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 sources into the workplace provides sustainability and knowledge of the respective energy sources. Climate change has created a high priority demand for renewable energy sources 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 is becoming more financially sensible to begin installing solar modules in less ideal locations. Organizations in Victoria, Vancouver and Toronto have been positive about the green movement yet 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]. That being said, the Canadian government will be providing subsidies and buying renewable energy projects in the near future [1][2]. Projections show British Columbia's appetite for power increasing 15% by 2030 and while we enjoy 87% of our supply being provided by hydro [3], a renewable energy source, it is ecologically damaging to continue building large scale dam sites such as site-C. The climate is warming, bringing with it changing weather patterns consisting of frequent sunnier days causing drought in areas of the province previously spared, 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]. Considering all this, it would be prudent to consider various solar based energy collection methods for the province in addition to hydro; additionally biomass and natural gas still make up over 5% of British Columbia's electric portfolio and can be cut further [3].

The problem we address with our project is reducing an existing building's power dependence on the grid in a small but widespread scale to assist in transitioning towards using renewable based energy production throughout the province. Our project, the Solar Office Companion (SOC), is a prototype window/wall mounted solar powered DC power hub meant for powering small electronic devices in the work or home office. The goal of our project is to demonstrate feasible returns on vertically oriented solar modules placed over unused or false window space of existing buildings. The scope of the work done involves designing and building a modular prototype unit and measuring the power output based on a southerly orientation. With no fabrication facility at our disposal we are limited to off the shelf components which are higher in cost. Only an educated cost/analysis using the gathered electrical and publicly available market data can be made regarding the potential energy feasibility beyond the prototype unit. It is not within the scope of this project to specify or design the mechanical fastenings required to mount the panels nor the aesthetic appeal of the visible components; 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 this work will influence other better 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 to help meet Canada’s 2050 net zero emission goal [2]. The potential user base for this idea ranges from individuals who want to use a small unit in their office to building owners wanting 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 and as it is meant to provide DC there is no AC inversion required.

II Objectives

- Perform preliminary investigation; investigate if similar products exist on the market and investigate 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 the components and sunlight calculations for our location (June 1)
- Weigh the costs, 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 provide a basis from which to perform further work/analysis and possibly create subsequent designs, it should be considered a proof of concept and a basic model for cost/feasibility analysis.

The system was envisioned to be discrete and modular meaning that only a portion of a window or wall would have to be covered with solar modules and the number could always be modified. The solar modules will be able to be wired in series or parallel to the solar power manager depending on the amount of sunlight available. The amount of battery modules used will also be scalable by having them wired in parallel to the solar power manager. The purpose of this is to be as compatible as possible with existing buildings and work spaces by fitting in solar collection and storage capability into unutilized spaces while not interfering with what exists around. The system is meant to operate year round and harvest any available solar energy available during the day. It is based on photovoltaic cells oriented vertically on a south facing building surface. An off the shelf solar power manager is used to regulate the solar module charging current for a 3.7V lithium battery module as well as provide a 5V 1.5A USB outlet. The basic prototype design consists of the following items as well as casing and wiring.

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

This design is meant to provide enough energy for keeping the battery bank full while fully charging a cellphone battery once daily. An overview of the system is given in figure 1 on the next page.

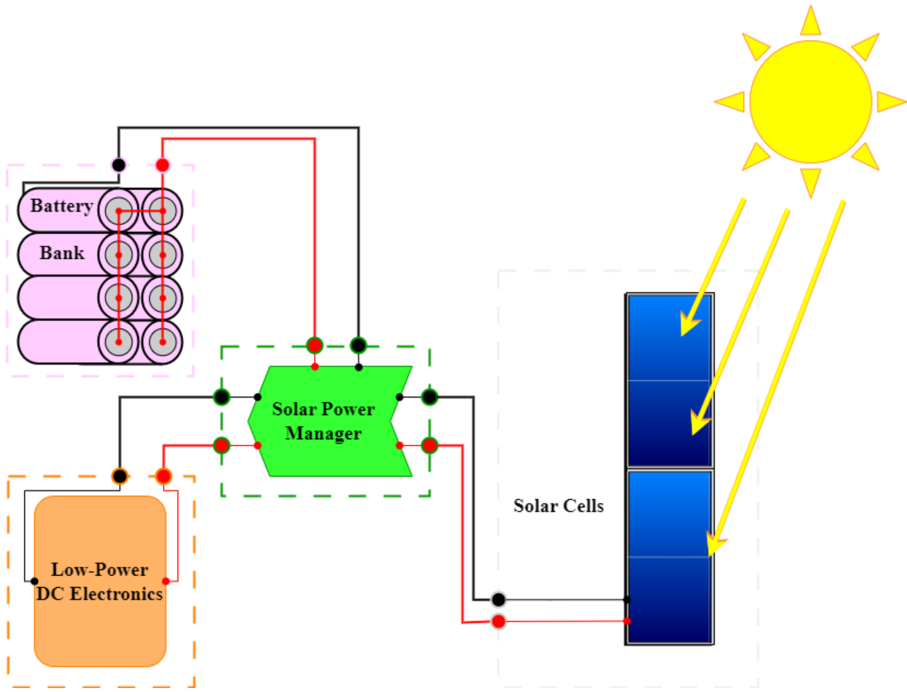


Figure 1. System block diagram consisting of two solar modules, charge controller, two battery modules and load

