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Unit Name/Code: Engineering Internship (ENG450)

Document: B.U.S Final report

Due Date: 19/11/2012

Date Submitted: 19/11/2012

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A report submitted to the School of Engineering and Energy, Murdoch University in partial fulfilment of the requirements for the degree of Bachelor of Engineering
I. Abstract

With rising energy costs and the carbon tax implementation in Australia, businesses concern with respect to energy efficiency have increased. As their operating costs rise, many have opted to explore sustainable energy solutions which serve to combat/decrease the effect of these rises. So much so, that Balance Utility Solutions (B.U.S) was formed in 2011 to service the growing market for integrated and sustainable energy solutions. To exemplify their renewable edge, the company had opted to replace 20kW (base load) of grid supplied electricity, with renewable energy by 2015. With this project serving to cover 4kW of the opted renewable replacement.

The 4kW system was an auction purchase (2nd hand system, with 2 years previous use), of a lump sum of many different components/parts. The parts specified for this project were, 4kW’s of photovoltaic panels, 2 grid tied inverters, and 24 x 2V batteries (48V DC battery bank), with one bidirectional battery Inverter as a backup.

The original aim of this project was to analyse, plan and install the system, with the capability of supplying power to the office load during daylight hours, thus decreasing the amount of electricity purchased from Synergy.

Due to changes being made on the roof, and a significant relationship formed by B.U.S and a leading solar technology supplier, the aim was modified to;

- Have all necessary documents, and plans ready and approved before the internship completion.
- Have a system design that was able to supply power to the grid during daylight hours, and also have the capability to be disconnected from the grid, and used as part of an island test facility.

Therefore this report is a breakdown of the processes, analysis, and modifications that were made to achieve these aims. Furthermore, the report serves to satisfy the stakeholder’s key interests of;

- Gaining an understanding of the systems components, with a greater emphasis on PV technology.
- And having a financial analysis of their investment.
Key findings throughout the project were;

- A system analysis output, with a generation of 7.171MWh/annually.
- A good payback period of 4.4 years, with an internal rate of return of 18.8%.
- Having the PV panels face north, instead of 35°, E of N (original orientation of building/roof), has no significant effect on the systems output.
- Having the panels sloped at 26° increased the incident annual solar radiation by 300kWh/m²/day, with respect to having them laid flat on the roof.
- This system could not apply for Renewable Energy Credits (REC’s), due to it being 2nd hand.
- Grid-tied inverters had transformers, however, the lack of galvanic isolation issues were negligible.
- Professional engineers constantly deal with dynamic/changes in their projects, and have to be quick and efficient in adapting to these changes.
II. Disclaimer

I sincerely declare that the work in this report is my own work, except where referenced, with respect to Murdoch University’s policy on plagiarism.

Signed: Gratias Matunda

December 2012
III. Acknowledgements

I would like to thank Balance Utility Solutions, Barclay Engineering (part of B.U.S group), and Murdoch University’s School of Engineering for supporting me through the length of this internship. This project would not have been commenced if it were not for the cooperation of these entities, and their staff. I would like to acknowledge the following individuals, as their skills and expertise greatly assisted me throughout this project;

Balance Utility Solutions

- Dr James Darbyshire, for supervising me throughout the length of the internship, and sharing his knowledge of various renewable energy technologies and projects.
- Mr Mike Laughton Smith, for his assistance in the electrical aspects, processes and procedures that my project would be subjected to.
- Mr Rod Hayes, for giving me an understanding of the financial and social aspects that most engineering projects are subjected to.

Murdoch University School of Engineering

- Dr Sujeewa Hettiwatte, for supervising the university aspect of this project. Which included assistance with different assessment criteria, answering all my electrical queries in a timely fashion, and giving feedback from marked assessments.
- Dr Gareth Lee, for assisting Balance Utility Solutions, and myself with all queries about the Murdoch Universities’ internship program.
- Dr Martina Calais, for supporting me with my renewable energy and electrical queries throughout the length of my degree
### IV. Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Abstract</td>
<td>2</td>
</tr>
<tr>
<td>II. Disclaimer</td>
<td>4</td>
</tr>
<tr>
<td>III. Acknowledgements</td>
<td>5</td>
</tr>
<tr>
<td>IV. Table of Contents</td>
<td>6</td>
</tr>
<tr>
<td>V. List of Figures</td>
<td>9</td>
</tr>
<tr>
<td>VI. Definitions</td>
<td>10</td>
</tr>
<tr>
<td>1 Project Background</td>
<td>14</td>
</tr>
<tr>
<td>1.1 Balance Utility Solutions Background</td>
<td>14</td>
</tr>
<tr>
<td>1.2 Stakeholder Expectations</td>
<td>15</td>
</tr>
<tr>
<td>1.3 Assumptions and Constraints</td>
<td>16</td>
</tr>
<tr>
<td>1.3.1 Assumptions</td>
<td>16</td>
</tr>
<tr>
<td>1.3.2 Constraints</td>
<td>16</td>
</tr>
<tr>
<td>1.4 System Equipment and Personnel</td>
<td>18</td>
</tr>
<tr>
<td>1.4.1 Main Components of The Project PV System</td>
<td>18</td>
</tr>
<tr>
<td>1.4.2 Equipment and Personnel</td>
<td>18</td>
</tr>
<tr>
<td>1.5 PV System Benefits and Disadvantages</td>
<td>20</td>
</tr>
<tr>
<td>1.5.1 Benefits</td>
<td>20</td>
</tr>
<tr>
<td>1.5.2 Disadvantages</td>
<td>21</td>
</tr>
<tr>
<td>2 System Background</td>
<td>22</td>
</tr>
<tr>
<td>2.1 PV panels</td>
<td>22</td>
</tr>
<tr>
<td>2.1.1 SunPower SPR-200-BLK</td>
<td>22</td>
</tr>
<tr>
<td>2.1.2 A-300 cell</td>
<td>22</td>
</tr>
<tr>
<td>2.1.3 Monocrystalline Material</td>
<td>23</td>
</tr>
<tr>
<td>2.1.4 Doping</td>
<td>23</td>
</tr>
<tr>
<td>2.1.5 Czochralski Process</td>
<td>25</td>
</tr>
<tr>
<td>2.1.6 How PV Solar Cell Works</td>
<td>27</td>
</tr>
<tr>
<td>2.2 Inverters</td>
<td>28</td>
</tr>
<tr>
<td>2.2.1 SMA Sunny Boy 2500</td>
<td>29</td>
</tr>
<tr>
<td>2.2.2 Fronius IG15</td>
<td>30</td>
</tr>
<tr>
<td>2.2.3 Sunny Island 5048</td>
<td>31</td>
</tr>
</tbody>
</table>
2.3   Batteries ......................................................................................................................... 31
       2.3.1   Ventilation of The Battery Enclosure ..................................................................... 34
2.4    Cables ............................................................................................................................ 34
       2.4.1   String Cables .......................................................................................................... 34
       2.4.2   String Cable Wiring ............................................................................................... 35
2.5    Frames ........................................................................................................................... 37
2.6    S-Box ............................................................................................................................... 38
2.7    Protection ......................................................................................................................... 40
       2.7.1   DC Switchboard ...................................................................................................... 41
       2.7.2   Breakers ................................................................................................................... 43
       2.7.3   Surge Arrestors ........................................................................................................ 46
       2.7.4   Earthing ................................................................................................................... 47
3    System Analysis .................................................................................................................. 48
       3.1    Location ..................................................................................................................... 48
       3.2    Software ..................................................................................................................... 48
       3.2.1   Homer 2.1.0.0 ......................................................................................................... 48
       3.2.2   RETscreen4 ............................................................................................................. 48
       3.2.3   Trimble SketchUp .................................................................................................... 48
       3.2.4   AutoCAD 2010 ........................................................................................................ 49
       3.3    Climatic Data .............................................................................................................. 49
       3.3.1   Solar Resource ........................................................................................................ 49
       3.4    Frame/Panel Placement .............................................................................................. 51
       3.4.1   Azimuth of The Panels ............................................................................................ 52
       3.5    PV System Performance ............................................................................................. 58
       3.5.1   RETscreen PV simulation ....................................................................................... 58
       3.5.2   Homer PV simulation ............................................................................................... 61
       3.6    Financial Analysis ..................................................................................................... 63
       3.7    Safety ........................................................................................................................ 66
4    Processes Encountered ........................................................................................................ 67
       4.1    Company Induction .................................................................................................... 67
       4.2    Diary ........................................................................................................................... 68
       4.3    Western Power Approvals Procedure ........................................................................ 69
       4.4    Key Problems and Solutions ..................................................................................... 70
4.4.1 Roof Change ............................................................. 70
4.4.2 Slight Change In Aim .................................................. 72
5 Internship Learning Experiences ........................................ 74
6 Suggestions ........................................................................ 75
   6.1 Monitoring Equipment .................................................. 75
7 Appendix ............................................................................. 76
8 References ........................................................................... 77
V. List of Figures
Figure 1 (accessed 04/11/12, from http://www.esru.strath.ac.uk/Courseware/Class-16110/ ) .... 24
Figure 2 Silicon cylinder creation ........................................................................................................ 25
Figure 3 (accessed 11/11/12, from http://www.periodictable.ru/014Si/slides/Si5a.jpg ) ............ 26
Figure 4 (accessed 11/11/12, from http://www.fsec.ucf.edu/en/consumer/solar_electricity/basics/how_pv_cells_work.htm ) ............. 27
Figure 5 48V DC block used ............................................................................................................... 32
Figure 6 Battery section in S-Box (side view) ...................................................................................... 33
Figure 7 Desired PV wiring loop ......................................................................................................... 35
Figure 8 Securing string cables ......................................................................................................... 36
Figure 9 PV frame mounting layouts ................................................................................................. 37
Figure 10 Location of S-box (red), and AC switchboard (yellow) .................................................. 39
Figure 11 S-Box front view ................................................................................................................. 40
Figure 12 Actual DC switchboard .................................................................................................... 42
Figure 13 DC switch board schematic .............................................................................................. 44
Figure 14 Sunny Island single line drawing ....................................................................................... 45
Figure 15 (accessed 09/11/12, from http://cuaje.en.alibaba.com/product/358593744-213269383/surge_arrester_for_Solar_Photovoltaic_PV_System.html) ....................... 46
Figure 16 Homer solar resource ....................................................................................................... 49
Figure 17 RETscreen climatic data ................................................................................................... 51
Figure 18 Allowed placement of panels ............................................................................................ 52
Figure 19 Panels North 1 .................................................................................................................... 53
Figure 20 Panels North 2 .................................................................................................................... 54
Figure 21 Panels building orientation 1 (35° west of north) .............................................................. 55
Figure 22 Panels building orientation 2 (35° west of north) .............................................................. 56
Figure 23 (Azimuth) North Vs 35° West of North ........................................................................... 57
Figure 24 Horizontal Vs Tilted Axis Graph for Barclay Eng ................................................................. 59
Figure 25 RETscreen simulation for location close to building (Jandkot Airport) ....................... 60
Figure 26 Homer PV simulation22 .................................................................................................. 61
Figure 27 Homer PV Inverter simulation22 ....................................................................................... 62
Figure 28 RETscreen financial analysis .......................................................................................... 64
Figure 29 Office roof changeError! Bookmark not defined ................................................................. 71
Figure 30 Initial Project system AC switchboard .............................................................................. 72
Figure 31 Current project system AC switchboard + Island test facility ......................................... 73
VI. Definitions

