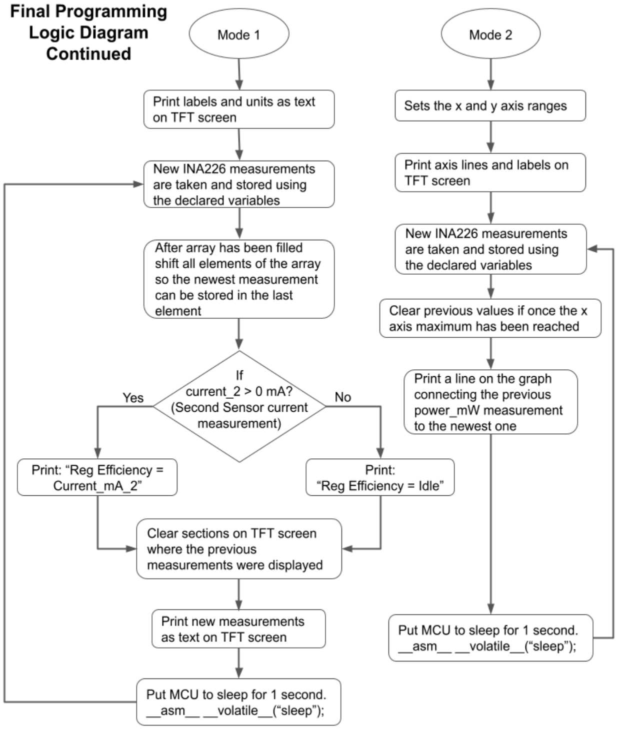


Fig. 7. Programming Logic Diagram showing the general progression through Mode 1 and Mode 2.

Mode 1 displays measurements from both sensors and calculations on the LCD in text form. These measurements include the voltage, current, and power measured on both sensors. The calculations include an turbine RPM calculation based off of the power generated and a regulator efficiency calculation based off of the power measured at both sensors. The turbine RPM calculations were adjusted after testing to ensure the accuracy of the readings. The regulator efficiency will vary depending on the load connected to the USB outlet. If the second sensor measures power below the nominal power threshold the regulator efficiency will instead display a “USB Idle” message..

Mode 2 displays power measurements from the first sensor in line graph form. The x axis represents time in seconds and the y axis represents power in watts. Both axes with appropriate labels and gridlines for each increment are printed first. Each second the graph is updated until the maximum value set for the x axis is exceeded. At this point the graph is reset and new values will be displayed. The limits for the x axis and the y axis are 30 seconds and 4 watts respectively, although this can be easily adjusted using global variables during testing.

VII. BOARD DESIGN (RAYAN)

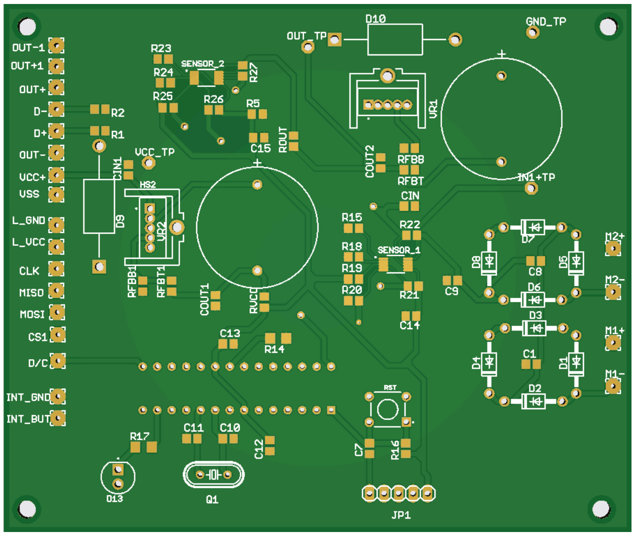


Fig. 8. Top view of the Final PCB board

The above figure shows the PCB board which will be wall mounted in our electronics casing and because of where it will be mounted, we put our external connections to the left and the connections for the motor to the rectifier on the bottom right of the board. The connections on the left are for our LCD display, screen change button, and the output ports. Also we have a 5 pin header at the bottom of the board which is used as an FTDI port in order to reprogram the MCU as needed using UART based communication with a USB to TTL serial adapter.

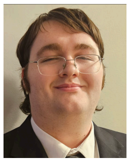
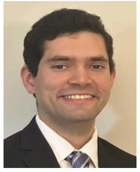
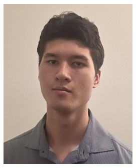
ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance and support of Dr.Weeks for introducing our group to the concept of this project and advising us on our PCB design.

We would also like to acknowledge and thank David Douglas for assisting in obtaining components for the PCB and breadboard testing, and James Essad for advising us on our mechanical designs and making the design realizable with the UCF machine shop.

Finally we would like to thank Dr.Chan and all of the committee members for consistently reviewing and guiding the project.

THE TEAM

	**Evan Mayne** is a 23-year old Electrical Engineer student graduating from UCF whose career goals involve hardware design and fabrication of circuits.
	**Carlos Molina** is a 24-year old Electrical Engineer student graduating from UCF. He has experience in the electric utility industry. Carlos is pursuing a career in designing and testing systems for renewable energy sources.
	**Alexander Weatherford** is a 22-year old graduating Electrical Engineer student from UCF. He has experienced PLC automation as an intern at WestRock. Alex plans on starting his Electrical Engineering career after graduating with a bachelors.
	**Rayan Baig** is a 20-year old Electrical Engineering student graduating UCF who has an interest in circuit design and substation work.

REFERENCES

[1] Arduino, “UNO R3 | Arduino Documentation,” *docs.arduino.cc*, 2022. https://docs.arduino.cc/hardware/uno-rev3

[2] Adafruit TFT Touchscreen Display ILI9341 2.8 in - Datasheet https://cdn-shop.adafruit.com/datasheets/ILI9341.pdf

[3] “INA226 data sheet, product information and support | TI.com,” *www.ti.com*. https://www.ti.com/product/INA226#description (accessed Dec. 02, 2023).

[4] “LM2576xx Series SIMPLE SWITCHER ® Power Converter 3-A Step-Down Voltage Regulator Fixed Output Voltage Version Typical Application Diagram,” 1999. Accessed: Apr. 05, 2024. [Online]. Available: https://www.ti.com/lit/ds/symlink/lm2576hv.pdf

[5] Kris Kasprzak, “Graphing/graph.ino at main · Graph.ino,” GitHub, https://github.com/KrisKasprzak/Graphing/blob/main/Graph.ino (accessed Nov. 14, 2023).