Solar Module

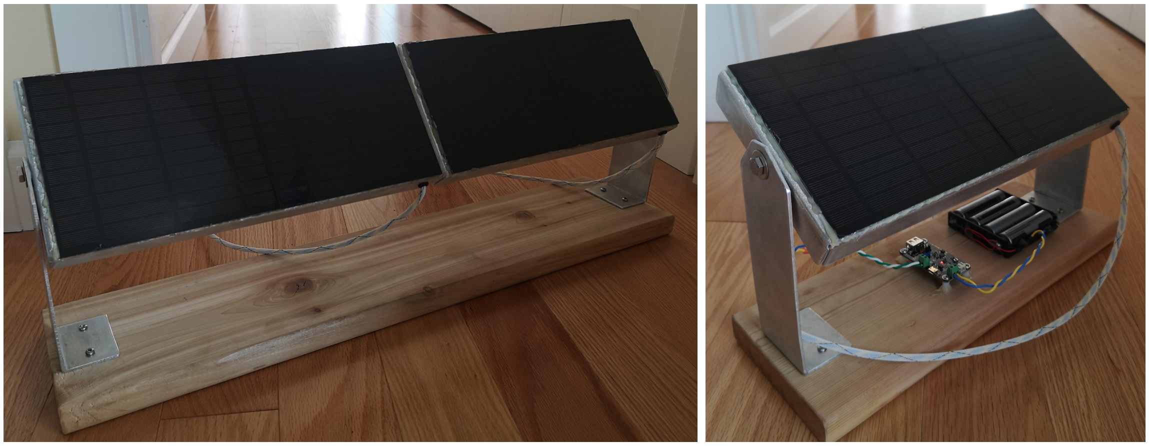
The solar cells (POW92136O) [6] characteristics of interest include their output voltage V_{pvO} = 5.5V, current I_{pvO} = 0.54A, output power $P_{pvO} \approx$ 3W with an efficiency η of 16% and dimension LxW = 0.160m x 0.138m giving an area of 0.02208m^2. The solar cells will be operating under slightly different conditions than normal which will be discussed in section VI. These cells were chosen based on being small enough to handle and demonstrate while still being able to provide 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 as will be discussed in section VI.

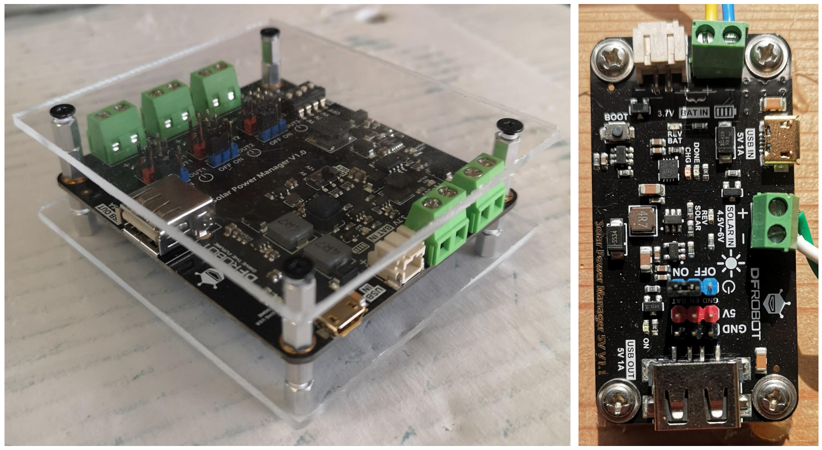


Figures 2a. and 2b. Prototype 2x2 and 1x1 solar modules.

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 - 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 η_{1A} = 78%. This solar power manager is a popular component used in solar powered applications like solar street lights and environmental sensing modules. It was chosen for its low price point while still being robust enough to demonstrate 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 doesn't happen to be close to the maximum power voltage. The smaller DFR0559 board may be used in the single module design to reduce cost; it does not have an adjustable maximum power point thus limiting its versatility. The DFR0559 is also limited to only 1A maximum input. Both boards have in circuit protection against overheating reversed connections on the battery and panels, as well as over current 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 and charge a 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 along with low price point; they can be combined in parallel and connected to the solar power manager without additional hardware. Four cells minimum will be 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 of 5V 1.5A the solar power manager is ideal for this task.

