Solar Office Companion

ECE 499 Design Project II

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University of Victoria

Group Information

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Acknowledgment

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Contents

Executive Summary

Integration of renewable energy into the workplace provides sustainability and knowledge of the respective energy sources. Climate change has created a high priority demand for renewable energy to combat this problem, as the earth's temperature continues to rise. This project is a modular solar device used in the workplace where sun is accessible via windows. It can power small electronic devices from the connected solar panels and battery pack, with a solar-regulating microcontroller providing accurate charging parameters. Due to the modular design, additional solar cells and batteries can be connected to power larger devices, including monitors or computers. This mitigates power consumption from non-renewable energy sources while using existing building infrastructure for simple integration.

I Introduction

As the cost of photovoltaic cells continues to decline, it's becoming more financially sensible to install solar modules in suboptimal locations. Despite organizations in Victoria, Vancouver and Toronto showing positivity towards the green movement, little has been done to help realize its goals in terms of completely shifting to renewable energy sources and preparing for the future [1][2]. However, the Canadian government is taking the appropriate steps by providing subsidies and investments in renewable energy projects for the near future [1][2]. Projections indicate that British Columbia's need for power will increase 15% by 2030. Although 87% of the province's power supply is currently provided by hydro, a renewable energy source, continuing to build large-scale dam sites with reference to site-C is ecologically damaging.

The climate is warming, leading to changing weather patterns with more frequent sunlit days, causing drought in previously spared areas of the province. For example, the Hoover Dam power station in California is dangerously close to shutdown due to dwindling water reserves at the time of writing this report [4]. Given these circumstances, it would be prudent to consider various solar-based energy collection methods for the province in addition to hydro. Furthermore, the dependency on biomass and natural gas, which together accounts for 5% of British Columbia's electric portfolio, can be further reduced [3].

Our project aims to reduce a building's power dependency on the grid at a small but widespread scale, promoting the utilization of renewable energy production throughout the province. The Solar Office Companion (SOC) is a prototype window/wall mounted DC power hub designed to power small electronic devices in the workplace using solar power. The goal is to demonstrate the feasibility of power generation on vertically oriented solar modules placed over unused or false window space of existing buildings. The scope of the work involves designing and building a modular prototype unit for measuring power output based on a southerly orientation.

As we don't have access to a fabrication facility, we’re limited to using off-the-shelf components at a higher cost. A cost analysis using gathered electrical data and publicly available market data will be conducted, assessing the potential energy feasibility beyond the prototype. However, specifying or designing the mechanical fastenings required to mount the panels and the aesthetic appeal of visible components are not within the scope of this project; only suggestions have been made in this regard thus far.

It is our wish to uphold the Engineers and Geoscientists of BC (EGBC) principles and to continue serving the public in a positive way [5], we hope that our work will influence funded groups to explore designing a vertically oriented solar system for installation over unused building spaces, or that it will inspire government bodies to write legislation requiring building envelopes to offset power costs, helping Canada's 2050 net zero emission goal [2]. The potential user base for this idea ranges from individuals who intend to utilize a small unit in their office, to building owners desiring to implement this over an entire wall of their structure. Any south-facing unused exterior wall or window space is a great location for this idea and any individual or property owner can stand to benefit from it. This system can operate alongside the existing grid, requiring no AC to DC conversion.

II Objectives

- Perform preliminary investigation; investigate if similar products exist on the market and the need/market space for the product (unused space on buildings, Canada's net zero emission goal) (May 20)
- Design prototype system (May 25)
- Source components (May 31)
- Analyze/predict the systems power parameters based on components and sunlight calculations for our location (June 1)
- Asses the costs and forecast power savings (June 16)
- Order components for the system (June 23)
- Receive components/materials (July 1)
- Build prototype (July 7)
- Complete prototype troubleshooting/testing; verify design and calculations (July 21)
- Submit final project report demonstrating future viability of our design (July 28)

III Design Specifications

Overview

The purpose of this initial design is to serve as a basis for further work and analysis, potentially leading to subsequent designs. It will be considered a proof of concept and basic model for our cost and feasibility analysis.

The envisioned system is intended to be discrete and modular, with only a portion of a window or wall covered with solar modules and the amount of coverage easily adjusted. The solar modules will be capable of series or parallel wiring to the solar power manager, depending on the amount of sunlight available. Additionally, the number of battery modules used can be scaled by wiring them in parallel to the solar power manager. The design aims for maximum compatibility with existing buildings and workspaces by integrating solar collection and storage capability into unutilized spaces, without interfering with the existing area.

The system is meant to operate continuously, harvesting any available solar energy. It relies on vertically oriented photovoltaic cells mounted on a south-facing building surface. To regulate the solar module charging current required for a 3.7V lithium battery module and a 5V 1.5A USB outlet, a readymade solar power manager is utilized. The basic prototype design includes the necessary items, such as casing and wiring.

solar cells…………………………………………………………………. 2
solar power manager………………………………………………………… 1
batteries……………………………………………………………………… 4

The purpose of the design is to ensure sufficient energy for keeping the battery bank full, while also fully charging a cellphone battery once daily. An overview of the system is provided in Figure 1 on the next page.

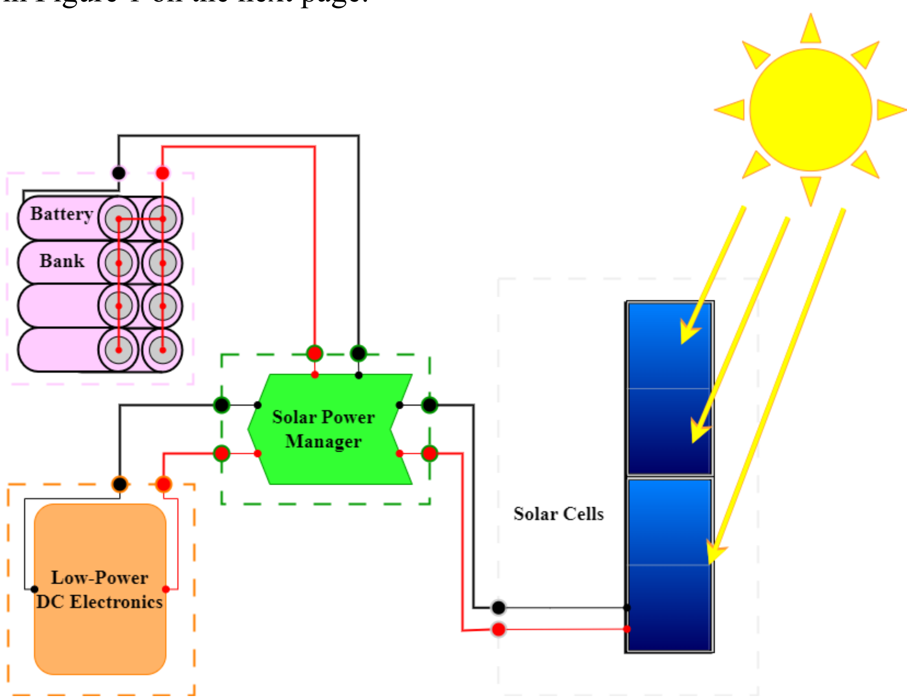


Figure 1. System block diagram consisting of two solar modules, charge controller, two battery modules and load

Solar Module

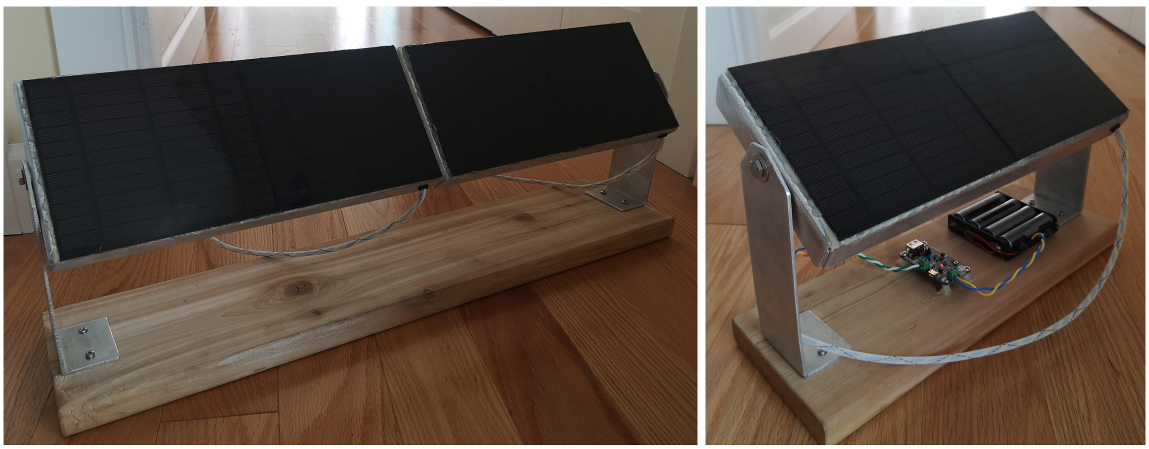
The solar cells (POW92136O) [6] characteristics of interest include output voltage V_{pvO} = 5.5V, current I_{pvO} = 0.54A, output power $P_{pvO} \approx$ 3W with an efficiency η of 16% and dimension LxW = 0.160m x 0.138m giving an area of 0.02208m^2. The solar cells will operate under slightly different conditions than normal, discussed in section VI. These cells were chosen based on being compact enough to handle and demonstrate while providing enough power for a proof of concept design and having a low price point on the market.

