# Design of supervisory controllers and ultra-low power data loggers for hybrid power systems

M. Eng Student:

Wei He

Supervised by:

Dr. M. Tariq Iqbal

Faculty of Engineering and Applied Science

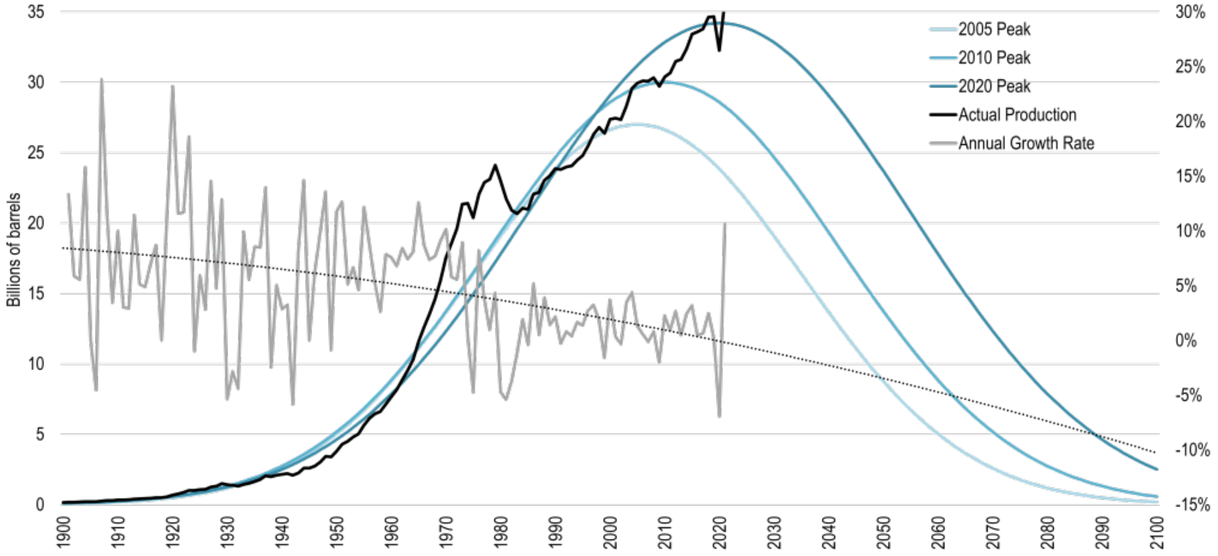
University of Newfoundland

# Outline

- Introduction
- Literature Review
- Research Objectives
- Power Consumption Minimization of a Low-Cost IoT Data Logger for Photovoltaic System
- A novel design of a low-cost SCADA system for monitoring standalone photovoltaic systems
- An Open-Source SCADA Architecture for Photovoltaic System Monitoring using ESP32, Banana Pi M4 and Node-RED
- An IoT-SCADA architecture for photovoltaic system monitoring, control, and inspection in real time
- Conclusion
- Future Works
- Acknowledgment
- Publications

# Introduction

- Limited fossil fuel, renewable energy as the alternative




*World Annual Oil Production 1900-2021 and Peak Oil 2005-2020 Scenarios.*

- In 2022, 25.9% of Canada's newly installed capacity is solar energy
- In Ontario, solar energy powers 517,000 homes

# Introduction

➢ Commercial data loggers are expensive, proprietary, and non-configurable

| No. | Product | Company | Power consumption | Cost range (€) (Sensors not included) | Number of inputs | Internal data storage | Data sending/saving interval | Market launch year |
|---|---|---|---|---|---|---|---|---|
| 1 | Delta Solivia Gateway M1 G2 | Delta Energy Systems GmbH | 1 W @ 5 V | 174 | 8 | \ | 15 min by def. | 2019 |
| 2 | Fronius Datamanager 2.0 | Fronius | < 2 W | 222-259 | 6-10 | \ | \ | 2013 |
| 3 | Q.reader | Gantner Instruments GmbH | 5 W | 600 | 2 | 8 GB | \ | 2010 |
| 4 | Smartlogger 3000A | Huawei | 8 W | 1495 | 4 DI, 4 AI | \ | \ | 2020 |
| 5 | Powador-proLOG M | Kaco | \ | 549-664 | 4DI, 4 AI | \ | 300-3600 s | 2009 |
| 6 | ADL-MXSpro | Meier-NT GmbH | 0.1 W-0.76 W | 980-1100 | max. 8 | 1 GB | 24 h | 2017 |
| 7 | SMA Data Manager M Lite | SMA Solar Technology AG | 4 W | 285 | \ | \ | \ | 2022 |
| 8 | Solar-Log 2000 | Solare Datensysteme GmbH | 3 W | 1031-1248 | 8 | \ | connected inverters < 30: 5min<br>connected inverters 30-59: 10min<br>connected inverters > 60: 15min | \ |
| 9 | MaxWeb XPN | SolarMax | 24 W (maximum) | 500-600 | 1 DI, 4 AI | \ | 15 min by def. | 2016 |

| No. | Methods and rate of communication | | | | | | Measurement on main connection point | Open interfaces for SCADA integration |
|---|---|---|---|---|---|---|---|---|
| | RS 485 | RS 422 | Ethernet | WLAN | USB | 2G/3G/4G | | |
| 1 | 19200 baud rate, by def. | \ | Yes | \ | \ | \ | Yes | No |
| 2 | Yes | Yes | Yes | Yes | \ | \ | Yes | Yes |
| 3 | Up to 115.2 kbs | \ | Yes | \ | 1s to 24h | \ | Yes | Yes |
| 4 | 1200-115200 bps | \ | Yes | Yes | Yes | Yes | Yes | Yes |
| 5 | Yes | \ | Yes | \ | \ | \ | \ | \ |
| 6 | 300-115200 baud | \ | 10/100 Mbit | \ | Yes | GSM module integrated | Yes | Yes |
| 7 | Yes | \ | Yes | Yes | Yes | \ | Optional | Yes |
| 8 | 2400-115200 bps | Yes | 10/100 Mbit | Yes | Yes | \ | Yes | Yes |
| 9 | Yes | \ | Yes | Yes | Yes | \ | Yes | No |

*Commercial products of data logger in PV systems.*

# Literature Review

*Comparison of HMI designs and data storage solutions in the literature review.*

| Reference | HMI Design | | | | Data Storage | |
|---|---|---|---|---|---|---|
| | Customized Web Server | Website/ Software | LCD | Mobile App | SD Card | Website |
| [1] | √ | | √ | | √ | |
| [2] | | √ | √ | | √ | |
| [3] | | | | √ | | √ |
| [4] | √ | | | | √ | |
| [5] | | √ | | | √ | |
| [6] | | √ | √ | √ | | √ |


1. Bouzguenda, M.; Chtourou, S.; Alarfaj, M.; Sumsudeen, R.M.; Shwehdi, M. Arduino Uno Wi-Fi DeMilitarized Zone-based monitoring of solar photovoltaic systems. Measurement and Control 2022, 55, 136-145, doi:10.1177/00202940221090553.
2. Khaleel, K.; Atyia, T.H.; Al-Naib, A.M.I. Design and Development of Real-Time Data Acquisition of Photovoltaic Panel Parameters via IoT. NTU Journal of Renewable Energy 2022, 3, 1-8.
3. Le, P.T.; Tsai, H.L.; Le, P.L. Development and Performance Evaluation of Photovoltaic (PV) Evaluation and Fault Detection System Using Hardware-in-the-Loop Simulation for PV Applications. Micromachines 2023, 14, doi:10.3390/mi14030674.
4. İnner, B. Data monitoring system for solar panels with bluetooth. In Proceedings of the 2017 25th Signal Processing and Communications Applications Conference (SIU), 15-18 May 2017, 2017; pp. 1-4.
5. C, B.; H, M.-A.; H. B. A, S.; A. Bennani-Ben, A.; I, S.-B.; H, S. A real time, wireless and low cost data acquisition system for residential PV modules. In Proceedings of the 2020 6th IEEE International Energy Conference (ENERGYCon), 28 Sept.-1 Oct. 2020, 2020; pp. 417-422.
6. Didi, Z.; El Azami, I. Experimental Analysis and Monitoring of Photovoltaic Panel Parameters. International Journal of Advanced Computer Science and Applications 2023, 14, 151-157, doi:10.14569/IJACSA.2023.0140219.

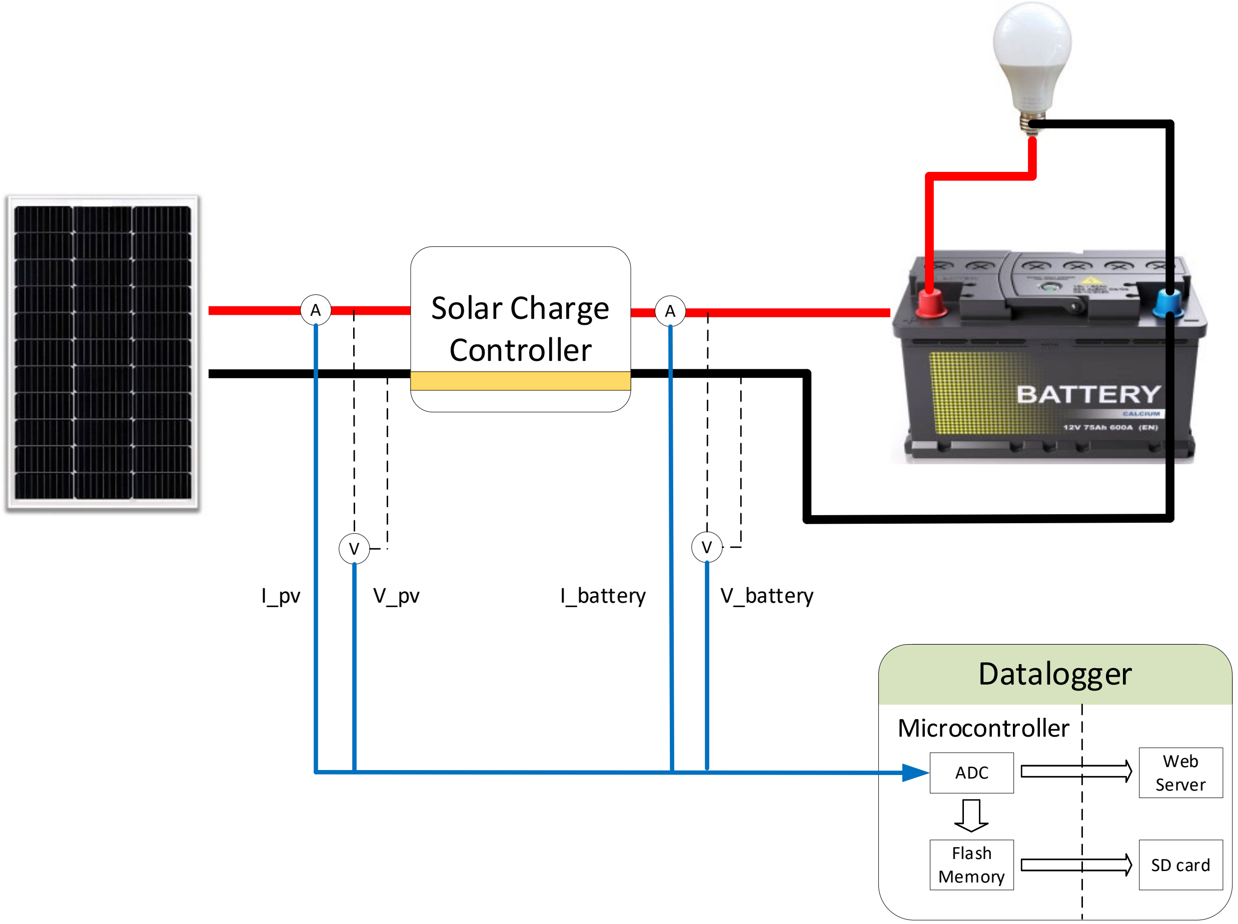
# Research Objectives

MEMORIAL UNIVERSITY

- Design a PV system data logger using different low-power strategies to minimize power consumption without compromising performance.
- Design a PV system data logger, using an HMI that consumes low power and displays historical data, and a remote data storage solution that supports large data storage without extra charge.
- Design an open-source SCADA system based on IoT for a PV system, using locally installed middleware to manage the data flow, provide customizable HMIs, and control the PV system load.
- Design an open-source IoT-SCADA system for monitoring and controlling a PV system, using two IoT platforms, increased the system robustness by the data redundancy. Images of the load can be accessed on a web server, enabling the visual verification of the load status.

# 1. Power Consumption Minimization of a Low-Cost Data Logger for PV system

MEMORIAL UNIVERSITY

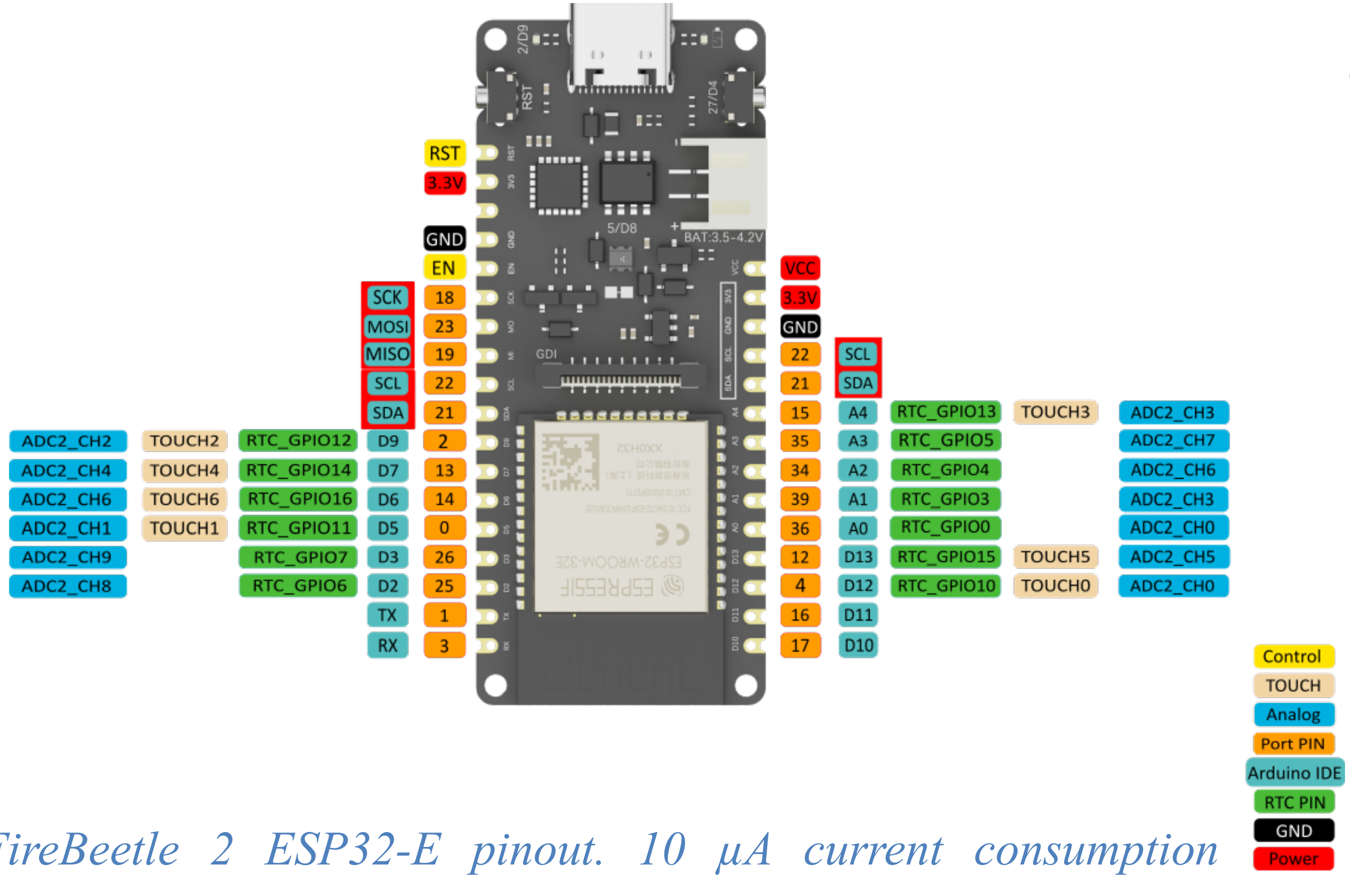



*Connection diagram of PV system and developed data logger.*

# 1. Power Consumption Minimization of a Low-Cost Data Logger for PV system

## Components

➢ FireBeetle 2 ESP32-E, supports Wi-Fi and Bluetooth




*FireBeetle 2 ESP32-E pinout. 10 µA current consumption during deep sleep*

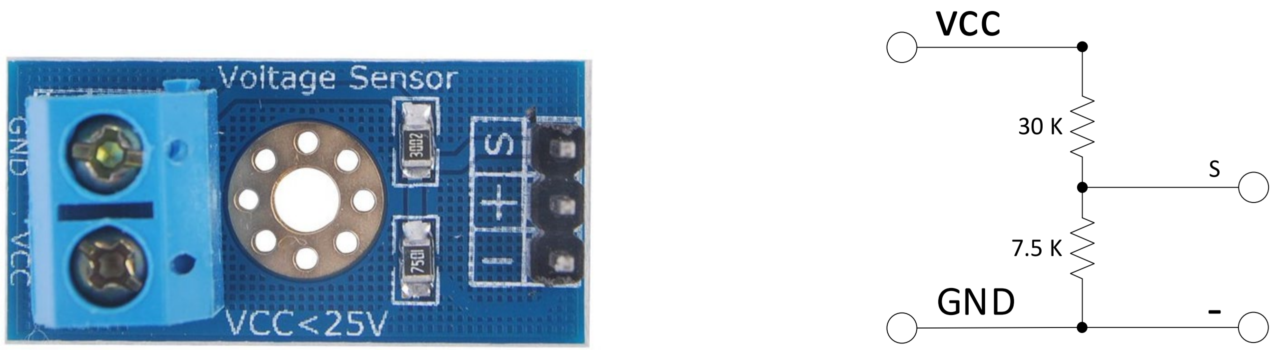
*Comparison of FireBeetle 2 ESP32-E and Arduino UNO.*

| Components | FireBeetle 2 ESP32-E | Arduino UNO |
|---|---|---|
| Processor | dual-core Tensilica LX6 | ATmega328P |
| Operating Voltage | 3.3 V | 5 V |
| CPU Speed | Up to 240MHz | Up to 16MHz |
| Analog In/Out/Dual Pins | 4/0/9 | 6/0/0 |
| Digital In/Out/Dual Pins | 0/0/10 | 0/0/8 |
| Flash | 4 MB | 32 kB |
| SRAM | 520 kB | 2 kB |

