EEE202 Design Project Report: Automated Solar Panel Power Meter

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1. Who is this designed for? What user needs were considered?

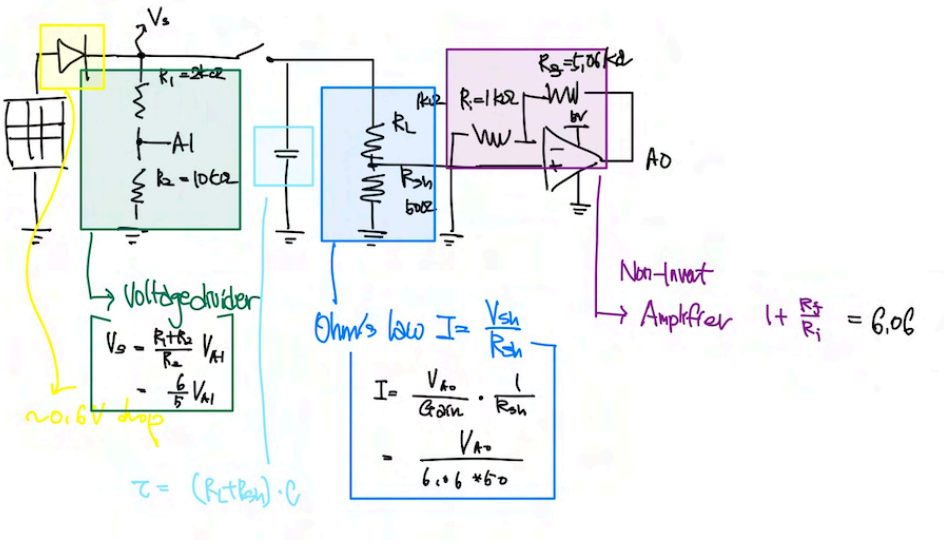
Customer: Sparky Solar Company

This device was designed for Sparky Solar Company, which requested an automated solar-panel power meter capable of displaying voltage, current, and power without relying on an external computer. To meet this requirement, the system was powered by a standalone 9V battery and controlled entirely through an on-board Arduino.

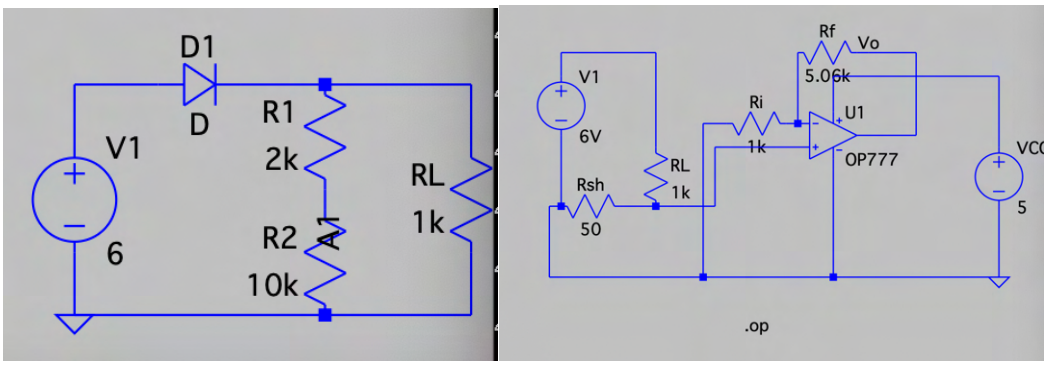
Several key user needs were considered during the design process:

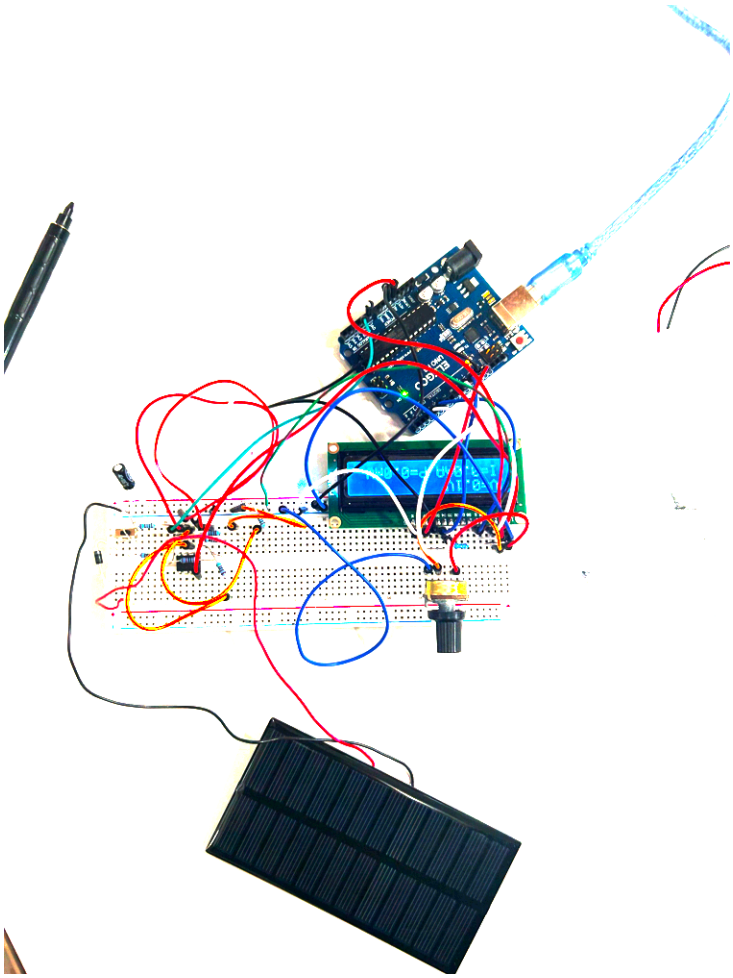
1. Cost-effectiveness components
   To keep the device inexpensive and easy to manufacture, components with good availability, low cost, and small physical size were prioritized.
   This influenced the selection of the load resistor, the voltage-divider values (R1 and R2), and all passive elements, ensuring that they delivered adequate performance without unnecessary complexity.
2. Ability to measure panel voltages up to approximately 6V
   The project requirements specified a maximum expected solar-panel voltage of ~6V.
   Therefore, the voltage-divider (R1 = $2k\Omega$ and $10k\Omega$) was chosen such that a max 6V input would corresponds to about 5V at the Arduino A1 pin, which is the upper safe limit of the voltage.
   This ensured that the system could read panel voltage while protecting controller by reducing the pure solar panel voltage.
3. Intuitive visual feedback through an LCD display
   An LCD module was incorporated and driven by the Arduino code, allowing the user to immediately read the panel's voltage, current, and power values directly in the field without extra equipment.
4. A measurement method that minimizes interference with the panel's operation
   To ensure that power measurements reflected the panel's true behavior, the design required the circuit to be as "electrically non-intrusive and independent" as possible.
   This was achieved by using a very small shunt resistor in series with the load, producing a small voltage drop proportional to current, and then using op-amp to amplify that drop to a readable level. This approach allowed the shunt power negligible and make the power measurement appreciable while keeping panel's operating conditions nearly unchanged.

2. How does the final design work - give a detailed description with images (*photos and schematics*)?



1. A diode was placed at the input to prevent reverse current and to ensure rectification if the panel polarity were reversed.
2. A voltage divider feeds the A1 pin so that the Arduino can measure a reduced and safe version of the solar-panel voltage, and then reconstruct the actual panel voltage through software.
3. The load resistor and shunt resistor were placed in series woith solar panel so that power is disspated through the load while the shunt remains relatively negiligible compared to the load.
4. Since the voltage drop across the shunt resistor is very small, this drop is amplified by an op-amp and then read through A0.
5. Using the amplified A0 reading, the Arduino computes the original shunt voltage (by dividing out the gain) and uses Ohm's law to calculate the current.
6. Since this current is the same current that flows through the load, multiplying load current by the reconstructed panel voltage (from A1 and the divider ratio) yeilds the dissipated load pwer, which the controller computes through code.
7. Because the shunt resistor is approximately $\frac{1}{20}$ of the load resistor, the power dissipated in the shunt is negligible, and the measured power closely approximates the true power.
8. To prevent issues csued by sudden disconections or instant voltage drops, a capacitor was added across the resistive branch so that the voltage decays smoothly rather than abrubtly.