The solar modules for the prototype are made up of two solar panels wired in series and placed on folded sheet metal mounts. Two panels in series are required to meet the minimum 7V input voltage requirement for the solar power manager.

$$V_{pmIN} = 7V - 30V \qquad V_{pvO} = 5.5V$$

$$2 \cdot 5.5V = 11V$$

The current for a series wired single solar module will still be $I_{pvO} = 0.54A$ and two modules wired in parallel will provide $I_{2pvO} = 1.08A$. One module will suffice for powering the system discussed in section VI.

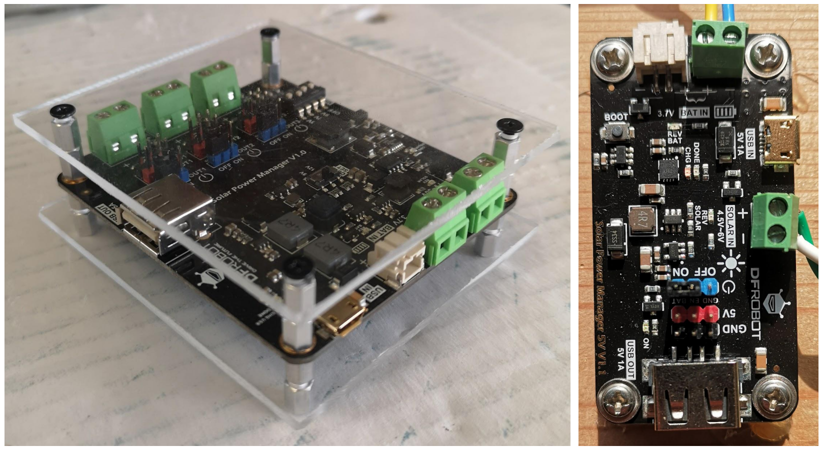


Figures 2a. and 2b. Prototype 2x2 and 1x1 solar modules.

The prototype solar modules are built to excessive strength for demonstration purposes; the weight and size is not reflective of what a commercial grade solar module could be or if a thin film panel was used.

Solar Power Manager Module

The solar power manager module is the DFR0535 board [7] mounted with pcb standoffs inside of a plexiglass enclosure. Characteristics of interest include solar input voltage range $V_{pmIN} = 7V$ to $30V$, maximum battery charge current $I_{pmBAT} = 2A$, battery bank voltage $V_{pmBAT} = 3.7V$, output voltage $V_{pmO} = 5V$, output current $I_{pmO} = 1.5A$ and solar charge efficiency $\eta_{1A} = 78\%$. This solar power manager is a popular component used in solar powered applications including solar street lights and environmental sensing modules. Selected for its cost-effectiveness, it maintains the necessary robustness to showcase a proof of concept design. The selectable maximum power point feature is beneficial as it helps extract more energy from the sun with a variety of solar panel outputs, when the output voltage isn't close to the maximum power voltage. The smaller DFR0559 board can be used in the single module design to reduce cost, though it doesn't have an adjustable maximum power point, limiting its versatility. The DFR0559 is also limited to 1A maximum input. Both boards have in circuit protection against overheating reversed connections on the battery and panels, as well as overcurrent protection.



Figures 3a. and 3b. DFR0535 and DFR0559 solar power managers. The latter was not selected for use.

Battery Module

The 18650 battery cells [8] chosen have a nominal voltage V_{BAT} = 3.7V, matching the solar power manager battery input voltage along with a charge capacity of 2600mAh. The energy capacity of a single cell is obtained by multiplying the charge capacity by the nominal voltage.

$$Ah \cdot V_{BAT} = E_{BAT} \tag{1}$$

$$E_{BAT} = 2.6Ah \cdot 3.7V = 9.62Wh$$

These cells were chosen for their versatility and affordability. They can be combined in parallel and connected to the solar power manager without additional hardware. Four cells minimum are used in a battery bank module due to available battery holder configurations and to provide sufficient charging capability. The method and reasoning will be discussed in section VI.

Figures 4a. and 4b. Prototype battery modules consisting of 8 and 4 cells

Load

The load will be a cellphone (Pixel 3a) [9] with nominal voltage V_{BAT} = 3.85V, charge capacity 3000mAh and energy capacity E_{phone} = 11.55Wh. This load was chosen because cellphones are a commonly used electronic device and can be considered the bare minimum an energy system should power. With an output voltage and current of 5V and 1.5A, the solar power manager is ideal for this task.

Casing/Enclosures

The panel backing varies depending on the end panel used. If the prototype solar panels were used, they're already prepared for installation with the folded sheet metal backing providing cover for the wiring. No cover is necessary for the panels due to its vertical positioning, reducing the probability of damage from falling debris. Given adequate time and care towards creating the solar modules, their construction can be refined with just the panel surface showing and a narrow bent collar offsetting them from a building. All wiring could be routed beneath the collar and hidden.

Plexiglass was chosen as the enclosure material for the solar power manager and battery modules, due to the low cost and relative workability of acrylic. Depending on personal preference, the transparent walls revealing the internal components can provide warranted aesthetics. Safety is improved with the transparent design, allowing any interior electrical faults to be visible.

Mounting/Placement

The solar module features a folded 3/32" aluminum sheet metal backing, allowing it to be mounted to a window by fastening to any side of the window ledge. Subsequent units can be fastened together if they do not contact an edge. This mounting capability enables the module to completely cover an unused window, faux window, wall, or partially cover a window that may be obstructed in certain places. The mounting angle is adjustable from vertical with the use of additional mounting brackets. Furthermore, the aluminum backing serves as a heatsink for the solar panels, enhancing cooling and improving electrical performance.

The battery and solar power manager casing is designed with a narrow form factor to fit in between desks, walls, and filing cabinets. These rectangular units can stack together, forming modular power walls. One idea for locking the modules together is using metal snap buttons that are sunk into the exterior walls of the modules, with electrical leads connected to them.

Comments

The maximum voltage reachable by this system is the 30V solar input voltage of the solar power manager. Voltages of 30V or below are considered safe and pose no shock hazard as per the Canadian electrical code [10]. In the spirit of the EGBC code of ethics, this measure safeguards the public and potential project re-creators.

IV Literature Survey

The need for upgrading existing structures is quickly approaching. In order to meet Canada's goal of net-zero greenhouse gas emissions by 2050, around 80% of existing buildings will need to be retrofitted with energy-efficient or energy-producing components and materials [2].

The costs of manufacturing and installing photovoltaics has declined over the years. Average efficiencies of commercially available solar panels are currently around 20% and the average installation cost per watt in British Columbia has fallen to $2.50/W [11][12]. Figures given by BC Hydro for Victoria tout a payback period of 17 years for a home solar array installed today; a generation capacity of 7kWh is said to produce 7700kWh of energy yearly [11][12]. By adopting the methods used to derive these values for vertically oriented solar panels, it's possible to make an educated feasible estimate for providing small scale DC power. BC Hydro has strict power quality requirements for those who wish to sell power to them with our design avoiding AC inversion and connection with the main electrical grid. The EGBC code of ethics is satisfied through practicing within the scope of our knowledge and not attempting to create grid connected devices without formal training or permission.

The declining costs associated with photovoltaics have spurred the emergence of new and niche solar applications. Companies like Renogy now offer commercially available extremely light and flexible panels with efficiencies of almost 20% and purchase costs of $1.75/W. These panels are specifically marketed for marine and RV usage, where weight issues, odd angles, and shapes are common [13]. They present an excellent option for creating smaller modular sizes suitable for vertical mounting.

Another emerging niche application involves miniature power systems like the BLUETTI, equipped with solar panel auxiliary charging features, making them suitable for camping or serving as backup power supplies for homes and offices [14]. However, these miniature power systems are currently prohibitively expensive, with a basekit including a 268Wh battery and 120W solar panel costing $800 [14]. The high cost is mainly attributed to the premium placed on packaging lithium batteries and high-powered inverters with solar charge controllers into a single unit designed for recreational purposes. Furthermore, the solar panel modules of these systems are considerably more expensive than competitors like Renogy, as mentioned earlier. Despite their ready-to-use nature, these prebaked miniature power systems may not offer the level of customizability we require for our specific use case.

A comparative analysis was conducted, examining the costs of existing solutions in contrast to building a prototype that implements our proposed solution. The study reveals a potential opportunity in the market for developing vertically placed solar panels, offering DC power in conjunction with or as an alternative to traditional photovoltaic installations, as Canada pursues its net-zero emission goals while photovoltaic prices continue to decline.