Casing/Enclosures

The panel backing would vary depending on the end panel used. If the prototype solar panels were to be used they are ready for installation as is with the folded sheet metal backing providing cover for the wiring. No cover is necessary for the panels as they are facing sideways and there is less of a chance for falling debris to damage them. Depending on the time and care spent on building the solar modules they could be made to look quite sleek 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 out of sight.

Plexiglass was chosen as the enclosure material for the solar power manager and battery modules for now due to the low cost and relative workability of acrylic. Depending on personal preference the transparent walls revealing the internal components can be seen as aesthetically pleasing or not. Safety is improved with the transparent design allowing for any interior electrical faults to be quite visible.

Mounting/Placement

The solar module folded 3/32" aluminium sheet metal backing allows the solar modules to be mounted to a window by being fastened to any side of the window ledge and having subsequent units fastened together if they do not contact an edge. This can be used to completely cover an unused window,faux window or wall, or to partially cover a window that is used but can be obstructed in certain places. The mounting angle could be adjusted from vertical with additional mounting brackets. Additionally the aluminium backing for the solar panels is assembled and designed as a heatsink for the panels to improve cooling and increase electrical performance.

The battery and solar power manager casing is designed with a narrow form factor so they can fit in between desks, walls and filing cabinets. The units are rectangular and can stack together to form modular power walls. Using metal snap buttons sunk into the exterior walls of the modules with electrical leads brought to them was one idea for locking the modules together.

Comments

The maximum voltage that can be reached by this system is the 30V solar input voltage of the solar power manager. Voltages of 30V or below are considered to be safe and pose no shock hazard as per the Canadian electrical code [10]. This protects the public and any would-be re-creators of this project in the spirit of the EGBC code of ethics

IV Literature Survey

The need for upgrading existing structures is fast 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 been declining 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 BChydro 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 is possible to make an educated estimate of their feasibility for providing small scale DC power. BChydro has strict power quality requirements for those who wish to sell power to them, our design avoids AC inversion and connection with the main electrical grid. The EGBC code of ethics is being 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 has spurred the birth of new and niche solar applications. Extremely light and flexible panels are now commercially available from companies such as Renogy with efficiencies of almost 20% and purchase costs of $1.75/W, these are currently marketed for marine and RV usage where weight issues, odd angles and shapes are common [13]. Panels such as these are a good candidate for making something similar but in smaller modular size made easy for vertical mounting. A new niche application is miniature power systems such as the BLUETTI with solar panel auxiliary charging features that can be taken camping or used as backup power supplies around the home and office [14]. Miniature power systems such as the BLUETTI are still currently prohibitively expensive, $800 for a basekit with 268Wh battery and 120W solar panel [14], this largely appears due to an apparent premium on packaging lithium batteries and high powered inverters with solar charge controllers in one unit meant for recreation; additionally the solar panel modules are far more expensive than competitors such as Renogy previously mentioned. They do however come already spec'd and ready to go whereas the previous solutions may be less costly but require additional work and components. This does also limit the customizability of prebaked miniature power systems and they may not be optimal for our use case.

A soft analysis has been carried by comparing the costs of existing solutions to the costs of building a prototype implementing our solution. There appears to be space in the market for developing vertically placed solar panels to provide DC power in concert with, or instead of traditional photovoltaic installations as Canada strives to meet its net zero emission goals and the price of photovoltaics continues to fall.

The proposed solution is a novel approach with little information existing on the topic of retrofitting existing buildings with solar cell modules over unused window/false window space to provide DC power. If a company such as Renogy or BLUETTI takes interest then it is assumed that production costs could be brought down to what those companies are currently paying. The prototype made using this solution is on the smallest scale that is still demonstrable to an audience. Due to the production costs associated with photovoltaics and lithium batteries it was not financially possible to prototype a heavier duty system with better economics. The purpose of this prototype is to provide proof of concept rather than a product that can compete with established products on the market which can be seen as far less costly 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 be easy to use once installed as it will just be a USB outlet providing 5VDC 1.5A. The panels are envisioned to be either mounted professionally as in residential solar or made easy to hang by users from 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. Now, 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 used 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 some of it is lost 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.

