ECEB Submetering System

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Design Document for ECE 445, Senior Design, Fall 2023

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13 September 2023

Project No. 39

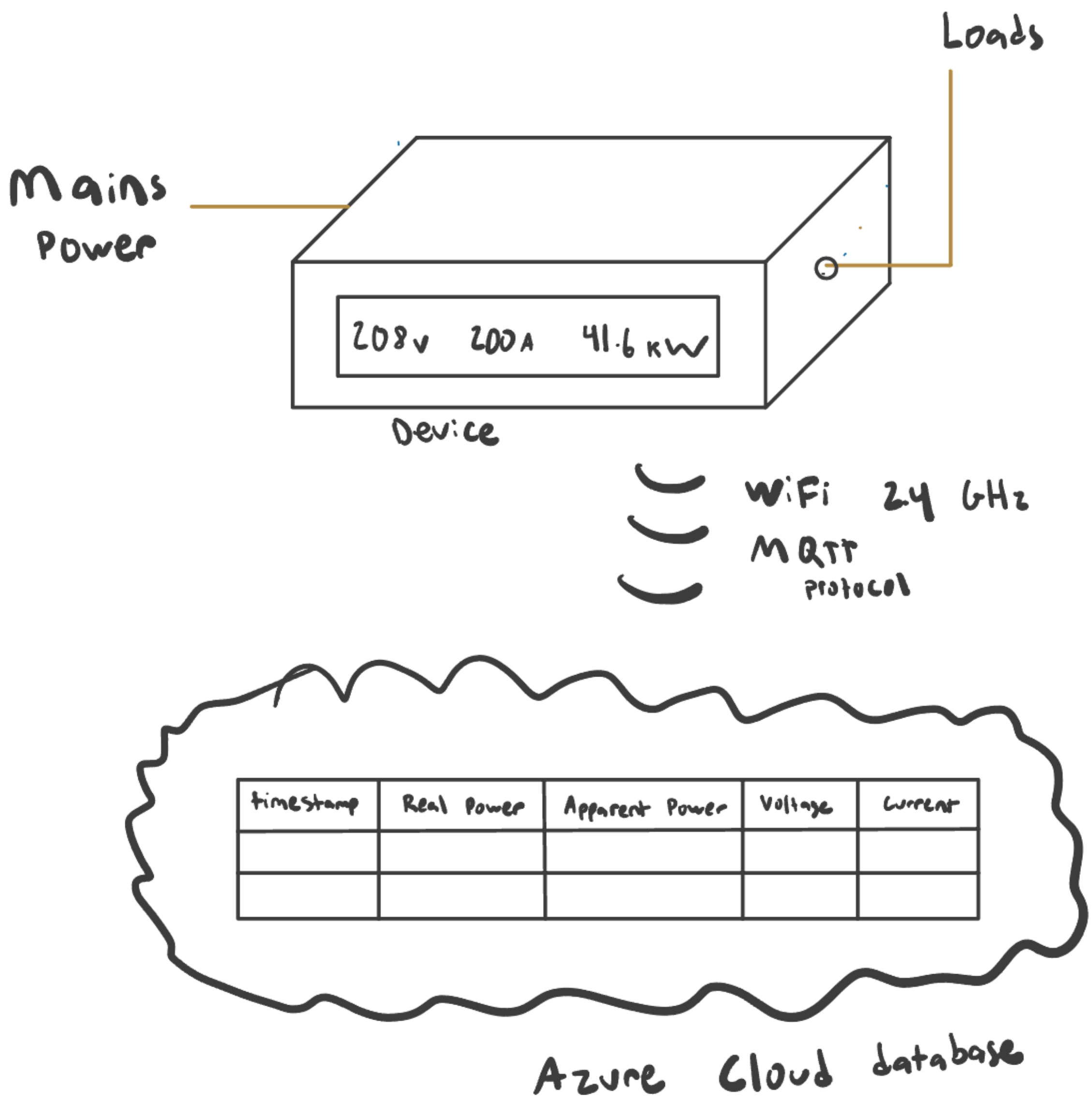
Contents

1. Introduction

Problem: The ECEB is a Platinum LEED certified building, powered by rooftop solar panels. To continually improve energy efficiency, it is necessary to further optimize power consumption. This can be done if building management has detailed power data, tracked over significant periods of time, to analyze trends in usage and opportunities to reduce idle consumption.

Solution: Our solution is to create power meters that can accurately measure power, voltage, and current of individual rooms within ECEB and upload this data to a database for future analysis and monitoring.