This is a list of some definitions that serve importance in this document. If no suitable definition is given, please find access to the electropedia or AS/NZS 5033:2012. Electropedia may be accessed through www.electropedia.org, and standard AS/NZS 5033:2012 can be obtained through www.standards.org.au. It should be known that both are copyright protected material, and noted that most of the definitions in this section are directly replicated from AS/NZS 5033:2012 section 1.4.

Directly
Taken from one source, without alteration of formatting styles.

Photovoltaic (PV) system
A system that uses solar panels to convert solar radiation into electricity.

Renewable Energy (RE) system
A system that uses naturally replenishable resources (e.g solar, wind), to generate power.

Uninterruptible power supply
Is a electrical device that has the ability to supply emergency electricity to a load, when its input power supply is lost.¹

Balance Utility Solutions (B.U.S)
The company that supervised this internship.

SWIS grid
South West Interconnected System grid, which is found in Western Australia, and managed by Western Power.

Available, readily
Capable of being reached for inspection, maintenance or repairs without necessitating the dismantling of structural parts, cupboards, benches or the like.

Bypass diode
Diode connected across one or more PV cells in the forward current direction to allow the module current to bypass shaded or broken cells to prevent hot spot or hot cell damage resulting from the reverse voltage biasing from the other cells in that module.

¹[IEC/TS 61836]
**Cable**

Assembly of one or more conductors and/or optical fibres, with a protective covering and possibly filling, insulating and protective material.

[IEV 151-12-38]

**Disconnected**

Mechanical switching device which provides, in the open position, an isolating distance in accordance with specified requirements.

NOTE: A disconnector is capable of opening and closing a circuit when either negligible current is broken or made, or when no significant change in the voltage across the terminals of each of the poles of the disconnector occurs. It is also capable of carrying currents under normal circuit conditions and carrying currents for a specified time under abnormal conditions such as those of short circuit.

**Earth**

The conductive mass of the earth, whose electric potential at any point is conventionally taken as zero.

**Equipotential bonding**

Electrical connections intended to bring exposed conductive parts or extraneous conductive parts to the same or approximately the same potential, but not intended to carry current in normal service.

**Extra-low voltage (ELV)**

Voltage not exceeding 50 V a.c. or 120 V ripple-free d.c.

[IEV 826-12-30]

**Functional earthing**

Earthing of a point in equipment or in a system that is necessary for a purpose other than safety.

[IEV 195-01-13]

**I_n**

The nominal rated current of an overcurrent protection device.

**I_{sc MOD}**

The short circuit current of a PV module or PV string at (STC), as specified by the manufacturer in the product specification plate.

NOTE: As PV strings are a group of PV modules connected in series, the short circuit current of a string is equal to I_{sc MOD}. 
Irradiance
Radiant solar power incident upon unit area of surface, measured in watts per square metre.

Lightning flash density (Ng)
The number of lightning flashes per square kilometre per year.

Main earthing terminal
The terminal or bar provided for the connection of protective conductors, including protective bonding conductors and conductors for functional earthing, if any, to the means of earthing.

Maximum power point tracking (MPPT)
Control strategy whereby PV array operation is always at or near the point on a PV device’s current-voltage characteristic where the product of electric current and voltage yields the maximum electrical power under specified operating conditions.

Maximum power voltage (Vmp)
Voltage at the maximum power point of a PV module under STC.

Protective bonding conductor
Protective conductor provided for protective equipotential bonding.
[IEV 195-02-10]

Protective equipotential bonding
Equipotential bonding for the purposes of safety.

PV array
Assembly of electrically interconnected PV modules, PV strings or PV sub-arrays comprising all components up to the d.c. input terminals of the inverter or other power conversion equipment or d.c. loads.
Does not include the PV array foundation, tracking apparatus, thermal control, and other such components.

PV array maximum voltage
Considered to be equal to VOC ARRAY corrected for the lowest expected operating temperature.

PV cell
The most elementary device that exhibits the photovoltaic effect, i.e. the direct non-thermal conversion of radiant energy into electrical energy.
[IEC/TS 61836 Def. 3.1.43 adapted].
NOTE: The preferred term is ‘solar photovoltaic cell’ or ‘photovoltaic cell’, colloquially referred
to as a ‘solar cell’.

**PV module**
The smallest complete environmentally protected assembly of interconnected cells.

[IEC 60904-3 and IEC 61277]

NOTE: A PV module is colloquially referred to as a ‘solar module’.

**PV string**
A circuit of one or more series-connected modules.

[IEC/TS 61836]

**PV string cable**
A cable interconnecting the modules in a PV string or connecting the string to a junction box, combiner box, PCE or other d.c. loads.

**Restricted access**
Access restricted to authorised persons only e.g. by a perimeter fence or barrier with access only via a padlocked or equivalently secured gate or door.

**Shall**
Indicates that a statement is mandatory.

**Should**
Indicates a recommendation.

**Standard test conditions (STC)**
A standard set of reference conditions used for the testing and rating of photovoltaic cells and modules. The standard test conditions are:

(a) PV cell temperature of 25°C.
(b) Irradiance in the plane of the PV cell or module of 1000 W/m$^2$.
(c) Light spectrum corresponding to an atmospheric air mass of 1.5.

