Mobile Monitoring Box for Solar Panels

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1 Introduction

1.1 Objective

Photovoltaic systems will most likely play a large role in a future, decarbonized energy sector. Solar installations are projected to continue growing and the cumulative power will surpass 100 GW by 2021 [1]. Currently, the inverter systems that these panel arrays rely on include string/central, microinverters, or string with power optimizers. Microinverters and power optimizers make a system more efficient and mitigate the detriments that a lone, poor-performing panel may have on the aggregate performance [2]. Popular microinverters, like those produced by Enphase, internally monitor and transmit data that is made available through their proprietary software [3]. Similarly, the top producer of power optimizers, SolarEdge, features module-level power electronics with monitor data that is sent through a built-in ethernet connection to be accessed in their monitoring server [4]. Although these modular options improve the system's efficiency and provide transparency in system failures or weakness, these installations involve extra infrastructure, come at a higher initial cost, and the data delivery is managed by the manufacturer's software. Without these devices, problems are experienced at the string level and detection still must be done. The percentage of systems without the monitoring benefits of module level power electronics is about 15% for residential and 35% for small non-residential arrays in 2018 [5]. The cost due to loss of energy production that an unmonitored system may face is the main factor in offsetting the extra initial costs for module level power electronics [6]. If a monitoring system had minimal installation and cheap and accessible data collection, then string inverter systems may benefit from its lower initial cost without the large risk for loss of energy production.

Our solution is a mobile monitoring device that can send the direct measurements back to its user via Wi-Fi. The device centralizes the measurement components, which drives cost down but sacrifices monitoring resolution. The function of the tool essentializes data collection by reading only current and voltage values associated with an individual panel, DC or AC. Having data directly transferred over Wi-Fi avoids excess architecture and allows the user to have greater freedom with data analysis, rather than being bounded by the manufacturer's software. Permanent installations would include a simple terminal block at each panel to measure DC values. Our goal is to lower the costs for a monitoring system by limiting resolution, simplifying the data set, and providing direct access to data analysis.

1.2 Background

AlsoEnergy's PowerTrack Platform performs numerous analysis and modelling for a PV array that users may want to know from their monitoring system [7]. However, there exists an over abundance of analysis tools and the program's subscription scales with system size. Our solution would supply only the fundamental data points necessary for system maintenance and places the responsibility and freedom with the user for analysis. The TS4 series, from Tigo, offers both retrofit modules and pre-installs that perform similar functions to our proposed device [8]. The optimization modules are comparable in price and operation to other power optimizers and their monitoring solutions use the PowerTrack Platform.

1.3 High-Level Requirements

- Device must safely monitor voltage and current levels on load and line without significantly affecting performance.
- Device must transfer data packets through WiFi to a local PC
- Device must be durable enough to withstand reasonable outdoor weather conditions