Visual Aid:

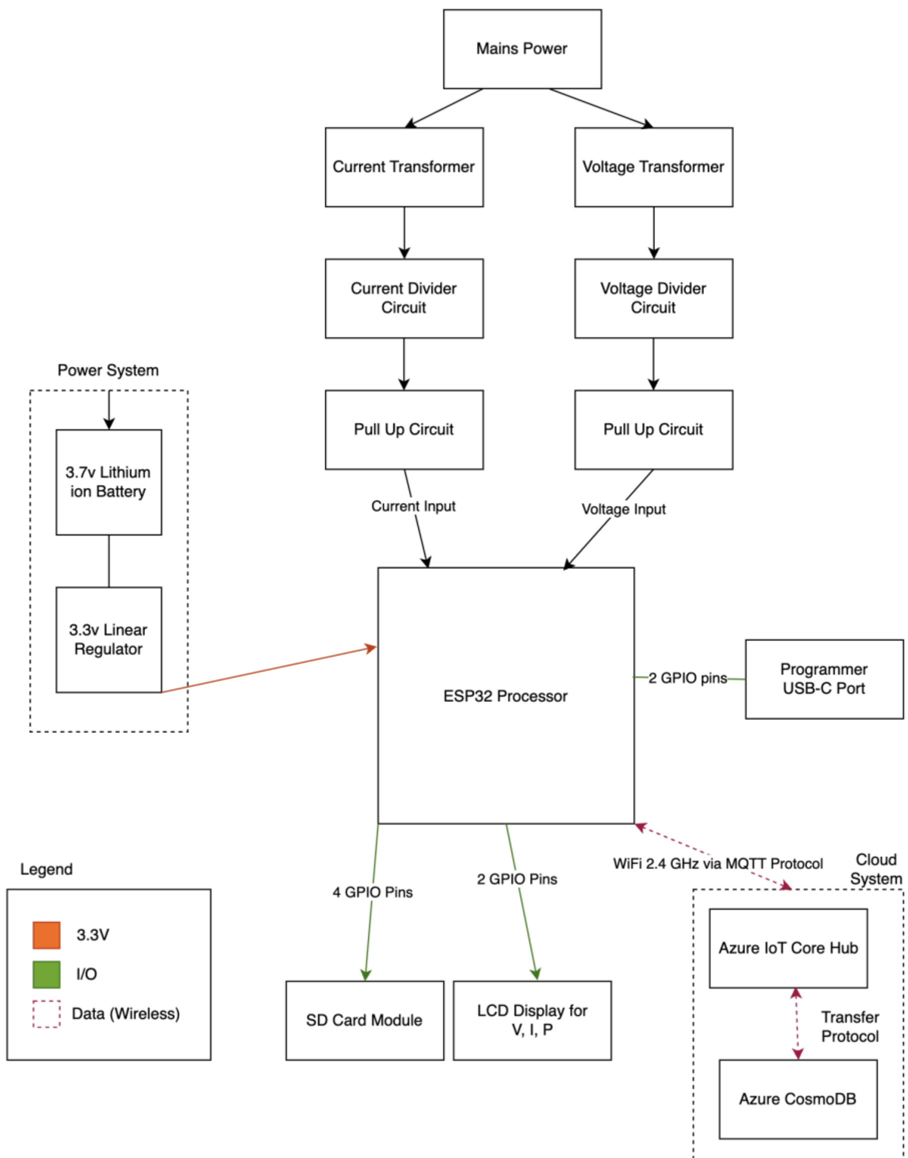


High-level requirements list:

- Sample a single-phase input for its voltage and current.
- The microcontroller will process the voltage and current samples to calculate apparent and real power. These data points are stored onto an SD card and to a cloud database.
- The device will display the instantaneous voltage and current as well as the real and apparent power.

2. Design

Block Diagram



Subsystem Overview:

The sensor unit will be used to monitor the voltage and current of a single-phase input. The sensors will take initial readings which will be filtered through a secondary circuit to convert the sensor outputs into a range that is readable by the microprocessor.

The power system is composed of a rechargeable battery and a set of regulators. The battery can provide at least 24 hours of continuous power to the monitoring unit (the main box which takes readings, stores data, and communicates with the external database) without being connected to an external power source. The regulators will adjust the base battery voltage into appropriate DC voltages, namely 3.3V.

The primary onboard processing component is the microcontroller, which will collect voltage and current data from sensors, calculate the real-time power according to the voltage and current, and store the voltage, current, and real and apparent power with time stamps to the SD card. The microcontroller (ESP32) will also be able to upload collected data to a cloud database through WiFi.

