ECE 445: Senior Design Laboratory

Project Proposal: Advanced Interface Box for Solar Panels

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1 Introduction

1.1 Problem Statement

There are 60 solar panels on top of the ECEB building, currently being used for research, which are not producing any power as of now and can potentially be integrated into the power grid. Additionally, they are not adequately monitored at the moment and this poses a large hazard, especially considering there are no protection interfaces between the panels and their connections to the power inverter.

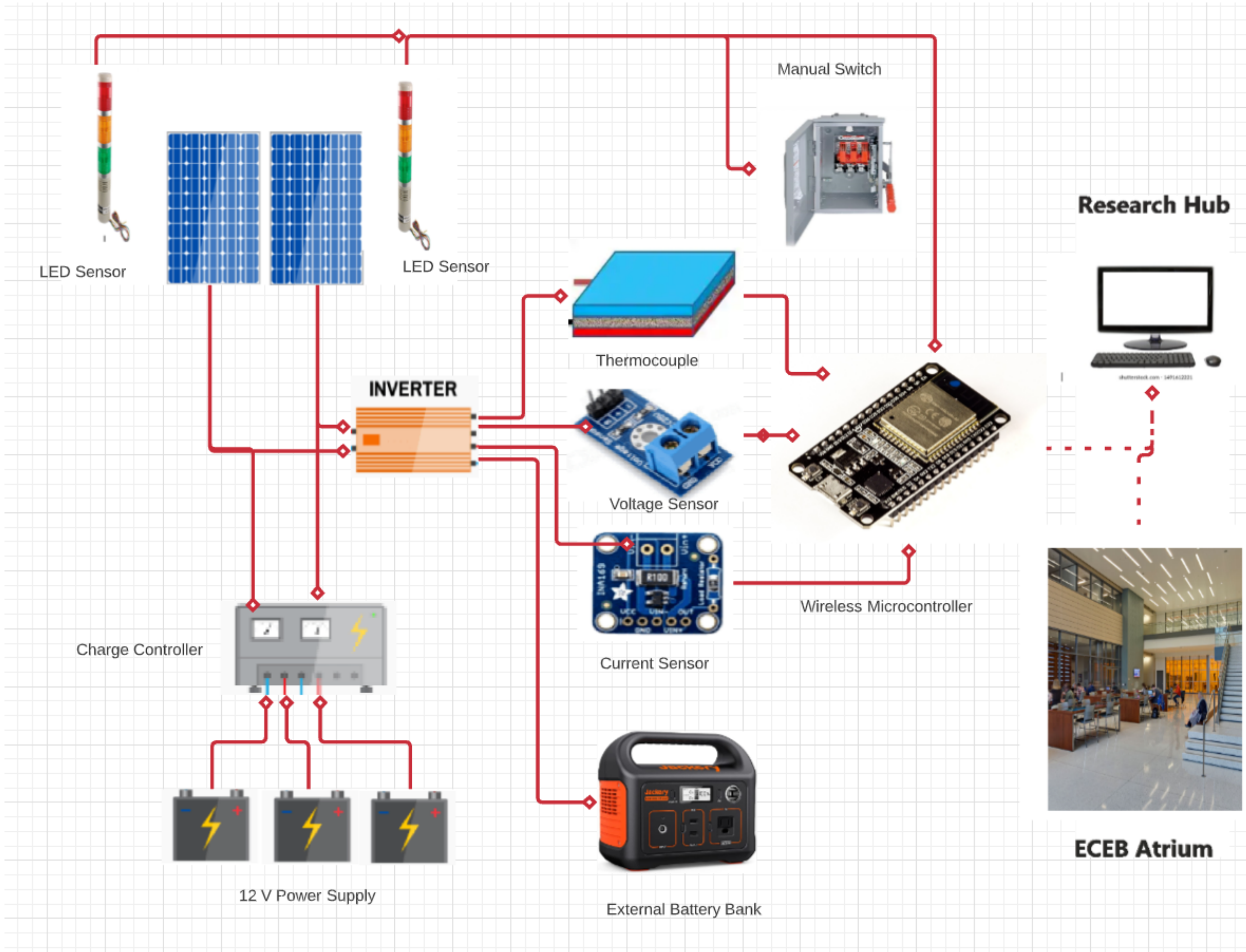
We want to design a smart interface box for these panels to allow for large-scale system behavior and output monitoring, as well as to support panel up-keep, to prevent any potential disasters like fires while also opening the possibility of future integration of these solar panels into other avenues. In previous semesters (FA19), a team of students were able to create an interface which was able to display a **single** panel's voltage and current, but the solution could not be scaled up to interface with multiple panels as is required. This previous solution attempt also now gives us a constrained size which we must utilize to communicate with multiple of these research solar panels.

