ECE 445

Spring 2024

ECEB Submetering

Mike Lee, Aleksai Herrera, Jonathan Izurieta

Introduction

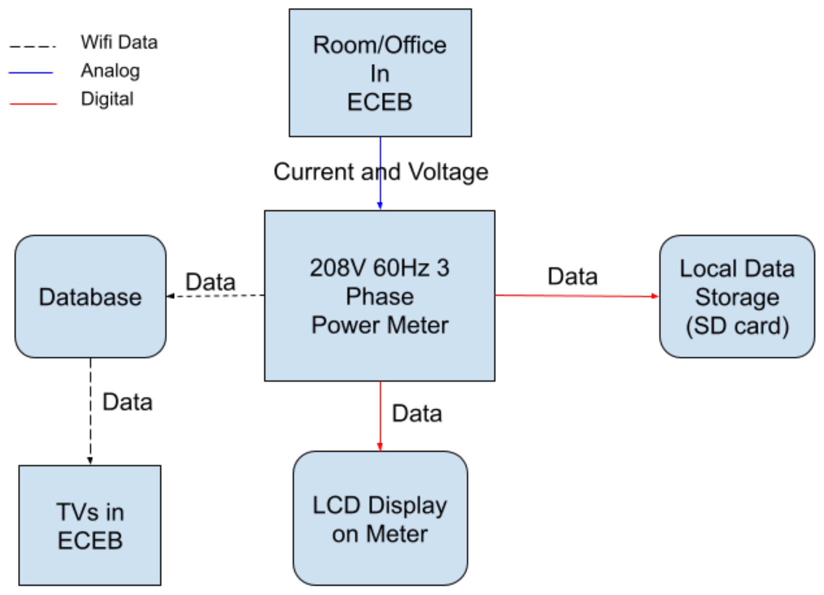
Problem

The ECEB is notably a net-zero energy facility, which is possible due to utilization of energy efficient methods such as the use of solar panels. We would like to be able to measure and share data collected from the energy generated by the solar panels in order to help track the efficiency and use of energy of the ECEB building. With regard to the ECEB submeter of previous semesters, we would like to improve upon the accuracy of the data recorded to yield more practical and useful results.

Solution

Our solution is to create power meters that can accurately measure power, voltage, and current of individual rooms within ECEB and be able to accurately get and store these data metrics as well as being able to display them to either an LCD or the TVs within the ECEB. We plan to improve upon many of the shortcomings the previous implementation faced.

Visual Aid

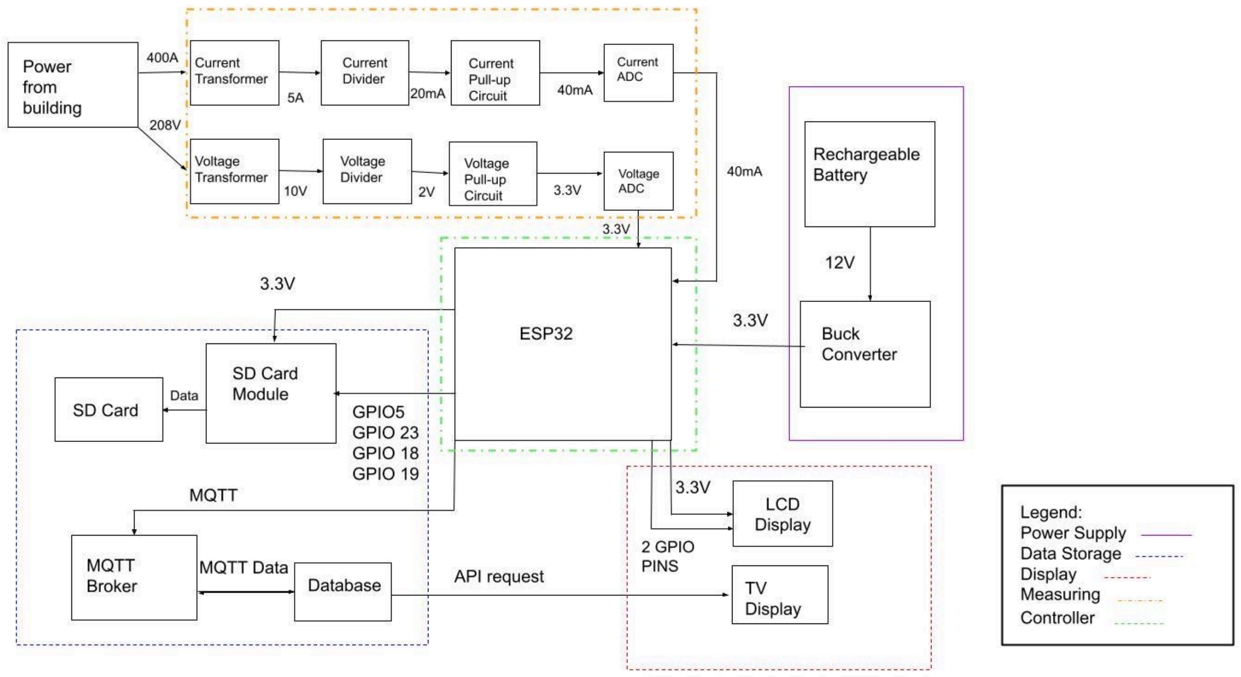


High Level Requirements List

- Be able to measure current and voltage for 3 phase systems within +/- 1% for loads of 200-400A.
- Be able to accurately measure the phase angle within +/- 1% and using the phase angle calculate Power Factor within +/- 2%.
- Be able to display calculated data to an LCD screen and the TVs in ECEB.