2 Design

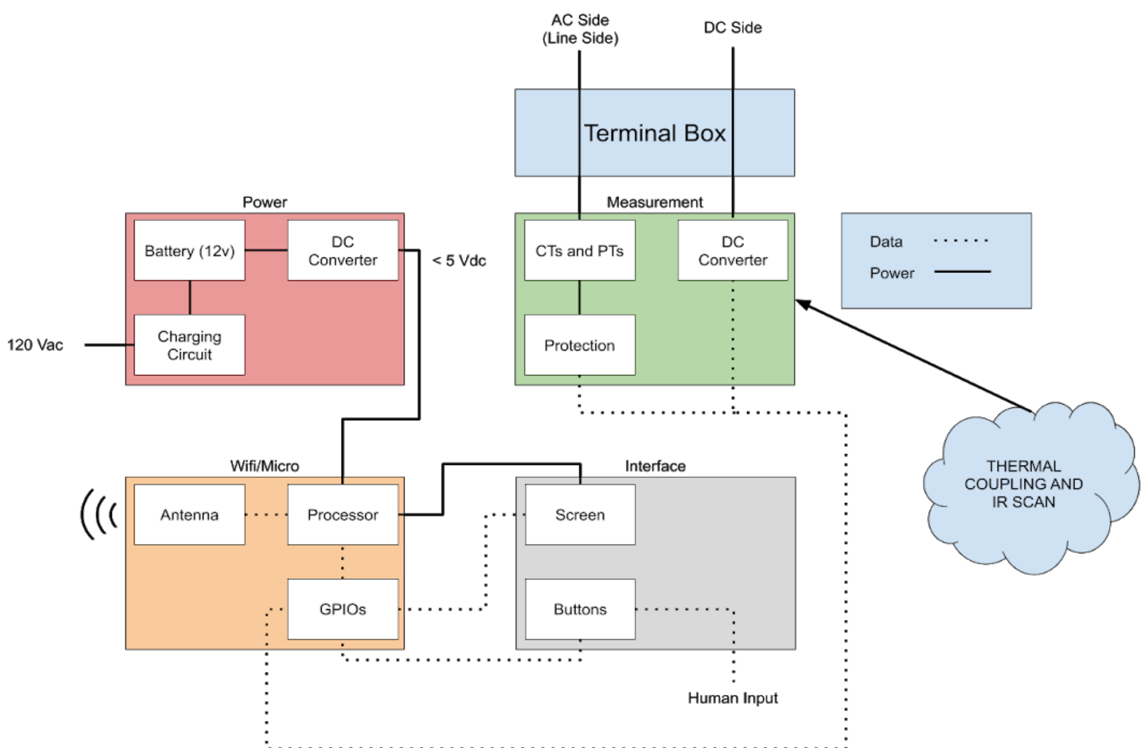

Figure 1: Block Diagram

There are 4 (5 if you include the terminal box) sections that allow this product to be accurate and easy to use. The power supply section provides the microprocessor with 3.3 V of power in order to run. The terminal box will connect to the photovoltaic system both before the inverter and after the inverter. The terminal will do nothing to the PV system, but give us easy access to ports that can measure the voltage and current before and after the inverter. The measurement section will connect to the terminal box, and then go through protection, AC-AC conversion, and DC-DC conversion to match the ratings of the microprocessor. The microprocessor section will then display the data on the screen. The interface will then give the user the option to send the data and in that case, the processor will send the data over WiFi to a computer.

2.1 Power Supply

The power supply is necessary to provide the microcontroller with the needed voltage to work. The power supply will run on a battery that will be rechargeable. The batteries' voltage will then be converted to the necessary voltage for the microprocessor using a buck converter.

2.1.1 Battery

The battery will be a 12V rechargeable battery. The battery will be charged using an external charging circuit. The battery will then also be the source voltage for the DC-DC converter.

Requirements:

- A rechargeable battery that consistently outputs 12V

2.1.2 Charging Circuit

The charging circuit will be outside of the device. The circuit will take the line power from the wall and convert it to a waveform to charge the battery.

Requirements:

- A circuit that will safely charge the 12V battery over time and stop once it is fully charged

2.1.3 DC Converter

The DC to DC converter will be a Buck converter. The converter will drop the voltage from the battery to 3.3 V to be able to power the microcontroller.

Requirements:

- A circuit that will output 3.3 V to power the microcontroller

2.2 Measurement

The measurement section interacts with the terminal box to collect the actual voltage and current from the photovoltaic system.

2.2.1 Terminal Box (Wire box)

The terminal box will take wires from the Solar Module, give us access to measure them through a port that we can plug into and then go to the inverter. The terminal box will also take wires coming from the inverter and do the same time. The terminal box won't do anything to the voltage or current, it will simply give us easy access to be able to measure the voltage and current without needing to turn the PV system off. (It is difficult to measure DC voltage without having direct access to the wires and this is a way around that.)

Requirements:

- A wire box that gives us safe access to the AC and DC sides of the inverters

2.2.2 CTs and PTs

The current transformers and power transformers will be used when measuring the AC side (the side exiting the inverter). The transformers will take the alternating current and voltage and drop it to a value that is always significantly less than 1V. This reduced value is then sent to a protection circuit before it is sent to the microcontroller.

Requirements:

- Current Transformers and Power Transformers safely step-down AC voltage to less than 1v for the microcontroller

2.2.3 Protection Circuit

Our device will be interfacing with potentially dangerous voltage and current levels. To protect our circuits and users, varistors and fuses with be used to ensure that only nominal levels enter the main circuit.