1. Power Consumption Minimization of a Low-Cost Data Logger for PV system

Components

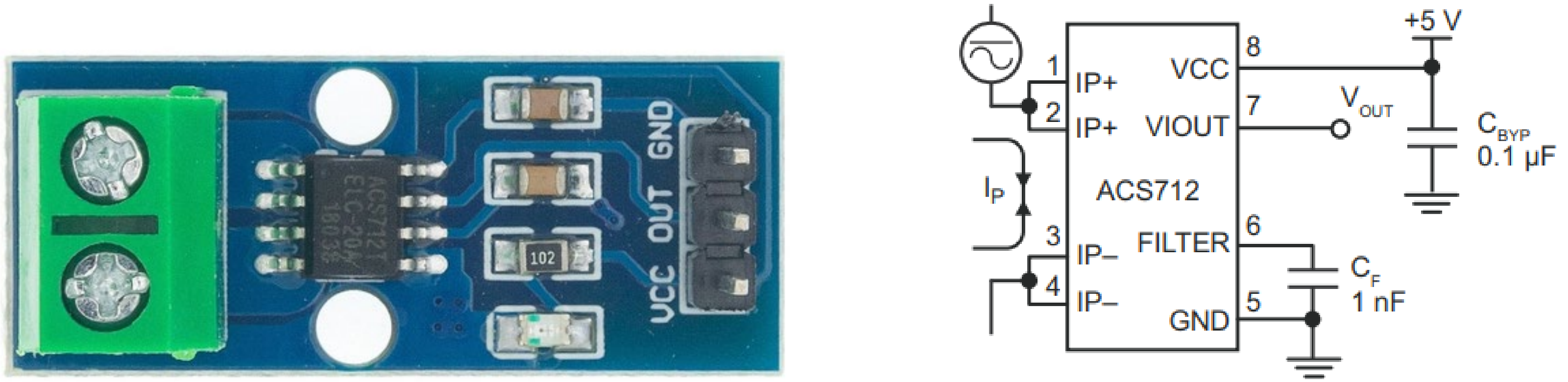
➢ 0-25 V Voltage divider




*DC 0-25V voltage sensor. (a) Real image. (b) Working diagram.*

Components

➢ ACS712 Current sensor



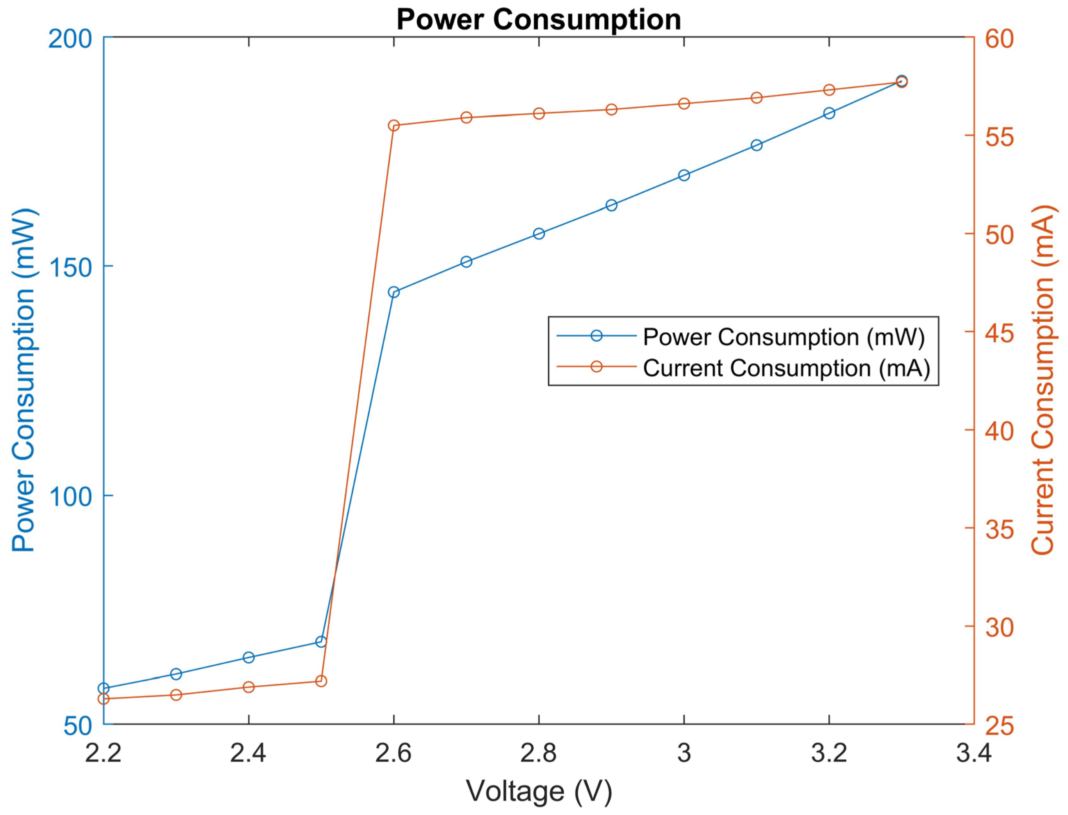

*ACS712-20A Current Sensor. (a) Real image. (b) Connection schematic.*

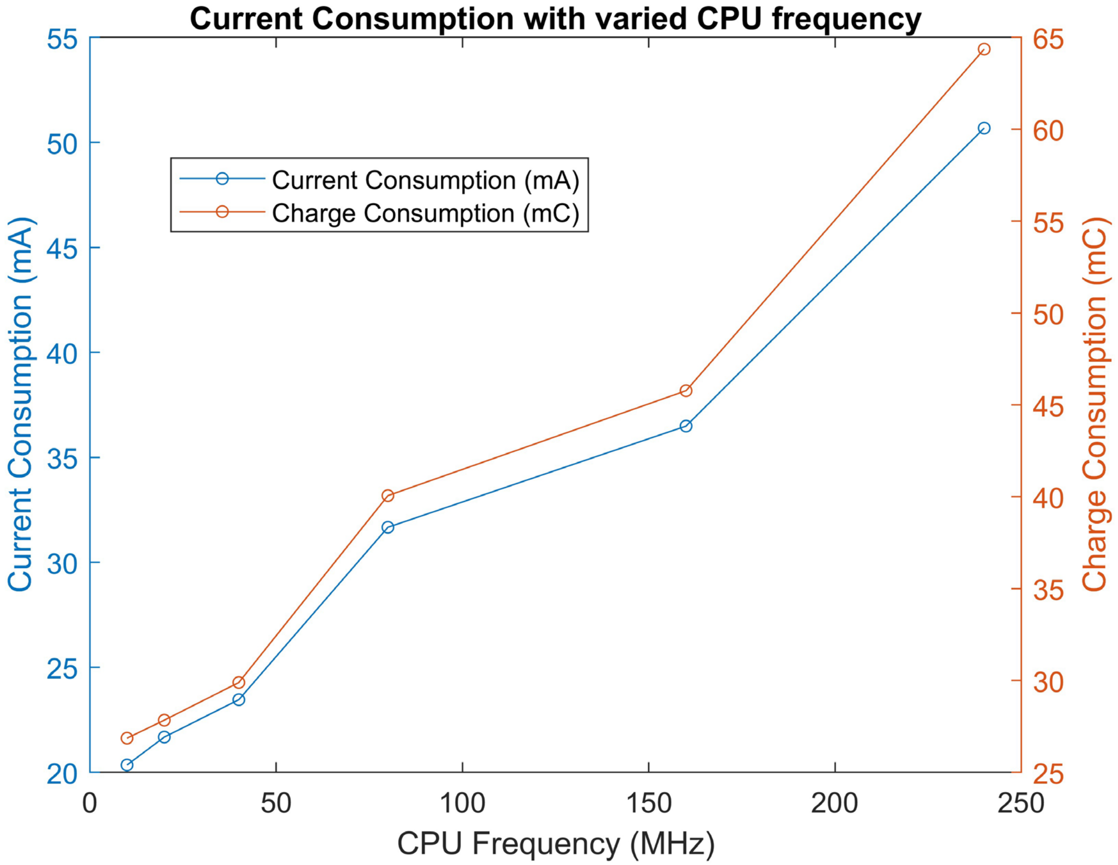
# 1. Power Consumption Minimization of a Low-Cost Data Logger for PV system

Low Power Techniques

$$p = CV^2 f$$

*C* is the total capacitance
*V* is the supply voltage
*f* is the operating frequency




Fixed *f*, *p* decreases when *v* decreases

Fixed *v*, *p* decreases when *f* decreases

MEMORIAL UNIVERSITY

## Low Power Techniques

*ESP32 power modes with their active components and corresponding current consumptions.*

| Power Modes | Active Components | Current Consumption |
|---|---|---|
| **Active** | ESP 32 core, ULP coprocessor, RTC, peripherals, Bluetooth, Radio, Wi-Fi | 95-240 mA |
| **Modem Sleep** | ESP 32 core, ULP coprocessor, RTC, peripherals | 2-4 mA @ 2 MHz<br>20~25 mA @ 80 MHz<br>30~50 mA @ 240 MHz |
| **Light Sleep** | ULP coprocessor, RTC, peripherals | ~0.8 mA |
| **Deep Sleep** | ULP coprocessor, RTC | 150 μA |
| | RTC | 10 μA |
| **Hibernation** | RTC (timer, part of RTC GPIOs) | 5 μA |

# 1. Power Consumption Minimization of a Low-Cost Data Logger for PV system

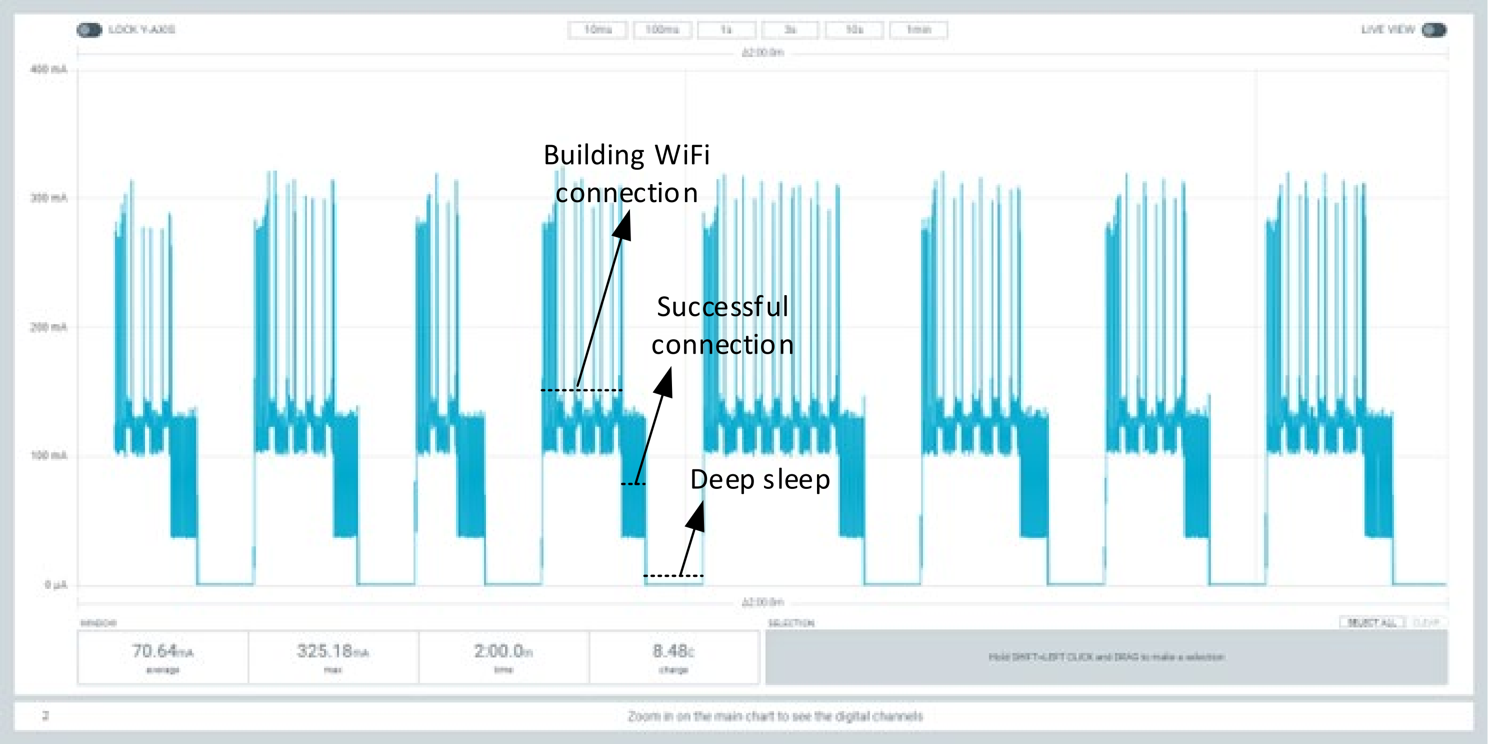
## Low Power Techniques

*Current and charge consumption comparison between SD card and the flash memory.*

| Memory | Operation | Current Consumption (mA) | Period (ms) | Discharge (mC) |
|---|---|---|---|---|
| SD card | Initialization | 65.49 | 4620 | 302.4 |
| | Read | 62.10 | 8.34 | 0.516 |
| | Write | 58.15 | 144.1 | 8.38 |
| Flash | Read | 38.84 | 13.05 | 0.507 |
| | Write | 41.64 | 10.11 | 0.421 |

# 1. Power Consumption Minimization of a Low-Cost Data Logger for PV system

## Low Power Techniques




*Current consumption during Wi-Fi connection.*

Average time required to build Wi-Fi connection: **7.575 s**

Average current during Wi-Fi building process: **118.27 mA**

Average current after Wi-Fi is connected: **61.5 mA**

Average current during deep sleep: **1.35 mA**

Deep sleep mode saves power, but waking up and reconnecting to Wi-Fi increase power

$$T \times 61.5\ \text{mA} = 7.575\ \text{s} \times 118.27\ \text{mA} + (T - 7.575\ \text{s}) \times 1.35\ \text{mA}$$

$T = 14.717$ s, as the shortest monitoring period

# 1. Power Consumption Minimization of a Low-Cost Data Logger for PV system

MEMORIAL UNIVERSITY

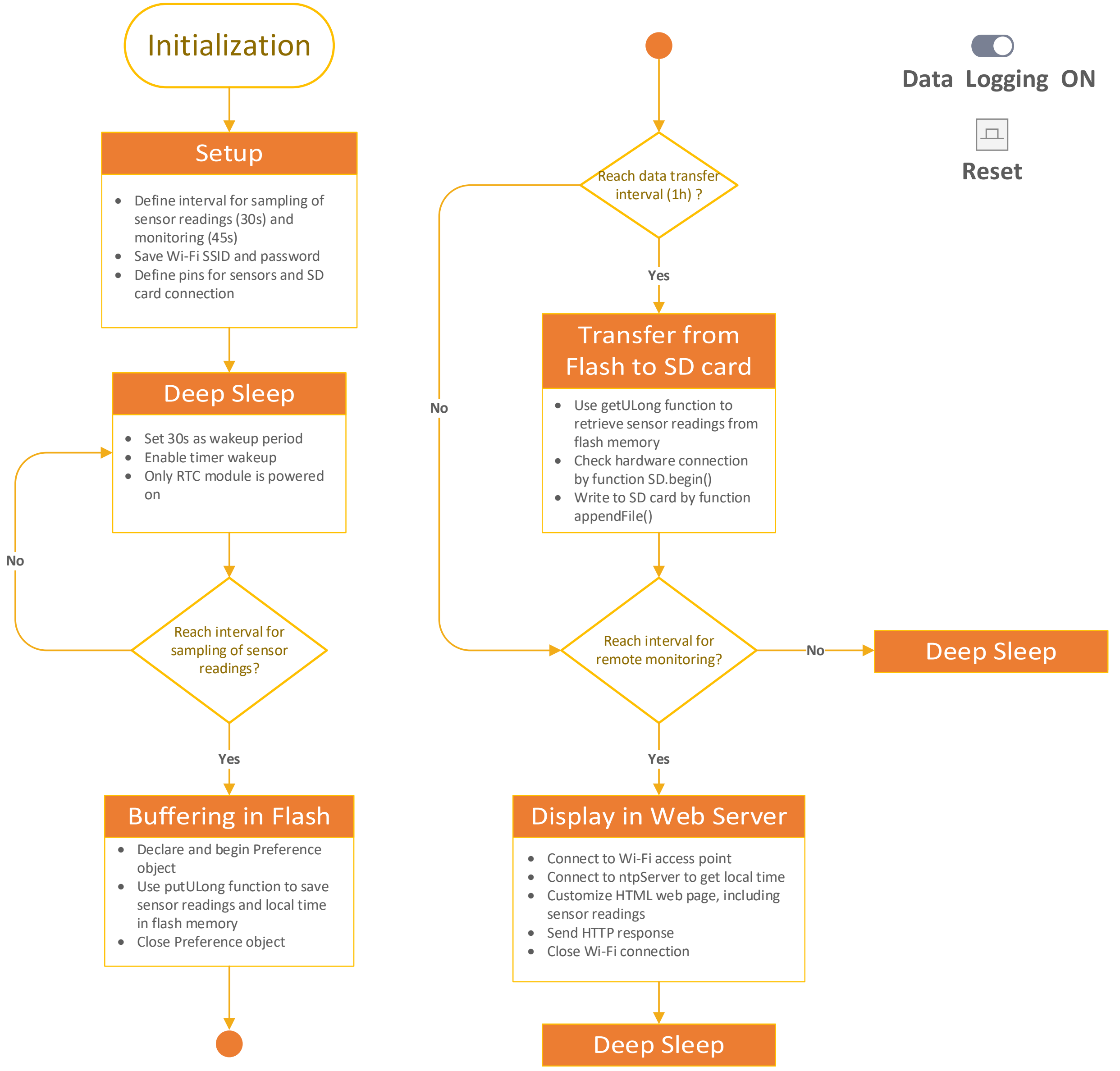
## Low Power Techniques

*The ratio of monitoring times to average current at different Wi-Fi connection intervals.*

| Wi-Fi connection interval (s) | 10 | 30 | 45 | 60 |
|---|---|---|---|---|
| Monitoring times within 600 seconds | 60 | 20 | 13.33 | 10 |
| Average current (mA) | 23.6 | 7.34 | 4.66 | 4.02 |
| Monitoring times/ average current | 2.54 | 2.72 | **2.86** | 2.49 |