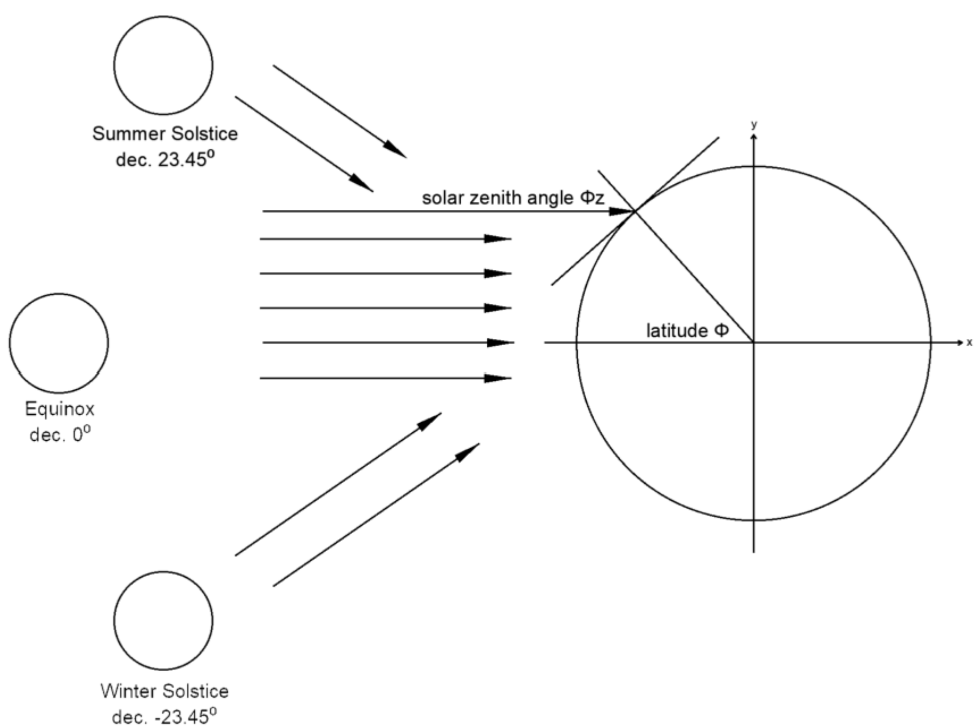


Figure 5. Changing declination of the Sun's rays on Earth throughout the year

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

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

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.

$$AM = \frac{1}{\cos 48} = 1.5 \text{ AM} \tag{4}$$

The minimum and maximum AM at solar noon are given using the complete formula eq.3 and eq.4

$$AM_{min} = \frac{1}{\sin 48.24 \sin 23.45 + \cos 48.24 \cos 23.45 \cos 0} = 1.1 \text{ AM}$$
$$AM_{max} = \frac{1}{\sin 48.24 \sin(-23.45) + \cos 48.24 \cos(-23.45) \cos 0} = 3.2 \text{ AM}$$

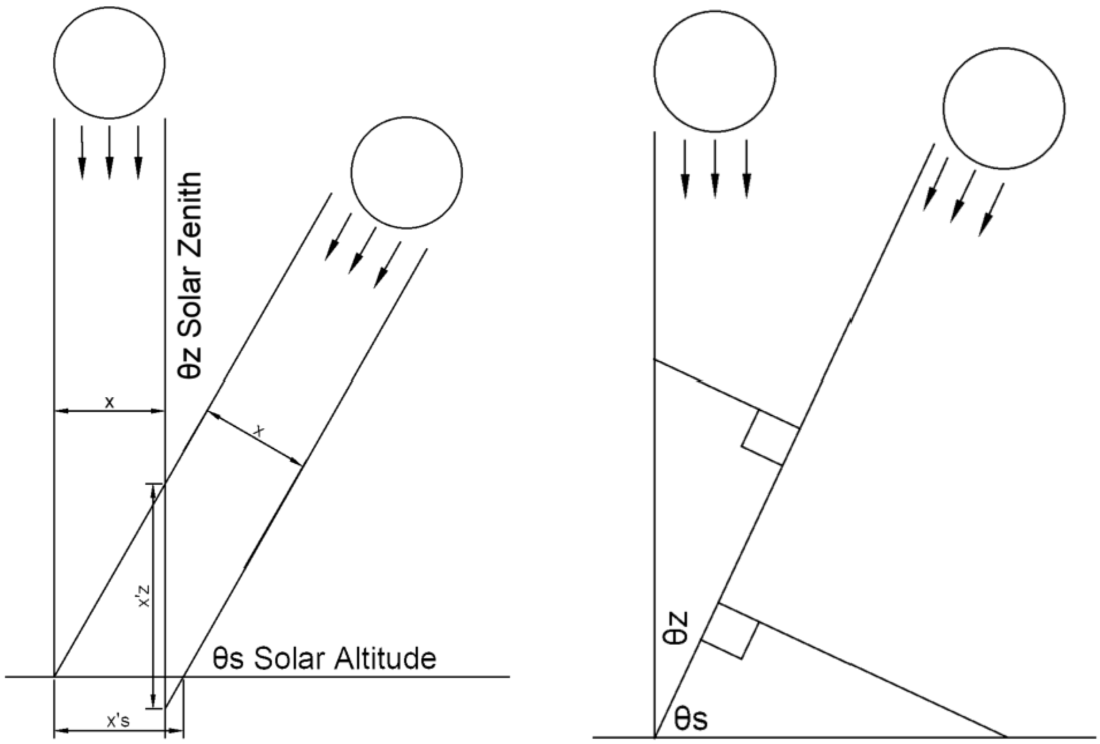
The solar insolation I_D reaching the earth at sea level is calculated using the experimentally derived equation [17][20].

