Home Based Solar Power Generation, Storage and Localised Grids

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Abstract

This project aims to determine the optimal and cost effective solar powered battery storage system for a Toowoomba resident in a small, medium and large household. The project was initially undertaken through a literature review of solar panels, batteries and microgrids. The background research also consisted of analysing various batteries and solar panels on the market to determine options available for analysis. For the analysis, load profile data of an Ergon Energy customer was acquired. The analysis was undertaken using the program Homer Pro created Homer Energy. The program is specifically designed for modelling microgrids and can evaluate using various architectures including a grid connection, battery storage, PV array and a load. Other options include hydro-electricity, wind power and so on however these are beyond the scope of the project. Homer Pro has access to default solar irradiance and climate data for various locations including Toowoomba and was included in the analysis. The analysis was undertaken for a small, medium and large household. The load profiles for the various hold holds was determined by comparing the actual data received from Ergon Energy and scaling the data according to typical usages based on the Australian Bureau of Statistics and Origin Energy data.

From the results, it was found that the optimal microgrid system for a typical Toowoomba household of all sizes is to have a 10kW PV array only. Investigation into the benefits of household PV found that the payback period varies according to household size. The payback period for the small household microgrid is between 12 and 13 years, for a medium household microgrid the payback period is between 10 and 11 years and for the large household microgrid the payback period is between 9 and 10 years.

To determine if having a PV array was a more economical option than remaining purely on the grid further testing was undertaken. For this, the evening peak load and hot water peak load for the medium household was shifted to the middle of the day when the power output of the PV array is at its greatest. The previous peaks were lowered to reflect less demand required. The results from the Homer Pro testing found that in both cases the system with a PV array had a lower cost of electricity, net present cost, operating cost and higher renewable fraction than just grid supply. The higher the powered PV the better the economic results. Therefore, it is recommended that for all households to install a high powered PV array.

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Certificate of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Steven Shephard

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Signature

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Date

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I would like to thank Associate Professor Paul Wen and Mr Andreas Helwig for their supervision and support throughout my research. I would also like to thank Michelle Taylor and Waqar Butt of Ergon Energy for offering expert opinion and customer load profiles respectively.

Finally, I would like to thank my family for their continuous and ongoing support.

Contents

List of Figures

List of Tables

Chapter 1 Introduction

1.1 Aims

The aim of the project is to design an economically optimal solar powered battery storage system for a small, medium and large house in Toowoomba, QLD. There are multiple reasons a consumer would invest in a solar powered battery storage system. These include to reduce energy costs, provide back up during a power outage, going off grid and for environmental purposes (Ergon Energy, 2016). For the purpose of this project, the optimal system will factor Cost of Electricity (COE), Net Present Cost (NPC) and payback as the primary considerations. This data will be calculated using the Homer Pro program (Hybrid Optimization of Multiple Energy Resources).

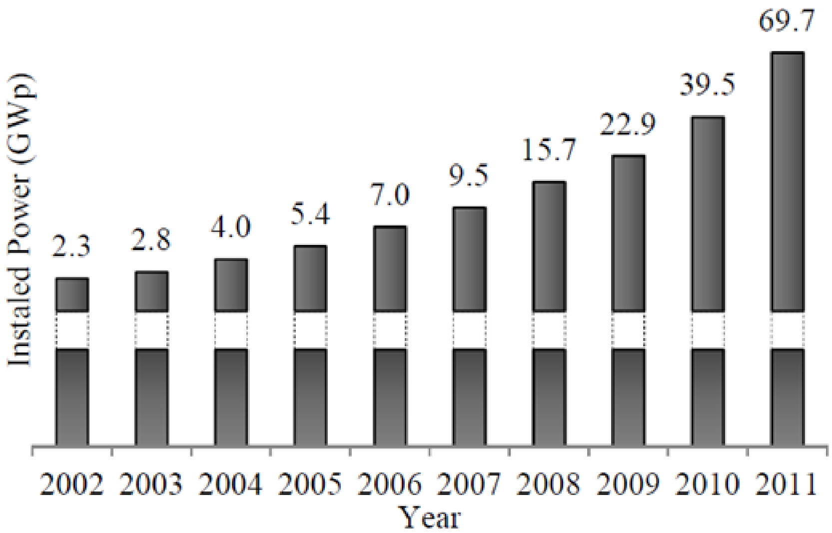


Figure 1.1: Growth of the global PV installed power (Cupertino, 2012)