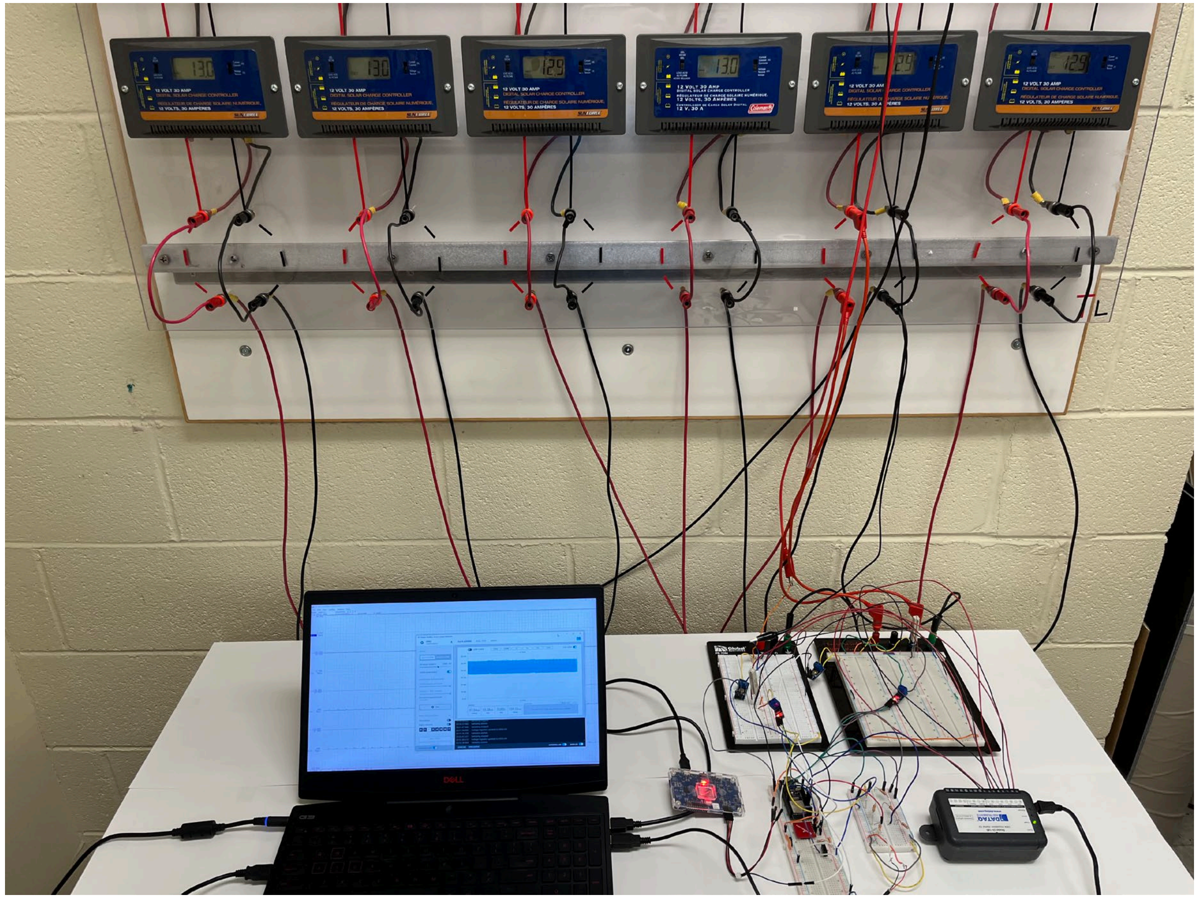
# 1. Power Consumption Minimization of a Low-Cost Data Logger for PV system

## Program Flowchart



## 1. Power Consumption Minimization of a Low-Cost Data Logger for PV system

MEMORIAL UNIVERSITY

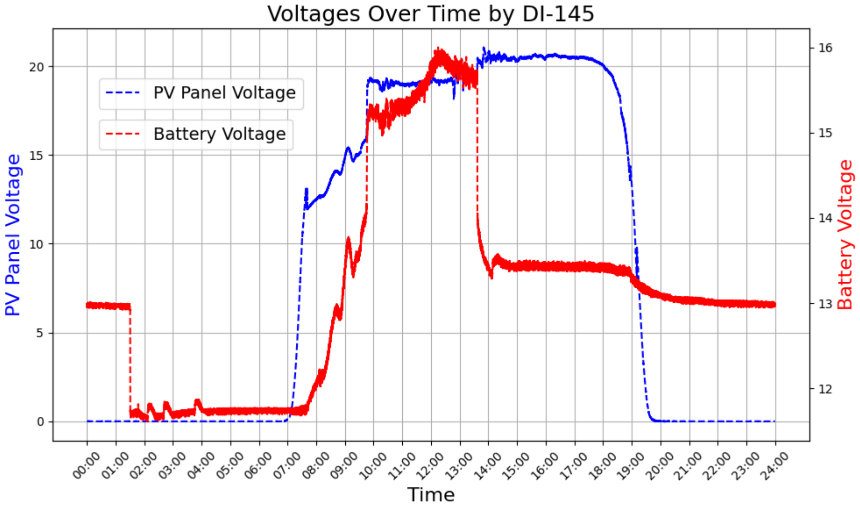


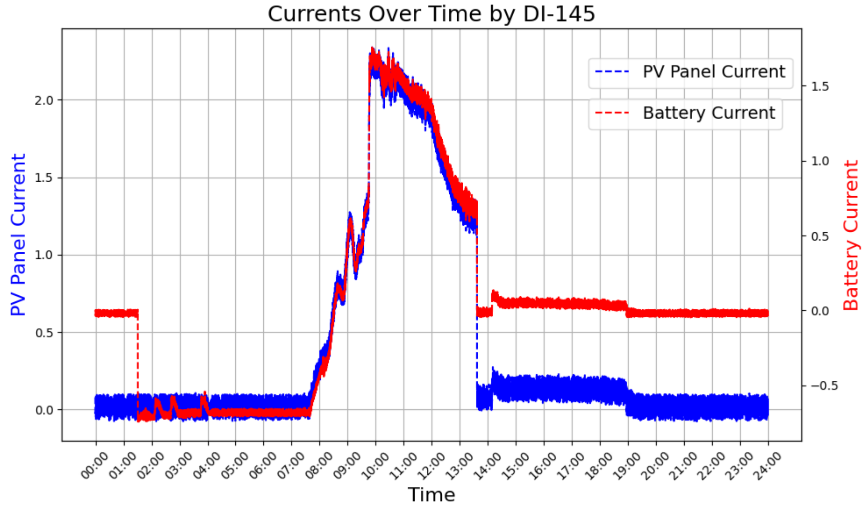
*Experiment test setup.*

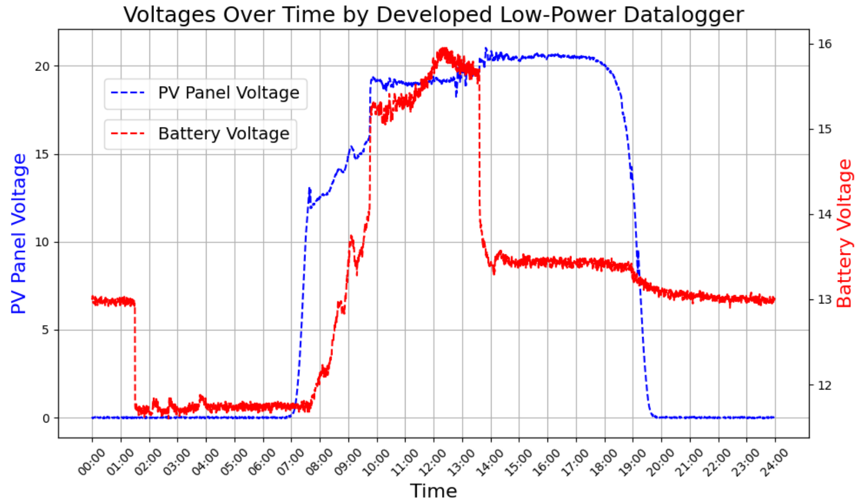
DATAQ® DI-145: a data acquisition device

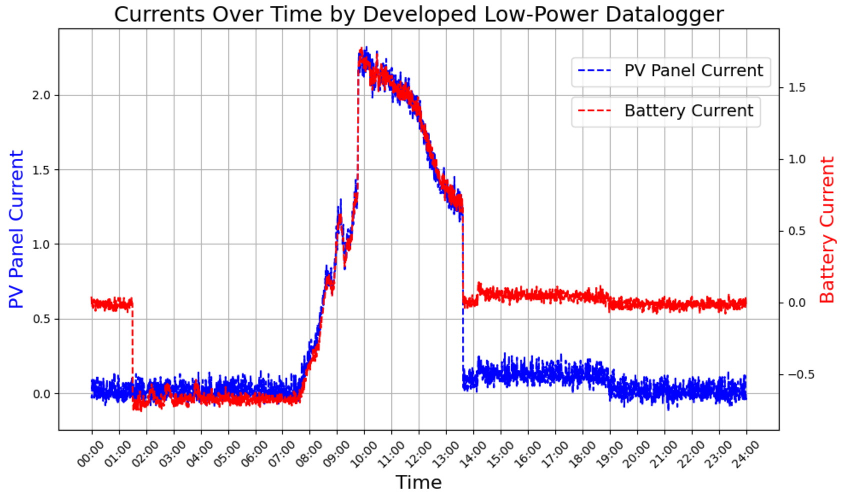
Power Profiler Kit II: measure the microcontroller power consumption

# 1. Power Consumption Minimization of a Low-Cost Data Logger for PV system



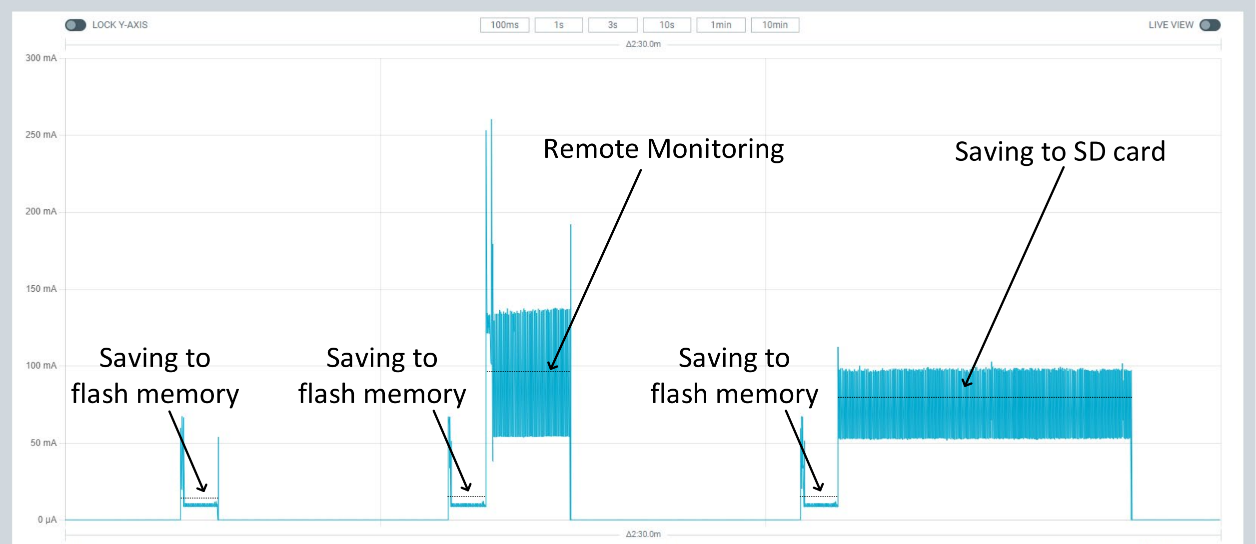




Data logger precision verification

# 1. Power Consumption Minimization of a Low-Cost Data Logger for PV system

MEMORIAL UNIVERSITY



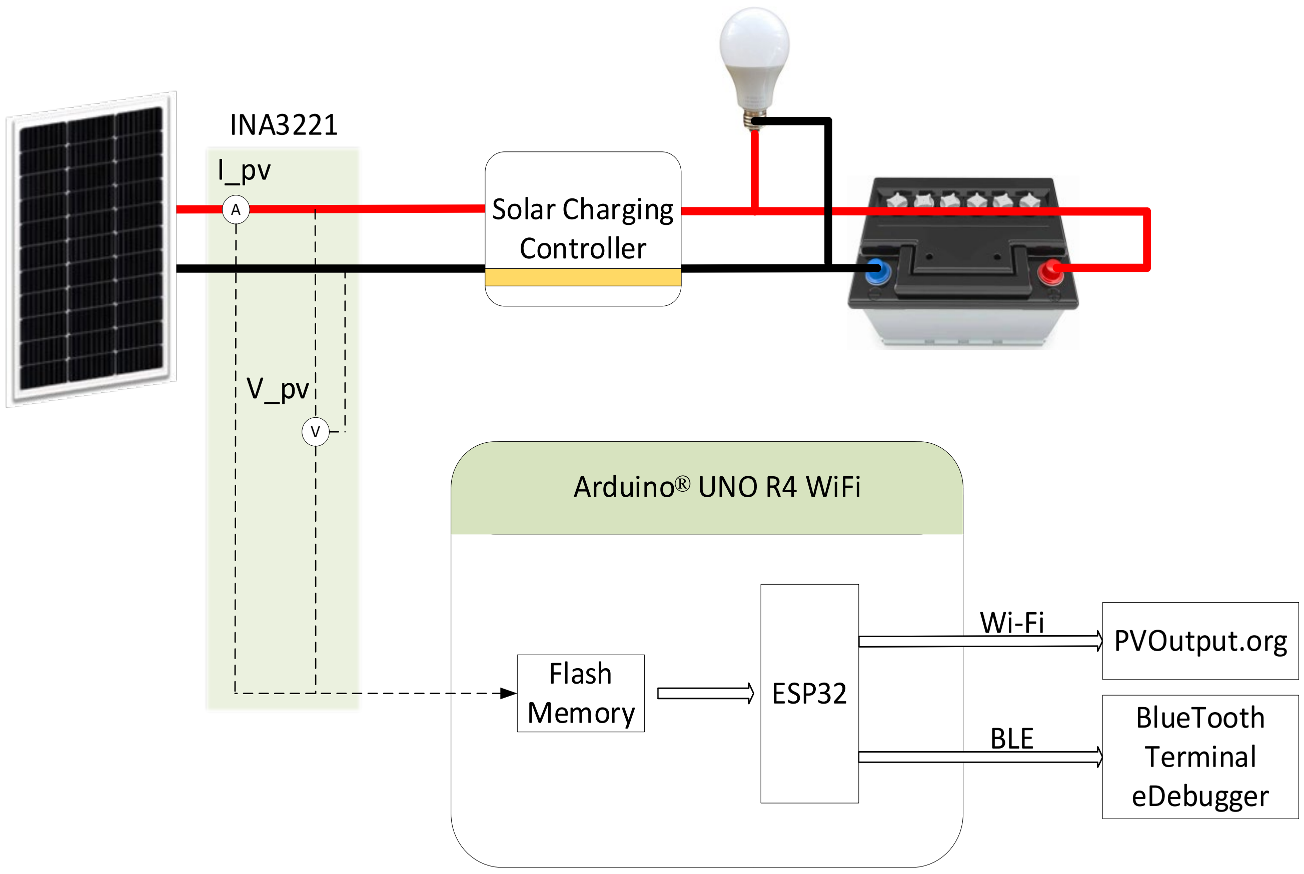

*Current consumption including all scenarios of the data logger tasks.*

*Web page showing electrical parameters of monitored PV system.*

**MUN ECE PV SYSTEM DATA LOGGER: REAL-TIME DISPLAY**

| Time | PV Panel Voltage (V) | PV Panel Current (A) | Battery Voltage (V) | Battery Current (A) |
|---|---|---|---|---|
| 11:38:27 | 19.01 | 1.93 | 15.44 | 1.40 |
| 11:39:12 | 18.99 | 1.97 | 15.44 | 1.43 |
| 11:39:57 | 19.01 | 1.94 | 15.46 | 1.43 |
| 11:40:42 | 19.01 | 1.92 | 15.50 | 1.42 |
| 11:41:27 | 18.99 | 1.94 | 15.44 | 1.42 |
| 11:42:12 | 18.94 | 2.01 | 15.36 | 1.43 |
| 11:42:57 | 18.90 | 2.08 | 15.33 | 1.45 |
| 11:43:42 | 18.91 | 2.05 | 15.40 | 1.47 |
| 11:44:27 | 18.91 | 2.04 | 15.39 | 1.46 |
| 11:45:12 | 18.89 | 2.05 | 15.37 | 1.45 |
| 11:45:57 | 19.00 | 1.90 | 15.43 | 1.38 |
| 11:46:42 | 18.97 | 1.94 | 15.45 | 1.41 |