The proposed solution represents a novel approach given the limited existing information concerning retrofitting existing buildings with solar cell modules over unused window or false window space. If a company like Renogy or BLUETTI shows interest, it is anticipated that production costs could be reduced to match what these companies are currently paying. The prototype created using this solution demonstrates the smallest scale that is still viable for showcasing to an audience.

Given the production costs associated with photovoltaics and lithium batteries, it was not financially feasible to prototype a more robust system with better economics. The primary aim of this prototype is to establish a proof of concept rather than creating a product that can directly compete with established offerings on the market, which may be significantly less expensive, as evident in the comparison below.

Comparison of Existing and Proposed Solutions

Residential solar installation [11]:

Cost ……………………………………………………………………………$2.50/W

Capabilities
- provides reliable solar energy for 20+ years
- known payback period of under 20 years
- can be connected to electrical grid
- provides AC power through an inverter
- 1W installed provides 1.1kWh yearly in BC
- customizable sizing and placement on roof or property

Ease of use
- professional installation but may take a few days and hinder homelife
- little maintenance required after installation

Commercially available traditional solar panels [15]:

Cost ……………………………………………………………………………$1.40/W

Capabilities
- provides reliable solar energy for 20+ years
- known payback period of under 20 years
- can be connected to electrical grid with proper education and components
- provides DC power with options to buy inverters
- customizable sizing and placement anywhere a panel can fit

Ease of use
- amateur installation may encounter setbacks
- little maintenance required if installed properly

Commercially available thin film solar panels [13]:

Cost ……………………………………………………………………………$1.75/W

Capabilities
- provides reliable solar energy for 20+ years
- known payback period of under 20 years
- can be connected to electrical grid with proper education and components
- provides DC power with options to buy inverters
- 70% lighter than traditional solar panels
- customizable sizing and wrapping around surfaces

Ease of use
- amateur installation may encounter setbacks
- little maintenance required if installed properly

Miniature power systems [14]:

Cost ……………………………………………………………………………$5.00/W

Capabilities
- *provides reliable stored energy for a minimum of 3 years or 1000 charge cycles with lithium battery
- meant for off-grid energy solutions
- provides AC/DC power with built in inverter
- cost per watt decreases when buying additional solar module after base set purchase
- solar panel modules are available for off-grid charging
- somewhat customizable panel and battery sizing

Ease of use
- no installation
- little to no maintenance

Solar Office Companion:

Cost ……………………………………………………………………………$11.82/W

Capabilities
- *provides reliable stored energy for a minimum of 3 years or 1000 charge cycles with lithium battery
- meant for off-grid energy solutions
- provides DC power with buck regulator
- cost per watt decreases when buying additional solar module after base set purchase
- designed to be completely solar reliant

Ease of use
- **see below

*Higher costs are associated with batteries included.

**The SOC is designed to offer user-friendly functionality once installed, acting as a simple USB outlet providing 5VDC 1.5A. The solar panels are envisioned to be installed either professionally, akin to residential solar installations, or made easy for users to hang outside or inside windows using lightweight, flexible panels.

V Team Duties & Project Planning

Alan – Manager (paperwork, minor design, team organization)

Overall the manager is meant to facilitate the needs of the group, upkeep communications both internally and externally and keep the project on track. Many of the managers deliverables are hinged on other team members deliverables. Ordering the components for the project required the lead designer to have a preliminary list of components and a group review from the team. The manager will continue to keep track of group deliverables and aid in system analysis now.

Deliverables:

- Organize meetings with supervisor and course coordinator

- Order project components (critical)

- Assist with system analysis and report

Nathan – Lead Design (design, system analysis)

The lead designer's role is to envision the system along with accompanying concepts and components. Once the system has been designed the designer will move on to system analysis. The lead designer was not able to begin until the group had chosen a direction for the project. Additionally, system analysis cannot begin until the parts have arrived.

Deliverables:

- Provide a feasible design solution to the groups problem (critical)

- Amass component list

- Build the system

- Analyze the system once it is built

Brandan – Research and Development (sponsor sourcing, product research, sunlight calculations)

The role of research and development is to come up with a potential solution to a problem that the group is trying to solve. Existing and alternative solutions are looked into and potential sponsors are approached.

Deliverables:

- Identify a specific direction for the project (critical)

- Interface with other members of the industry asking for sponsorship in the form of components for prototyping

- Analyze the amount of usable sunlight available for collection in regards to office windows/wall as well as the projected loads for the system and then compare with system analysis

Matthew – Testing and Development (prototype setup, product research, load calculations)

The role of testing and development is to assist research and development as well verifying the system analysis performed. A comparison between real world performance and practical loads will be produced from testing.

Deliverables:

- Verify theoretical system analysis with lab work and testing

- Create team website (critical)

- Test practical load in real world conditions and provide analysis

VI Design Methodology & Analysis

Due to the intermittent and unpredictable nature of weather, the following design methodology follows an average approach when calculating solar insolation and device power output. Formulas are numbered when represented for the first time.

Solar Insolation Incident Upon a Vertically Oriented Surface

The solar constant, 1361 W/m^2 [16], is the amount of radiation energy per square meter that arrives at the edge of Earth's atmosphere from the Sun, otherwise named solar insolation. Before this energy reaches the surface, losses occur due to atmospheric effects combined with the length of the path taken through the atmosphere. These effects are described together as the air mass (AM) above a given area and it can be found using the following formula [17]

$$AM = \frac{1}{cos\theta_z} \tag{2}$$

where θ_z [18] is the solar zenith angle, the angle between the vertical direction and the sun's rays. A quick way to calculate the average yearly AM over an area is to use the area's latitude as the solar zenith angle. This holds true due to the Earth's tilt relative to the Sun, periodically changing from -23.45° to 23.45° throughout the year, which averages to the equivalent of the sun remaining at equinox with 0° declination [19]. Only latitude will affect the solar zenith at equinox with a 0° latitude at equinox, resulting in a 0° solar zenith angle and the sun being directly overhead. Figure 5 below illustrates this concept.

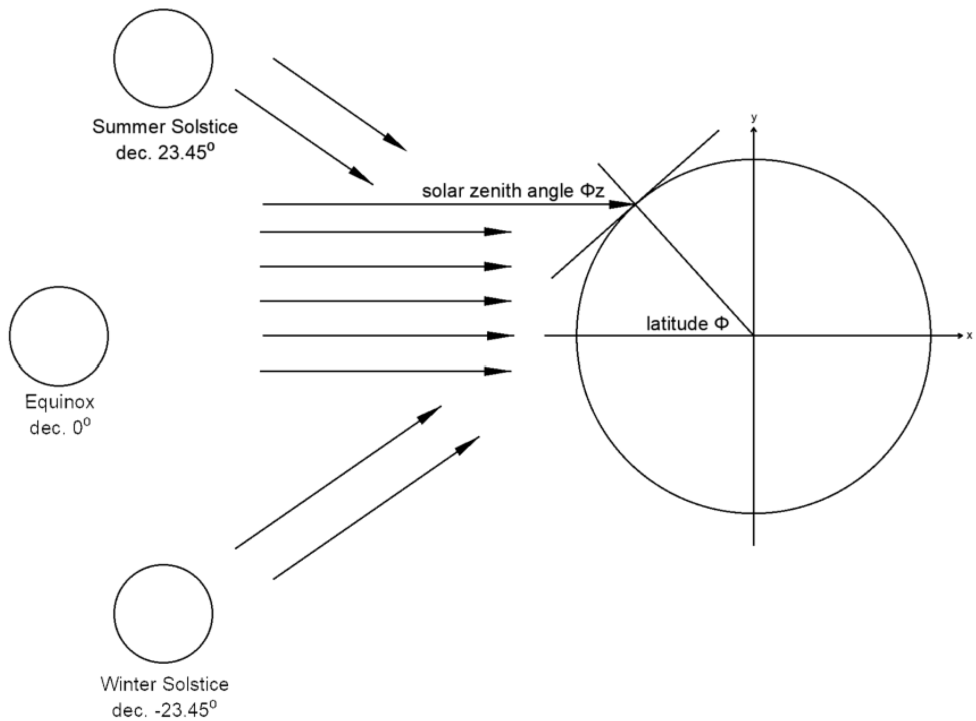


Figure 5. Changing declination of the Sun's rays on Earth throughout the year

The comprehensive formula below for solar zenith angle may be used if calculating more specific times of year. For our latitude, both this formula and the previous holds true [17][18].

$$cos\theta_z = sin\phi sin\delta + cos\phi cos\delta cosh \tag{3}$$

θ_z Solar zenith angle
ϕ Local latitude
δ Sun declination
h Hour angle (12 hours of day broken up into 15° pieces, morning corresponds to -90° and evening to 90° with solar noon being 0°)

The accepted AM for Victoria is given using its latitude.