[IEC/TS 61836]

**Open circuit voltage of a PV module (VOC MOD)**
The open circuit voltage of a PV module (VOC MOD) at STC, as specified by the manufacturer in the product specification.$^2$
1 Project Background

This section will give a background analysis of the Balance Utility Solutions (B.U.S), whom supervised my internship, and its expectations for the project.

1.1 Balance Utility Solutions Background

Balance Utility Solutions was formed in 2011 to service the growing market for integrated and sustainable energy solutions.

Their Executives come from an environment where life cycle investment decisions are based on developing a clear understanding of the trade-off between capital cost, lifelong performance and the operating costs of assets.

The company felt that the current energy market was only delivering certain parts of the viable energy solution, and needed the ability to integrate these various parts, to deliver genuinely sustainable long term solutions.

Renewable energy systems are a key example of this problem, and only through expert knowledge of the whole system dynamics, can a solution be implemented. Many renewable project implementations lack the integration requirements and control technologies that allow them to operate and interact seamlessly with existing assets.

Therefore Balance Utility Solutions has a combination of technical expertise, with utility management insight that provides clients with the best fit solution for their particular energy needs.
1.2 Stakeholder Expectations

From the company’s induction documents, I was able to comprehend the procedures needed to set up a meeting with key stakeholders. Subsequently after this meeting was set up, I was able to document key views of the personnel in the meeting. The key stakeholder personnel included the C.E.O’s of Balance Utility Solutions, and Barclay Engineering, as well as management teams from these companies. Before the meeting, I created a list of benefits and disadvantages of the system (refer to section 1.5), which I handed out to the meeting personnel. This was done to act as a catalyst for conversation within the meeting. As the meeting was taking place, key views were written down on a piece of paper, to later be summed up into one sentence. The original summation sentence when the project commenced was ‘to have a fully installed system that would decrease the office’s power bills and have the capability of a UPS if the grid was to fail’. Though due to the decision of a roof change, as well as a integral relationship made by the company, another meeting had to be called to reassess the key stake holder expectations. This meeting was held in the same fashion as the first stakeholder meeting. With the summation sentences from this meeting, being ‘to have all documentation, analyses, and planning ready and approved, for the installation as soon as the roof was changed. And also to have this system as part of a test facility (This test facility is not included in this project scope) that will decrease the company’s electricity bills, as well as be capable of being tested as a grid-hybrid or island system’. Also of importance, was the interest key personnel shared, in being able to better understand the PV system components and how they work, with a greater emphasis on the PV panel technology. As a consequence of this, an understanding of the key components that make up the PV panels, how they are made, and how they work, was added to the scope of the project. Furthermore the company wanted to have a financial analysis, to assess the financial returns from their investment in this system, which was also added to the project scope.
1.3 Assumptions and Constraints

1.3.1 Assumptions
The following assumptions were made as soon as the internship project commenced;

- Management will ensure that relevant company personnel are available as needed, to assist in the completion of project tasks and objectives.
- Management will participate in the timely execution of the Project Plan (i.e., timely approval cycles and meetings when required).
- Failure to identify changes to project tasks within the time specified in the project plan will result in project delays.
- Management will support project goals and objectives.
- The project plan may change as new information and issues are revealed.
- Assistance from all supervisors will be given in a timely manner.
- All components of the system purchased, had already been tested and were in good working condition.

1.3.2 Constraints

1.3.2.1 Project Constraints
- Project funding sources are limited, with no contingency.
- Space needed for system inverters and batteries.
- The roof where PV panels were to be installed, was being changed in the near future.
1.3.2.2 Related Projects

- The building of an island test facility (it should be noted that this is a confidential project, excluded from my internship project scope.)

1.3.2.3 Critical Project Barriers

These are insurmountable issues that can be destructive to a project’s initiative. Possible critical barriers for this project are the:

- Removal of project funding
- Natural disasters
- Western Powers Process for approval of PV systems (if lengthy)
- Changes to aims and expectations of the project
1.4 System Equipment and Personnel

1.4.1 Main Components of The Project PV System

- Twenty 200W (total of 4KW) SunPower SPR-200-BLK panels, which are a monocrystalline technology with efficiencies of 16.1%.
- One Fronius IG15 Inverter, with efficiencies of 94.2 %
- One SMA Sunny Boy 2500, with efficiencies of 94.1 %.
- 24 x 2V Enersys DDM batteries (48V).
- One SMA Sunny Island 5048
- 20 panel framing unit designed by Balance Utility Solutions.

1.4.2 Equipment and Personnel

The following is a list of the equipment and personnel needed for the project.

1.4.2.1 Personnel

- Qualified Electrician from B.U.S
  - Give advice on the buildings electrical circuitry and assist with its installation.
- Supervising Engineer (Dr James Derbyshire)
  - Mentor, and give advice on system design and any changes made by management.
- Electrical Engineering Intern (Myself – Gratias Matunda)
  - Safely project manage all aspects of the system, while abiding with Murdoch University ENG450 program (refer to Appendix B1) and all relevant Australian standards.
1.4.2.2 Equipment Needed for Project Implementation

- Electric screwdriver
- Safety gear
- Safety glasses
- Steel cap boots
- Safety Helmet
- Induction danger/risk of connecting the system
- Multimeter
- Cloth (cover the panels while transporting them, can be used to later clean them)
- Nuts and bolts for frames, and PV module connection to frames
- Wire cutter, stripper and crimper
- Conduit for wires
- UV protected Zip ties to secure conduit
1.5 PV System Benefits and Disadvantages

An analysis of the advantages and disadvantages was created to signify whether or not the system would serve as a benefit for the company. This section was presented to key stakeholders as the first stakeholder meeting was initiated, and served as catalyst for the topics that would be discussed in the meeting.

1.5.1 Benefits

The company’s benefits with relation to this project include:

- The electricity generated by the solar power system is clean and renewable, which helps reduce the company’s amount of greenhouse gas emissions.
- The solar panels have a life expectancy of 30+ years, while inverters have a life expectancy of 10+ years. Exemplifying the robustness of the equipment and technology.
- As the electricity price go up with the carbon tax and other costs imposed by the supplier, the company will be able to reduce its electricity bills, thus decreasing operating costs.
- There lies an advantage in being associated as a green business. With most of the globe growing more environmentally conscious and seeking to limit their carbon footprints, the fact that the business utilises a renewable energy system, will boost the company’s brand and corporate image.
- Solar panels are an investment, not a cost. The cost savings from electricity generation are able to pay themselves back in just a few years. By generating income when the system captures excess energy that the business does not use, and selling it back to the grid, even more savings could be made.
- The company will be able to apply for Renewable Energy Certificates (RECs), as the test facility is implemented, thus increasing financial advantage.
- The system is of low maintenance, with most of the maintenance procedures easy enough to be done by the company’s electrician, thus saving maintenance costs.
- The system is silent, with the only moving parts (switches) being in the inverter. And due to the inverter being housed in an S-box, this noise is negligible. Therefore the company would not be affected by any noise from this system.
The addition of an island test facility (to which this system will be a component of), will serve as an important tool for the company’s research and testing of renewable energy hybrid systems.

1.5.2 Disadvantages
The company’s disadvantages with relation to this project include;

- Usually the initial cost is very high, though it should be noted that this PV system was purchased second hand.
- The PV panel performance decreases as they are covered by clouds (inevitable phenomenon).
- The system is only able to work while there is sunlight. Conversely, when the sun is absent, the system does not generate electricity. It should be noted that the batteries are only used as a backup if both the grid and test facility AC switchboard fail, and not to supply power during times when the PV panels are not generating electricity.
- The efficiency of the PV panels slowly derates with time.
2 System Background

This section will give a background analysis of the key components that make up the project system.

2.1 PV panels

Due to the key stakeholders' desire to better understand the PV technology, and the fact that this project report is to serve both the company and the university. The brief section on PV technology and how it works has been included in this report. It should be noted that due to the supervisors' knowledge of PV technology, this section would not have been included if it were not for the company's desire.

2.1.1 SunPower SPR-200-BLK

The PV panels (4kW) used in this project are SunPower SPR-200-BLK (refer to appendix A1). The panels had previously been bought from a building that had only used them for approximately 3 years, therefore minimal derating from their previous use was assumed. These panels are state of the art with inbuilt bypass diodes to protect the panels from shading conditions. These panels were designed mainly for on-grid residential systems, where high module efficiency (16.1% at STC) and outstanding appearance is desirable. The high efficiencies of these panels are due to the use of Sun Powers A-300 mono-crystalline solar cell, which has an efficiency of 21.5%. One Sun Power SPR-200-BLK solar module utilizes 72 series connected A-300 cells.