## Block diagram



MEMORIAL UNIVERSITY

Components

➢ Arduino UNO R4 Wi-Fi

supports Wi-Fi and Bluetooth

| | Arduino® UNO R4 Wi-Fi | Arduino® UNO Rev3 |
|---|---|---|
| SKU | ABX00087 | A000066 |
| Microcontroller | Renesas RA4M1<br>(Arm® Cortex®-M4) | ATmega328P |
| Digital I/O Pins | 14 | 14 |
| Analog Input Pins | 6 | 6 |
| Operating Voltage (V) | 5<br>(3.3, for ESP32-S3) | 5 |
| Input Voltage (V) | 6-24 | 7-12 |
| DC Current per I/O Pin (mA) | 8 | 20 |
| Clock Speed (MHz) | 48<br>(up to 240, for ESP32-S3) | 16 |
| Memory | 256 kB Flash,<br>32 kB RAM | 32 kB Flash,<br>2 kB SRAM |
| Wi-Fi & Bluetooth connectivity | Yes | No |
| $I^2C$ | Yes | Yes |

*Comparison of technical specifications between Arduino® UNO R4 Wi-Fi and Arduino® UNO Rev3.*

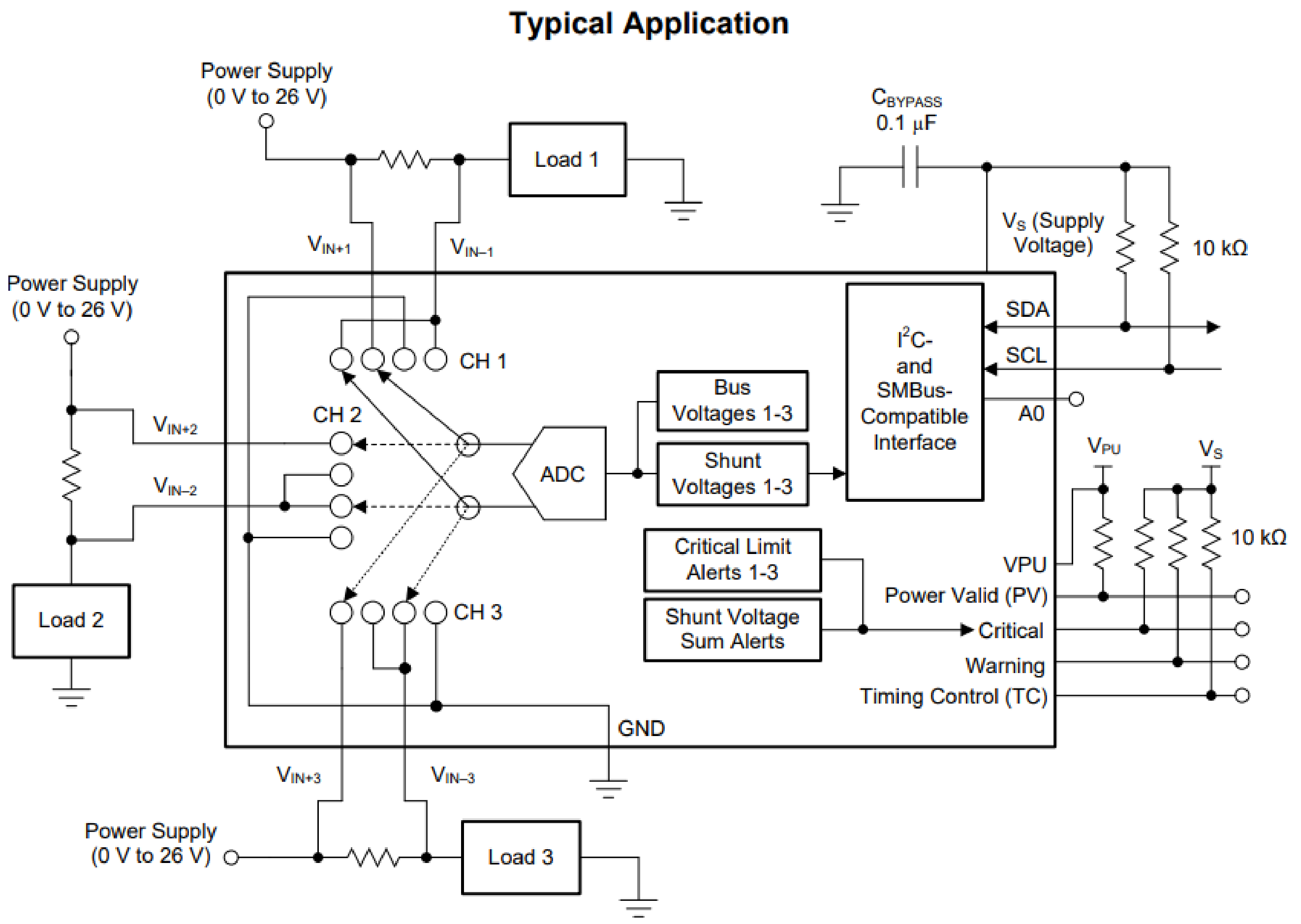
Components

➢ INA3221:

shunt and bus voltage monitor, able to measure voltage and current

I = Shunt voltage/ shunt resistor

V = Bus voltage




*INA3221 schematic diagram*

## 2. A novel design of a low-cost SCADA system for monitoring standalone PV systems

Components

- ➢ BlueTooth Terminal eDebugger

Bluetooth debugging assistant application running on Android OS

- ➢ PVOutput.org

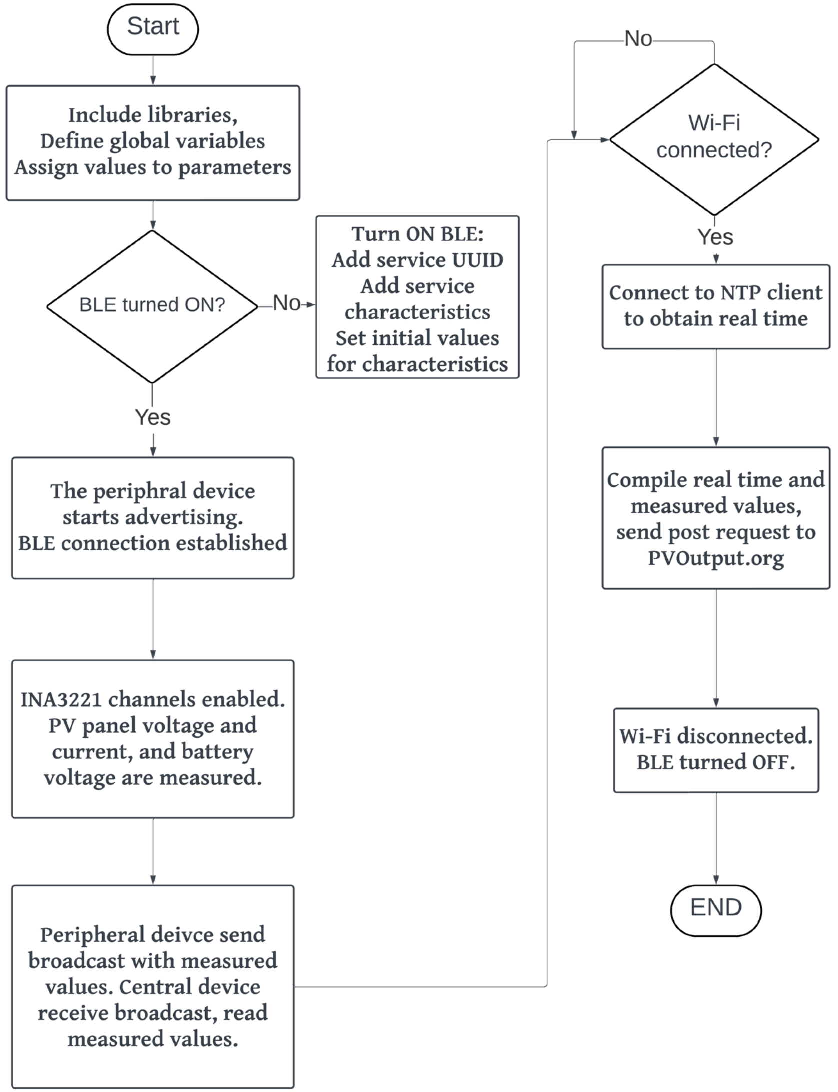
free service for sharing PV output data

2,515,654 solar panels monitored

61,480,020 PV panel outputs recorded

| | CSV loader | Live loader |
|---|---|---|
| Maximum Previous Days | No Limit | 14<br>(90, in Donation Mode) |
| Data Interval | Up to one day | Up to five minutes |
| Maximum Number for per upload | 200 | 288 |
| Supported Parameters by both | Output Date,<br>Energy Generation,<br>Energy Consumption | Output Date,<br>Energy Generation, Energy Consumption |
| Supported Parameters by CSV loader exclusively | Energy Exported, Peak Power, Peak Time, Conditions, Temperature Min, Temperature Max, Comments, Import Peak, Import Off Peak, Import Shoulder, Import High Shoulder, Export Peak, Export Off Peak, Export Shoulder, Export High Shoulder | / |
| Supported Parameters by Live loader exclusively | / | Output Time,<br>Power Generation, Power Consumption, Temperature, Voltage |

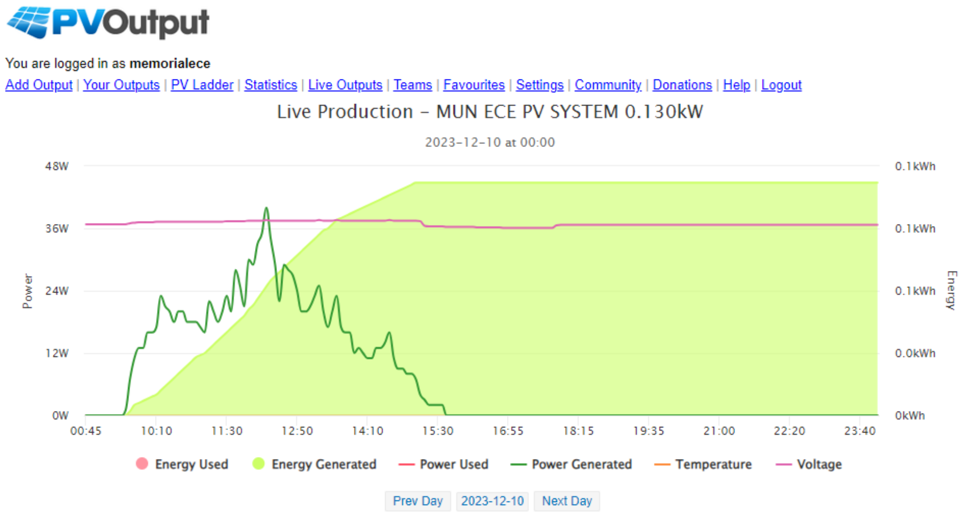
Program flowchart



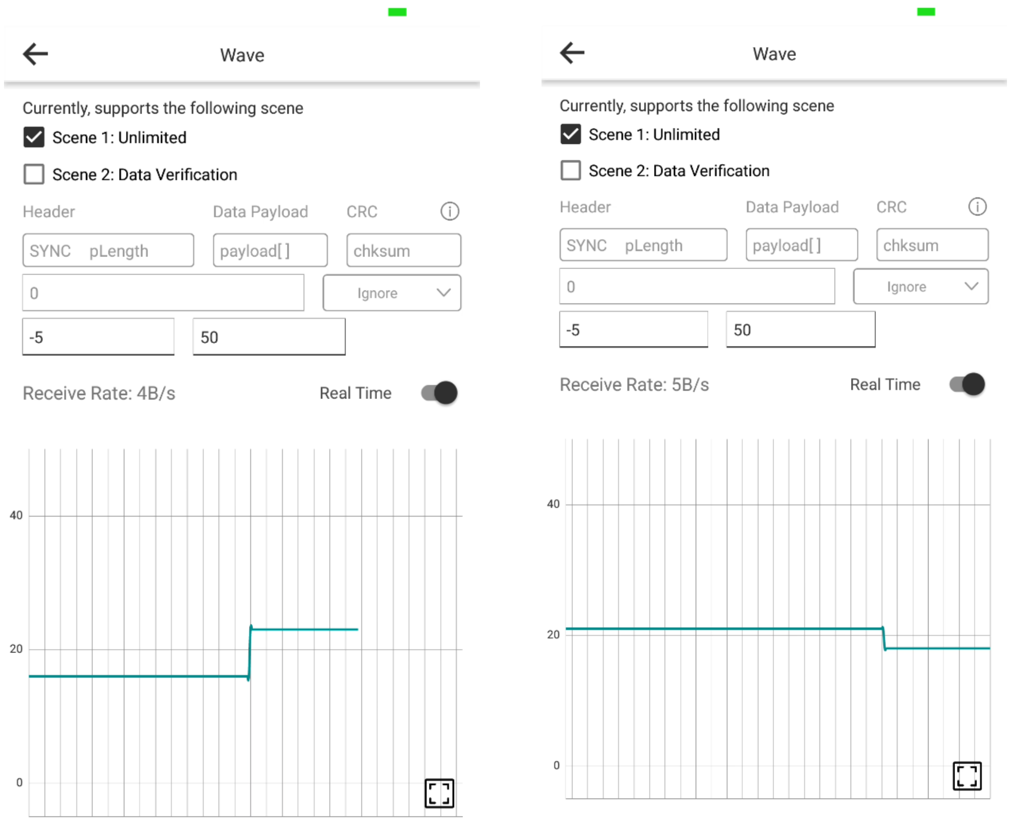
## Experimental Results

| PV System BLE Service | UUID | Result |
|---|---|---|
| Generic Access | 00001800-0000-1000-8000-00805f9b34fb | \ |
| Generic Attribute | 00001801-0000-1000-8000-00805f9b34fb | \ |
| PV power Service | 0000180f-0000-1000-8000-00805f9b34fb | \ |
| Power Characteristic | 00002a19-0000-1000-8000-00805f9b34fb | \ |
| Property | \ | Read, Notify |
| Value | \ | (0x)19 |