1.2 Solution Overview

Our solution to monitoring and maintaining the research solar panels is a smart interface box that will interface with **multiple** solar panels to produce a single wireless gateway of panel information that feeds into a visually attractive Research Hub for observation and access to research panel data.

The system will be powered from an isolated power supply. The power generated by each monitored solar panel will run through our smart interface box, giving us the ability to detect overvoltage and overcurrent conditions and disconnect individual panels if necessary to prevent hazardous situations. Other features of the box will include reconfigurable tapping to allow users to determine which solar panels themselves are being observed. We will also provide the possibility of manual configuration of solar panels through a wireless interface, allowing users to configure and monitor the solar panel remotely through a server/PC. Finally, LEDs will be used on the box to indicate the dynamic status of panels as well as the interface. As a fail-safe for remote management of the interface being unavailable, the configuration of the interface can also be controlled manually via onboard switches.

1.3 Visual Aid

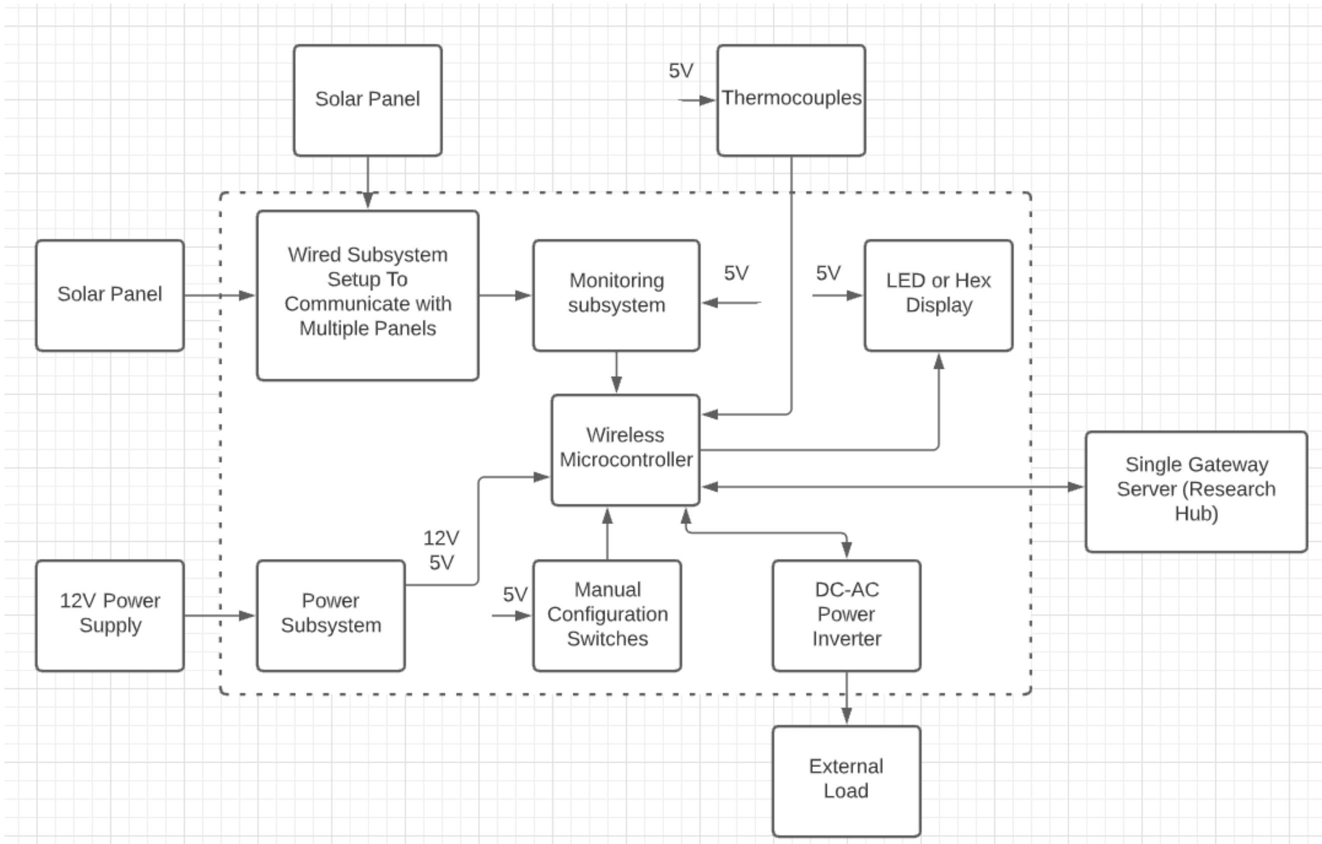


1.4 High-Level Requirements

- Recording 4 key solar panel data values - voltage, current, power output, temperature
- Wireless communication capability with solar panels (with access portal)
- Scalability - capability of interface box retrieving data and communicating with more than 1 solar panel

2 Design

2.1 Block Diagram



2.2 Subsystem Overview

- Switching Subsystem: Contains the ability to reconfigure which sections of the solar panel are being displayed to the wireless interface
- Manual Switches: For manual configuration of the interface box in which the wireless service access may be unavailable. The switches on the interface box can configure the solar panels and will be mounted on the enclosure. Most likely done through combinational or sequential logic depending on how much functionality we can implement
- LED Display: Displays the current status of information gathered from the panels and distinguishes whether the interface box is active or whether the wireless communication is accessible at the moment.
- Thermocouples: Measuring the temperature of the panels in a parallel manner so that a collective combination of data from different panels can be displayed.

- Microcontroller: The main processor for our interface box which has functionality such as being able to communicate the data received from the solar panels, shut down its 12V operations or limit any protection from overvoltage/current, and to determine areas in which certain panels may be overheating. Contains an electrical monitoring system to measure the voltage and current of the panels. We plan on displaying additional data beyond that which may include detailed waveforms and power calculations to our display system.