$$AM = \frac{1}{cos48} = 1.5\ \mathrm{AM} \tag{4}$$

The minimum and maximum AM at solar noon are given using equations (3) and (4)

$$AM_{min} = \frac{1}{sin48.24sin23.45+cos48.24cos23.45cos0} = 1.1\ \mathrm{AM}$$
$$AM_{max} = \frac{1}{sin48.24sin(-23.45)+cos48.24cos(-23.45)cos0} = 3.2\ \mathrm{AM}$$

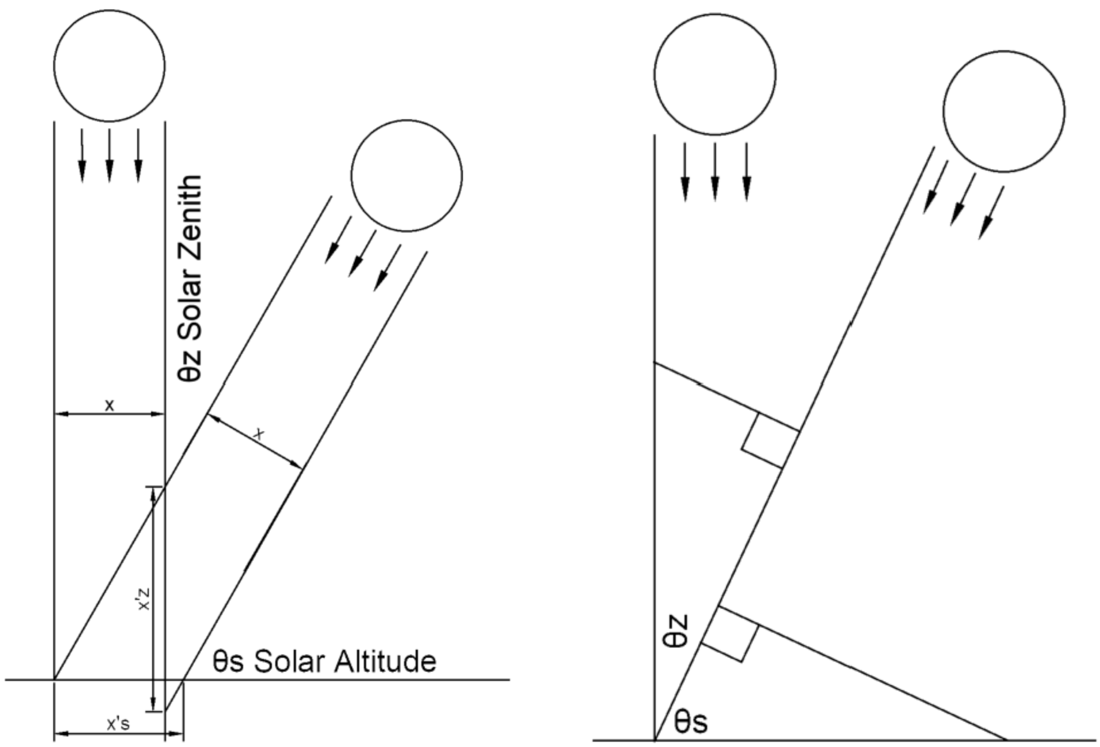
The solar insolation I_D reaching the earth at sea level is calculated using the experimentally derived equation [17][20].

$$I_D = 1.353 \cdot 0.7^{AM^{0.678}} \tag{5}$$

The value 1.353kW/m^2 is the value of solar constant used by the makers of this experimentally derived formula and it is known to fluctuate [16][21-24]. The observed data takes into account atmospheric effects, giving a power value of 0.678. The solar insolation reaching Victoria according to this model is given below with a modifier term accounting for indirect radiation. A number of sources discuss indirect radiation components that contribute to solar panel performance[16][21-24]. One paper mentions determining indirect radiation but due to a lack of critical data, only the governing equations have been written. Accepted estimates of the indirect radiation component place it to be an additional 10% of the direct insolation [17].

$$I_D = 1.353 \cdot 0.7^{1.5^{0.678}} = 0.846\, kW/m^2 \quad \text{and } I_G = 1.1 I_D = 0.931\, kW/m^2 \tag{6}$$

The simplest way to describe indirect solar radiation is to imagine a solar panel on a darker cloudy day still producing limited energy. This is due to indirect solar radiation getting through cloud cover, along with reflecting from all the surfaces around the panel.



Figures 6a. and 6b. depicting the relationship between surface angles and surface area energy intensity

When picturing a solar beam of arbitrary width, the maximum beam intensity is achieved when intercepted head on. As the beam takes an angle to the intercepting surface, its area is dispersed, reducing the beam intensity. This can be extended to a point source; Figures 6a and 6b illustrate the concept where x'_z and x'_s are the scaled intercept areas resulting from varying solar angles. Using geometry and knowing the sun can be approximated as a point source an infinite distance away, it can be deduced that the intensity of solar insolation falling upon an area at a given angle is related to the hypotenuse of the right triangle, made by the angle of the Sun's ray and the surface of concern using the sin of the angle in question [23].

$$I_{D\theta_z} = I_D sin\theta_z \tag{7}$$

Since the solar modules will ideally be placed on south facing surfaces, the average solar declination they'll experience is equal to the latitude of their location as mentioned earlier in this section. For simplicity, it's assumed that the same percentage of indirect solar radiation will contribute to energy production.

$I_{D48°} = 0.846 sin\, 48° = 0.629\, kW/m^2$ and $I_{G\theta_z} = 1.1 I_{D\theta_z} = 0.692 kW/m^2$

This concept is illustrated in Figure 4 below which depicts the path of the sun relative to the vertically oriented south facing solar modules.

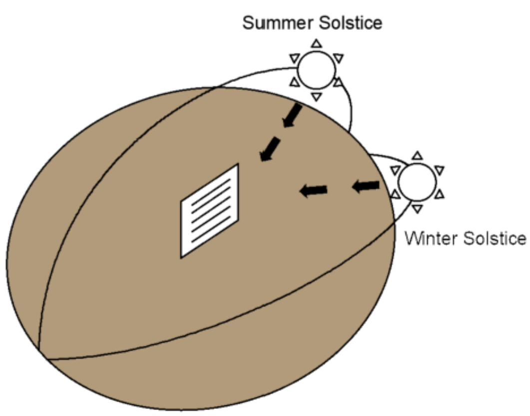


Figure 7. Sun's path through the sky depending on time of year

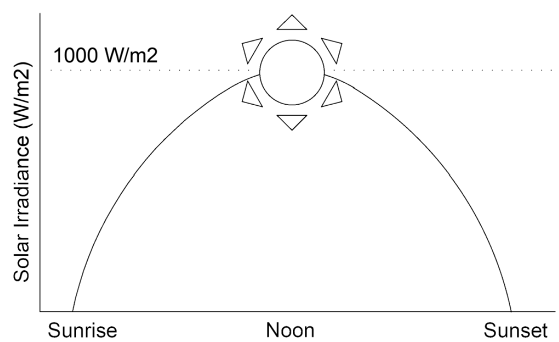


Figure 8. Peak Sun hours over a surface

It can be observed that during the winter months, the solar modules will experience more direct solar radiation as the sun sits lower over the horizon, whereas in the summer, the sun will be more directly overhead. This intensity of light is based on the vertical inclination and should not be confused with the hour angle of the sun, which ranges from -90° to 90° throughout the day. Referring to Figure 7 and Figure 8 above, it can be seen that even for a vertically oriented surface, the most direct incident sunlight occurs during the peak of the Sun's traverse across the sky.

The sun does not shine with maximum intensity throughout the day; the number of peak sun hours in a day corresponds to the equivalent number of hours of the sun shining at its accepted average of 1000W/m2. For example, if a 1m2 solar panel with a 1kW output produced 3kWh in a day, it could be said that the day had 3 peak sun hours. However, the day may not have experienced any peak sun hours but rather a lower level of insolation throughout the day due to cloud cover [25][26].

Solar Power Calculations for Vertical Cell

The total average incident power due to solar insolation on a vertical solar cell is given by multiplying its collection area by the total solar insolation incident upon it at a 48° latitude.

$$P_{incident48°} = Area_{cell} \cdot I_{G48°} \tag{8}$$

$$P_{incident48°} = 0.02208m^2 \cdot 0.692kW/m^2 = 15.28W$$

The panel output is governed by its efficiency

$$P_{solar48°} = \eta_{solar} \cdot P_{incident48°} = 0.16 \cdot 15.28W = 2.44W \tag{9}$$

Control Calculations are made to determine this methods accuracy

$$P_{incident} = 0.02208m^2 \cdot 0.931kW/m^2 = 20.56W$$

$$P_{solar} = 0.16 \cdot 20.56W = 3.28W$$

$$Percentage\ error = |\frac{3W-3.28W}{3W}| \times 100\% = 9.3\%$$

With a percent error under 10% between the rated and calculated values for the cell under normal conditions, it’s deemed acceptable to continue the analysis. It’s possible that the panels are slightly underrated, and more significantly, the area calculation was based on the entire surface of the solar cells without considering contacts and bus bars, which do not generate energy. Current generation solar cells typically have around 5-10% of their sun-facing surface covered by metal contacts and pathways designed for carrying current [27]. Although the analysis method remains valid, it should be anticipated to yield slightly higher results and this should be accounted for with a factor of 5-10%.