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

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 which give the power of 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 but still producing some energy, this is due to indirect solar radiation still getting through the clouds as well as 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 source takes an angle to the intercepting surface its area is spread out 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 that the sun can be approximated as being 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 can be 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 will experience is equal to the latitude of their location as mentioned earlier in this section. For simplicity it is assumed the same percentage of indirect solar radiation will contribute to energy production.

$I_{D48°} = 0.846 sin48° = 0.629\ kW/m^2$ 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.

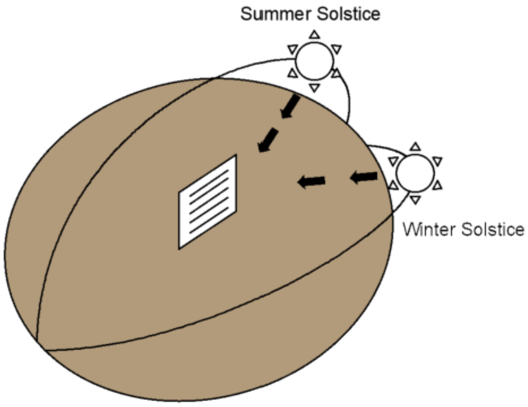


Figure 7. Sun's path through the sky depending on time of year

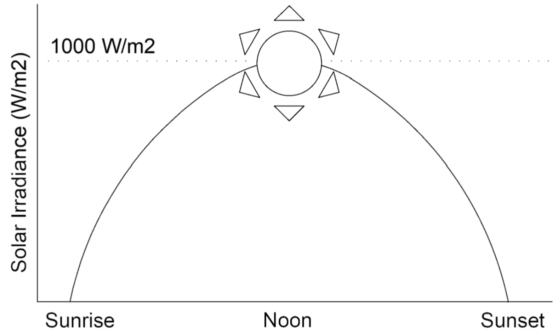


Figure 8. Peak Sun hours over a surface

It can be seen that in the winter months the solar modules will experience more direct solar radiation as the sun sits lower over the horizon while in the summer the sun will be more directly overhead. This is the intensity of light based on the vertical inclination and should not be confused with the hour angle of the sun which will proceed from -90° to 90° throughout the day. Referring to figure 7 and to figure 8 above it can be seen 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/m^2. For example if a solar panel 1m^2 in size with 1kW output produced 3kWh in a day it could be said that the day had 3 peak sun hours. The day in reality 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

Total average expected 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 latitude 48°.

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

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

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 should be acceptable to continue the analysis. The panels may be underrated by a small amount and more importantly the area calculation was for the entire surface of the solar cells without accounting for contacts and bus bars which do not produce energy. Current generation solar cells have anywhere from 5-10% of their sun facing surface covered by metal contacts and pathways meant for carrying current [27]. The analysis method is still valid but can be expected to give slightly higher results and should be accounted for with a factor of 5-10%.

It can be seen from analysis in eq (9) that the panels should no longer be able to produce their rated output power of 3W in this configuration. The converter efficiency further hampers performance.

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

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 which uses twp 2x1 modules in parallel.

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

Data available from BChydro states that for residential solar 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 which state 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

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

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

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 needs of charging a cellphone once daily, 15.6Wh vs 11.55Wh respectively. Keeping in mind the 5-10% overestimate for solar cell surface a full charge the load can be shown as a portion of the solar cell 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. It is difficult to determine without experimental data from both summer and winter seasons which is better suited for vertically oriented solar panels. There generally are brighter sunnier days in the summer but the winter puts the Sun in its best possible declination relative to the solar cells.

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 and there is enough capacity to fully charge a phone 3 times only from the reserve.

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

Amount of load battery charges available $\frac{38.48Wh}{11.55Wh} = 3.33\ charges$ (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 right now 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 in order 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 the 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 subsystem that converts the output power of the solar panel(s) to a stabilized battery charging and device powering outputs. Due to the time constraints of this project the choice to use a consumer power management device for embedded systems. Alternatively a specialized custom device could be designed to lower manufacturing costs and device footprint. Thus the charge controller must be selected based upon a combined metric of versatility, cost, and safety. Two boards that fit these requirements are the DFR0559, and the DFR0535 boards [7]. The DFR0559 is a lower power 5V 1A maximum input device, the DFR0535 has a 7V - 30V and 2A maximum input. Both boards have integrated 3.7V - 4.2V lithium ion battery chargers and a regulated USB-A output. These metrics lay the groundwork for the following subsystem designs. These selected power management boards are hot-swappable and may be replaced when allowable solar panel systems are connected. The boards are assembled with stand-offs to elevate them off of the mounting surface, the DFR0535 board includes a plexiglass cover. A pigtail with spade connectors is connected to the provided screw terminals to allow for quick connection of battery sub-systems and solar panel sub-systems. This can be seen below in figure 9.