- Wireless Microchip: Utilizing a microchip to bring about wifi functionality to push data at high speeds from the interface box to the research hub

- Wireless sensor network: In order to scale up the project to have our microprocessor communicate with multiple solar panels, there needs to be a wireless node network. We cannot strictly rely on wiring which communicates one panel's information, instead having a range of sensor nodes spatially dispersed to monitor and record the conditions of each individual solar panel which help bring in collective data to our display.

- Remote Configuration Portal: An external server-based system will be set-up with two-way communication with the box's wireless network capabilities to allow for easy managing of the solar panels. Only authorized ECEB personnel will have access to this portal and it is intended for internal use, so the interface will be secured as such. The focus will be on porting the in-box button and switch capabilities to a remote setting for usage.

    - Data Visualization: Data collected and reported for monitoring purposes will need to be presented in an aesthetic manner on the access portal itself. A web-based visualization of the data could also then be adapted and provided for public display as well. Irrespective of final implementation, this too will be secured to only allow authorized ECEB personnel to control the data.

2.3 Subsystem Requirements

- Wireless Microcontroller (ESP32 MCU): Wi-Fi Connectivity within a large radius. Operates at a temperature range from -40°C to 105°C.
    - Performs more accurate DC voltage measurements (Analog to Digital Converters with Higher Resolution) - Eighteen 12-bit ADCs
    - Replaced our original design of utilizing an arduino for analog to digital conversion to measure voltage and current

- Power Subsystem consists of a Step-Down Buck Converter: Utilized to step down the DC-DC voltage to power up 3.3V/5V LEDs, switches, etc.

- Remote Configuration portal: Relevant data for monitoring can be stored in a local external database and a python-based framework will be able to extract and transmit commands for this effectively, while JavaScript/Java can also be used to build up the framework. REST API can be utilized for the back-and-forth data communication stream. The communication link to the microcontroller will be further established using the on-chip network and its corresponding protocols (probably TCP).

- Data Visualization: Aesthetic data visualization itself can be achieved with a combination of Python-based data science tools along with HTML to build it up on a webpage. In the case of a separate display as well, once again, a python-based framework paired with JavaScript/Java and REST API-based communication can be used.