Design

Block Diagram



Subsystem Overview

Power Supply Subsystem

- The system will be powered by a battery, and this battery will be attached to a linear regulator, a buck converter, to bring the voltage to a level usable by the ESP32. This power supply will power a majority of the components in our project as seen in the block diagram.

Measuring Subsystem

- Our measuring system will take the power from the building and scale voltage and current down through a transformer, and then again scale the two down using divider circuits, afterwards using pull-up circuits to bring the values to the max values allowed by the ESP32, being 40mA and 3.3V. These analog values will then be converted to digital using ADC's and be inputted into the ESP32 to be measured.

Data Storage Subsystem

- The ESP32 will act as the central microcontroller of our project measuring the values of the inputs received. It will routinely store and deliver data to the SD card via the SD card module and onto a time series database(TSDB). The microcontroller will send MQTT messages, then the TSDB will ingest the data which will allow data analysis and visualization. It will also deliver the data to the LCD display and TV to display the data and waveform.

Display System:

- The display system will include an LCD display and a TV display. It will connect to the LCD using 2 GPIO pins, and to the TV display which will display data through a website. The LCD display will show immediate data in terms of voltage, current, and power. The cloud data will be displayed on the TV of the ECEB lobby where further visualizations and analysis of power usage over a larger time frame will be shown.

Controller Subsystem:

- This subsystem consists of the ESP32 microcontroller itself as well as its connections to other subsystems. It will perform the processing of data and will interface with the SD card module and time series database via wifi. It will also be programmed via USB with a USB to UART module which is then sent to the ESP32.

Subsystem Requirements

Power Supply Subsystem

- Step down 12V battery down to 3.3V (+- 0.3V) for the ESP32 since it can tolerate voltage ranges from 3.0V to 3.6V.
- The battery needs to provide a 24 hour life.

Measuring Subsystem

- Measuring the 208V and 400A and brings the voltage and current to a level acceptable, which is max 40mA and 3.0V (+-0.3V), as an input to the ESP32 without impacting or changing the actual values in order to yield high accuracy.

Data Storage Subsystem

- Voltage, current, and power will be recorded 10 times a second onto the SD card
- The data will need to be uploaded onto a time series database(TSDB) through MQTT protocol at least 4 times an hour.
- The energy data will need to be stored and maintained for 5 years. The local memory storage will need to hold 96 hours of data.

Display Subsystem

- Realtime voltage, current, and power will be visible on an LCD display on the meter.
- Data and visualization will be displayed on the TV within 15 minutes of recording the data on the meter.

Controller Subsystem

- Data inputs are received and the power and power factor are calculated.

Tolerance Analysis

Data Storage Subsystem:

- MQTT Protocol will cover connection instability issues we encounter, but we can set an alarm system that sends notifications when data has not been ingested for an hour.

ESP Internal Clock

- Although the ESP32 has a problem where the clock can drift up to 8 minutes a day, we can ensure that correct data tracking with correct date and time is within 10% of the minute. As data is being recorded over a few years and data is measured 10 times a second, that amount of drift can lead to inaccurate data. The drift is 8 minutes a day, and assuming constant drift, this equates to 20 seconds an hour, which is 5 seconds every 15 minutes. 15 minutes is how often we offload data to a database. The last data entry will be off by 5 seconds on the minute which is 8.3%. In order to solve this, we can add a RTC module or the ESP32 clock can be reset by synching to the web. This synchronization will occur at the same time we offload the data to ensure accurate times within 10% of the minute.

Power Supply

- Due to noise sensitivity in analog components we decided to use a low noise linear regulator to supply the power for these devices in order to maintain their accuracy
- The rechargeable battery will provide 24 hours of power after being disconnected from the initial source with a 10% margin of error

Voltage Sensing Circuit

- When inputting a 206V 60Hz voltage, our transformer steps down the voltage to an RMS value of 2.5576 Vrms. The RMS value before stepping down is 146.29 Vrms. This leads us to a step down ratio, Vout/Vin, of 0.017483. The stepped down voltage is then passed through a non inverting amplifier with gain Vout = Vin(1 + R2/R1) - (R2/R1)1.65. After this we pass the signal through an RC low pass filter and finally through another op amp to act as a buffer before finally sending the data to the ADC on the ESP-32. The Vrms value at the ADC is 2.5233. Taking this to the ratio we found when the voltage transform occurred, (2.5233/0.0017483) yields us a Vrms of 144.328. This Vrms value is only 1.3% off the original voltage value that is passed in. This was done in testing in LTSpice, and we are able to conclude that our measurement of the Voltage will be within +- 1.5% of the actual value.

Ethics and Safety

With regards to safety we are going to need to take into consideration the CAT Rating. This relates to safety equipment ratings needed when handling different types of electrical devices or systems, which can pose a danger in the event of arc flashes[1]. Our device is a CAT II rating as it will be attached to a single-phase AC load. Ideally we would need to take into account arc flashes and sudden harmonics in the power grid which could cause irregularities when measuring voltage and current.

We will make sure that the data presented is allowed to be public, and that displayed values are not manipulated. This falls under maintaining integrity aspect of the IEEE code of ethics by not lying about our results to improve perceived accuracy [2]. When handling potentially private data we must take the proper precautionary methods to make sure that this data is not shared, which is why we will only display public data on to the TV's [3].

References

[1] N. Fire and N. Fire, *NFPA 70E*. National Fire Protection Association (NFPA), 2004.
[2] IEEE Code of Ethics. (n.d.). https://www.ieee.org/about/corporate/governance/p7-8.html
[3] “IEEE SA - IEEE 7002-2022,” IEEE Standards Association.
https://standards.ieee.org/ieee/7002/6898/