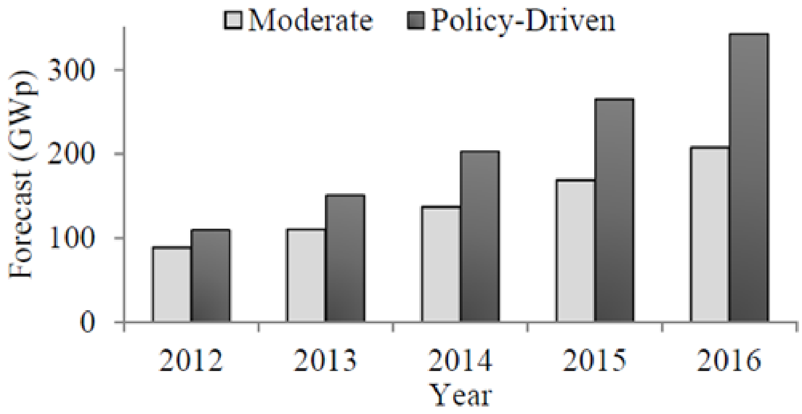


Figure 1.2: Forecast until 2016 for solar voltaic installed power (Cupertino, 2012)

Considerable amounts of forecasts have been undertaken to predict the amount of power generated by global photovoltaics (PV). This increase has facilitated the project as more and more people care purchasing solar panels and many are considering purchasing batteries. This project hopes to help consumers make an educated and informed decision about microgrids and how to select the optimal system.

1.2 Objectives

The objective of the project is to design an optimal and cheapest solar powered battery storage system for Toowoomba residents living in a small, medium or large household. This will be achieved by determining the required specifications of systems to meet the requirements for each sized household. Once determined, a group of components deemed to be the optimal will have simulations undertaken for further analysis. From the simulations results, recommendations will be made as to which system is the most appropriate.

1.3 Australian Standards

The following standards that apply to Solar Grid Connected Solar PV systems (Clean Energy Council):

Table 1.1: List of applicable standard for solar panels

Standard	Description
AS/NZS 3000	Wiring Rules
AS/NZS 5033	Installation of Photovoltaic (PV) Arrays
AS/NZS 4509.2	Stand-alone Power Systems – Design
AS 1170.2	Wind Loads
AS 4777.1	Grid Connected – Installation
AS/NZS 1768	Lightning Protection
AS/NZS 3008	Selection of cables

As this project will be theoretical and undertaken in software, the standards will not be considered because the scope pf the project is based on deciding the optimal PV array and batteries for a microgrid and not how it will be connected or installed.

1.4 Consequential Effects/Ethics

There a few ethical issues that need to be addressed in this project. Primarily, the load profile data that is being provided from Ergon Energy is protected through confidentiality. It would be very beneficial to have as much information as possible regarding to the household to better understand their electrical usage. Unfortunately, only minimal metadata is kept for Ergon Energy's load profiles.

Chapter 2 Literature Review

2.1 Introduction

Home energy storage solutions consist of a solar panel that converts solar energy into DC electricity through the use of the photoelectric effect. The DC electricity is then utilised to charge the battery or converted into AC through an inverter which is used to power home appliances. Initially, any excess DC electricity is used to charge the battery and once the battery is fully charged the excess electricity not used in household consumption at that time of day is then supplied to the electrical grid. This concept is illustrated in figure 2.1.