Upon analyzing equation (9), it becomes evident that the panels are no longer able to produce their rated output power of 3W in this configuration. The converter efficiency further impacts performance.

$$P_{converter48°} = \eta_{converter} \cdot P_{solar48°} = 0.78 \cdot 2.44W = 1.90W \tag{10}$$

A minimum of two solar cells in series are required to meet the input voltage requirements of the DFR0535 board as outlined in section III. The DFR0559 board requires a 5V input and hence only one panel in series at most. Because each module consists of 2 solar panels in parallel, the power generated will be doubled for a single module and doubled again for the 2x1 module. The value below is taken as the expected energy output for the 1x1 and 2x1 solar modules when connected to the DRF0559 and DFR0535 solar power manager respectively. A 2x2 DRF0535 module is also shown, utilizing two 2x1 modules in parallel.

$$P_{1x1\,module48°} = 2 \cdot P_{converter48°} = 2 \cdot 1.90W = 3.8W \tag{11}$$
$$P_{2x1\,module48°} = 4 \cdot P_{converter48°} = 4 \cdot 1.90W = 7.6W \tag{12}$$
$$P_{2x2\,module48°} = 4 \cdot P_{converter48°} = 8 \cdot 1.90W = 15.2W \tag{13}$$

Data available from BC Hydro states that for residential solar power, every 16 solar panels with 7kW output the equivalent yearly energy harvest of 7700kWh/year. Assuming standard residential solar panels have an efficiency of 20% and area of 1.65m^2 this translates to

Total area	$16 \cdot 1.65m^2 = 26.4m^2$
Solar array yield	$1kWh \cdot 26.4m^2 \cdot 20\% = 5280W$
Peak Sun hours	$7700kWh/5280W = 1458\,hours$
Daily average peak Sun hours	$1458h/365\,days = 4.1\,hours/day$

This data is corroborated by other sources, stating an average of 1200-1600 peak sun hours for Victoria [25][26]. The average daily and yearly outputs per solar module can now be calculated

$$P_{1x1\,module48°/day} = 3.8W \cdot 4.1\,hours = 15.6Wh/day \tag{14}$$
$$P_{2x1\,module48°/day} = 7.6W \cdot 4.1\,hours = 31.2Wh/day \tag{15}$$
$$P_{2x2\,module48°/day} = 15.2W \cdot 4.1\,hours = 62.3Wh/day \tag{16}$$

$$P_{1x1\,module48°/year} = 15.6Wh \cdot 365\,days = 5.7kWh/year \tag{17}$$
$$P_{2x1\,module48°/year} = 31.2Wh \cdot 365\,days = 11.4kWh/year \tag{18}$$
$$P_{2x2\,module48°/year} = 62.3Wh \cdot 365\,days = 22.7kWh/year \tag{19}$$

Load Calculations

The load is meant to be a Pixel 3a smartphone with a battery capacity of E_{phone} =11.55Wh. Assuming fully charging the phone once a day gives the following.

$$E_{phone/year} = E_{phone} \cdot 365\, days = 11.55Wh \cdot 365 = 4216Wh/\text{year} \quad (20)$$

The daily average energy output of a solar module is greater than the energy needed to charge a cellphone once daily, with respective values of 15.6Wh and 11.55Wh. Considering the 5-10% overestimate for solar cell surface area, a full charge for the load can be illustrated as a portion of the solar cell's daily production capacity.

$$\frac{11.55}{15.6(0.9)} x100\% = 82\% \quad (21)$$

This analysis predicts that two 3W solar cells with 16% efficiency will be able to fully charge a smartphone once daily throughout the year on average. It should be noted that there will be seasonal differences in energy production, which may warrant an additional solar module. Indeed, determining the optimal suitability of vertically oriented solar panels without experimental data from both summer and winter seasons can be challenging. While summer generally offers brighter and sunnier days, the winter positions the Sun in its best possible declination relative to the solar cells. Without empirical data comparing their performance in different seasons, it is difficult to ascertain which season may be more favorable for vertically oriented solar panels. Proper analysis based on real-world measurements from both seasons will provide a clearer understanding of their efficiency and effectiveness.

Battery Calculations

Four 18650 cells are to be packaged using 4 pack battery holders. The energy capacity of such a battery module will be

$$4 \cdot E_{BAT} = 4 \cdot 9.62Wh = 38.48Wh \quad (22)$$

Charging the cellphone completely will only draw 30% of the battery module's capacity with enough capacity to fully charge a phone 3 times only from the reserve.

Load vs battery capacity $$\frac{11.55Wh}{38.48Wh} = 30\% \quad (23)$$

Amount of load battery charges available $$\frac{38.48Wh}{11.55Wh} = 3.33\, charges \quad (24)$$

Alternate Designs

Two alternate designs using different solar power managers were investigated; the less expensive DFR0559 [28], and the costlier Renogy 40A MPPT [29] with lesser and better characteristics respectively.

The DFR0559 will not perform adequately as its input voltage range is 4.4V to 6V and limits connecting solar modules to only in parallel. The output charging current and battery charging currents are also lower, at 1A each vs 1.5A and 2A respectively for the DFR0535.

Renogy 40A MPPT controllers with a 100V max input only cost $100 currently, but the solar panels necessary for demonstrating a better product economy are too large or are the right size but too costly when considering the larger batteries required. The economics of this system would already be an improvement to the prototypes.

VII Design & Prototype

Design Objectives

This stand alone photovoltaic system's specific design requirements are:

- The system must be modular and each subsystem must allow for interconnection to increase battery storage, solar panel output, and change power management.
- Power and/or charge low power DC electronics.
- Provide stability with respect to temperature and other environmental impacts.
- Congruent with code 1 of the EGBC code of ethics [5], the prototype must be safe for the public. This is especially important when using lithium ion batteries and power electronics.
- Achieve low system cost.
- Approximately 3-month development time.

The abstract design of a stand-alone photovoltaic system includes three subsystems, the charge/solar controller, the solar panels, and the energy storage solution. The design of each subsystem will be discussed separately in the following sections. The order of these sections is indicative of the actual design workflow due to the interdependencies of each subsystem.

Charge/Solar Controller

The charge solar controller is a crucial subsystem responsible for converting the output power of the solar panel(s) into stabilized battery charging and device powering outputs. Given the time constraints of this project, a consumer power management device for embedded systems was chosen. Alternatively, a specialized custom device could be designed to reduce manufacturing costs and device footprint. Thus, the selection of the charge controller is based on a combined metric of versatility, cost, and safety. Two boards that meet these requirements are the DFR0559 and the DFR0535 boards [7].

The DFR0559 is a lower power device with a maximum input of 5V and 1A, while the DFR0535 offers a wider input range of 7V to 30V and a maximum input of 2A. Both boards feature integrated 3.7V to 4.2V lithium-ion battery chargers and regulated USB-A outputs. These metrics form the foundation for the following subsystem designs. Importantly, these selected power management boards are hot-swappable and can be replaced when compatible solar panel systems are connected.

The boards are assembled with stand-offs to elevate them off the mounting surface, and the DFR0535 board includes a plexiglass cover. A pigtail with spade connectors is connected to the provided screw terminals, facilitating quick connections of battery sub-systems and solar panel sub-systems. This configuration is depicted in Figure 9 below.

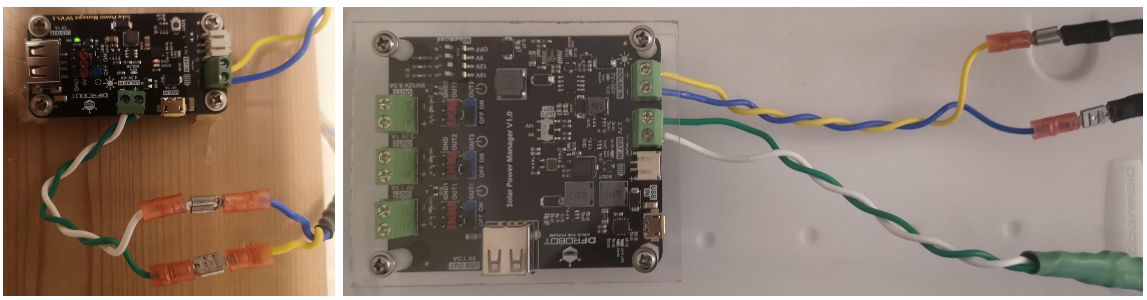


Figure 9: DFR0559 (left) and DFR0559 (right) showing pigtail connections.