2.1.2 A-300 cell

The A-300 cell is a 125-mm, single-crystal cell with the ability to generate three watts of electricity (refer to appendix A2). On February 27, 2004, SunPower Corp announced that its A-300 silicon solar cell had been measured at 21.5% efficiency by the National Renewable Energy Laboratory (NREL) in Golden, Colorado, USA. This efficiency resulted in a world record for large area (five inch) silicon solar cells, thus providing the most efficient cost per watt solution in the photovoltaic (PV) industry at that time. One of the advantages of these cells is they incorporate all electrical contacts on the back surface. This allows for a higher conversion efficiency of light to electricity, while eliminating the unsightly reflective front-side contacts. The properties found in the A-300 cell are those of the solid silicon/monocrystalline material, which is one of the most efficient PV cell materials.
2.1.3 Monocrystalline Material
Photovoltaic monocrystalline cells are usually made from doped silicon. Silicon is usually doped in order to alter the electrical properties of the silicon cell. This is because the silicon atom has four valence electrons in its pure state, one atom bonds weakly with the valence electrons of four other silicon atoms, thus achieving a stable crystal state (refer to Figure 1). Due to this, there are very few free electrons available for carrying the electric current within a pure silicon crystal. In order to have more free electrons in the structure, other elements are introduced as useful impurities, in a process known as doping.

2.1.4 Doping
Doping is usually done with elements that have 3 or 5 valence electrons, with the purpose being that when they are introduced to silicon crystals;

- Those with 5 valence electrons (e.g Phosphorous) will share their electrons and have 1 free electron that is easily dislodged from the atomic cell (refer to Figure 1). This dislodgment is caused as energy is introduced, thus making that part of the crystal negatively charged, also known as an N-Type semiconductor.
- Those with 3 valence electrons (e.g Boron) will share electrons and have 1 deficiency of an electron, therefore creating a hole (refer to Figure 1). This means that part of the crystal will carry a positive charge because it needs extra electrons to fill the hole, thus making it a P-Type semiconductor.
Figure 1 shows the structure of doped silicon, in which the two semiconductors are used to generate the electric field that is necessary for electricity to flow in the solar cell. This is by means of the free electrons (N-Type) being energized by solar radiation, and using this energy to move and fill the holes on the P-Type semiconductor. It is this flow of charge that signifies electricity. The wafers used in PV cells are made from silicon ingots, which were created using the Czochralski process.
2.1.5 Czochralski Process

After the silicon is doped, a rod with a monocrystalline silicon seed on one end, is dipped into high purity molten silicon. After which the rod is slowly pulled upwards while being rotated as seen in Figure 2. With the control of the pulling and rotating rates, cylindrical ingots which vary in length and diameter can be created. To reduce impurities, this process is usually performed in an inert atmosphere, such as argon, while in an inert chamber, such as quartz.⁸

Figure 2 Silicon cylinder creation⁹
These cylindrical ingots are then cut in thin slices, to make wafers (similar to Figure 3). And it is these wafers that are later fabricated and used to create PV monocrystalline cells.

Figure 3 (accessed 11/11/12, from http://www.periodictable.ru/014Si/slides/Si5a.jpg)
2.1.6 How PV Solar Cell Works

An average monocrystalline PV cell is usually composed of a thin wafer consisting of an ultra thin layer (N-type) of silicon on top of a thicker layer (P-type) silicon. An electric field is created in the cell where these two materials contact, called the P-N junction. When sunlight is incident on the surface of the PV cell, this electrical field gives momentum and direction to light stimulated electrons, and consequently a flow of current is created when the solar cell is connected to an electrical load (refer to Figure 4).10

Figure 4 (accessed 11/11/12, from http://www.fsec.ucf.edu/en/consumer/solar_electricity/basics/how_pv_cells_work.htm)10
2.2 Inverters

The inverters used in this project are:

- 1 Fronius IG15 (F15) Inverter, with efficiencies of 94.2 % refer to appendix A3
- 1 SMA Sunny Boy 2500 (SB2500), with efficiencies of 94.1 % refer to appendix A4
- 1 SMA Sunny Island 5048 (SI) efficiencies of 95%, refer to appendix A5.

The SB2500 and F15, will each be used to supply single phase 240V, 50Hz outputs. It should be noted that more of an analysis of the inverter topologies was given to the Fronius IG15 and SMA Sunny Boy 2500, as the Sunny Island (SI) was not a crucial part of the designing and functioning of the grid tied system. This is because of the decision to have the SI act as a UPS if the grid was to fail, had changed to, a standalone UPS if both the grid and island test facility were to fail. And due to the low probability of that occurring the, this inverter would mainly be used for testing purposes (refer to appendix A9).

The two string inverters (F15, SB2500), adhere to all the requirements specified for PV grid connected inverters in AS4777. The SB2500 inverters are equipped with low frequency transformers in their topologies, therefore issues associated with the lack of galvanic isolation are negligible.

These issues being;

- DC currents in AC networks. (it should be noted that this is still possible in the F15, as the use of high frequency topologies still has a rectification stage between the galvanic isolation and the grid).
  
  With possible negative effects on distribution transformers, electricity meters and other Devices.

- Electric shock hazard from direct contact to active conductors of the PV array installation.

- Electric shock hazard from indirect contact, through capacitive coupling with the PV array by touching modules or the module/array frame (leakage currents). Error! Bookmark not defined.

The negligibility of these issues, serves as the major advantage with respect to transformerless (TL) inverters. It is due to this, that the protection components of this system (grounding) aren’t as many as those of their transformerless counterparts, thus saving in cost and installation complexity.
2.2.1 SMA Sunny Boy 2500

SB2500’s are 2300kW single phase, outputting inverters, that are used in the most diverse AC grids, thanks to their advanced technology and galvanic isolation. [In addition, these devices are suitable for simple grounding of the PV array. Their integrated ESS DC switch disconnector makes installation simpler while also reducing installation costs. Equipped with the OptiTrac MPPT process, they will always find the best working point, even under dynamic weather conditions, and reliably converts solar energy into solar yield]11. The SB2500 exemplifies a low frequency full bridge, transformer inclusive topology similar to that in Error! Reference source not found. (from early sunny boy B700). These inverters have a few disadvantages with respect to SMA transformerless inverters. For example;

- They have lower efficiencies, due to energy being lost in their transformers, and
- Do not have adjustable displacement factor capabilities (power factor control).
2.2.2 Fronius IG15

Fronius IG15’s are 1300kW single phase outputting inverters, with some of the highest level of protection guaranteed. This is due to electrical isolation and over-voltage limiters providing extra safeguards on the DC and AC input terminals\textsuperscript{12}. This inverter topology is similar to that of the SB2500, only that this uses a high frequency, transformer topology.
2.2.3 Sunny Island 5048

The Sunny Island 5048 is a bidirectional battery inverter and charger, that is ideally suited for use in standalone grid operation. It should be noted that under Western Power's current PV connection rules, this inverter is not allowed to be connected as a grid tied inverter/UPS. It is due to this reason that this inverter is only used as a standalone backup system for the island test facility and building, rather than be used as a grid tied back up for the building. This inverter allows for the charging of lead acid batteries, using various power sources provided on the AC side (eg. diesel generator, PV inverter). And is capable of creating an AC voltage with a range of 202V - 253V, which can be used as standalone grid, single phase or multiphase (only with multiple SI's). It does this by using the energy stored in the batteries, thus allowing the stable operation of loads connected to its AC output.12

2.3 Batteries

The batteries used are twenty four 2V Enersys DDM batteries as seen in Figure 5. These are be connected in series to create a 48V block with a C100 rating of 1200Ah. This will allow for a 100hrs with a capacity voltage of approximately 1.85V/battery and a series current of 12A. It should be noted that before including the batteries to the project, I had to assess the capacities of each individual cell. This was because the batteries had been sitting idle since their purchase, and their state of charge was unknown before the project commenced. This was done by using a multimeter, to check if each cell had a voltage above 1.9V, for which they all passed. The batteries were to be housed inside the S-box unit (explained later), which also holds the inverters and protection devices. In designing the section that would house the batteries, careful consideration was given to all the relevant standards (refer to footnotes1, 2, 3, 4). The S-Box is to be located in a restricted area found within the manufacturing warehouse, and will be positioned adjacent to a wall. Due to the confidential nature of the companies’ architectural drawings, I have not included any architectural drawing of S-Box/battery housing inside the building.