The cloud storage will continue to receive data from the ESP32 and will keep that data at most for 5 years for analysis purposes.

The local LCD display would show the real-time voltage, current, and power from the single-phase input.

Physical Design

The sensing unit will be constructed inside a grounded box, with an input and output port through which mains power should be connected. The box will be dimensioned such that it can be mounted on a wall or placed on a rack, but the transformers and battery will make the unit relatively heavy, so a rack of some sort is recommended.

Subsystem Requirements
Power Supply System:
The power system, composed of a 3.7V 5.2Ah Li-Ion battery and a 3.3V linear regulator will provide consistent power at 3.3V for all digital and analog components.

Requirements	Verification
A rechargeable battery that can power the metering unit without being charged for at least 24 hours, with a margin of 15%.	The metering unit will be left on without being connected to power, and requests for data will be made at 2 hour intervals until the battery dies.
Power regulators must provide 3.3V DC power to each sensor, the microcontroller, the SD card, and the local display, such that the pull up circuits in the sensors have a +1.65 V bias and the microcontroller I/O pins have outputs between 0 and 3.3V.	Use Keysight multimeters as voltmeters to test that the SD card and ESP32 have an input voltage of no more than 3.3V.

Sensor Unit:

The sensor unit needs to be able to observe 208V peak-to-peak AC voltage and 400 amps of current without significantly impeding power at the load. This will be achieved via a current transformer and a voltage transformer, which will also isolate the sensing unit from mains power.

Requirements	**Verification**
The power delivered at the load is reduced no more than 0.5% in comparison to the unmetered value.	An ammeter and voltmeter will be used to measure the current and voltage above the meter and below the meter, such that the power consumption of the meter in comparison to the load can be calculated.
The voltage at the voltage sensor's analog input pin scales proportionally to the measured voltage, such that measured voltage is no more than 3% off from actual voltage.	A multimeter or voltmeter will be connected in parallel with the source such that it can be compared to the measured voltage for inputs 0V-208V.
The current at the current sensor's analog input pin scales proportionally to the measured current, such that measured current is no more than 1% off from actual current.	A multimeter or ammeter will be connected in series with the source such that it can be compared to the measured current for inputs between 0A- 400A.

Onboard Processing:
The ESP32 processes the input measurements to produce power calculations. This data will then be sent to various sources: a cloud database, SD card, and the local LCD display.

Requirements	**Verification**
Calculate real and apparent power within 4% of the actual value based on sampled measurements from the voltage and current sensor.	Observe the real power from the source using a wattmeter and calculate the apparent power from the RMS voltage and current, which can be observed by placing a voltmeter in parallel and an ammeter in series with the load.
Offload measurements onto the SD card from the ESP32 flash memory once per second.	Insert SD card into a computer and verify the information and timestamps are 0.1 second intervals.
Upload the voltage, current, and power measurements to the Azure Cosmos database every 15 minutes using WiFi and the MQTT Protocol.	Check if the database has datapoints that display 0.1 second intervals.
Present real-time measurements on the LCD Display.	The LCD Display accurately shows the voltage, current, and power measurements.

Tolerance Analysis:
Power system

- The battery should provide 24 hours of continuous power to the metering unit with a tolerance of 15%.

Sensor unit

- The phase voltage measured by the meter at the interconnection point will be no more than 3% above or below the RMS voltage indicated by a lab bench voltmeter.

- The phase current measured by our meter at the interconnection point will be within 1% of the RMS current indicated by a lab bench ammeter.
- The single-phase power measurement will be within 4% of the lab bench wattmeter reading.

Onboard Data Processing

- The ESP32 supports communication through WiFi with 20 Mbit/s
- The ESP32 uses the SPI communication protocol to read the SD card that requires at least 10 Mbits/s
- There is a risk on the SD card storage module on board. Because it stores all the data collected and the data source when the web server requests data from the device. If the SD card doesn't work properly, the system can't either load data into the storage nor send data to the web server.

Uploading data to web server via WiFi

- There is a connection risk when streaming data from the ESP32 to the web server. Since the device will be in active building with multiple connections occurring simultaneously, we may face connection issues and have unsuccessful data transfer. We will handle connection issues by communicating with the cloud services where we will get confirmation receipts of received data to the cloud and attempt an internet reconnection request if we do not receive a confirmation receipt within 30 seconds.