2.4 Risk Analysis

Our biggest risk while implementing this project is our ability to have a functioning wireless microcontroller that is able to communicate with our research hub and solar panels without the use of ethernet cables. The microcontroller we are planning to use is able to transmit data at 802.11n @ 2.4 GHz up to 150 Mbit/s. In contrast, an average, commonly used ethernet cord is able to transmit about about 100Mbits/s. While 50Mbits/s does not seem to be consequential, there are nearly 3.154e+7 seconds per year, meaning we would miss out on around 1577000000 bits per year per solar panel, which justifies the higher transmitter rating. Another risk that can be taken into account when analyzing our microcontroller is if our signal goes down and we are unable to receive any data for a certain period of time. Thankfully, as all of Illinois is connected to the same signal, we are able to null the effects of our signal going down through the administrative end and focus on our microcontroller. If our microcontroller is not able to convey our measurement outputs to our research hub, we would immediately be able to tell through our visual LED aids. Again, we believe this risk can be justified by the safety and the environmental concerns that ethernet cables would hold in its stead.

3 Ethics and Safety

3.1 Ethical Issues

- Project Issues:
  - Solar Energy should not contribute to net greenhouse gas emissions and exacerbate global climate change, and our peripheral device additions shouldn't affect this either
    - Fix: We are exploring potentially recharging the power supply to our interface box by diverting some of the cleanly-made solar energy
- General Solar Panel Issues:
  - Costs and benefits of Solar energy should be distributed in an equitable way by regulatory agencies
  - Solar Energy should be environmentally sustainable - the recycling of solar panels at the moment is a huge impediment to their overall sustainability [1]
  - The manufacture of solar panels has also seen negative outcry due to problems like forced labor camps for polysilicon [2]

3.2 Safety Concerns

- Arc Flashes - Flash Burn and Blast Hazards
- Electric Shock, with particular scrutiny on faulty wiring as well
- Falls - due to the location itself of the solar panels for this project (ECEB roof)
- Thermal Burn Hazards
- Over-current/voltage - ideally will be directly countered by our interface box

3.3 Safety and Regulatory Standards

- IEEE Ethics Code #1: 'hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment' [3]
- IEEE Ethics Code #7: 'to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others' [3]
- IEEE 1547-2018 - IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces [4]

- NREL/TP-550-38603 October 2005: Procedure for Measuring and Reporting the Performance of Photovoltaic Systems in Buildings [5]

The following are standards and procedures we intend to follow when computing and collecting our measurements for our project. We plan to follow these guidelines carefully in order to keep ourselves and others safe.

4 Conclusion

Our final goal is to have an easy-to-use interface supported by our smart box that allows for accurate and convenient monitoring and up-keep of multiple ECEB research solar panels. We aim to have a prototype that can easily be scaled to meet the entire requirement of available solar panels, and in the end be successfully deployed in the ECEB!

4.1 Success Criteria

- With a focus on scaling up to meet the requirements of the solar panels available, we need to be able to interface with at least 10 research solar panels to be successful
- Interfacing with a solar panel successfully encompasses accurately monitoring its voltage, current, power output, and temperature while simultaneously reporting this data to an external server. *(Higher functionality may include satellite imagery or different interpretations of the data received to determine the power usage during different times throughout the day.)*
- Remote Wireless Access towards the panels for the authorized ECEB personnel will be successful when it allows for these personnel to configure the solar panels from an external system. A successful interface will also provide aesthetic visualizations of panel data for observation (and possibly for general viewing).
- A successful prototype will also maintain the ability to manually control the interface box with in-box buttons and switches as a fail-safe

5 References

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[2] J. Gudmundsen, 2020 Jason Hayes | March 25, and 2020 Jack McHugh | December 18, “There are ethical concerns surrounding solar energy,” *Mackinac Center for Public Policy*, 12-Jul-2021. [Online]. Available: https://www.mackinac.org/the-ethical-concerns-surrounding-solar-energy. [Accessed: 15-Sep-2021].

[3] “IEEE Code of Ethics.” Institute of Electrical and Electronics Engineers. 2016. https://www.ieee.org/about/corporate/governance/p7-8.html [Accessed Sept 19. 2021]

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[5] Pless, S., et al. “Procedure for Measuring and Reporting the Performance of Photovoltaic Systems in Buildings.” *UNT Digital Library*, National Renewable Energy Laboratory (U.S.), 3 Dec. 2015, digital.library.unt.edu/ark:/67531/metadc785614/.