*BLE service information between BTeD and the RTU.*



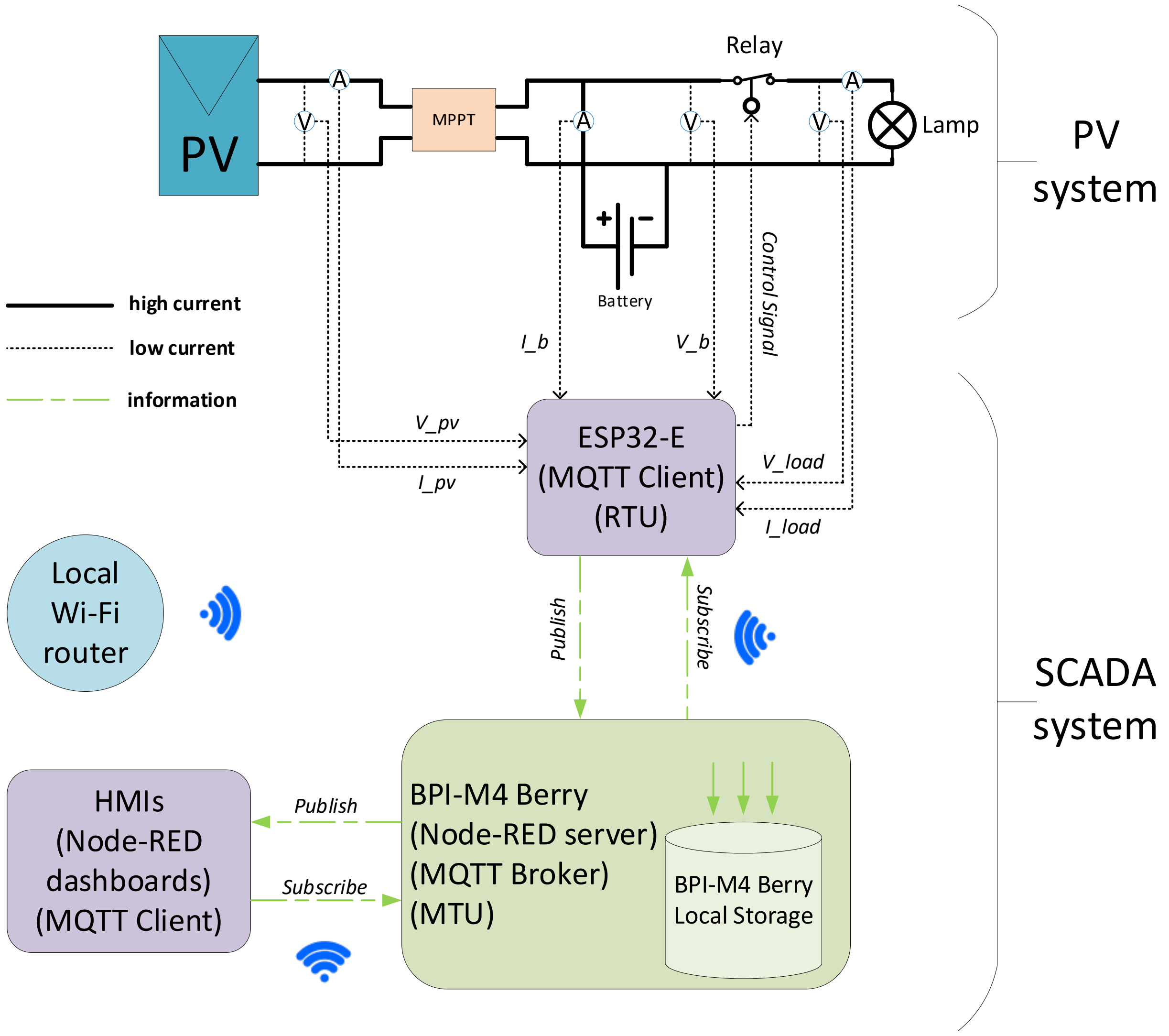

*PV panel output power on Dec. 10, 2023, recorded in PVOutput.org.*




*BTeD live recording of the PV panel output power.*

*(a) Increased power (b) Decreased power.*

- System Diagram




*Overview of proposed SCADA Design.*

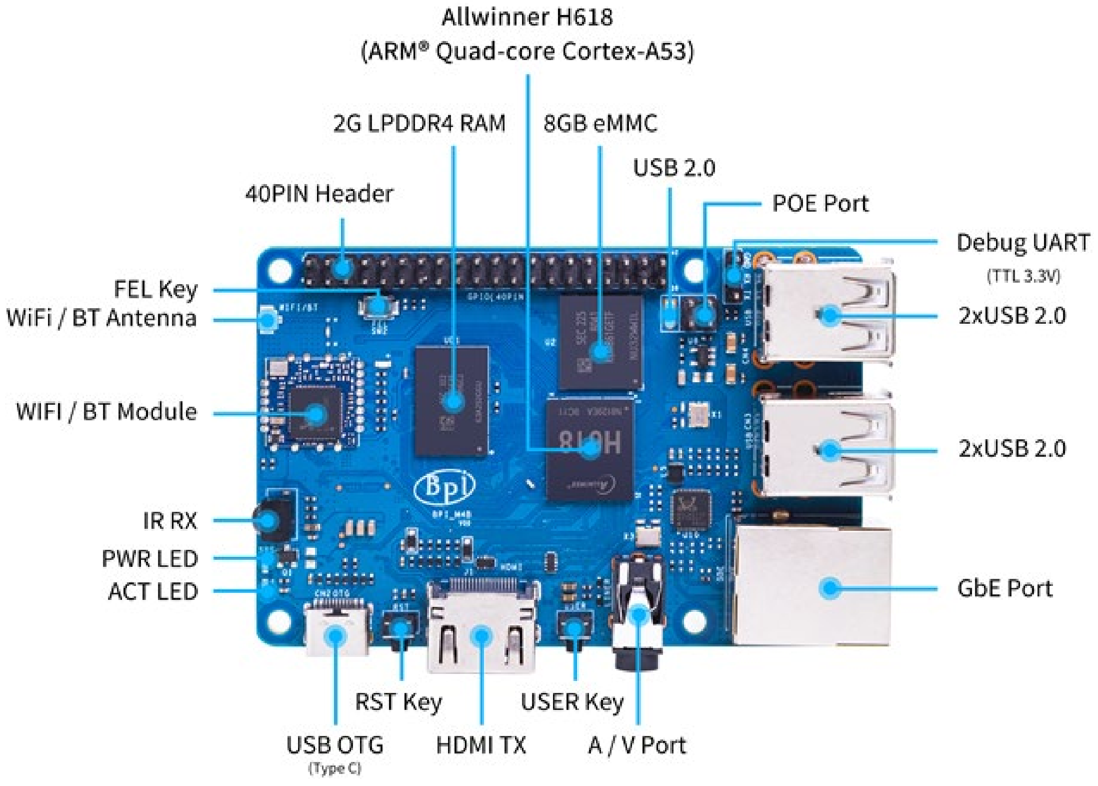
Components

➢ Banana Pi M4 Berry

- Single Board Computer (SBC) powered by the Allwinner H618 System-on-Chip (SoC)
- Full HDMI connector and M.2 PCIe 2.0 slot
- 2GB of LPDDR4 memory, 8GB of embedded

Multi-Media Controller (eMMC) storage

- Integrated Wi-Fi and Bluetooth capabilities



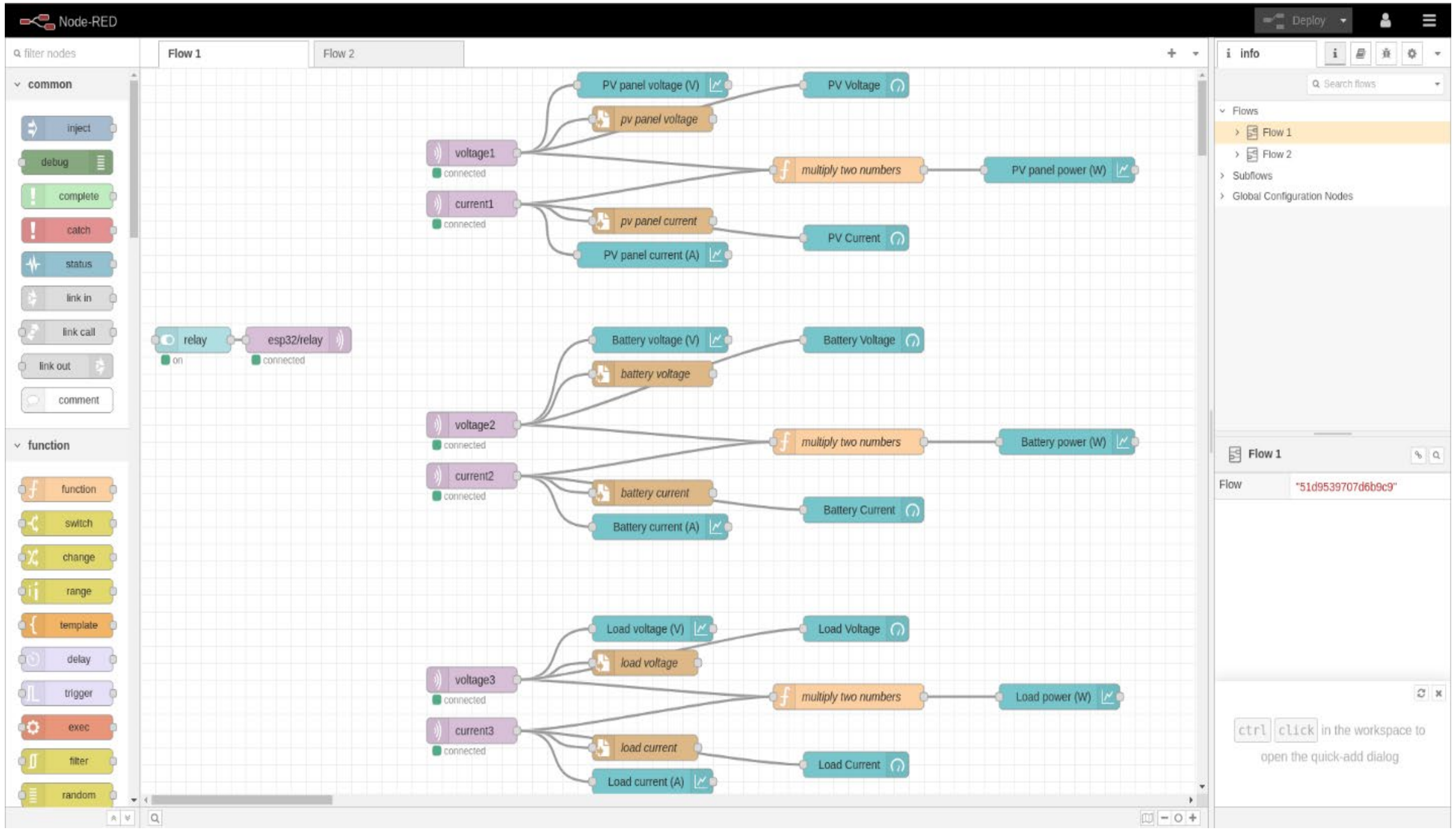

*BPI-M4 Berry*

MEMORIAL UNIVERSITY

## Components

➢ Node-RED

- flow-based programming using nodes
- Each node has a specific function: receiving data, performing an operation on this data, and then forwarding the processed data onwards.
- easy implementation of MQTT protocol
- supports local running



MEMORIAL UNIVERSITY

## Program Flowchart and Algorithm

**Algorithm 1:** Data acquisition, automatic control, display, and logging.

Initialization;

1. ESP32-E connects to the local TCP/IP Wi-Fi network;
2. Voltage/current sensors measure voltages/currents from the PV panel, the battery, and the load;
3. ESP32-E reads sensor values on Pin 36, 39, 35, 34, 12, 15;
4. ESP32-E (MQTT publisher) sends a connect request to the Node-RED server (MQTT broker) over IP;

**While** *ESP32-E receives a return code of 0* **do**

5. ESP32-E publishes the sensor data to the Node-RED server over the Wi-Fi network;
6. Node-RED logs the sensor data in the local BPI-M4 Berry flash memory;
7. Display the sensor data in Node-RED dashboards, and any other device over the Wi-Fi network;

**If** *the battery voltage is less than 13 volts or subscription message from Node-RED is OFF* **then**

8. Turn off the relay;

**Else**

9. Turn on the relay;

**End**

**End**

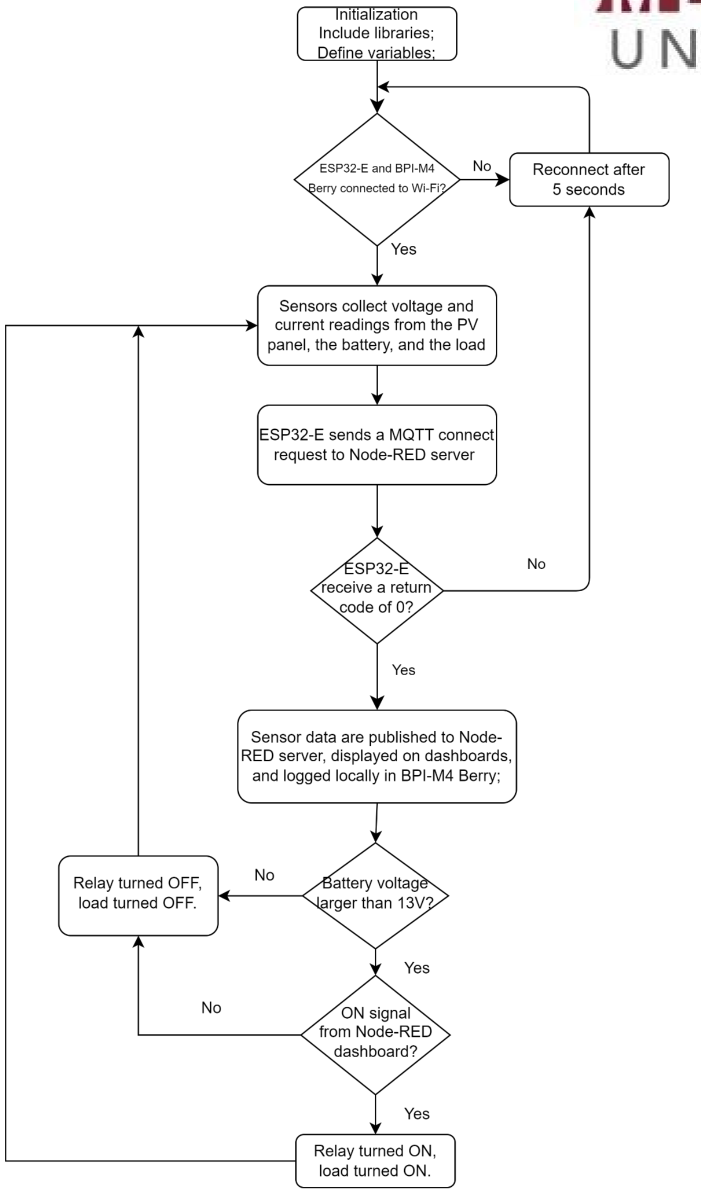
**If** *ESP32-E does not receive a return code of 0* **then**

10. Print “Attempting MQTT connection” in Arduino IDE Serial Monitor, reconnect in 5 seconds;

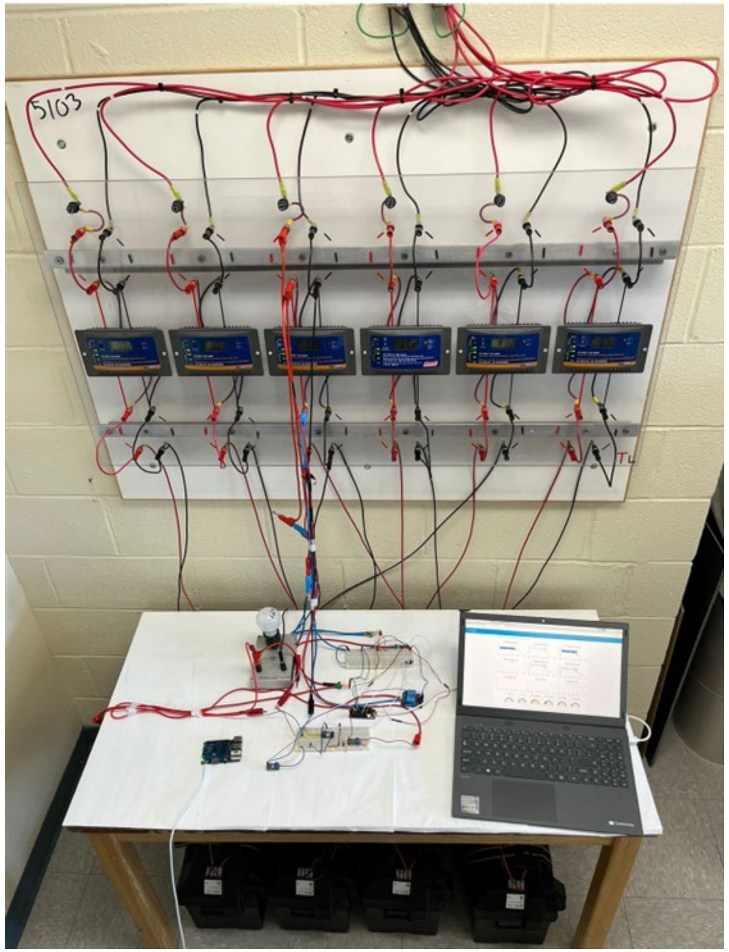
**Else**

11. Go to Step 1;

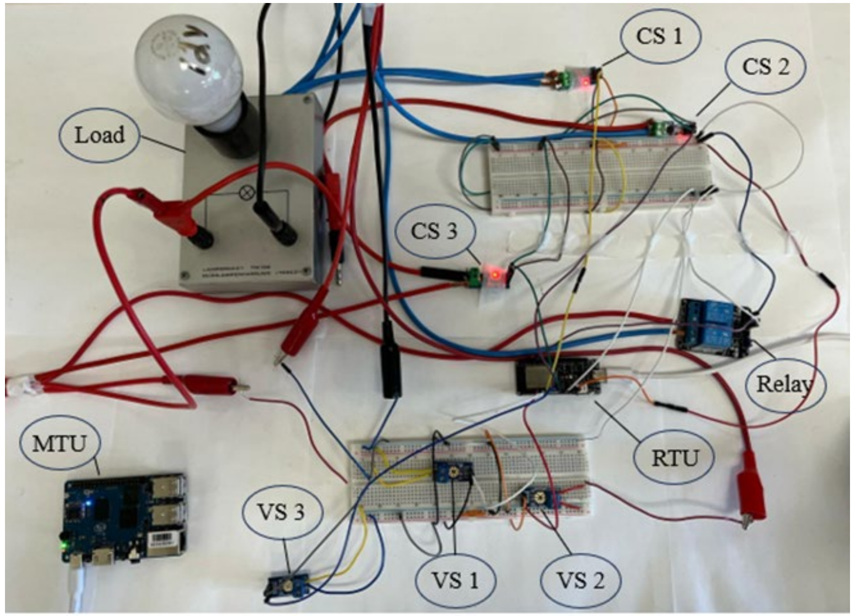
**End**



## Experimental Setup

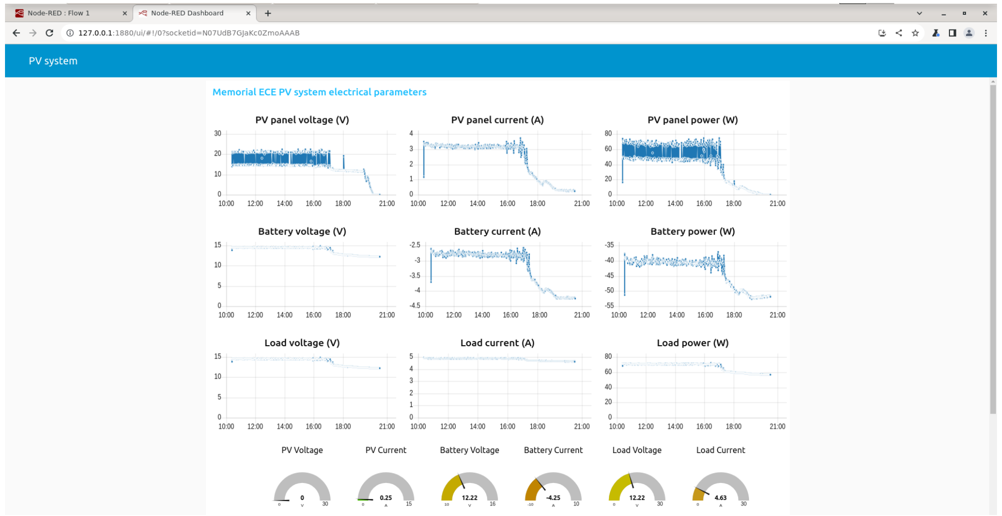



Experimental setup at MUN ECE laboratory.

