ECEB Submetering System

By

Houji Zhou

Sophia Marhoul

Vincent Nguyen

Final Report for ECE 445, Senior Design, Fall 2023

TA: Tianxiang Zheng

13 September 2023

Project No. 39

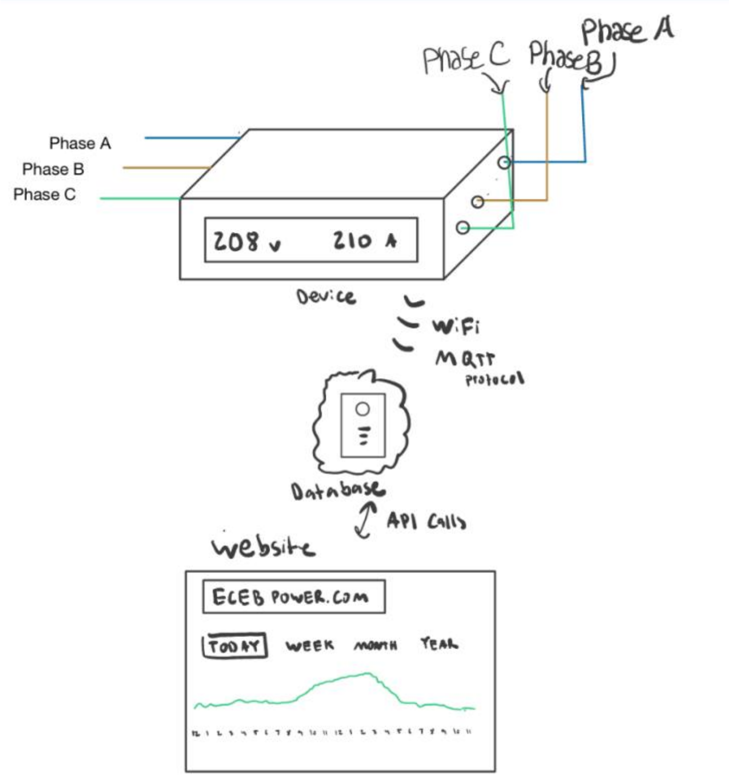
Contents

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 server for future analysis and monitoring.

Visual Aid:

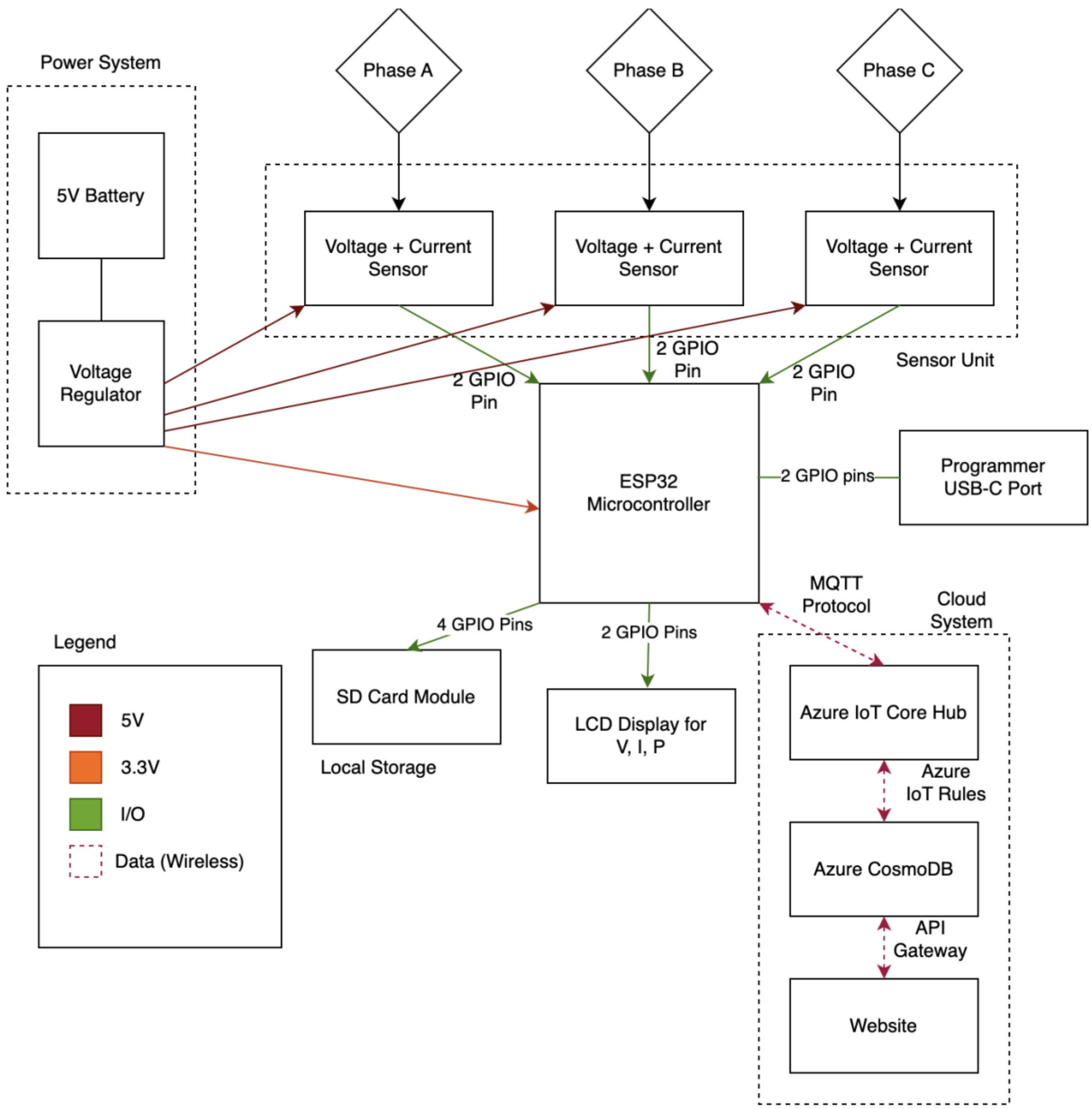


High-level requirements list:

- The voltage and current of the 3-phase input is observed by the sensors.
- Power is calculated in the microcontroller, and the three data points are saved every 0.1 seconds along with a clock time onto an SD card.
- The voltage, power and current data is displayed locally, and the time-stamped data is sent to the cloud database every 15 minutes. A website will display a graph of the data of daily, weekly, and monthly usage.

2. Design

Block Diagram



Subsystem Overview:

The sensor unit will be used to monitor the voltage and current on each phase of the 3-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 6 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 5V and 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 power with time stamps to the SD card. The microcontroller (ESP32) will also be able to communicate with the web server through WiFi and send data collected to the cloud storage.

The cloud storage will continue to receive data from the ESP32 and will keep that data at most for 5 years for analysis purposes. Also, the user can request to download the data with csv format from the web server.

The local LCD display would show the real-time voltage, current, and power from the 3-phase input.

Subsystem Requirements

Power System:

The power system will provide consistent power at appropriate voltages for every sensor, every component on the PCB, and the on-board display. The main components will be:

- A rechargeable battery that can power the metering unit without being charged for at least six hours.
- Power regulators provide 5V and 3.3V DC power to each sensor, the microcontroller, the SD card, and the local display. The regulators should each be able to maintain a 5W output.

Sensor Unit:

The sensor unit needs to be able to observe 208V peak-to-peak AC voltage and 400 amps of current without impeding the apparent power. The main components will be:

- Voltage sensors for each phase which detect instantaneous voltage. They will need to tolerate 208V and not impact the apparent voltage. We believe that a voltage divider circuit with an overall impedance around 1MΩ will be sufficient, but a voltmeter could also be used.
- Hall effect current sensors, which can measure current with 1% accuracy up to 400A. The Tamura 400A Hall Effect Open Loop Bidirectional Module (Digikey MT7178-ND) is the sensor we expect to use.

Onboard Processing:

- The microcontroller would collect the data from the sensor unit and calculate the power according to the instantaneous voltage and current.
- The microcontroller will send the power, voltage, and current data every 15 minutes to a cloud service using WiFi and the MQTT protocol.
- The ESP32 uses SPI communication protocol to read the data from local storage by SD cards that can receive and store 96 hours of data sent from the microcontroller.

Cloud Storage:

- The cloud database stores the data uploaded by the ESP32 for a period of 5 years and will process any required computing for analysis.
- Users will be able access a website that displays the data from the webserver and be able to download csv data.

Tolerance Analysis:

Power system

- The battery should provide 168 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 and three 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. 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 3 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.