PROJECT PROPOSAL

Smart Interface Box for Solar Panels

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Team #3

Dillon Vadgama (dvadga2)

Douglas Lee (dlee242)

Sachin Reddy (ssreddy2)

0.1 Introduction

In 2018, a fire broke out on the roof of a Walmart in Beavercreek, Ohio due to Tesla's unmaintained solar panels suffering from hot-spots. These hot-spots resulted in the cracking of the back sheets of the solar modules and compromised their electrical insulation. There was no protection system to detect this type of unwanted behavior and shut down the system before a fire broke out. As a result, Walmart sued Tesla over the flaws present in their solar panels and an overall lack of system protection.

The Electrical and Computer Engineering building (ECEB) at the University of Illinois at Urbana-Champaign has a roof of 60 solar panels that are used for research; however, there are no protection interfaces between the solar panels and their connections to the power inverter. As a result, these solar panels are at risk for suffering the same type of failure as the one stated above. A smart interface box attached to each solar panel that has the ability to shut off the entire operation in the event failure conditions are met and allows users to remotely monitor system behavior/parameters could help prevent a disaster like Walmart's. The following are the goals, benefits, and high level requirements of the proposed system:

1. Goals
   - Prevent a hot-spot disaster by protecting the interface outputs from over-voltage and over-current, and the solar panel from overheating.
   - Provide the user with the ability to monitor system configuration, behavior, and parameters during use.
2. Benefits
   - Allows remote access to measured voltage, current, power delivery, and panel temperatures from an online server through an Ethernet interface.
   - Allows for the remote configuration of the solar panel connection to the inverter from an online server through an Ethernet interface.
3. High Level Requirements
   - The output of the interface will be configurable to be connected to either 32 cells, 64 cells, or 128 cells, and will able to be controlled via either an Ethernet connection or through the manual switches that will be mounted on the box.

- The output of the interface box will be disconnected from the power inverter in the event a panel failure condition occurs (over-voltage, over-current, or overheating), or the isolated 12 V supply powering the interface box is no longer connected.
- The enclosure of the interface will be weather-proof along with any cable jacks used.