---

Figure 5 48V DC block used
The batteries would be placed on a modified battery stand (as shown in Figure 6) which would allow space for a drip tray to be placed below the stand. This drip tray will be used to protect the S-Box housing, and personnel working in the warehouse in the event of a battery leak. This drip tray will be made from Makrolon, which is a material that is non-reactive and slightly absorbent with the battery’s sulphuric acid. This product was also selected for it had the ability to be fashioned into whatever shape the tray needed be, and is expected to outlast the batteries themselves. For extra protection, the corners of the tray will be filled with silicon, which is also non-reactive to sulphuric acid.

![Figure 6 Battery section in S-Box (side view)](image-url)
2.3.1 Ventilation of The Battery Enclosure

From AS 2676.2, it was decided to have the ventilation of the enclosure as large as possible. This was achieved by designing the S-Box without a front door. This door less S-Box design was also due to the test facility aspect of the system. As this allowed easy access to the S-Box components, for testing, maintenance, and also the addition of any future S-box components. It should be noted that due to the location of the S-Box being restricted, this door less S-box design did not pose as a threat to the manufacturing/warehouse personnel.

2.4 Cables

All the cables used in this system had to be sized and selected with respect to AS/NZS 3008.1. To increase safety, the main criteria all cables had to pass were:

- They had to be sized to withstand 1.5 (increased safety factor) times the PV panels short circuit current.
- And they had to be coated by a UV protective material, and able to withstand Australian conditions as exemplified in AS/NZS 2053.1.

2.4.1 String Cables

The DC cables that lead from the PV strings, to the inverters had to be sized to withstand currents of Isc x 1.5;

- 5.4A x 1.5 = 8.1A

Therefore the cable selected for this purpose, was the OLEX 1mm (2x1) core PVC copper enclosed in air cable, which had a rating at 13 Amps\textsuperscript{15}. It should be noted that the cable rating is higher than 8.6A previously calculated, which increases the safety factor, as well as decreases $I^2R$ losses (which was well within 3%). Of importance is that the OLEX cables used were made in Australia, to withstand Australian UV conditions, and made to adhere to AS/NZS 3008.1.
2.4.2 String Cable Wiring

The string cables will be wired in a fashion that will decrease the area of conductive loops. This will be done with respect to AS/NZS 5033:2012 4.4.4.3, and exemplified in Figure 7. Consequently reducing the risk of lightning induced voltage surges.

![Figure 7 Desired PV wiring loop](image)

With respect to AS/NZS 3000, all string cables will be placed within UV protective conduit (as exemplified in Figure 8), and be secured to the frames using UV protective cable ties. This conduit will then be fed into the building, using drillable conduit holders. Moreover, the conduit will also protect the wires from most of nature’s elements.
Figure 8 Securing string cables\textsuperscript{16}
2.5 Frames

Initially the company had decided to use the framing unit purchased with the second hand system, though after the decision to add a test facility, this was changed. The frame mounting technology that will be used for the Balance Utility Solutions (B.U.S) test facility panels, was designed for Australian conditions and for the ability to be easily installed by the average person. This technology is a collaboration between B.U.S and a large scale Asian PV technology supplier, and due its nature of not being commercially available, and confidentiality purposes, this technology cannot be detailed. Though I am able to mention that the layout that the system mounting will have, which consists of 20 panels side by side, and orientated in the a portrait manner, as exemplified in Figure 9. The choice to have them orientated in a portrait manner was clearly to minimise the roof space taken up by the panels. The PV frames will have axles that have the ability to change the tilt angles of each PV panel as well as the whole frame. The whole frame will be fixed at 21° (as the roof is already tilted at 5°), with respect to the PV system simulations that were performed.
2.6 S-Box

The S-Box will be the name of the rectangular housing that encloses the inverters and most of the protection equipment from the test facility. Though the only parts of the S-Box that will be analysed is the section, are those that contain this projects components. These components being, the DC switchboard, two grid tied inverters, one standalone battery inverter, measuring equipment, switches and protection devices. This S-Box will be built in a restricted area, located within the manufacturing warehouse. This location (Figure 10) was important, as it was close to the building’s main AC switch board as well as the PV panel location, thus;

- decreasing the DC cable length going from the panels, to the DC switchboard,
- and decreasing the AC cable length needed to connect to the AC switchboard.
- Therefore decreasing the losses associated with the resistivity increase, as cable lengths are increased.
It should be noted that Figure 10 below only serves to show an overlay of the S-Box location with respect to the PV panels and Main AC switchboard, as the exact placement of the S-Box will be within the building.

![Figure 10 Location of S-box (red), and AC switchboard (yellow)](image)

The restricted nature of the location meant the risk of accidents triggered by manufacturing personnel would be minimal. The S-Box will not have a front door, and be built adjacent to a wall within the warehouse.

The reason for the door less design is explained in the battery section, while the reason to have it built adjacent to a wall, was so the inverters were able to have their holders drilled onto the wall as seen in Figure 11. Therefore reducing the amount of space the S-Box would take up.
2.7 Protection
2.7.1 DC Switchboard

The DC switch board was custom made, and will house the;

- DC protection.
- Have voltage measuring equipment.
- And be equipped with a patch panel, and plug and play sockets for DC isolation (refer to Figure 12).

This patch panel will serve an important role with respect to testing, as it will allow different combinations to connect the PV panel strings, thus allowing the voltage and current characteristics of the system to be altered by staff. This is important for testing, as alterations in these parameters, will allow the performance of different breakers, inverters e.t.c, to be tested. It should be noted that isolation breakers should be sized and changed to accommodate for these altered parameters.
Figure 12 Actual DC switchboard
2.7.2 Breakers

Breakers/disconnectors will be used to protect the system from overload and short-circuit conditions. These will work by detecting the over currents and breaking the circuit, thus protecting the system. The DC side of the strings had to be protected according to AS:NZS 5033:2012. This was calculated, and concluded to have a DC switchboard, as shown in Figure 13, that would house;

- Two 10A fused breakers per string, as the solar input isolation (entering DC switchboard patch panel). Refer to Appendix A6 for the data sheet of the selected breaker.
- And two 10A fused breakers per string, as the solar output isolation (exiting DC switchboard patch panel). Refer to Appendix A7 the data sheet of the selected breaker.
Figure 13 DC switch board schematic
The AC side of the SB2500 and F15 inverters would each have 25A breakers protecting their outputs, refer to appendix B2 for the selected breaker. This is because the currents that are outputted by the inverters (inclusive of a safety factor of 1.25) are below 25A (refer to appendix A3 and A4). The battery unit will have a 160A DC dual pole breaker to isolate the DC side, which leads into the Sunny Island (refer to Appendix A9). In addition to the Sunny Islands inbuilt AC protection (refer to Appendix A5), it was chosen to also have protection on the outputs of the AC sides. These would be 25A AC breakers similar to the two other inverters, and exemplified in Figure 13 DC switch board schematic.
2.7.3 Surge Arrestors

Surge arrestors/lightning arrestors are used to protect the insulation and conductors of the system from transient voltages caused by lightning strikes.\(^{17}\) The buildings location does not have a high lightning flash density (Refer to Appendix G of AS 5033:2012), and therefore does not experience a significant amount of thunder days. This meant the system didn’t necessarily have to have additional surge protection added to that of its inverters. Since it was a recommendation suggested in AS/NZS5033:2012, we decided to proceed with. The DC side of the strings will have surge arrestors positioned within the DC switchboard as exemplified in Figure 15 (in orange). These will be DEHNguard PV 500 SCP’s (refer to Appendix A7). The outputs of the two grid-tied inverters and Sunny Island, will also have surge arrestors positioned after their AC breakers. These will be DEHNguard M, DG 275’s (refer to Appendix A8) and will be installed similar to Figure 15. With all surge arrestors grounded via the system’s earth.