3. **What components did your team specifically determine and explain your reasoning for your choices?**

R1 and R2 were chosen as $2k\Omega$ and 10 $k\Omega$ so that the voltage seen at A1 is approximately $\frac{5}{6}$ of the solar-panel voltage. Assuming a maximum panel voltage of ~6V and knowing that A1 can only accept up to ~5V, this ratio ensured safe operation while still preserving measurement resolution.

For the non-inverting amplifier, Ri = $1k\Omega$ and Rf = $5.06k\Omega$ were selected to create a gain of approximately 6.06. This were based on the theoretical maximum shunt voltage: with a $1k\Omega$ load and 50Ω shunt, the total series resistance is 1050Ω, so at 6V the shunt drops about 285mV. A gain of 6.06 produces a maximum of roughly ~1.7V, which stays well within the 0-5 ADC range.

4. What trade-offs were made is this design?

Because the design uses a shunt resistor, some unavoidable off in the measured power appears, since the shunt itself slightly changes the circuit conditions. However, using a shunt greatly simplifies current measurement compared to more complex sensors, and the ease of measurement using shunt and op-amp outweighs the small loss in accuracy.

A capacitor was added to improve stability, but this introduces slower response at the beginning and the end of a voltage change. However, the delay is negligible and the stability benefits are worth the trade-off.

5. What did you learn about theoretical design versus physical design during the entire EEE 202 lab?

In theoretical design, all component values are fixed and simulations assume ideal behavior, so results rarely deviate from expected values. In practice, every component has tolerances, and different device types produce different behaviors. For example, the solar panel's maximum voltage was assumed to be 6V but physically reach around 6.5V. The diode's forward drop also differed from textbook values, and resistor tolerances introduced small variations as well.

6. Describe one thing that went wrong in the simulating, building, or testing of this design? How did you troubleshoot the problem(s) and what was the correction that needed to be made?

In TinkerCad simmulation, the maximum measurable voltage matched exactly the theoretical value of 5.4V (6V – 0.6V diode drop). However, when building the physical circuit, the measured value reached about 5.90-5.99V. This revealed that the actual panel voltage was closer to 6.5V under full Illumination. Even accounting for diode drop, the load still experienced around 5.9V at maximum light. From this, I concluded that if the panel voltage can reach above ~6.6V, the divider ratio should be adjusted so that A1 receives a slightly smaller fraction for improved safety(upper limit ADC for A1 ~5V).

7. If this design were scaled up for large solar panel systems, what environmental, technological, societal, and/or financial considerations would need to be made?

As the solar-panel voltage range increases, the ratio $\frac{R2}{R1+R2}$ must be reduced further so that Arduino's input stays safely within range. In larger systems, wider panels cause larger variations in sunlight, so capacitors would need to be used more strategically for smoothing.

Additionally, larger systems require attention to environmental factors such as waterproofing and dust protection, and temperature swings would introduce larger resistor-tolerance and circuit errors. These considerations become more significant at scale.

8. What skills have you developed in working on this project that will help you in your future career? (*this part can be written in 1st person*)

I learned how to safely interface a controller with limited voltage tolerance by using a voltage divider to match allowable input ranges. I also learned how to measure current independently using a shunt resistor and an op-amp without significantly disturbing the original circuit. Additionally, I developed an understanding of how capacitors can be used to safely discharge systems and buffer sudden transients. Finally, I gained experience integrating these measurements into an LCD interface and designing a system that meets quantatitve customer requirements.