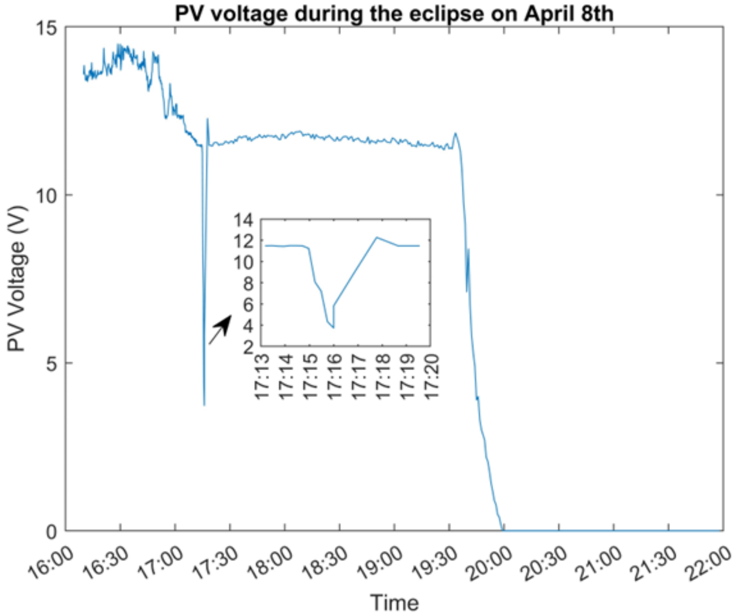


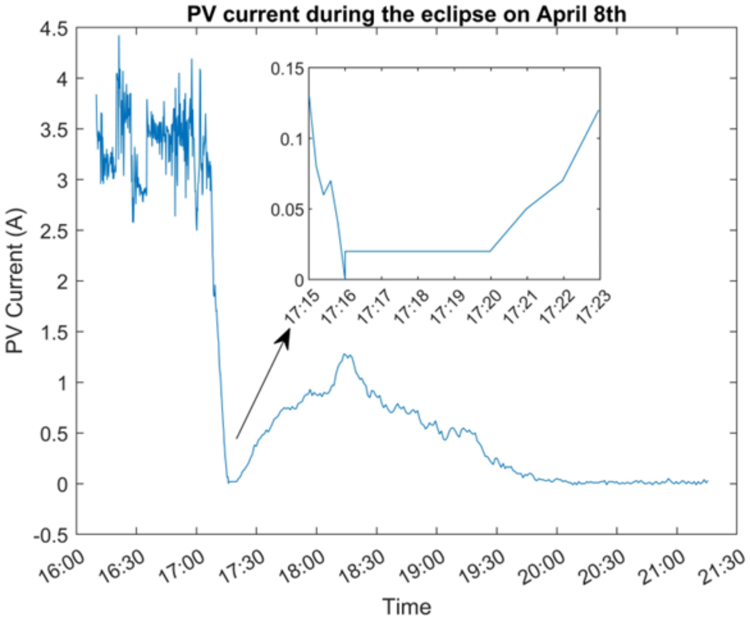

*Hardware implementation of the proposed SCADA system.*

## Results

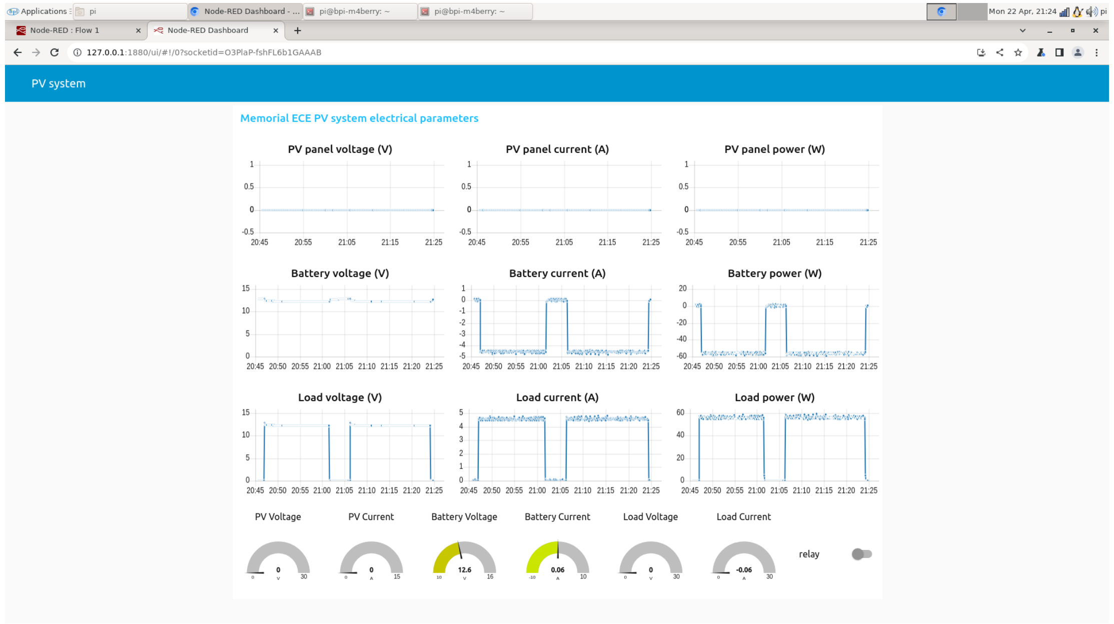



Node-RED dashboards showing the monitored values of the PV system.

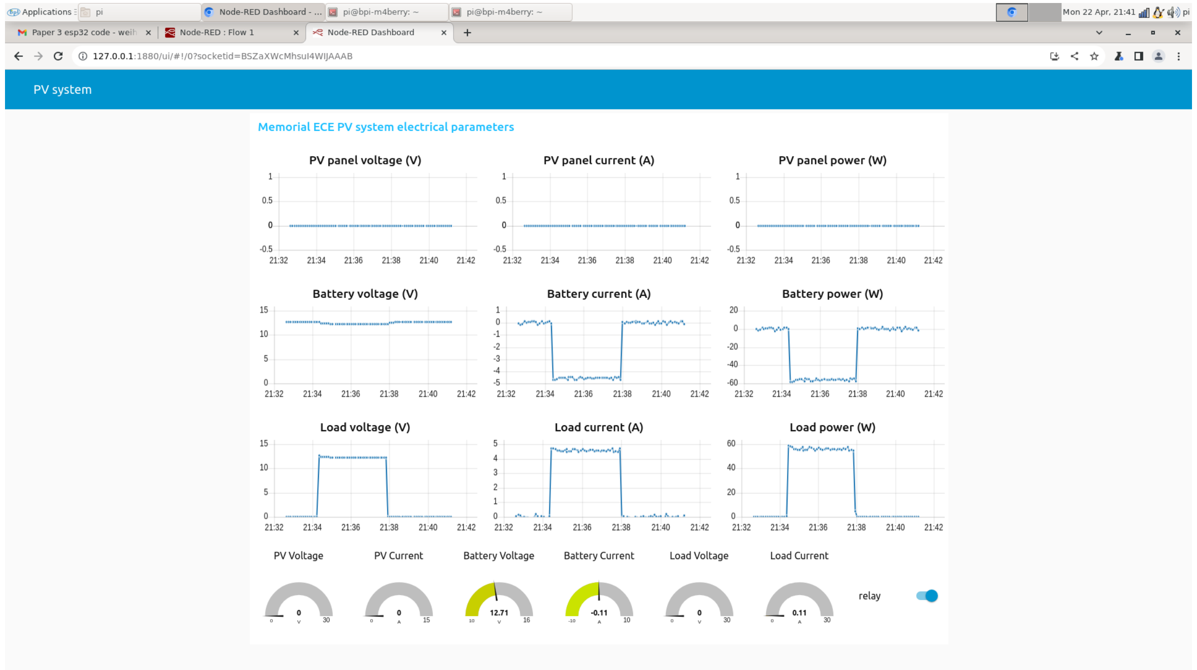


# Results



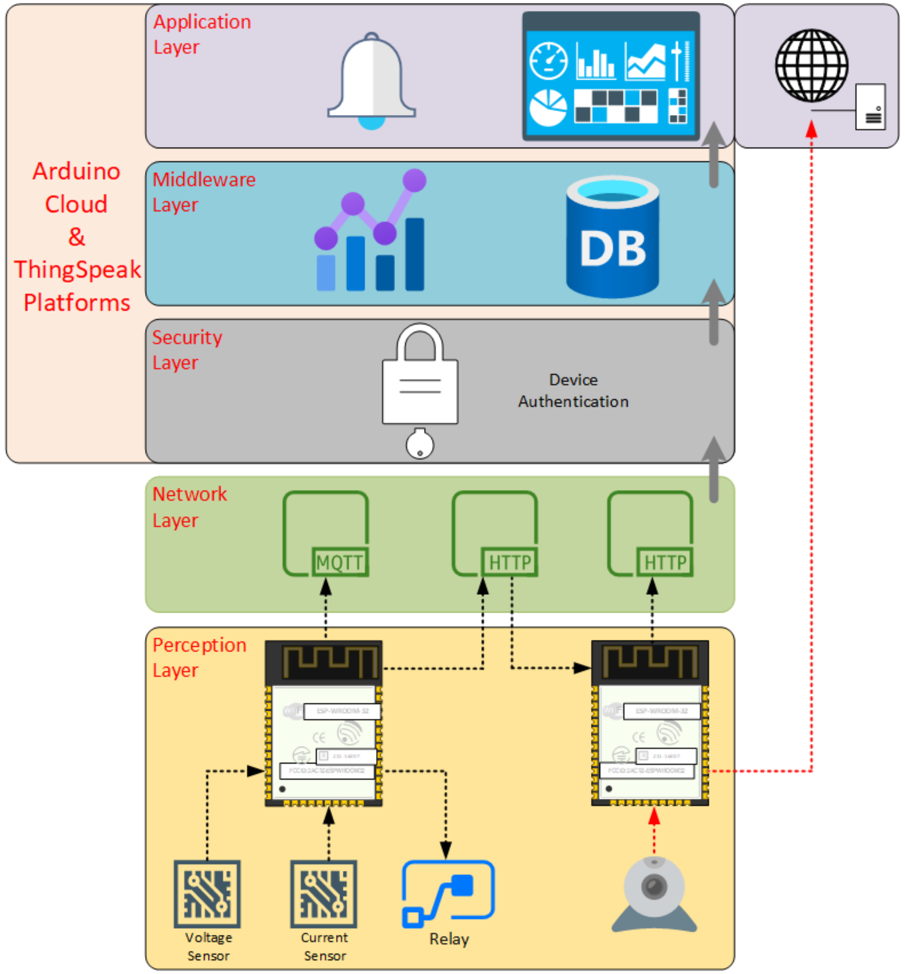

*Test results for supervisory control.*



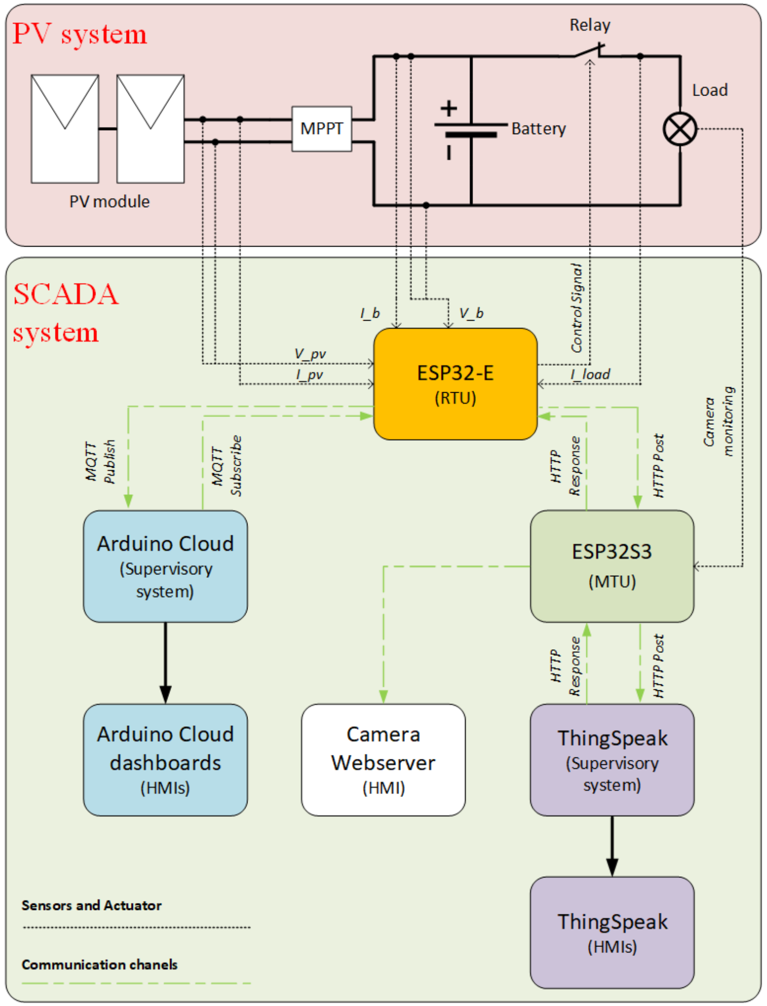

*Test results for local control.*

## System Diagram

*5-layer IoT-based SCADA architecture*




*Proposed design of 5-layer IoT-based SCADA architecture.*




*SCADA components of the proposed design.*

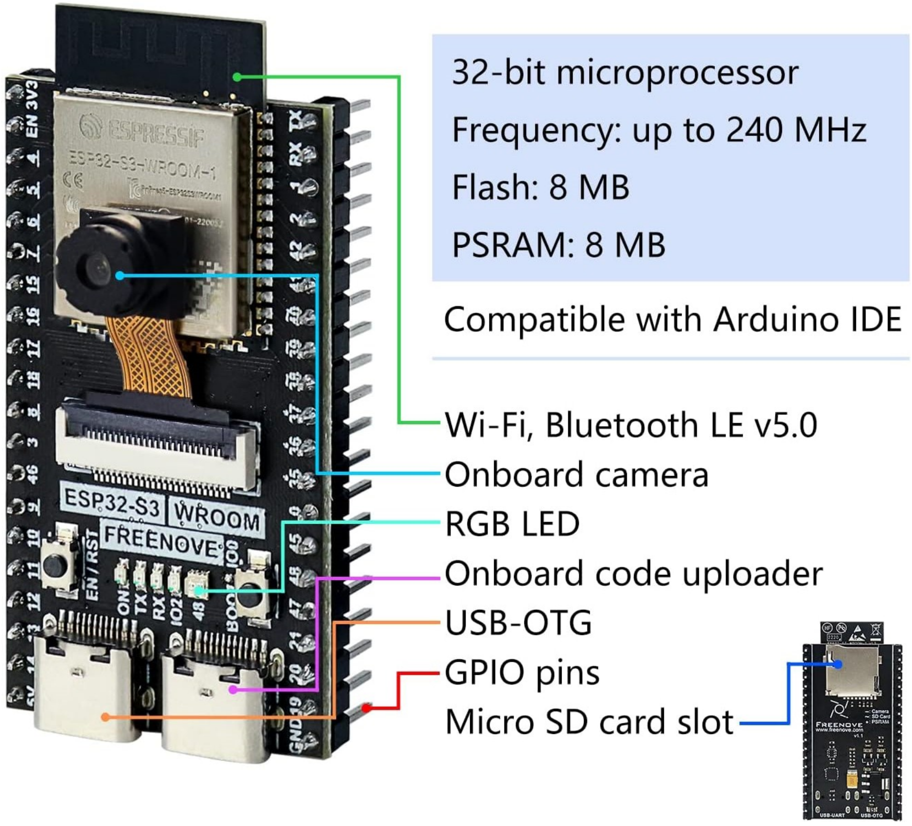
Components

➢ ESP32-S3

Xtensa® 32-bit LX7 dual-core processor, more advanced than Xtensa® 32-bit LX6 dual-core Processor in ESP32-E