Solar Panels

The selected solar panels must be compatible with the mentioned charge controllers, requiring an ideal single panel operation voltage of 5V, low cost, high efficiency, and a small footprint. The solar module designed for the middle-sized module incorporates variable maximum power point voltage settings using the DFR0535. As a result, cost limitations primarily dictate the selection of solar panels, with an additional goal of maximizing power-to-area ratio. Thus, 3W 16cm x 14cm monocrystalline silicon solar panels were chosen.

A total of 10 panels were ordered to demonstrate modularity and three functional system sizes. These system sizes include a 1x1 module system, where each module consists of two solar panels in parallel, achieving an operating voltage of approximately 5V for efficient use of the DFR0559 board. Additionally, a 2x1 system and a 2x2 system are incorporated within the design parameters, with the 2x1 system having two modules in series, and the 2x2 system having two modules in series and two in parallel. These systems will employ the larger power DFR0535 board. Notably, the approximate power output of each system doubles from 1x1 to 2x1 to 2x2.

To create the solar panel mounts, aluminum 3/32” sheet metal was folded into a five-sided rectangular box. The largest face measures 32cm in length and 14cm in width, while the other four edge sides are 3cm high. Two 1.5” holes were drilled at the mounting location of the center of each solar panel, and two more ⅜” holes were drilled on the short edge of the box for later module connection and/or mounting. A final ⅜” hole was drilled on the bottom long edge for the wiring to be run through.

The solar panel modules were assembled onto the large face of the aluminum mount using a heat sink compound to enhance thermal conduction, which were then securely glued around the perimeter of the panel. The electrical contacts of the panel were left exposed by the 1.5” holes, allowing the panels to be wired in parallel and then connected to an external module pigtail utilizing spade connectors. Rubber grommets, braided wire sheathing, and heat shrink were used to create durable and safe connections. The assembled module is shown in Figure 10 below.

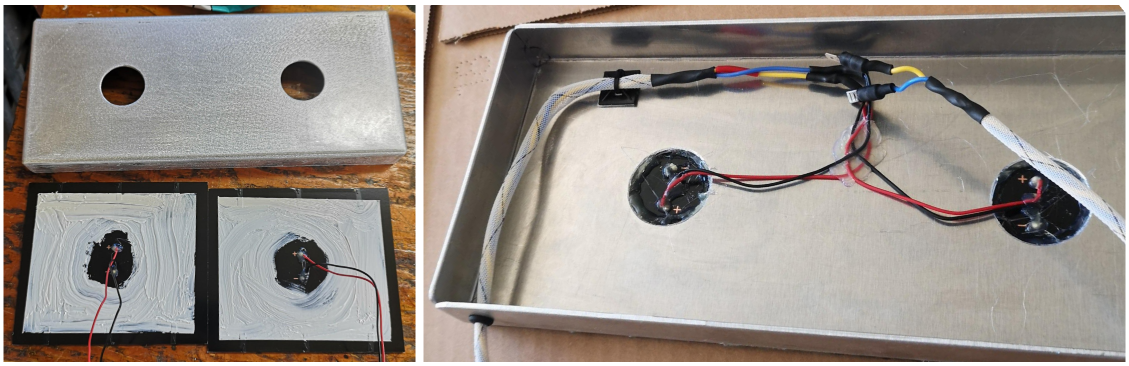


Figure 10: Solar panel mount and wiring connections.

Energy Storage

The energy storage system utilizes lithium-ion batteries due to the included charging option in the selected power management boards, taking advantage of their high energy density and relatively low cost. The power management boards are specifically designed for charging batteries with a voltage range of 3.7V to 4.2V, which is why the 18650 battery cells connected in parallel were chosen [8]. To achieve this, the battery packs connecting four batteries in series were selected and modified to hold the battery cells in a parallel arrangement. Interconnections between the battery packs utilize 18-gauge wire, which exceeds the 2A board limit and provides wire strength to handle repeated flexing.

It's important to note that using more than two battery packs, which means more than eight cells, would require a larger charging current to achieve a reasonable charge time. The subsystem can be seen in Figure 11 below.

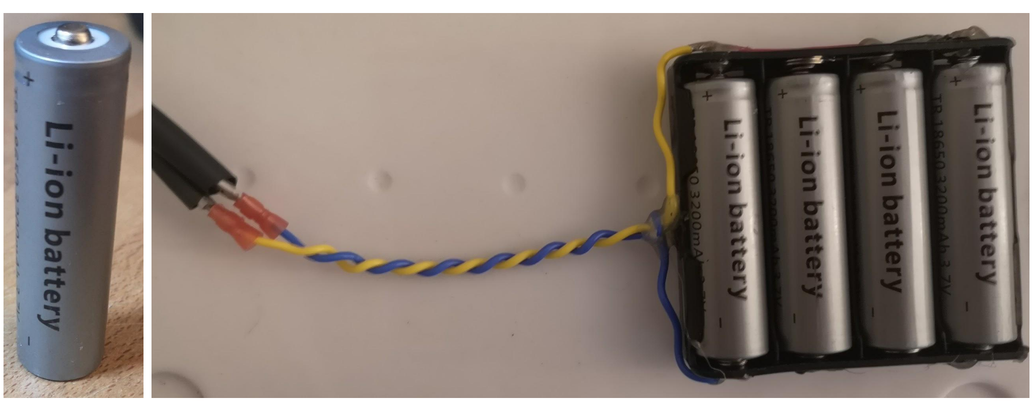


Figure 11: Lithium ion 18650 cell (left), and energy storage subsystem (right) with quick disconnects.

Final Prototype

The final prototype successfully fulfills all stated objectives and achieves the maximum power-to-cost ratio within the limited prototyping funding and period. Subsystem modularity was accomplished by employing spade connectors crimped to the end of the wires, ensuring that both the wire and crimps can handle currents exceeding 2A, which is the requirement (approximately 14A). This design allows each subsystem to be easily swapped out or parallelized to modify system specifications. The final systems, depicted in Figure 12, consist of a 1x1 system and two 2x1 systems that can be combined to create a 2x2 system. All of these configurations can power small DC electronics requiring an input of 1A at 5V through USB.

For instance, the smallest 1x1 system can charge an average cell phone once per day and maintains an approximately 3-day reserve when the battery pack is fully charged. The total cost of the 1x1 module was approximately $100, which is reasonable for a prototype. A polished product could further reduce costs through use of custom charge controllers and by reducing the overall size of the panel mount. Additionally, increasing the purchase volume of solar panels would result in further cost reductions.

The final product generates the predicted power output, as discussed in the validation section, while demonstrating the ability to function under standard environmental conditions and temperatures due to proper wire connections sealing and effective heat sinking of the solar panels.

Figure 12: Final prototype systems from top to bottom 1x1, 2x1, 2x1. Note that the two 2x1 systems may be combined to create one 2x2 system.

VIII Testing & Validation

Solar Module IV Characterizing:
The first test to take place after the final prototype was developed is the measurement of the current-voltage (IV) curve. At a material level, the silicon solar panel is created using a pn junction analogous to that of a silicon diode. As a result, there's great similarity in the output IV characteristics with an additional offset due to solar generated current in the reverse direction. This results in a traditional diode IV curve shifted down by the maximum output current of the panel (short circuit current I_{sc}).

As it's infeasible to provide an idealized solar source, the measurements were collected in the aforementioned Victoria, BC environment during a sunny day. The IV curve test plan is as follows:

1. Measure I_{sc} under full sun at approximately normal angle. Do this by attaching a current meter to the positive and negative terminals of the panel in series. Remove the panel from the sun to minimize temperature change during the test.
$$I_{sc\ sunny} = 1.006A$$
2. Place the panel in a shaded location where there's still a measurable power generation. Measure I_{sc}.
$$I_{sc\ shaded} = 153mA$$
3. While shaded, connect a variable resistive load and voltmeter in parallel with the solar panel module and an ammeter in series, as seen in the Figure 13 below.

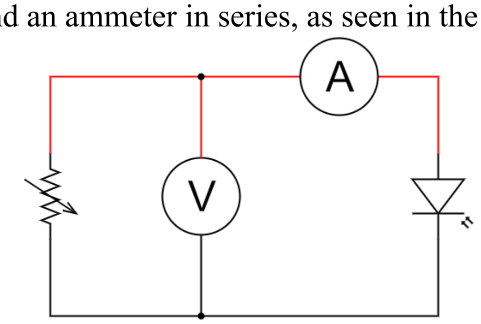


Figure 13: Solar panel IV test setup diagram.

4. Increase the resistive load until there is no measurable current and begin recording the measured current, voltage and load resistance. Reduce the load resistance and repeat the measurements.
5. The data collected is the IV curve in the shade. To represent the IV curve in full sun, the full short circuit current must be corrected for. To achieve this, the difference of I_{sc} in the sun must be subtracted from each current measurement. See Table 1 below for actual measurements.