0.2 Design

1. Block Diagram

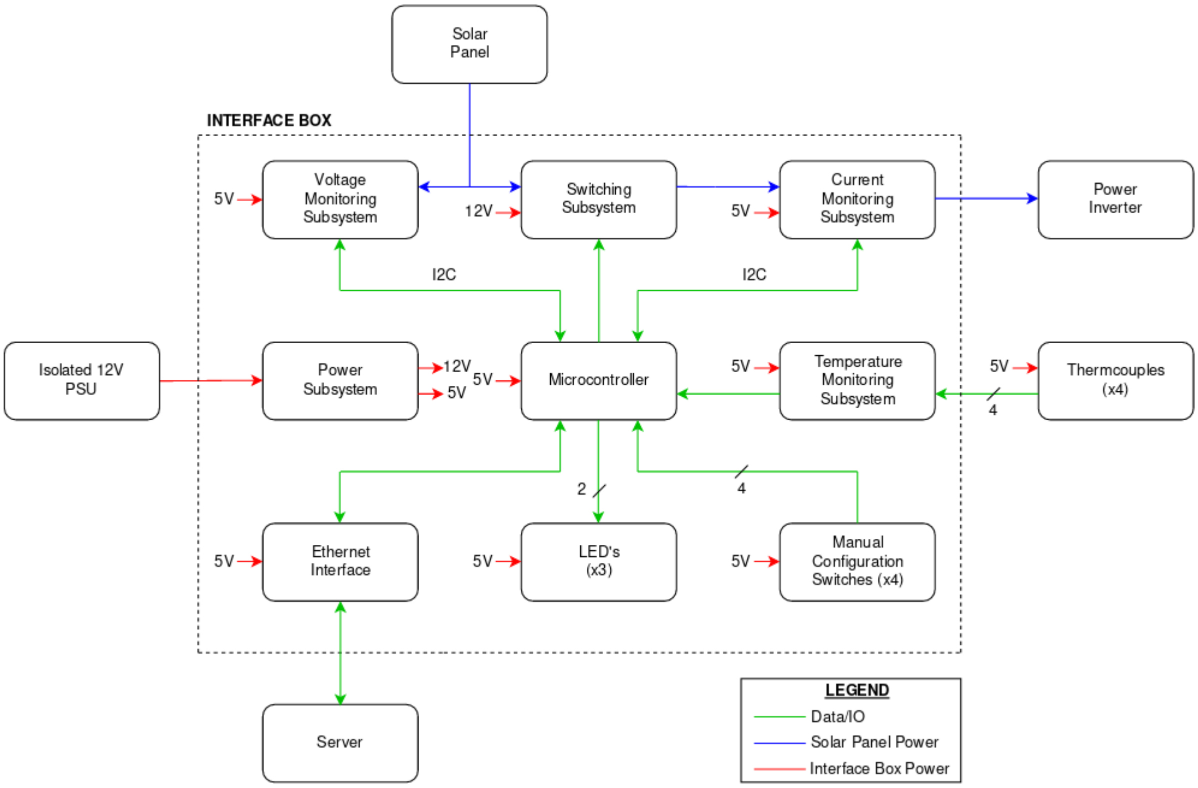

Figure 1: Block Diagram

2. Block Descriptions

   (a) Switching Subsystem

      i. Contains switching components (most likely relays) responsible for connecting different sections of the solar panel (32 cells, 64 cells, or 128 cells) to the output or disconnecting the solar panel altogether.

      ii. The switching configuration will be controlled by the micro-controller using its digital I/O pins.

      iii. The relays will be powered by the 12V supply.

   (b) Current Monitoring Subsystem

      i. Connects directly to the output of the switching subsystem and is responsible for measuring current delivered by the solar panel to the power inverter.

ii. The subsystem has two outputs: one that communicates current data to the micro-controller via an I2C bus and another that passes power generated by the solar panel to the output of the interface box.

iii. The subsystem is powered by the 5V line from the Power Subsystem.

(c) Voltage Monitoring Subsystem

i. Connects to the output of the solar panel is responsible for measuring the voltage of its terminals.

ii. The input impedance of this subsystem (at the measurement terminals) will be very high to ensure that power dissipation is minimized, system power efficiency is maximized, and current/voltage measurement accuracy is maximized.

iii. The subsystem communicates voltage data to the micro-controller via an I2C bus.

iv. The subsystem is powered by the 5V line from the Power Subsystem.

(d) Temperature Monitoring Subsystem

i. Contains all of the circuitry necessary to extract temperature data sourced from the thermocouples that will be mounted on various areas of the solar panel.

ii. Data that is outputted from the Temperature Monitor Subsystem will be sent to the micro-controller for further analysis.

iii. The subsystem is powered by the 5V line from the Power Subsystem.

(e) Thermocouples

i. Sensors that are used to measure the temperature of specific portions of the solar panel.

ii. Raw sensor data is sent to the Temperature Monitoring Subsystem for further processing.

iii. The subsystem is powered by the 5V line from the Power Subsystem.

(f) Micro-controller

i. An internal micro-controller (most likely an ATmega328P) will be used to communicate with and control other subsystems present in the interface box.

ii. Detects over-current conditions using data sent by the Current Monitoring Subsystem.

iii. Detects over-voltage conditions using data sent by the Voltage Monitoring Subsystem.

iv. Detects hot-spots and overheating using data sent by the Temperature Monitoring Subsystem.

v. Controls the Switching Subsystem to set the output configuration the solar panel or disconnect it altogether if a failure condition is met.

vi. Packages and sends relevant data and receives configuration commands from the user through the Ethernet Interface.

vii. Reads the switch states from the Manual Configuration Switches to control the configuration of the solar panel if an Ethernet connection has not been established.

viii. Based on the state of the interface box, this subsystem will set the Ethernet and power output status LED's as appropriate.

ix. The subsystem is powered by the 5V line from the Power Subsystem.