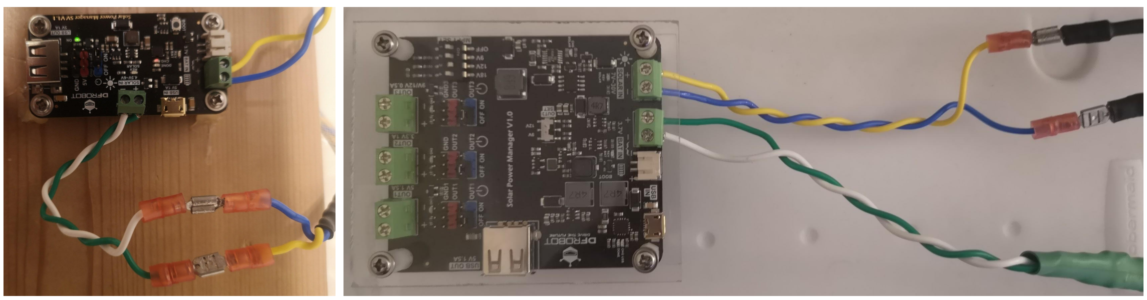


Figure 9: DFR0559 (left) and DFR0559 (right) showing pigtail connections.

Solar Panels

The solar panels selected must be compatible with the aforementioned charge controllers thus an ideal single panel operation voltage of 5V, low cost, high efficiency, and small footprint. The solar module designed for the middle sized module has variable maximum power point voltage settings using the DFR0535. Thus the limitations on cost chiefly dictate solar panel selection with a secondary goal of maximizing power/area. The selected panels were the 3W 16cm x 14cm monocrystalline silicon solar panels.

10 panels were ordered to exhibit the modularity and three functional system sizes. These system sizes are a 1x1 module system where each module consists of two solar panels in parallel to achieve an operating voltage around 5V for efficient use of the DFR0559 board. A 2x1 and 2x2 system are also included within the parameters of this design, where a 2x1 system has two modules in series and a 2x2 system has two modules in series and 2 modules in parallel. These systems will utilize the larger power DFR0535 board. Note that the approximate power output of each system doubles from 1x1 to 2x1 to 2x2.

The Solar panel mounts were made by folding aluminum 3/32" sheet metal into a 5 sided rectangular box. The largest face being 32cm long and 14cm wide the other four edge sides are 3 cm high. Two 1.5" holes were drilled at the mounting location of the centre of each solar panel. two more ⅜" holes are drilled on the short edge of the box for later module connection and/or mounting. A final ⅜" hole is drilled on the bottom long edge for the wiring to be ran through.

The solar panel modules were assembled onto the large face of the aluminium mount with heat sink compound to increase thermal conduction, and glued around the perimeter of the panel.The electrical contacts of the panel were left expose by the 1.5” holes allowing for 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 can be seen in figure 10 below.

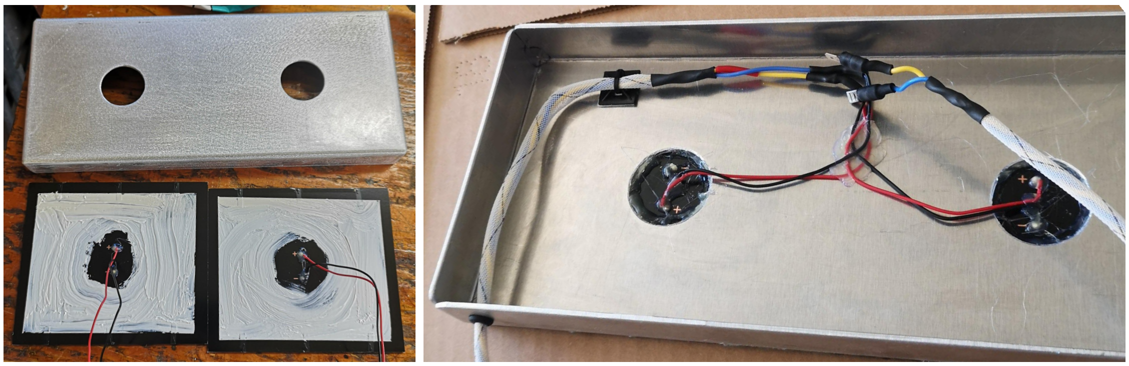


Figure 10: Solar panel mount and wiring connections.

Energy Storage

The energy storage system selected was lithium ion batteries due to the included charging option in the selected power management boards as well as the high energy density and relatively low cost. Because the power management boards are designed for charging 3.7V to 4.2V batteries the 18650 battery cell connected in parallel was chosen [8]. Four battery series connected battery packs were selected and modified to hold the battery cells in a parallel arrangement. 18 gauge wire is used for the battery pack interconnections that limits the maximum well above the 2A board limit and provides wire strength to handle repeated flexing. Utilizing more than two battery packs, that is more than eight cells would require a larger charging current for a reasonable charge time. The subsystem can be seen below in figure 11.