Voltage [V]	Resistance [Ω]	I_{shade} [mA]	I_{sun} [mA]	P_{sun} [W]
6.39	5111	0	-856	5.47
6.26	911	-7	-863	5.40
6.26	811	-7	-863	5.40
6.25	711	-8	-864	5.40
6.24	611	-9	-865	5.40
6.23	511	-11	-867	5.40
6.22	411	-15	-871	5.42
6.20	311	-20	-876	5.43
6.16	211	-28	-884	5.45
6.05	111	-55	-911	5.51
5.99	91	-65	-921	5.52
5.93	81	-73	-929	5.51
5.87	71	-83	-939	5.51
5.78	61	-95	-951	5.50
5.62	51	-110	-966	5.43
5.30	41	-130	-986	5.23
4.43	31	-145	-1001	4.43
3.02	21	-147	-1003	3.03
1.53	11	-147	-1003	1.53
1.34	9	-147	-1003	1.34
1.19	8	-145	-1001	1.19
1.06	7	-147	-1003	1.06
0.93	6	-150	-1006	0.94
0.78	5	-151	-1007	0.79
0.68	4	-152	-1008	0.69
0.48	3	-152	-1008	0.48
0.33	2	-152	-1008	0.33
0.17	1	-152	-1008	0.17
0.02	0	-153	-1009	0.02

Table 1: Solar panel IV measurements.

6. The next step is to plot the values recorded in the table and fit the idealized solar panel equation to the measured data. This will provide a reasonable approximation for the complete full sun IV curve. The fitting equation is shown below.

$$I = I_0\left(e^{\frac{Vq}{k_B Tn}} - 1\right) + I_{sc} \tag{26}$$

Where n is an ideality factor, and I_0 is a solar panel material dependent constant. The empirically determined values were $n = 16.5$, and $I_0 = 70\ nA$. Given that n will vary with temperature and I_0 is in the nano-ampere range, these values are reasonable.

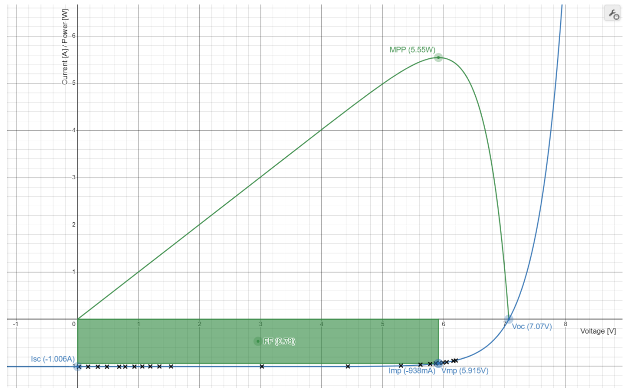


Figure 14: Single solar panel module full sun characterization, with measurements in black.

This test method was selected to ensure a consistent temperature during the measurement phase, considering the high temperature dependence of monocrystalline silicon solar panels. The resulting characteristic curve provides valuable information on the fill factor and maximum power point for the solar module, facilitating comparisons with other panel technologies and validating predictions.

Moreover, the test data can be utilized to accurately estimate the performance of other multi-module systems without the need for re-measurement. This approach was necessary as re-measuring would have been impractical, requiring a relatively high-power variable resistor. Figure 15 displays the characterizations of two such systems: the first system features two modules in parallel, while the second system includes two modules in series and two in parallel.

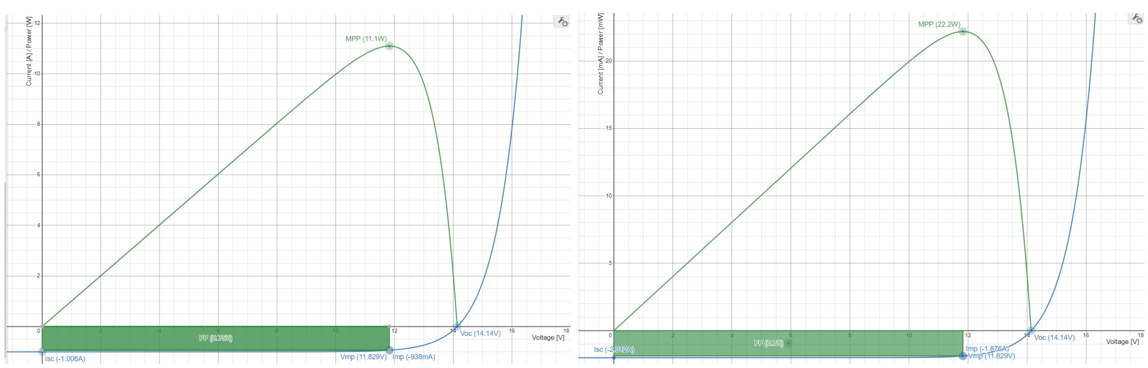


Figure 15: 2x1 (left) and 2x2 (right) solar panel module full sun characterization.

Solar Module Performance Measurements:

The following tests measure the performance of each module during an example deployment. The efficiency of the system is predominantly determined by the solar charge controller module, given its variable voltage conversion and controlled charging. As a result, the efficiency of the system is dependent on both the load and operating point. However, a complete charge cycle observation with constant solar insolation and temperature is required to measure this accurately, which is beyond the scope of this report. Nevertheless, the following test presents the data collected.

The test method used to demonstrate the power generation and consumption of each of the three solar module arrangements is as follows:

1. Begin by arranging the module south-facing and at a vertical angle with respect to the horizon. The test should occur close to solar noon for minimal air mass.
2. Connect ammeters and voltmeters in series and parallel with each sub system of the module. This allows a measurement of power generated (positive) and power consumed (negative) for each sub system.
3. Record the current and voltage measurements for each sub system of each module arrangement. This test observed the module arrangements 1x1, 2x1 and 2x2, representing one module, two modules in series and two modules in parallel respectively.
4. Re-arrange the modules such that they're approximately normal to the sun, repeat steps 2 and 3. The final observed measurements are shown below in table 2.

	Vertical Mounting			**Solar Normal Mounting**		
Module(s)	1x1	2x1	2x2	1x1	2x1	2x2
P_{USB} [W]	-6.00	-4.30	-5.95	-4.15	-3.75	-4.85
V_{USB} [V]	+5.00	+5.00	+5.00	+5.00	+5.00	+5.00
I_{USB} [A]	-1.20	-0.86	-1.19	-0.83	-0.75	-0.97
P_{BAT} [W]	-5.01	-1.88	+0.30	-2.08	-0.84	+0.38
V_{BAT} [V]	+3.85	+3.77	+3.81	+3.93	+3.80	+3.83
I_{BAT} [A]	-1.30	-0.50	+0.08	-0.53	-0.22	+0.10
P_{PANEL} [W]	+3.24	+6.39	+9.56	+5.46	+8.66	+10.54
V_{PANEL} [V]	+4.44	+12.05	+12.23	+5.30	+12.20	+12.84
I_{PANEL} [A]	+0.73	+0.53	+0.78	+1.03	+0.71	+0.82

Table 2: Solar module subsystem power measurements vertical vs ideal normal mounting angle at solar noon.

Validation

This section will validate the correct operation of the three stand alone photovoltaic systems. Briefly discussed will be the power output of the module, as the regulated DC output will depend on the connected load. This includes the battery and DC electronics along with the current charge of each load.

The measured operating voltage for the 1x1 solar module is 4.44V with vertical orientation, given a measured interconnection resistance of 0.45Ω and current output of 0.73A at the time of measurement. The actual panel voltage can be calculated as:

$$V_{meas\ solar48°} = 4.44V + 0.5\Omega \times 0.73A = 4.805V \tag{27}$$

From the measured IV curve of the 1x1 module, it can be seen that at 4.805V the output power is 4.809W. The predicted output power for a single 1x1 module utilizing two solar panels with vertical mounting is seen below:

$$P_{1x1\ solar48°} = 2 \times 2.44W_{1-panel} = 4.88W \tag{28}$$

The percentage error is calculated as follows. This percentage error will be true for all modules since it's linear combinations of the same equation. This percentage error is extremely low, validating the predicted power to area and power per module calculations.

$$Percentage\ Error\ =\ |\frac{4.88W-4.809W}{4.88W}|\ \times\ 100\%\ =\ 1.54\% \qquad (29)$$

From the data presented in Table 2 above, which illustrates example usage measurements, it is evident that each of the modules is capable of charging both the batteries and low-power DC electronics successfully. As expected, the smallest module primarily charges the battery bank. However, the largest 2x2 system can simultaneously charge both the battery bank and the DC electronics when mounted vertically or ideally positioned.

The calculated estimated output power per solar module in section VI was 15.6Wh/day and the test data estimated output power per solar module is:

$$P_{1x1\ module48°/day}\ =\ 3.44W\ \cdot\ 4.1\ hours\ =\ 14.1Wh/day \qquad (30)$$

$$Percentage\ Error\ =\ |\frac{15.6W-14.1W}{15.6W}|\ \times\ 100\%\ =\ 9.6\% \qquad (31)$$

The percentage error between the theoretical and tested values is under 10%. This seems acceptable when considering the variability of the solar data used for theoretical calculations and the insolation variability during testing.