Support PSRAM integration

More suitable for camera use



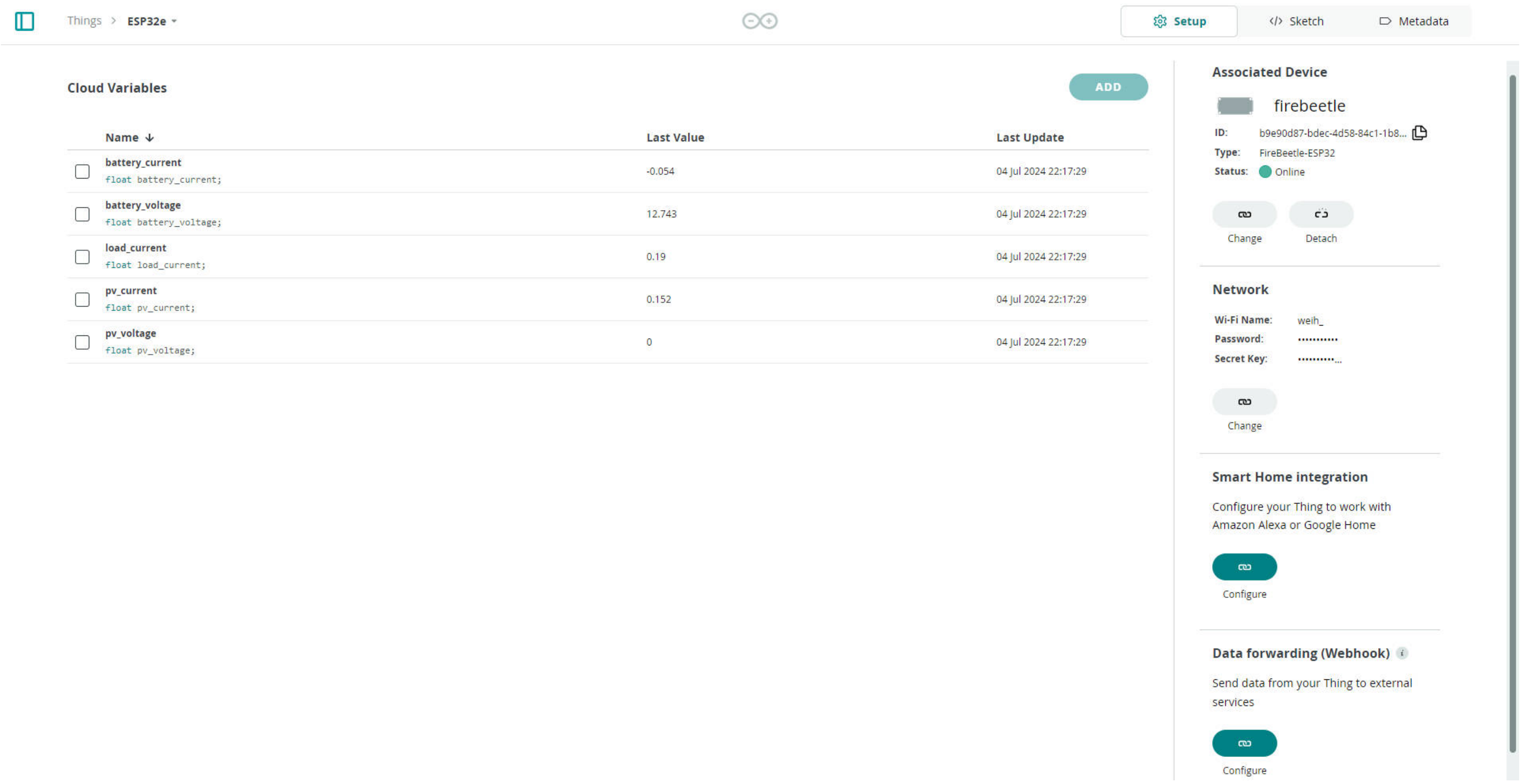

*ESP32-S3*

## 4. An IoT-SCADA architecture for PV system monitoring, control, and inspection in real time

### Components

➢ Arduino Cloud

- Device Management
- Security
- Data Visualization
- Cloud Programming
- Remote Control
- Over-the-Air Updates
- Cloud Services Integration

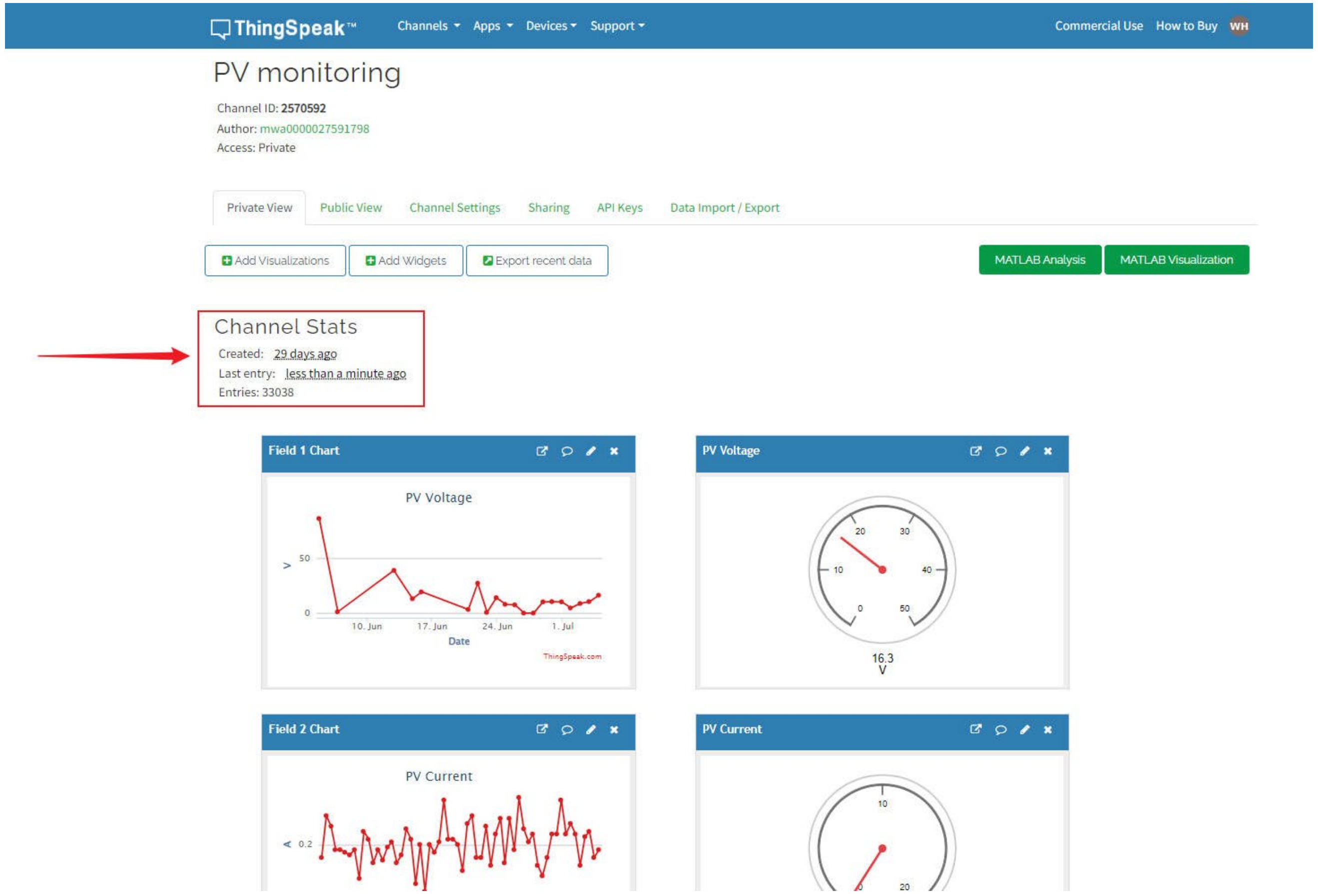



*Arduino Cloud interface*

Components

➢ ThingSpeak

- IoT analytics platform
- MATLAB integration
- Various analysis app available
- Cloud storage

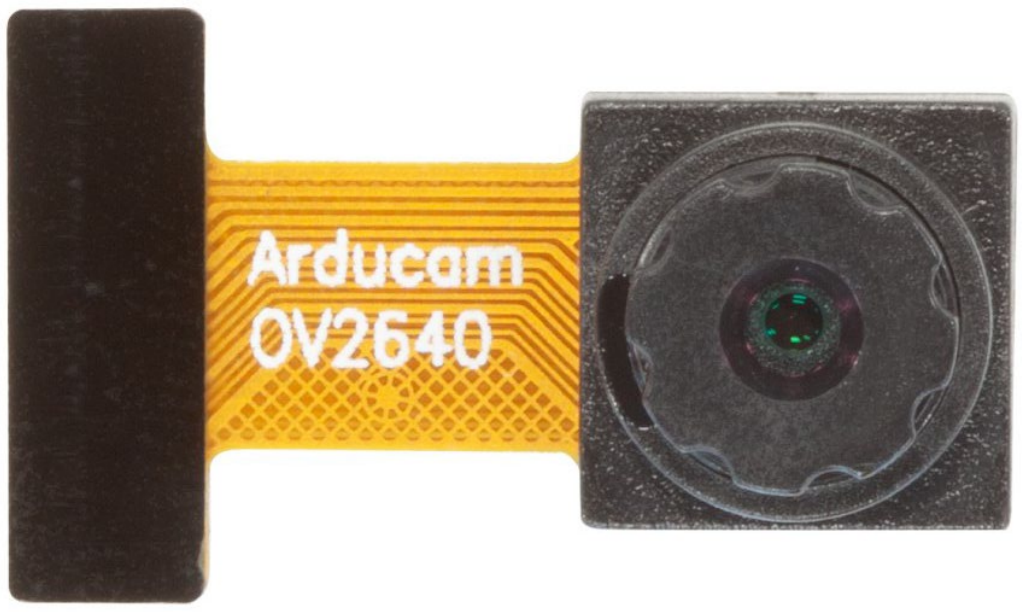



*ThingSpeak interface*

Components

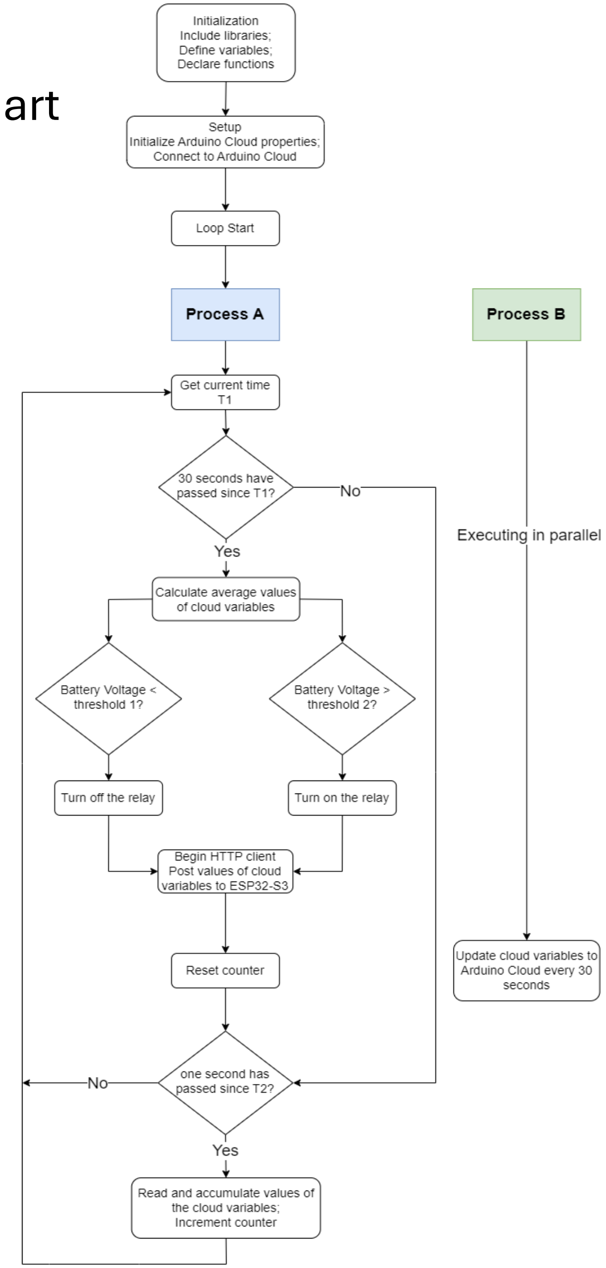
➢ OV2640 Camera

- 1/4 inch CMOS image sensor
- combination of a single-chip UXGA (1600×1200) camera and an image processor
- Supports different image sizes
- resolution, frame rate, exposure control, white balance, gain control, noise reduction can all be configured
- 3.3V supply voltage, compatible with MCU

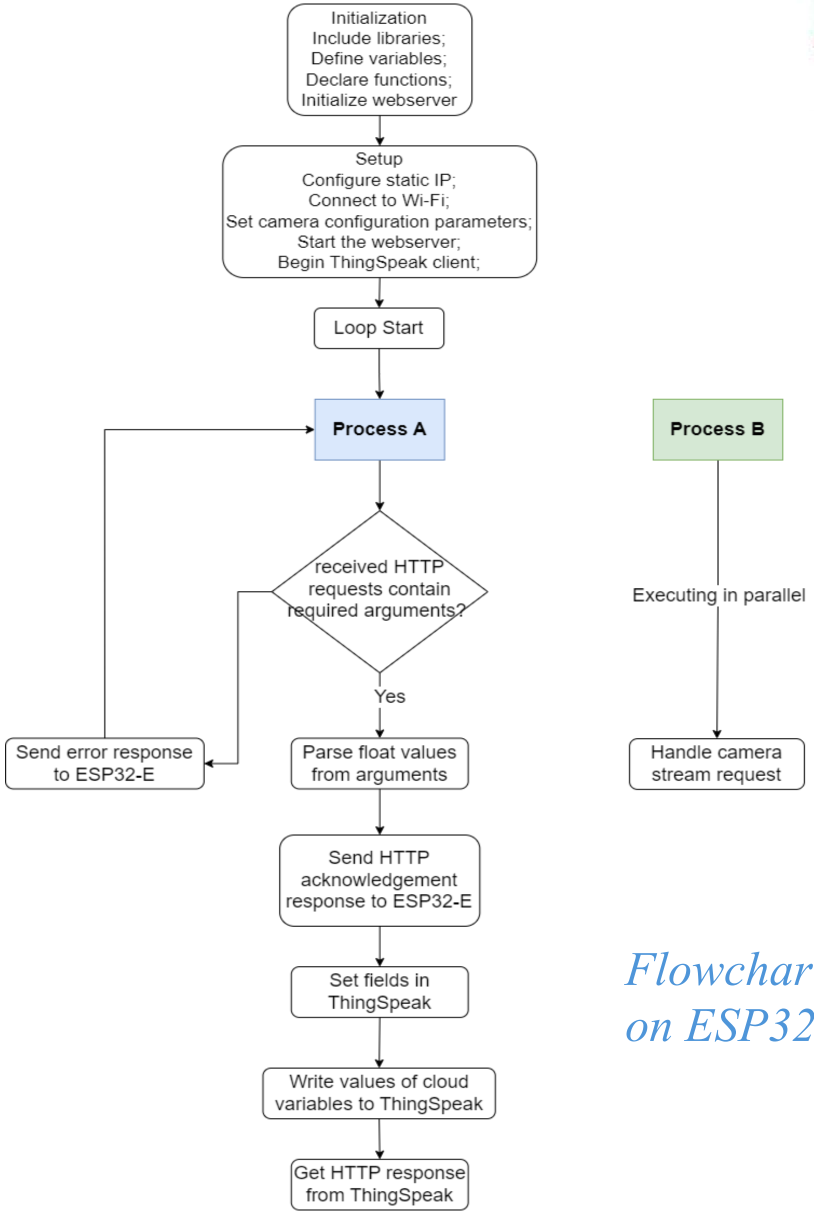



*OV2640 camera module*

# Program Flowchart



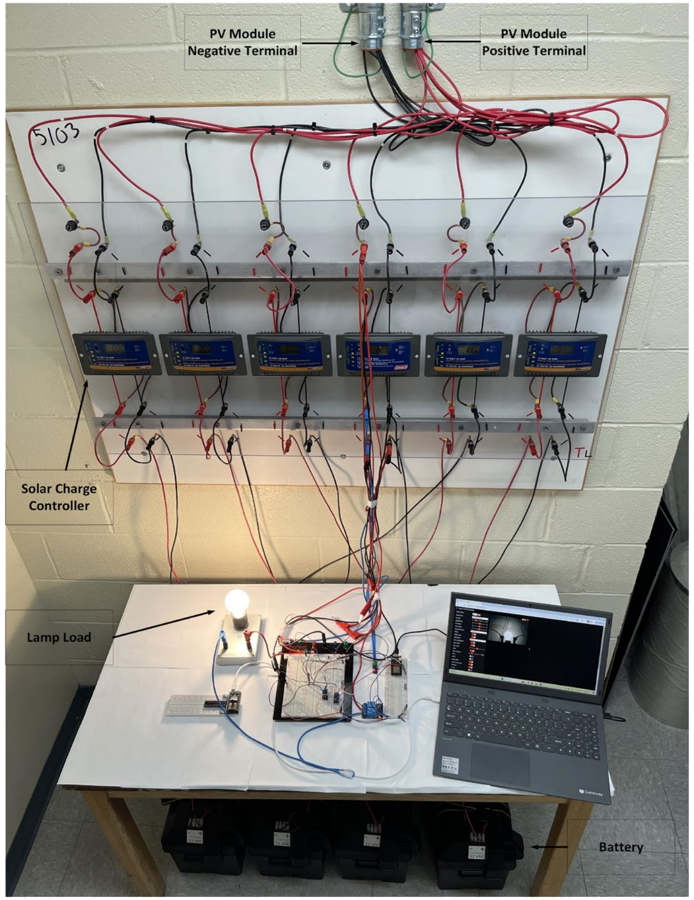

*Flowchart of programs on ESP32-E*

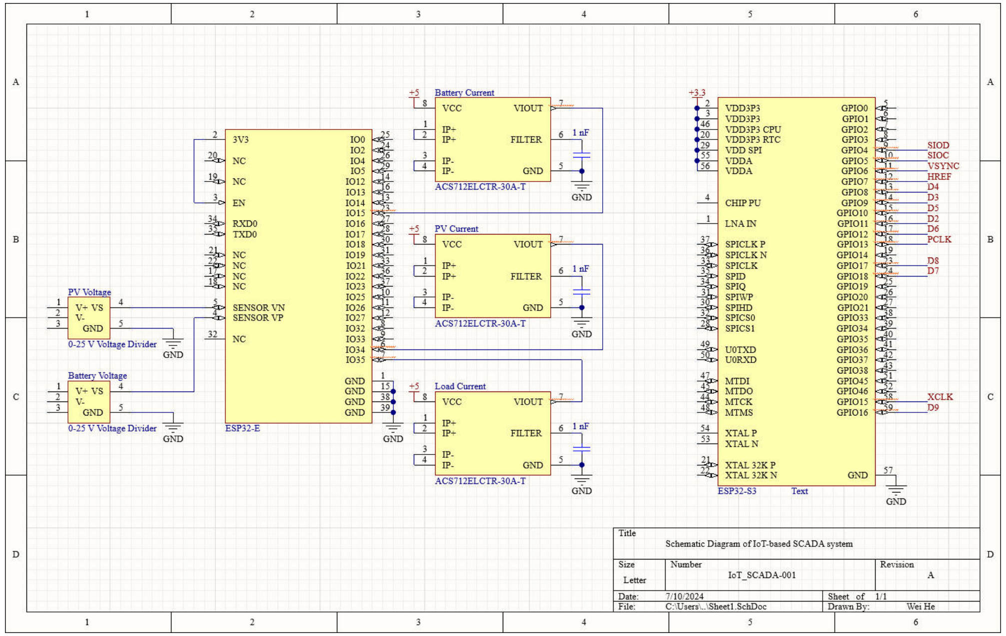



*Flowchart of programs on ESP32-S3*

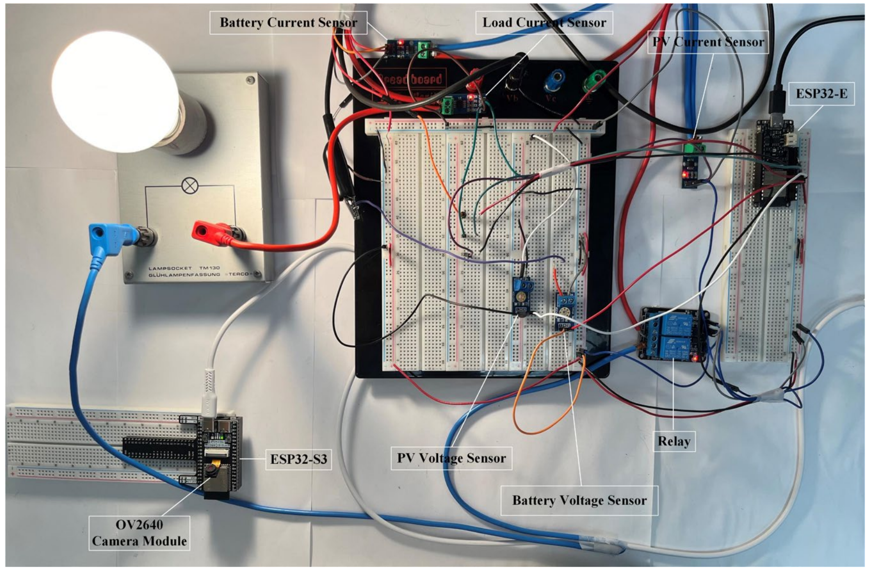
# 4. An IoT-SCADA architecture for PV system monitoring, control, and inspection in real time