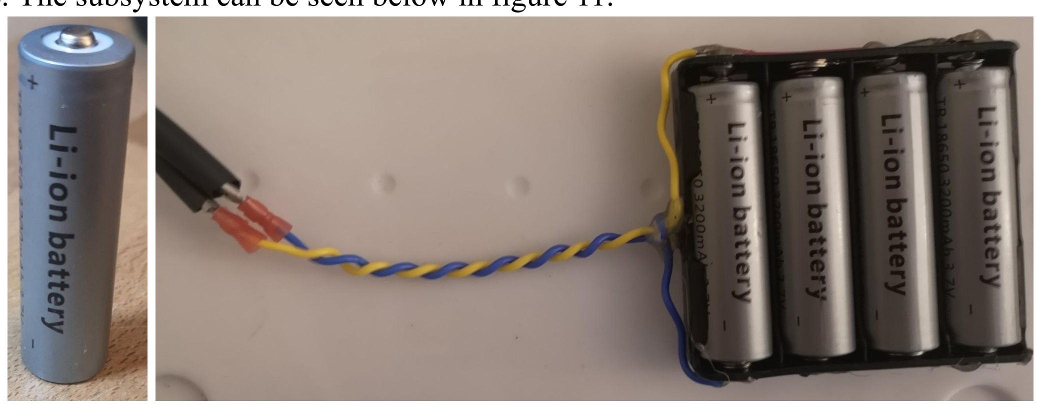


Figure 11: Lithium ion 18650 cell (left), and energy storage subsystem (right) with quick disconnects.

Final Prototype

The final prototype successfully completes all stated objectives and achieves maximum power to cost ratio for the limited prototyping funding, and prototyping period. Modularity of subsystems was achieved through use of spade connectors crimped to the end of the wires; both the wire and crimps maintain a maximum current in excess of 2A, the requirement (approximately 14A). This also allows each subsystem to be swapped out and/or parallelized to change system specifications. The final systems can be seen below in figure 12, showing a 1x1 system, and two 2x1 systems which can be connected to create a 2x2 system. All of these systems can power small DC electronics expectant of an input of 1A at 5V through USB. For example, 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 system cost achieved was about ~$100 for the smallest system. This is a reasonable value for a prototype and a polished product could reduce costs significantly through use of custom charge controllers and reducing the size and thickness of panel mount. Increasing purchase volume of solar panels would also greatly reduce costs. The final product archives close the predicted power generated as to be discussed in the validation section while being able to operate under standard environmental conditions and under high temperatures due to proper wire connections sealing and the 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 is 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}).

Because it is infeasible to provide an idealised solar source the measurements 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 is still a measurable power generation, measure I_{sc}.
$$I_{sc\ shaded} = 153mA$$
3. While still in the shade 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.

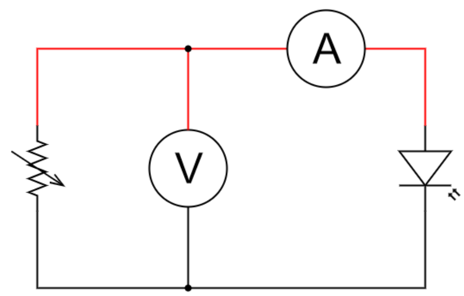


Figure 13: Solar panel IV test setup diagram.

4. Increase the resistive load until there is no measurable current, 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 do 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.

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

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.

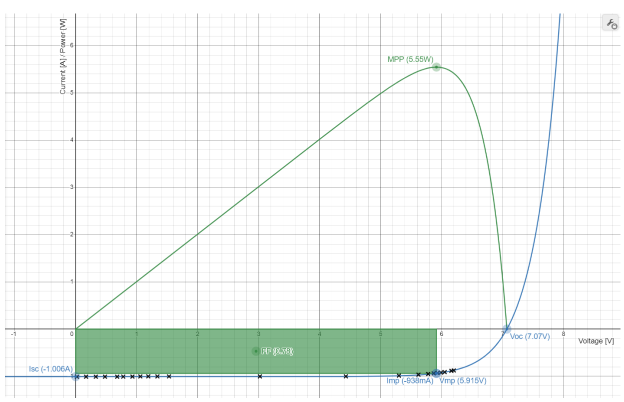


Figure 14: Single solar panel module full sun characterization, with measurements in black.

This test method was chosen so as to maintain the most constant temperature during the measurement phase due to the high temperature dependance of monocrystalline silicon solar panels. The resultant characteristic curve also provides information on the fill factor and maximum power point for the solar module useful for comparing against other panel technology and validating predictions. Finally the test data can be used to develop an accurate estimation of other multi-module systems without re-measuring. This was also infeasible due to the need of a somewhat high power variable resistor. Two of such systems characterizations are shown below in figure 15, the first system has two modules in parallel and the second system has two modules in series and two in parallel.