![Figure 15](http://cuaje.en.alibaba.com/product/358593744-213269383/surge_arrestor_for_Solar_Photovoltaic_PV_System.html)\(^{18}\)
2.7.4 Earthing

It should be noted that AS/NZS 5033:2012 requires earthing of all exposed parts. Our system will have frames earthed and arrays floating, and will emphasis equipotential bonding by having all the panels bonded to the mounting rails using stainless steel tooth edged plates, refer to Appendix B3 for installation guide. These toothed edges are designed to break the anodized layers on both the PV module frame and aluminum mounting rail, thus making a better electric conductive bond. This bonding will avoid the uneven potentials across the system, and serve as an electrically conductive path with the capacity to allow the current to safely flow to the ground.
3 System Analysis
This section will serve to give an insight into the software used, safety, and performance analysis exemplified within the project.

3.1 Location
Balance Utility Solutions is situated at unit 12-16 Catalano Road, Canning Vale, WA, 6155. The company shares this building with Barclay Engineering, with geographic coordinates being -32.06161 north, and 115.902168 east.

3.2 Software
From past experience, the best software for the gathering of climatic data, and simulating the performance of a PV system with respect to this data was Homer and RETscreen. It is these programs that played a crucial role in predetermining the performance of the system. Trimble SketchUp was used to create scaled models of the PV panel placements, to assist in assessing the best locations for the PV panels to be placed. And AutoCAD was used to make all necessary 2D drawings.

3.2.1 Homer 2.1.0.0
HOMER 2.1.0.0 is a powerful energy modelling software tool, that is used "for designing and analysing hybrid power systems, which contain a mix of conventional generators, combined heat and power, wind turbines, solar photovoltaics, batteries, fuel cells, hydropower, biomass and other inputs. It is currently used all over the world by tens of thousands of people. For either grid-tied or off-grid environments, HOMER helps determine how variable resources such as wind and solar can be optimally integrated into hybrid systems."19

3.2.2 RETscreen4
"RETscreen 4 is an Excel-based clean energy project analysis software tool that helps decision makers quickly and inexpensively determine the technical and financial viability of potential renewable energy, energy efficiency and cogeneration projects."20

3.2.3 Trimble SketchUp
"Trimble SketchUp is a 3D modelling program optimized for a broad range of applications such as architectural, civil, mechanical, film as well as video game design."
The program includes a drawing layout functionality, and enables placement of its models within Google Earth.\textsuperscript{21}

3.2.4 AutoCAD 2010

A computer aided drafting program that allows you to make accurate 2D and 3D drawings.

3.3 Climatic Data

3.3.1 Solar Resource

![Solar Resource Inputs](image)

Figure 16 Homer solar resource\textsuperscript{22}

Figure 16 illustrates the solar resource that is found at the B.U.S site. It is immediately seen that the summer periods Nov-Feb exemplify the highest clearness indexes and solar radiation. Though of more importance is the solar annual average of 5.5kWh/m$^2$/d, which signifies the location has a good
solar resource. As from previous knowledge, most resources above 5kWh/m²/d exemplify good solar resource locations.

RETscreen was used to confirm whether data from Homer (Figure 16) was accurate. Though it should be noted that, the free version RETscreen has results that differ slightly. This is due to the fact that RETscreen only has specified locations where climatic data can be acquired from. Therefore it doesn’t give the user the ability to input geographic coordinates, juxtaposed to Homer. Figure 17’s data was taken from the location closest the B.U.S (Jandakot Airport). Even though monthly averages differed, the data illustrates the same solar annual average as in Figure 16, thus signifying the accuracy of Homer’s data. Also of importance is the wind data from (Figure 17 RETscreen climatic data), as this shows the average wind speeds the frame mounting will be susceptible to. The framing system being designed by the company will be able to withstand wind speeds of 20+ m/s, therefore these wind speed are well below the fame’s tolerance levels. Due to constraints of space on the roof, the frame layout had to be assessed to accommodate for these constraints.
3.4 Frame/Panel Placement

After the 1st stakeholder meeting, it was found that the company had a constraint on where the PV panels could be placed. The location specified can be seen in Figure 18 (black rectangle), this area was chosen by the company because, it was the entry to the building, and would best exemplify the business’s green edge to customers and the public.
Because of the constraint of space on the roof, and the fact that the building front/face did not face north (refer to Figure 18), an analysis of the azimuth of the panels had to be considered.

### 3.4.1 Azimuth of The Panels

An analysis of the azimuth of the panels had to be done to assess whether the panels would be mounted to follow the building's orientation (refer to Figure 21 and Figure 22), or have them face true north (refer to Figure 19 and Figure 20). This had to be done, as having the panels face north meant they would face the equator and consequently increase the PV system output, but added more complexities to the system design. These complexities mainly related to:

- Having installers measure angles on the roof (which may have been dangerous)
- Having to calculate and install different sized frame vertical poles to allow for the 5° inclination of the roof.
- DC cabling would have to be increased, which would increase costs and I^2R losses.

#### 3.4.1.1 Facing North

To have the panels faced North, this could only be achieved by splitting the framing sections, and this was due to the constraint of space on the roof. This split was achieved by having each sub frame hold one string of panels, which subsequently were the inputs for the 2 grid tied inverters. This also added
to the complexity of shade minimization between structures, therefore the sub frames were positioned such that this shading was negligible (7m apart).

Figure 19 Panels North 1
Figure 20 Panels North 2
3.4.1.2 Orientated With Building

While with the panels orientated with the building (approximately 35° West of North), it was possible to have the mounting installed in a way that had all 20 panels, placed together, side by side. Thus easing the complexities previously explained and allowing for a uniform frame tilt of 21°, thus having the panels tilted at the 26° (21°+ roof tilt (5°)). 26° being the tilt that RETscreen had simulated as the best, when an azimuth of 35° west of north was inputted.

Figure 21 Panels building orientation 1 (35° west of north)
Figure 22 Panels building orientation 2 (35° west of north)
The decision of whether we would go ahead with the north facing azimuth, lied on whether there was a significant difference in output when compared to the buildings orientation of 35° west of north. This was done using RETscreen to simulate the performance difference of the azimuths, this difference being 0.09MWh/m²/d per annum (refer to appendix B6). As seen in Figure 23, the advantage of having the panels face north (increase of 0.09MWh/m²/d per annum) was minimal. This advantage was too minimal to be adequate enough for the consideration of being the panels preferred Azimuth. Therefore it was chosen to have panels oriented with the building. For an analysis of the RETscreen Inputs used in creating Figure 23, refer to appendix B6.

![Figure 23 (Azimuth) North Vs 35° West of North](image)

**Figure 23 (Azimuth) North Vs 35° West of North**
3.5 PV System Performance

It should be noted that the grid in these simulations is used to show how much energy is produced by the PV system, and not necessarily how much is sent to the grid. This is due to the fact that the business is run during daylight hours, when the PV system is switched on, and due to the buildings load being significantly higher than 4kW, all the energy generated by the PV system would be consumed by the building. The only times the system would feed a significant amount of excess energy into the grid, would be on weekends and work holidays. Furthermore, the batteries and Sunny Island were not used in simulations as they were not functioning as storage for the solar, but more as a standalone back up device.

3.5.1 RETscreen PV simulation

After the decision to have the panels azimuth 35° W of N, an analysis had to be done to find out whether there was a significant difference in performance, with respect to having the panels installed;

- Flat on the roof (5° tilt), which was the cheaper and easier option, or
- to have them tilted at 21° (as the best tilt angle from RETscreen was 26°).
3.5.1.1 PV Module Slope Analysis

The best angle to slope the PV panels was found to be 26°, as this gave the maximum annual electricity generation according to the RETscreen simulation. This slope was found by altering the slope above and below the locations latitude angle (32°). This decreased the seasonal differences in solar radiation exemplified in Figure 24. The alteration from the latitude angle is due to the fact that, at this angle more solar radiation is captured annually. An analysis was then done to comprehend whether having the panels slope at 26° was significantly better than having them placed flat on the roof (which was a cheaper option). This analysis is shown in Figure 24, which found that having them placed flat on the roof;

- decreased the annual output by 300kWh’s
- And exemplified more of a seasonal effect

The seasonal effect refers to the variability of monthly averages, with daily solar radiation horizontal analysed to have more of a variability, and thus more of a seasonal effect. Therefore justifying the decision to have them sloped at 26°. For the RETscreen inputs used to obtain Figure 24, please refer to Appendix B6.

![Horizontal Vs Tilted Axis Graph for Barclay Eng.](image-url)

**Figure 24 Horizontal Vs Tilted Axis Graph for Barclay Eng.**
3.5.1.2 Final System Performance

Figure 25 shows the generated output for a 4kW PV system located in Jandakot. This location was selected, since was the closest location to B.U.S that RETscreen allowed me to select.