Requirements:

- Fuses rated to create an open circuit when current levels are too high
- Varistors to block voltage transients and create open circuits with prolonged overvoltage conditions

2.2.4 DC Converter

When measuring the DC side of the inverter (the power coming from the Solar Module), the voltage will be dropped to a voltage significantly less than 1v. This value is then sent to the microcontroller to be processed.

Requirements:

- A circuit that steps down the DC voltage to less than 1v for the microcontroller

2.3 WiFi/Microprocessor

The microcontroller operates on input from the measurement section to display data on the interface, manage controls from the buttons, and sends data to the IoT through WiFi communication.

2.3.1 Processor

The processor is powered by the power supply and interacts with data from multiple locations. The processor interacts with the screen to display the data measured. The processor must also take inputs from buttons, reflect the input from the buttons on the screen, and follow through commands selected. The processor must also use the antenna to send the data over WiFi to a terminal.

Requirements:

- A processor must be able to collect data from the measured devices
- The processor must be able to display the data on the screen as well as display commands on the screen
- The processor must be able to take input from the buttons, reflect that on the screen, and follow through with the commands selected
- The processor must be able to connect with the WiFi and then be able to send the data over the WiFi to a computer

2.3.2 GPIO

The GPIO connects with elements that are trying to send or receive data from the processor. The GPIO then connects to processor and sends the data as needed.

Requirements:

- The GPIO must be able to connect the screen and buttons to the processor and interact accordingly

2.3.3 Antenna

The antenna works with the processor to connect to the WiFi. The antenna is then used to send the data over the WiFi to a computer.

Requirements:

- The antenna must allow for the processor to connect to the IoT through WiFi

2.4 Interface

The interface involves a screen and buttons that allows the processor to display data and take commands from the buttons.

2.4.1 Screen

The screen will be used to display the data that is measured from the PV system. It will also have a menu to display possible commands such as when to send data over WiFi to a computer.

Requirements:

- The screen must display the data that is measured
- The screen must show the commands that the user is able to make

2.4.2 Buttons

The buttons work to be able to collect data via human input. It allows the user to scroll through commands and to select commands.

Requirements:

- The buttons let the user interact with the processor and select the commands the user wants to perform

2.5 Risk Analysis

The microcontroller poses the largest risk to the completion of our project. The data needs to be accurately read and transmitted and that needs to be done to through the processor. The microcontroller also needs to control the interface with the user.

All our teammates have a focus in power and so we have a good grasp of the power supply and measuring the elements properly and safely. We have the least amount of experience with the processor, coding it accurately, and communicating via WiFi.

3 Safety and Ethics

Our solution is intended to be operated by personnel in normal outdoor weather conditions. This creates many potential hazards in terms of damage to equipment and/or operators.

Foremost, our terminal box connects directly to the AC side of the invertors of the panels. In some systems, this could be directly tied to the supply side of a facility's utility connection. This requires that we follow strict guidelines created by the NEC, specifically those in NFPA 70. Section 110 covers general requirements for electrical devices, but our project will need to adhere to more strict regulations in sections 690, 691, and 705 which provide relevant standards for grid-tied PV installations. Section 690 covers circuits connected to PV installations (690.8.A.2), over-current protection (690.9), disconnects (690.15), wiring (690.31), and grounding (690.41). Section 691 covers additional requirements for large scale PV installations. Section 705 covers general grid-tied connections [9]. While each PV system may not require adhering to all these standards, the versatility of our solution requires that we follow the strictest practices.

Furthermore, both our enclosures (monitoring device and terminal box) must be able to withstand weather conditions. The enclosures must meet at least NEMA Type 3 specifications, with the terminal box requiring the strictest standards, Type 6 or better. These specifications cover outdoor enclosures and their resilience to water, ice, and particle ingress [10].

Lastly, our design should follow the Ethical Engineering Code proposed by the IEEE council. Most notably, #9: "to avoid injuring others, their property, reputation, or employment by false or malicious action".

Following the above standards will assist us in making sure our solution is safe for personnel handling and equipment installation, but we must consider the safety of persons and property with each device element. Additionally, since our device collects and transmits data, we must adhere to #5 and #6 by assuring that our data is reliable and improves the development and use of PV installations [11].

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