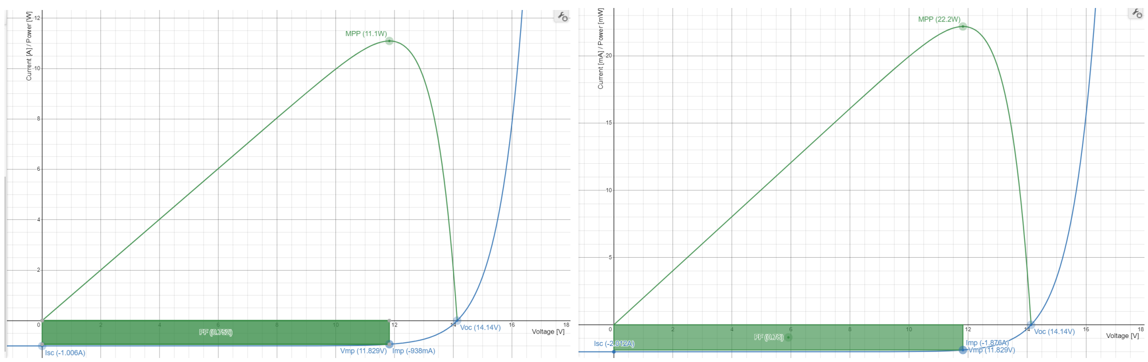


Figure 15: 2x1 (left) and 2x2 (right) solar panel module full sun characterization.

Solar Module Performance Measurements:

The following tests measure the performance of each module during an example deployment. The efficiency of the system is determined largely by the solar charge controller module. Because of the variable voltage conversion and followed by controlled charging the efficiency of the system is dependent both on load and operating point. Such a measurement would require the observation of a complete charge cycle with constant solar insolation and temperature which is beyond the scope of this report. The following test shows some example 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 at or around solar noon for minimal air mass.
2. Connect ammeters and voltmeters in series and parallel with each sub system of the module. This will allow for 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 which represent one module, two modules in series, and two modules in series and two modules in parallel respectively.
4. Re-arrange the modules such that they are approximately normal to the sun, repeat steps 2,3. 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 each 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, that is battery and DC electronics as well as 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:

$$V_{meas\ solar 48°} = 4.44V + 0.5\Omega \times 0.73A = 4.805V \tag{27}$$

From the measured IV curve for 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:

$$P_{1x1\ solar 48°} = 2 \times 2.44W_{1-panel} = 4.88W \tag{28}$$

The percentage error is calculated as follows. This percentage error will be true for all modules as they are just linear combinations of the same equation. This percentage error is very low and validates the predicted power to area and power per module calculations.

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

From table 2 above depicting example usage measurements the use of each of the modules to charge both the batteries and a low power DC electronics is proved. The smallest module can be seen charging majorly through the battery bank as expected, but the largest 2x2 system can charge the battery bank and the DC electronics simultaneously when mounted vertically or ideally.

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:

$$P_{1x1\ module 48°/day} = 3.44W \cdot 4.1\ hours = 14.1Wh/day \tag{30}$$

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

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 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

<u>Tentative pricing and ROI calculations:</u>

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 will roughly provide $0.68 worth of energy a year with an ROI of 147 years. Clearly there are far more efficient solar systems being installed in residential and commercial markets. The point is that this system is not meant for commercial release but rather proof of concept for vertical solar panels being feasible for use in Victoria. With only a 27% difference in performance between the two configurations we believe that a larger company will be able to develop vertical solar panel systems for a lesser profit. With the upcoming energy crisis and the Canadian government's plan to increase renewable spending there might be tax incentives or the like involved to help lower costs and increase profits.

System costs can be reduced through scaling and optimizing the design. Scaling involves a larger company mass producing this product and optimizing the design would involve using custom designed solar power managers and solar modules.

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 a system as described would be able to incrementally add photovoltaic power to offset traditional power production incrementally with a lower initial overhead.

The low overhead and invasiveness of this photovoltaic solution makes it desirable and achievable compared to other systems through 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, this means 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 fact cuts down on system components required by interfacing with both AC electronics and AC power systems, and will still be able to power 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 some users may experience longer times without significant sunlight but when there is sunlight the irradiance is significant enough not to warrant additional costly panels, these users may supplement their system with additional battery packs. These reasons justify the proposed solution and furthermore allow the user to replace system parts as needed due to either wear, or technological advances further decreasing their carbon footprint over the subsequent years.

The plan for this project is to demonstrate the viability of such a photovoltaic system described. To do this prototype miniature systems will be developed that will provide power to a small battery bank and USB output. three systems will be realised with slightly different qualities, one with a larger charge controller, and two identical systems that can be combined to demonstrate the modularity of the system. After completion of this project consumers will be able to view and handle a tangible small scale example of solar energy and they will be able to understand how approachable the gradual conversion to renewable energy can be.

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Appendix

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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Website Details:
https://matthewtran1.github.io/SolarOfficeCompanion/