3. Cost and Schedule

3.1 Cost Analysis

Labor

Assuming an approximate average salary of an ECE graduate of $40/hour, each team member cost comes to ($40/hour) x 2.5 (overhead factor) x 8 hours/week x 11 weeks = $8800.

Since we have 3 team members and won't be utilizing any machine shop labor, our total labor cost comes to $8800 x 3 = $26,400.

Parts

Description	Cost	Quantity	Part #	Manufacturer	Link
ESP32 Processor	2.50	1	SP32-WROOM-32E-N4	Expressif Systems	link
I2C LCD Display	8.95	1	CN0295D	SunFounder	link
Micro SD Card Module	5.20	1	DFR0229	DFRobot	link
Micro SD Card	7.55	1	TF64GKT*3	KOOTION	
208V/24V Voltage Transformer	19.43	1	TCT40-05E07AB	Triad Magnetics	voltage transformer link

400A/5A Current Transformer	26.00	1	CTF-5RL-0400	AcuAmp	current transformer link
10Ω 50W Resistor	4.10	1	KAL50FB10R0	Stackpole Electronics Inc	
3.7V Lithium Ion Battery	26.99	1	31001	Tenergy	battery link
1A Smart Charger for Li-Ion/Polymer Battery Pack	29.99	1	01281	Tenergy	charger link
3.3V Linear Regulator	0	1	AZ1117CD-3.3TRG1DITR-ND	ECE Supply Shop (Diodes Incorporated)	linear regulator link
Total Parts Cost	157.70				

Grand Total Cost

Labor Cost + Part Cost = $26,400 + $157.70 = $26.557.70

Summing up all the costs, we get a total cost of $26.557.70 to make this project possible.

3.2 Schedule

Week	Sophia	Vincent	Houji	Everyone
9/25	Research methods to measure single phase power and research local power supply	Familiarize with ESP32 by uploading and running code	Get familiar with SD card module and how to connect it with ESP32	Design Document finalized
10/2	Order components. Design PCB and construct early versions of sensor circuits.	Write program to allow ESP32 to upload mock data to database via WiFi	Construct the PCB design with Sophia and start programing the data transferring between ESP32 and SD card module	Create prototype on breadboard, verify and program measure calculations, PCB Design Finalization
10/9	Develop calibrations for sensors. Verify PCB Design	Write program that shows measurements on an LCD Display and design a housing unit for device	Finish and send order of PCB	PCB Ordering
10/16	Contribute to theoretical design of code.	3D print housing unit	Testing SD card reading and writing.	

10/23	Construct, test, and debug sensor circuits. Continue refining parameters for sensor inputs.	Ensure PCB is functional and order backup if needed.	Solder parts on PCB. Test and debug the on-board performance.	PCB ordering backup
10/30	Responsible for technical explanations regarding power measurements.	Responsible for diagrams and some programming explanations.	Responsible for technical explanations regarding on-board data handling.	Final Project Document finalized.
11/6	Execute tests	Create testing guidelines.	Verify test results are accurate	Final Testing
11/13	Practice presenting voltage and current measurement methods and PCB Design.	Practice presenting database, display, and housing unit.	Practice present SD card, data calculation, and PCB design.	Mock Demo
11/20	Fall Break	Fall Break	Fall Break	Fall Break
11/27	Present voltage and current measurement methods and PCB Design.	Present database, display, and housing unit.	Present SD card, data calculation, and PCB design.	Final Demo
12/4	Present voltage and current measurement methods and PCB Design.	Present database, display, and housing unit.	Present SD card, data calculation, and PCB design.	Final Presentation

4. Ethics and Safety

The data being handled by our meter is not personal in nature, and will be posted in a public location, so we will not need to account for data privacy in our design. The primary safety risk is that of shock from single-phase power. To protect the safety and health of the public, we will ground the outside of our metering box and electrically isolate the interior. We will also label it clearly as a high voltage device.

We do not know of any conflicts of interest at play, and certainly do not anticipate unlawful conduct.

We will review our work with others to ensure its accuracy, carefully track testing data to ensure honesty in our claims and make every effort to credit any reference we use in developing this device. This device is a technical project which will improve our competence in power sensing, data gathering, and database management.

5. Citations

[1] X. Wu, X. Shen and T. Wang, "ECE 445 Submetering the ECEB," May 2020. [Online]. Available: https://courses.engr.illinois.edu/ece445/getfile.asp?id=16751. [Accessed 28 September 2023].

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[6] IEEE Board of Directors, "IEEE Code of Ethics," IEEE, 2020.