## Experimental Setup




*Hardware schematic diagram*



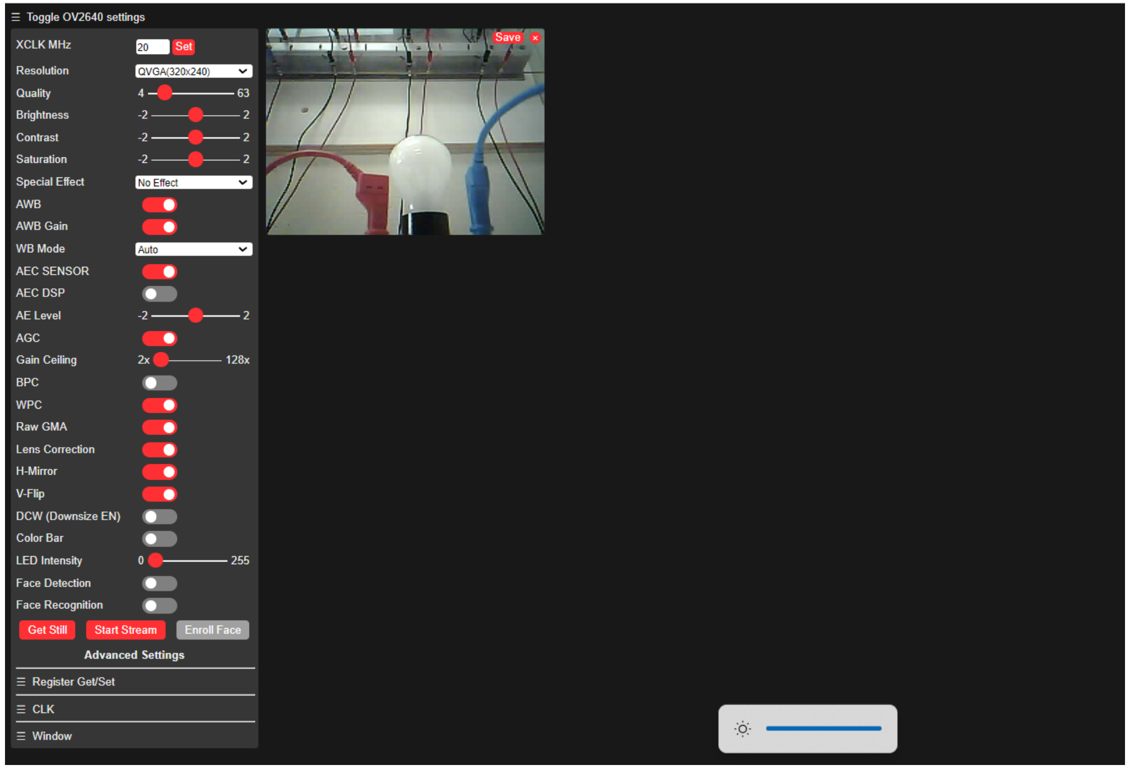

*Hardware setup of IoT-SCADA system*

MEMORIAL UNIVERSITY

## Experimental Setup

```matlab
% Store the channel ID for the PV monitoring channel.
channelID = 2570592;
readAPIKey = 'GW5DUUKETI09WJTU';

% Provide the ThingSpeak alerts API key.  All alerts API keys start with TAK.
alertApiKey = 'TAKzIUH98ogbRUuzpzu';

% Set the address for the HTTTP call
alertUrl="https://api.thingspeak.com/alerts/send";

% webwrite uses weboptions to add required headers.  Alerts needs a ThingSpeak-Alerts-API-Key header.
options = weboptions("HeaderFields", ["ThingSpeak-Alerts-API-Key", alertApiKey ]);

% Set the email subject.
alertSubject = sprintf("Low Battery Voltage");

% Read the recent data.
BV_Data = thingSpeakRead(channelID,'ReadKey',readAPIKey,'NumPoints',30,'Fields',3);

% Check to make sure the data was read correctly from the channel.
if isempty(BV_Data)
    alertBody = ' No data read from battery. ';
else
    % Get the most recent point in the array of battery voltage data.
    lastBV_Value = BV_Data(end);
    lastBV_Value

    % Set the outgoing message
    if (lastBV_Value <= 12.5)
        alertBody = ' The battery voltage is low! ';

    else (lastBV_Value > 12.5)
        alertBody = 'The battery voltage is normal. ';
    end
end

 % Catch errors so the MATLAB code does not disable a TimeControl if it fails
try
    webwrite(alertUrl , "body", alertBody, "subject", alertSubject, options);
catch someException
    fprintf("Failed to send alert: %s\n", someException.message);
end
```

*MATLAB program for email alert when the battery voltage is below 12.5 V.*



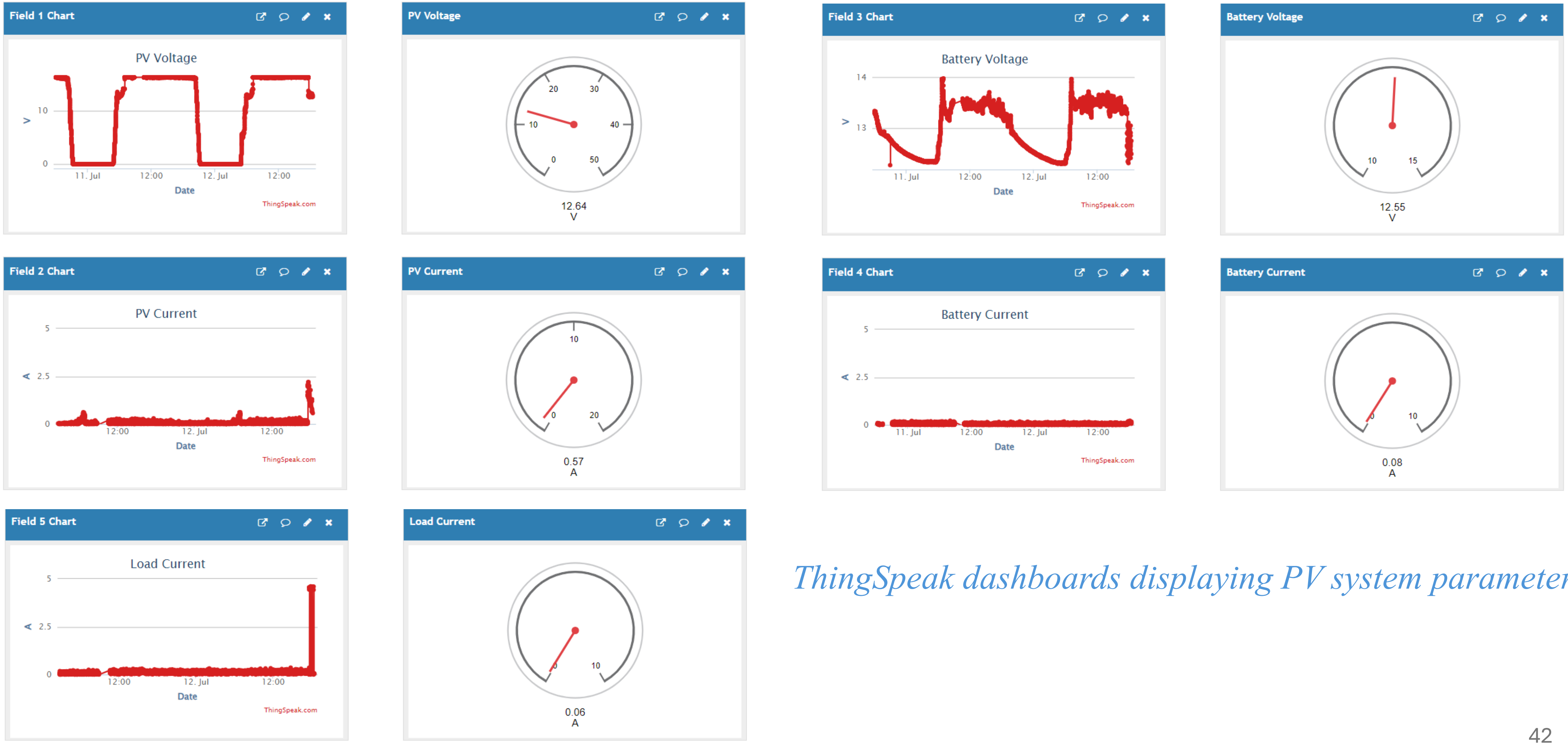

*Camera server interface*

# Results


*Arduino Cloud dashboards on July 11 and 12, with 1D time scale.*


*Arduino Cloud dashboards on July 12, with 1H time scale.*

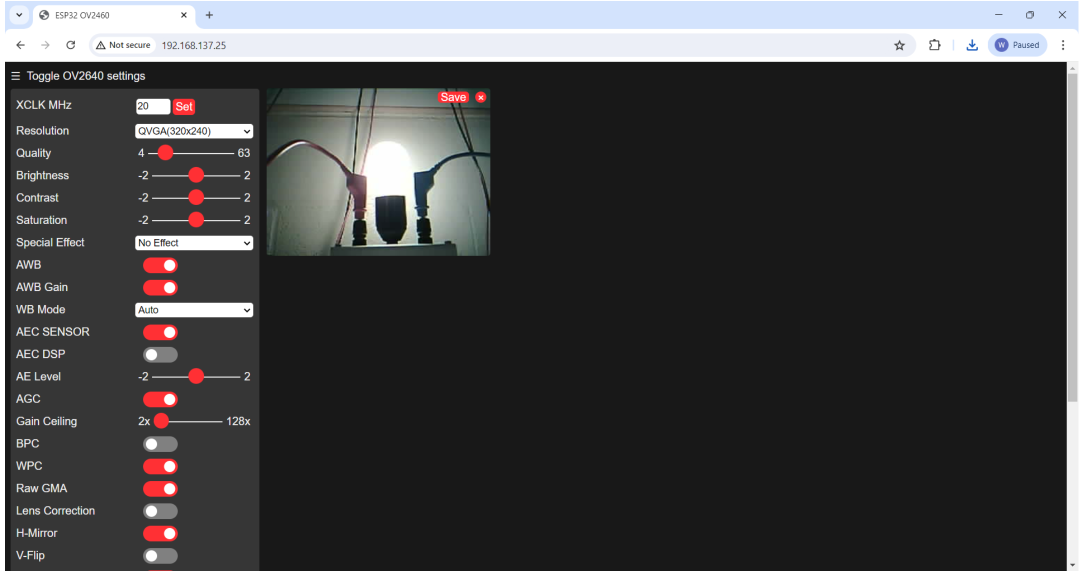
# Results



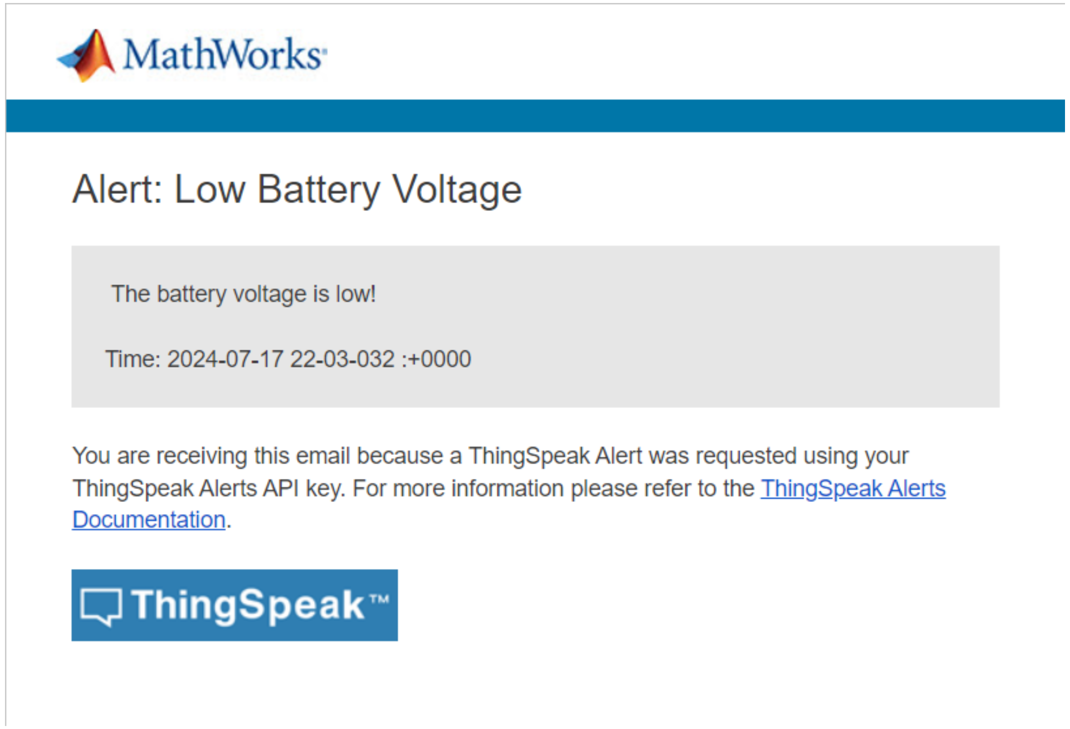

*ThingSpeak dashboards displaying PV system parameters.*

MEMORIAL UNIVERSITY

## Results




*Load on when battery voltage is larger than 13.0 V.*




*Email alert noticing that battery voltage is less than 12.5 V.*

# Conclusion

MEMORIAL UNIVERSITY

- ❖ Being low power consumption and affordable, an IoT data logger specifically designed for PV system monitoring was studied. Different power-saving techniques were employed.
- ❖ A new design of HMI and a data storage solution featuring remote, extensive, and low-cost characteristics was proposed for the SCADA system to monitor standalone PV systems.
- ❖ Total solar eclipse data were recorded, using an IoT data logger based on BPI-M4 Berry single board computer and Node-RED middleware, featuring easy-to-implement and versatility
- ❖ An IoT-SCADA system was proposed to monitor and inspect the PV system, using Arduino Cloud and ThingSpeak. Such data redundancy increased the system robustness.

# Future Works

- Wireless communication between the smart sensors and actuators
- Non-intrusive DC current sensors.
- One integrate solution that achieves local HMI, local data storage, cloud HMI, and cloud data storage.

# Acknowledgement

I want to sincerely thank:

- ❖ Dr. Tariq Iqbal as my academic supervisor
- ❖ Dr. Mirza Jabbar Aziz Baig as the co-author
- ❖ Administrative staff at the Faculty of Engineering & Applied Science
- ❖ My family, lab friends, course friends, and home friends

# Publications

- He, W.; Iqbal, M. T. Power Consumption Minimization of a Low-Cost IoT Data Logger for Photovoltaic System. *J. Electron. Electric. Eng.* **2023**, *2*, 241–261.
- He, W.; Iqbal, M. T. A Novel Design of a Low-Cost SCADA System for Monitoring Standalone Photovoltaic Systems. *J. Electron. Electric. Eng.* **2024**, *3*, 101–109.
- He, W.; Baig, M.J.A.; Iqbal, M.T. An Open-Source Supervisory Control and Data Acquisition Architecture for Photovoltaic System Monitoring Using ESP32, Banana Pi M4, and Node-RED. *Energies* **2024**, *17*, 2295. https://doi.org/10.3390/en17102295
- He, W.; Iqbal, M.T. An IoT-SCADA architecture for photovoltaic system monitoring, control, and inspection in real time. Manuscript submitted to *Electronics* for publication.
- He, W.; Mumtaz, K.; Sajjad, A.; Javaid, M.; Iqbal, M.T. Energy use analysis and simulation of MUN CSF Building using BEopt. Presented in The 32nd Annual Newfoundland Electrical and Computer Engineering Conference, November 14, 2023, St. John's, Newfoundland and Labrador.

All questions are welcome!