![Solar tracking mode table]

<table>
<thead>
<tr>
<th>Month</th>
<th>Daily solar radiation - horizontal kWh/m²/d</th>
<th>Daily solar radiation - tilted kWh/m²/d</th>
<th>Electricity export rate $/kWh</th>
<th>Electricity exported to grid MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>6.47</td>
<td>7.85</td>
<td>250.0</td>
<td>0.789</td>
</tr>
<tr>
<td>February</td>
<td>7.56</td>
<td>7.56</td>
<td>250.0</td>
<td>0.953</td>
</tr>
<tr>
<td>March</td>
<td>6.02</td>
<td>6.44</td>
<td>250.0</td>
<td>0.653</td>
</tr>
<tr>
<td>April</td>
<td>4.25</td>
<td>5.11</td>
<td>250.0</td>
<td>0.512</td>
</tr>
<tr>
<td>May</td>
<td>3.06</td>
<td>3.88</td>
<td>250.0</td>
<td>0.411</td>
</tr>
<tr>
<td>June</td>
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<td>3.39</td>
<td>250.0</td>
<td>0.354</td>
</tr>
<tr>
<td>July</td>
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<td>3.98</td>
<td>250.0</td>
<td>0.384</td>
</tr>
<tr>
<td>August</td>
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<td>4.37</td>
<td>250.0</td>
<td>0.465</td>
</tr>
<tr>
<td>September</td>
<td>4.99</td>
<td>5.49</td>
<td>250.0</td>
<td>0.562</td>
</tr>
<tr>
<td>October</td>
<td>6.52</td>
<td>6.60</td>
<td>250.0</td>
<td>0.669</td>
</tr>
<tr>
<td>November</td>
<td>7.13</td>
<td>6.38</td>
<td>250.0</td>
<td>0.753</td>
</tr>
<tr>
<td>December</td>
<td>6.49</td>
<td>7.85</td>
<td>250.0</td>
<td>0.765</td>
</tr>
</tbody>
</table>

An annual solar radiation - horizontal is 2.01 kWh/m², and annual solar radiation - tilted is 2.11 kWh/m².

![Photovoltaic table]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>mono-Si</td>
</tr>
<tr>
<td>Power capacity</td>
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</tr>
<tr>
<td>Manufacturer</td>
<td>Sunpower</td>
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<tr>
<td>Model</td>
<td>SP-270S-BK</td>
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<tr>
<td>Efficiency</td>
<td>16.9%</td>
</tr>
<tr>
<td>Normal operating cell temperature</td>
<td>45°C</td>
</tr>
<tr>
<td>Temperature coefficient</td>
<td>0.435</td>
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<tr>
<td>Solar collector area</td>
<td>24 m²</td>
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<tr>
<td>Miscellaneous losses</td>
<td>5.0%</td>
</tr>
<tr>
<td>Inverter efficiency</td>
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</tr>
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<tr>
<td>Miscellaneous losses</td>
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<tr>
<td>Summary</td>
<td>20.2%</td>
</tr>
<tr>
<td>Capacity factor</td>
<td>20.2%</td>
</tr>
<tr>
<td>Electricity exported to grid</td>
<td>7.044 MWh</td>
</tr>
</tbody>
</table>

Furthermore, Figure 25 shows the electricity generated by the system was 7.044MWh, though it should be noted that the panels selected amounted to a power capacity of 3.99kW, which is slightly less than the desired 4kW. Consequently equating to annual electricity saving of $2524, if Synergy’s L3 tariff price of $0.352/kWh is assumed. Also of importance is the Net annual GHG emission reduction of 6.4 tonnes of CO2 calculated using RETscreen, which is equivalent to 2706L of gasoline not used or 1.2 light trucks not being used (refer to appendix B6). This GHG emission reduction is of importance because these credits can be later traded/sold in the carbon trading market.

Miscellaneous losses accounted for the environment, and the slight derating of the panels due to their second-hand nature. While the inverter data related to the summing of the two inverter capacities. Subsequently amounting to a capacity factor of 20.2%, which exemplifies a good capacity factor with respect to PV systems.
3.5.2 Homer PV simulation

The Homer simulation was later used to confirm the results obtained from the RETscreen simulation. All inputs into Homer were direct duplicates of those entered in RETscreen, (refer to Appendix B7 for detailed homer simulation inputs). Figure 26 shows the PV panels would be able to generate 7.618MWh annually with a capacity factor of 21.7%, and shows the amounts and times of the day when the PV panels produce electricity. Of more importance is Figure 27, as it shows the energy outputted by the inverter would be 7.161MWh, thus giving the system a capacity factor of 20.4%. Both the annual energy output of the system and the capacity factors outputted by the Homer simulation are very similar to those found from the RETscreen simulation, thus justifying the results.

Differences in simulation results related to slight differences in the inputs of each program, for example, Homer had sections for the derating and reflectance of the PV panels, while RETscreen did not.

![Simulation Results Table]

![PV Output Graph]

Figure 26 Homer PV simulation
Figure 27 Homer PV Inverter simulation
3.6 Financial Analysis

The original system was purchased for AUD $16500, at a ‘Solar Sales LTD’ auction in Belmont, around the period of May 2011. This did not allow for the individual components of the system to be costed. The main components of the original purchase consisted of:

**Components used for project system**

- Twenty 200W (total of 4kW) SunPower SPR-200-BLK panels, which are a monocrystalline technology with efficiencies of 16.1%
- One Fronius IG15 Inverter, with efficiencies of 94.2%
- One SMA Sunny Boy 2500, with efficiencies of 94.1%
- 24 x 2V Enersys DDM batteries (48V)
- One SMA Sunny Island 5048

**Components not used in project system**

- Custom DC switchboard
- One 20 panel generic framing unit.
- One battery switchboard
- One SMA Sunny Boy 1200
- 12 x 2V Enersys DDM batteries (24V).
- One Blue Sky Energy - Solar Boost 3024i battery charger

Therefore a financial analysis of the project system would not have been appropriate, since not all components were used. This is because the components not used in the project, still remained components that make up the AUD $16500 paid. Therefore it was assumed that the cost of all the unused components amounted to approximately one third of the whole system cost, equating to $5,500 AUD. This made the cost of the project PV system AUD $11,000, and this was used in RETscreen financial analysis (Figure 28).
Figure 28 can also be accessed from Appendix B6, and exemplifies the simple payback of the PV system. The simple payback calculated shows how long it would take the company to pay off its initial investment of AUD $11000, with the income coming from money saved from the company’s electricity bill. This payback amounted to 4.4 years, though it should be noted that this did not take into account any rises in electricity prices, which would amount to more savings and a shorter payback period. In addition Incentives like REC’s certificates had not been included as the system was not new, and these could not be applied for. The operation and maintenance (O&M) costs were not included as the O&M would be done by the companies electrician, and assumed to be negligible. Therefore the payback period of 4.4 years, with an internal rate of return of 18.8%, served as a very good return on the company’s investment in the system.
3.7 Safety

An access plan was created to highlight the main hazards of the system, and the ways in which access to the system would be granted, (refer to Appendix B10). The system was made safer by acknowledging the procedures exemplified in AS/NZS5033:2012 (Section 5 & Appendix A), and creating signage to mark all potential hazards. This section covered most aspects related to the following:

- Equipment marking
- Requirements for signs
- Labelling signs for PV cables and enclosures
- Fire emergency information
- Labelling/signs for disconnection devices
- Labelling of fuse holders
- Documentation

Therefore, these signs would serve to warn all personnel and customers, about the potential risks of the different components of the system, thus increasing their safety.
4 Processes Encountered

This section covers the main processes and procedures that served of importance, as well as the key problems that surfaced after the projects commencement.