IX Cost Analysis

Tables 3-5 below provide the costs associated with our project; both direct and indirect. Direct costs are the materials and hardware used for prototyping while indirect refers to the time worked by all members.

Hardware/Materials	Quantity	Cost Per Unit (CAD)	Total (CAD)
Solar Cell	10	$17.33	$173.30
DFR0535	2	$43.36	$86.72
DFR0559	3	$11.46	$34.38
18650 Battery Cell	16	$3	$48
Battery Holder	3	$2.16	$6.48
PCB Standoffs	48	$0.41	$19.94
Plexiglass ⅛"	2' x 2'	$35	$35
Sheet Metal Aluminum ⅛"	10' x 12'	free scrap	free scrap
Swivel Mounts	6	free scrap	free scrap
Wood	8" x 2" x 8'	free scrap	free scrap
Wiring	40'	free scrap	free scrap
Total Costs with 12% Tax:	-	-	$457.32

Table 3. Total Direct Costs

5 hours were worked on average per week for about 13 weeks, giving 65 hours per person. Average senior co-op wage is about $3,935 per month for full-time Electrical engineering students, therefore about $22.70/hr, as per UVic's data [30]

Member Name	Total Hours Worked (Hrs)	Hourly Wage(CAD)
Alan	~65	$22.70
Nathan	~65	$22.70
Brandan	~65	$22.70
Matthew	~65	$22.70
Total	260	$5902.50

Table 4. Total Indirect Costs

Funder	Amount Received (CAD)
CEWIL	$359.32
UVic	$95.46
Total Funding:	$454.78

Table 5. Funding

Tentative pricing and ROI calculations:

The cost of one prototype system using a 1x1 module is broken down in table X below

Hardware/Materials	Quantity	Cost Per Unit (CAD)	Total (CAD)
Solar Cell	2	$17.33	$34.66
DFR0535	1	$43.36	$43.36
18650 Battery Cell	4	$3	$12
Battery Holder	1	$2.16	$2.16
PCB Standoffs	16	$0.41	$6.56
Plexiglass ⅛"	7" x 7"	$5	$5
Sheet Metal Aluminum ⅛"	1' x 2'	free scrap	free scrap
Swivel Mounts	2	free scrap	free scrap
Wood	8" x 2" x 2'	free scrap	free scrap
Wiring	10'	free scrap	free scrap
Total Costs with 12% Tax:	-	-	$103.74

Table 6. Prototype Cost

At our current capability when not factoring in working time an additional solar and battery module will cost roughly $45 and $15 to produce, for ease of calculation the cost of making one base unit will be approximated to $100. If lots of these units were to be produced, shipping and manufacturing costs would begin to decrease.

BC Hydro's energy rate is 9.59 cents per kWh and our system produces

$$P_{1x1\ module 48°/year} = 14.1Wh \cdot 365\ days \approx 5.1kWh/year$$

using one solar and battery module each. This only provides $0.50 worth of energy a year with an ROI of 200 years if the base kit costs $100. Calculations made for our system using optimal placement relative to the sun only gives:

$$P_{converter} = \eta_{converter} \cdot P_{solar} = 0.78 \cdot 3W = 2.34W$$
$$P_{1x1\ module} = 2 \cdot P_{converter} = 2 \cdot 2.34W = 4.68W$$
$$P_{1x1\ module/day} = 4.68W \cdot 4.1\ hours = 19.1Wh/day$$
$$P_{1x1\ module/year} = 19.1Wh \cdot 365\ days \approx 7kWh/year$$
$$Percentage\ Error = |\frac{7kWh - 5.1kWh}{7kWh}| \times 100\% = 27\%$$
$$\$0.68 = \frac{\$0.50}{(1 - 0.27)}$$

Using this system in an optimal placement relative to the sun would yield approximately $0.68 worth of energy per year, resulting in a return on investment (ROI) of 147 years. It is evident that there's much more efficient solar systems being installed in residential and commercial markets. However, it's essential to note that our particular system is not intended for commercial release; instead, it serves as a proof of concept for the feasibility of vertical solar panels in Victoria.

Despite the modest 27% performance difference between the two configurations, we believe that larger companies can develop vertical solar panel systems with lower profit margins. The forthcoming energy crisis and the Canadian government's plans to increase renewable spending may also result in potential tax incentives or other measures aimed at reducing costs and increasing profits.

To achieve cost reduction, scaling and design optimization are critical factors. Scaling involves larger companies mass-producing this product, while design optimization entails utilizing custom-designed solar power managers and solar modules. By implementing these measures, system costs can be significantly reduced.

X Conclusion & Recommendations

This project aims to design a relatively small stand-alone photovoltaic system for consumer use. The final prototype demonstrated the ability to charge and store energy for use with low power DC electronics. The proposed design is a modular system that consists of a charger controller, solar panel, and battery bank. Furthermore, the prototype system demonstrates the modularity of a stand-alone system and how it may be sized differently for varying system requirements. Such a system can be built-upon if requirements grow, and removes the need for grid connections and system distribution. A user implementing this system as described would be able to incrementally add photovoltaic power, offsetting traditional power production with a lower initial overhead.

The low overhead and invasiveness of this photovoltaic solution makes it desirable and achievable compared to other systems through use of careful design constraints. Firstly, the system is designed for use with DC electronics only. Currently AC systems make up the majority of grid systems and grid to user connections, meaning that DC electronics that make up a majority of electronics sold require conversion from AC to DC. This system is designed for DC use only. This cuts down on system components required by interfacing with both AC electronics and AC power systems, powering a majority of consumer products. The modularity of the system allows users to incrementally add upon their design and replace modules with different technologies.
For example, users may experience extended periods without significant sunlight but when it's present, the irradiance is significant enough not to warrant additional costly panels, with users supplementing their system with additional battery packs. These reasons justify the proposed solution, allowing the user to replace system parts as needed due wear or technological advances, further decreasing their carbon footprint over subsequent years.

The purpose of this project is to demonstrate the viability of the photovoltaic system described. To achieve this, prototype miniature systems will be developed, supplying power to a small battery bank and USB output. Three systems will be created, each possessing slightly different qualities: one with a larger charge controller, and two identical systems that can be combined to showcase the modularity of the system. Upon project completion, consumers will have the opportunity to observe and interact with a tangible, small-scale solar energy demonstration, gaining an understanding of how easily attainable the gradual shift to renewable energy can be.

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Appendix

Appendix One: EGBC Code of Ethics [5]

ENGINEERS &
GEOSCIENTISTS
BRITISH COLUMBIA

CODE OF ETHICS

The Code of Ethics required under the *Professional Governance Act,* S.B.C. 2018, c. 47 and created in the Bylaws of Engineers and Geoscientists BC provides a set of principles that all registrants are required to follow.

A registrant must adhere to the following Code of Ethics:

Registrants must act at all times with fairness, courtesy and good faith toward all persons with whom the registrant has professional dealings, and in accordance with the public interest. Registrants must uphold the values of truth, honesty, and trustworthiness and safeguard human life and welfare and the environment. In keeping with these basic tenets, registrants must:

1. hold paramount the safety, health, and welfare of the public, including the protection of the environment and the promotion of health and safety in the workplace;
2. practice only in those fields where training and ability make the registrant professionally competent;
3. have regard for the common law and any applicable enactments, federal enactments, or enactments of another province;
4. have regard for applicable standards, policies, plans, and practices established by the government or Engineers and Geoscientists BC;
5. maintain competence in relevant specializations, including advances in the regulated practice and relevant science;
6. provide accurate information in respect of qualifications and experience;
7. provide professional opinions that distinguish between facts, assumptions, and opinions;
8. avoid situations and circumstances in which there is a real or perceived conflict of interest and ensure conflicts of interest, including perceived conflicts of interest, are properly disclosed and necessary measures are taken so a conflict of interest does not bias decisions or recommendations;
9. report to Engineers and Geoscientists BC and, if applicable, any other appropriate authority, if the registrant, on reasonable and probable grounds, believes that:
    a. the continued practice of a regulated practice by another registrant or other person, including firms and employers, might pose a risk of significant harm to the environment or to the health or safety of the public or a group of people; or
    b. a registrant or another individual has made decisions or engaged in practices which may be illegal or unethical;
10. present clearly to employers and clients the possible consequences if professional decisions or judgments are overruled or disregarded;
11. clearly identify each registrant who has contributed professional work, including recommendations, reports, statements, or opinions;
12. undertake work and documentation with due diligence and in accordance with any guidance developed to standardize professional documentation for the applicable profession; and
13. conduct themselves with fairness, courtesy, and good faith towards clients, colleagues, and others, give credit where it is due and accept, as well as give, honest and fair professional comment.

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Appendix Two: Project Website URL and Front Page
https://matthewtran1.github.io/SolarOfficeCompanion/