(g) LED's

i. Several LED's will be present to show information about:

A. Status of the Ethernet connection: Whether or not an Ethernet connection is active.

B. Status of interface output connection: Whether or not the interface box has connected the solar panel to the power inverter.

C. Status of interface box power: Whether or not the isolated 12V supply is powering the interface box.

ii. The power output and Ethernet connection LED's will be controlled by the micro-controller while the interface box power LED will be powered by the 5V line from the Power Subsystem.

(h) Manual Configuration Switches

i. In case of a loss of connection to the internet and the server is unable to access the interface box, there will be manual switches mounted on the enclosure to control the configuration of the solar panel and shutoff the system entirely.

ii. Four switches will be available to engage the output and change which set of cells to attach the output to.

iii. The states of each of the four switches will be sent to the micro-controller for processing.

iv. The subsystem receives power from the 5V line from the Power Subsystem.

(i) Ethernet Interface

i. Facilitates communication via Ethernet between a server/PC and the micro-controller installed in the interface box.

ii. Allows the command, control, and monitoring of the solar panel to take place.

iii. Ethernet should be able to connect to the network.

iv. The subsystem is powered by the 5V line from the Power Subsystem.

(j) Power Subsystem

i. Regulates the isolated 12V supply into a 5V supply and distributes the appropriate voltage levels to the subsystems that require them.

(k) Server

i. The server receives/stores data from the micro-controller and sends command and control signals to the micro-controller via the Ethernet interface.

ii. Data must be stored in a database.

iii. A GUI will be able to extract, transmit commands, and display the data, providing a user-friendly experience.

iv. Both the database and the GUI should be secured to prevent unauthorized users from controlling the solar panels.

3. Risk Analysis

The monitoring system is highly dependent on the functionality of the switching subsystem, voltage/current monitoring subsystems, and the micro-controller all working in-tandem to ensure that the solar panel can be disconnected if any failure conditions should occur. This is most essential part of the monitoring system and is responsible for preventing a hot-spot disaster.

Along with the statement above, it is essential that all the subsystems of the interface box can work along side the micro-controller, so that they can send/receive the proper data and control the output accurately. Each subsystem is fed power from the power subsystem and it is essential that if this subsystem fails for any reason, solar panel will be disconnected from the output and not deliver any power. Additionally, because this interface will be mounted on the back of the solar panel outside, these components must all be kept safe from environmental damage in a weather-proof enclosure.

0.3 Ethics and Safety

The user of this monitoring device will be directly involved with the operation of the device; thus, it is important that we ensure a safe and reliable product. There must be safeguards in place to protect both the product and the user. For instance, if a user manually shuts off the device working to work on the solar panels, commands and controls from software should not override the box to turn it back on.

The one major component in the device that could be considered hazardous is the electrical circuitry when connected to the solar panel. The open circuit voltage of the solar panels is 85.6 VDC and sufficient actions should be taken to protect the user from coming into contact with these voltage levels. Since this is a device that is mounted in an outdoor environment, sufficient casing must protect the internal electrical circuitry to prevent harm to the user.

In addition to weather-proofing the device, we must be able to allow for reliable circuitry to maintain the monitoring system notify the user if a failure condition has been met or closed to being met. Notifying the user of this event and shutting down the operation will ensure that a hot-spot disaster will not occur. This then complies with the 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'[1].

As testing and user-feedback comes in, we must take all problems into consideration and make adjustments to the device with no hesitance. Since this device is meant to prevent a potentially dangerous situation from unfolding, all constructive criticism will be considered for future revisions of the design. This adheres to the 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'[1].

Citations and References

[1] "IEEE Code of Ethics." Institute of Electrical and Electronics Engineers. 2016. https://www.ieee.org/about/corporate/governance/p7-8.html [Accessed Sept 6. 2019]