4.1 Company Induction

Upon commencement of this internship, it was found that in order for me to work inside the company building, I had to pass the companies induction test. Therefore the first thing I had to do, was read the companies induction documentation and be tested on how well I understood the information. The induction consisted of a file with documents relating to the company’s location, safe workings and culture. The most emphasised document was that of the safe workings, as the optimum goal for the company was to keep all its personnel safe. As my understanding was tested, I found how important it was to prevent safety risks whenever possible, as this protects not only myself, but also the people around me. Additionally it also gave me an understanding of:

- where the main risk hazards are located
- where the first aid kits were located
- where the safety exits were located
- what procedures need to be followed (e.g. wearing steel cap boots) before gaining access into certain areas
- What procedures need to be taken if an accident is witnessed, and who is in charge (superintendent) of the different areas where the accidents may taken place
- The phone numbers of key company personnel

Furthermore, the documents on location and working culture assisted me in understanding:

- The size of the building, its many different areas.
- How employees should engage with customers. With a major emphasis on understanding that the customers are key the components/stakeholders in the business, and should be treated with the uppermost respect.
- What type of attire should always be worn by the staff working in the different areas of the business.
- Ways in which staff can deal and cope with external issues (e.g. stress, pregnancy).
4.2 Diary

The importance of a diary was very evident to the success of the project. Due to the many different developments the company allowed me to experience, this was the best way of keeping track of the tasks to be undertaken in the project. This was done in a chronological order with the dates as headings and the following bullet points under each heading:

- What needs to be done this week?
- What did I learn?
- What did I achieve?
- What needs to be done next week?

This diary also served as a chronological database for all the experiences I have gained from this internship.
4.3 Western Power Approvals Procedure

The Western Power ‘approval to connect a solar PV system’ procedure was made up of different components (refer to Appendix B5). Firstly, one had to find out which class, the PV system size was placed in. This was done by logging on to the Western Power website (www.westernpower.com.au), following the links to the ‘approval to connect a solar PV system’ page, and analysing which class the PV system was placed in. This system was found to be in the second class, which was systems larger that 3kW, but smaller than 30kW. The classes defined the processing times and criteria the systems would have to abide by, for western power to approve and evaluate their installation and connection to the SWIS grid. Furthermore, in order to connect any grid tied inverters to the grid, one would have to assess whether their inverters fall within Western Power’s approved inverters list (refer to appendix B4). Both the SMA Sunny Boy 2500 and Fronius IG15 were within this approved list, and since the Sunny Island was not going to be grid-tied, it did not, and was not within this approved list. After which one would have to fill out the relevant sections within Western Power’s application to connect small scale renewable energy systems (refer to Appendix B5). As this was being done, areas which caused most concern were the connection date, and attachment of inverters regulatory certificates. The connection date was a concern, as it was unknown when the roof would be changed. And regulatory certificates were of concern due to the system being second hand, therefore most of all its paper work had been lost. Therefore I contacted Western Power (WP), to obtain clarity on these sections. From contact with Western Power, it was informed that we had a one year connection period starting from the date placed, for which 1st January 2013 was placed. All the certificates were also downloaded from the inverter manufacturer’s websites, and attached to the approvals form. For our class, the approval process was estimated to take approximately one month, though it was noted that this time period may vary. After completing all relevant sections of the form, this was sent to Western Power, and was approved 28 days later, which exemplified the final key milestone of this project.
4.4 Key Problems and Solutions

After my project proposal was handed in to my university supervisor, a few external factors within the company had surfaced, which altered the progress of the project. The two main complexities relating to these factors were:

- The roof, on which the PV panels were to be installed, was going to change in the near future. And the new building design was still being worked on as my internship was taking place.
- The aim to have the PV system act as a supply of extra electricity in daylight hours, had changed to have the system be used more as part of an integrated testing facility.

4.4.1 Roof Change

One of the main drawbacks was the announcement of the roof alteration. With respect to Figure 29, after my internship had already commenced, it was later found that the roof where the PV panels were to be placed, was going to be changed in the near future. Therefore the architectural drawings of the new roof were still being assessed for a roof completion date, sometime in early 2013 (the exact date had not been finalised). This led to a significant constraint, which I had no control over, and, therefore I had to find a solution that enabled me to work around this constraint, in the quickest and most efficient way possible.
4.4.1.1 Solution To Roof Change

Because of this constraint, the project road map (Gantt chart) had to be reconfigured, which is exemplified by the difference between Appendix B8 and B9. The new road map related to, making sure all un-roofed (e.g. PV panels, and frames) components had their necessary documentation (schematics, spec sheets e.t.c), ready and approved before the end of this internship. Therefore, after the roof was remodelled and constructed, all that will be left was the installation of the roof components, and making all necessary connections to already installed inverters, consequently saving time and costs in the future. These road map reconfigurations were submitted to the management, and later accepted and approved as adequate.
4.4.2 Slight Change In Aim

Due to the company’s partnership with a leading solar supplier, management had opted to construct a PV, Diesel, Battery, island testing facility. The designing of the test facility would not be part of this project, and thus was not included in the scope of this report. Though the project system I designed was affected by this facility, as exemplified in the differences between Figure 30 and Figure 31. In that:

- The PV inverters did not connect directly to the grid AC panel/switchboard as shown in Figure 30, but connected to an AC Bus, which connects to an AC island sub panel shown in Figure 31.
- The Battery backup system was used solely to back up loss of power from this AC bus, (i.e. loss from both the grid, and the components connected to the test facility AC bus). This Battery back up being done with the Sunny Island 5048, refer to A5.
- And because of this, the project plan had to be reconfigured slightly.

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![Figure 30 Initial Project system AC switchboard](image-url)
4.4.2.1 Solution To Slight Change In Aim

This change made no major difference to the system modelling as the fundamental components of the project system remained the same. The scope of work did not change much, due to the fact that it was not part of my project to design the new test facility. Though project alterations made were as follows:

- The grid connect schematics (AC switchboard connection),
- The adding of a new inverter to the Western Power PV installation application (ABB PVS300-TL 4600W-2). Which was within Western Power’s approved inverters list, and did not change the application class from its original (Class 2).
- And the re-analysis of the inverter housing (S-Box), as more inverters/batteries were to be used in the test facility.

All these alterations were worked on, with the assistance of the supervisor, and are exemplified throughout this report.
5 Internship Learning Experiences

This internship project, which involved myself, Balance Utility Solutions, and Murdoch University has served as a very insightful experience into the world of a qualified engineer. It has been a great privilege to represent Murdoch School of Engineering and Energy, while working as part of a professional engineering business. The knowledge I have gained from the hardworking staff of the Murdoch University School of Engineering, has significantly assisted me in being an effective member of the Balance Utility Solutions team.

The project has greatly deepened my understanding of project management, as it gave me a firsthand experience of the key components that make an engineering project. The real life aspect of a conventional project was extended, when the delay of the Barclay roof change was employed. This gave me firsthand experience of how dynamic engineering projects can be, and how these changes have to be adapted. As these adaptations serve as foundations of what may make or break a project. It also helped me understand the importance of rehabilitating former systems/equipment to save costs, as the system analysed was a second hand purchase. In doing so, it gave me an appreciation of how Standards change, and force engineers to reconfigure old systems to correlate and apply to these changes. This standard change was exemplified as the Standard AS/NZS 5033 changed on the 16th of July 2012, which was a few days after this internship commenced.

Furthermore, experiences such as liaising with professionals in this field has expanded my network base, and broadened my understating of the culture that has been established in this field. Additionally it allowed me to gain an experience of the problems the engineers in the company come up against, and the ways in which they solved them. Of significance was the use of brainstorming sessions, and the alterations of former solved problems to tailor solutions that suited their different customers.
6 Suggestions

6.1 Monitoring Equipment

It should be noted that the monitoring equipment in this section relates to equipment that would monitor climatic data (e.g. anemometer, wind vanes, pyrheliometer e.t.c). The inverters and the DC switchboard already have energy monitoring functions built in. These equipments would be of importance, as it would allow the company to have data that correlates to the systems performance. This data can later be used to estimate the systems future performance, as well as be extrapolated to analyze other systems in similar locations. Despite this equipments not being part of my scope of work, it is suggested that it be included as part of the test facility in the future.
7 Appendix

For Appendices stated throughout this project report, please refer to the CD attached.

Appendix A
A1 SPr BLk 200
A2 A-300 data sheet
A3 Fronius_IG 15
A4 SB2500
A4.1 SB2500 Installation Guide
A5 sma 50000 inv SI5048-11-EE3107_Prosa
A6 Breaker ABB S201-C10
A7 Breaker ABB S200 serries
A7 DEHNguard_DG_PV_500_SCP_36
A8 DEHNguard TT 275 1 phase
A9 4kW B.U.S Project schematic

Appendix B
B1 ENG450
B2 ABB protection solutions
B3 earthing components
B4 WP_approved_inverters
B5 Application to connect small scale renewable energy systems
B6 RETscreen PV simulation
B7 Homer PV simulation
B8 Project plan 12-9-12
8 References

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