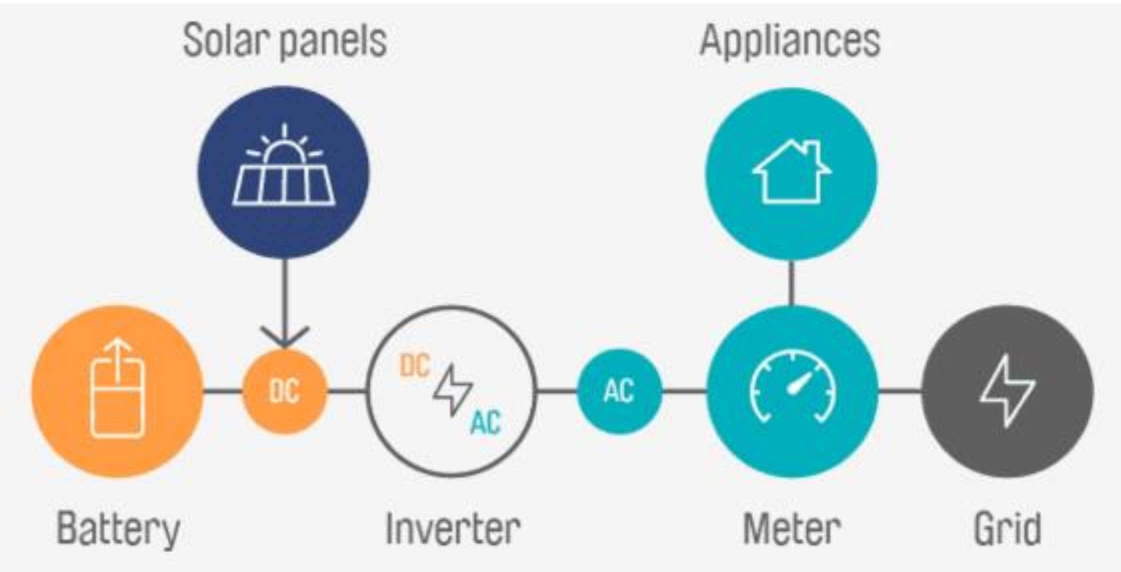


Figure 2.1: Diagram of a conventional solar powered battery storage system (AGL, 2016)

In PV array architecture, the basic element is a solar cell. A group of solar cells compose a module, a set of modules constitute a panel and a group of panels make an array as shown in figure 2.2.

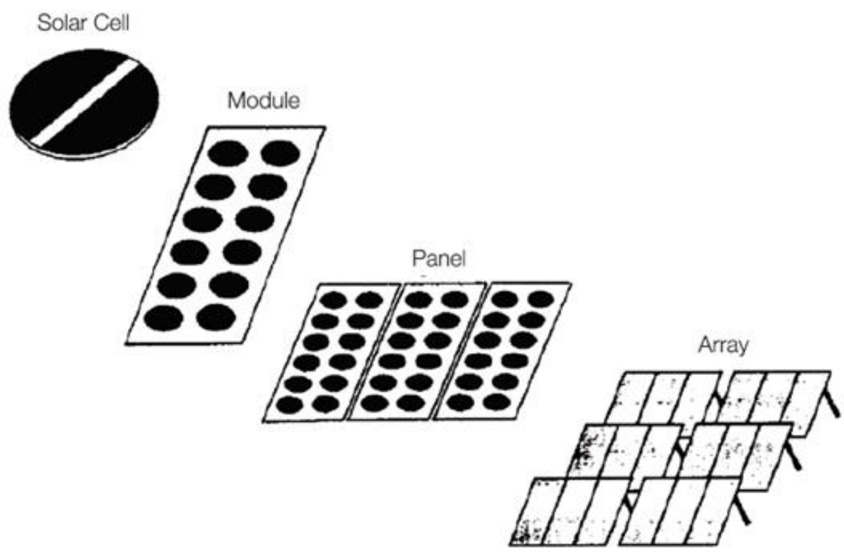


Figure 2.2: Solar Voltaic Hardware Hierarchy (Clean Energy Council, 2013)

2.2 Batteries

The current rechargeable batteries in production are generally made from Nickel Metal Hydride (Ni-MH), Nickel Cadmium (Ni-Cd) and Lithium ion (Li-ion) (Texas Instruments, 2011).

Table 2.1: Properties of various rechargeable batteries (TI, 2011)

Cell Type	Ni-MH	Ni-Cd	Li-ion
Gravimetric Density (Whr/kg)	55	50	90
Volumetric Density (Whr/L)	180	140	210
Self-Discharge at 20^{O}C (%/Month)	20-30	15-20	5-10
Typical Slow Charging Time (Hrs)	12-36	4 - 10	1-2 (However requires different charging method to Ni-MH and Ni-Cd)
Typical Fast Charging Time (Hrs)	1	0.25 - 1	1.5

As can be seen from table 2.1, Lithium ion battery are superior in almost every way. One major issue with Lithium ion batteries is the propensity to ignite and start fires. Both Lithium ion and NiMH require cooling systems to ensure thermal run away and consequential self-ignition do not occur.

A further consideration is the price of the batteries. Ni-Cd is the cheapest rechargeable battery followed by Ni-MH and finally Li-ion is the most expensive. Ni-MH is typically 50%-100% more expensive then Ni-Cd while Li-ion is primarily used in applications where performance is the highest consideration. It should be noted that Ni-Cd is the least long-term environmentally friendly having Cadmium within it.

Lithium ion batteries also present short duration environmental threats. If ignited, biologically destructive fluorine or hydrogen-fluorine gas is emitted for up to an hour.

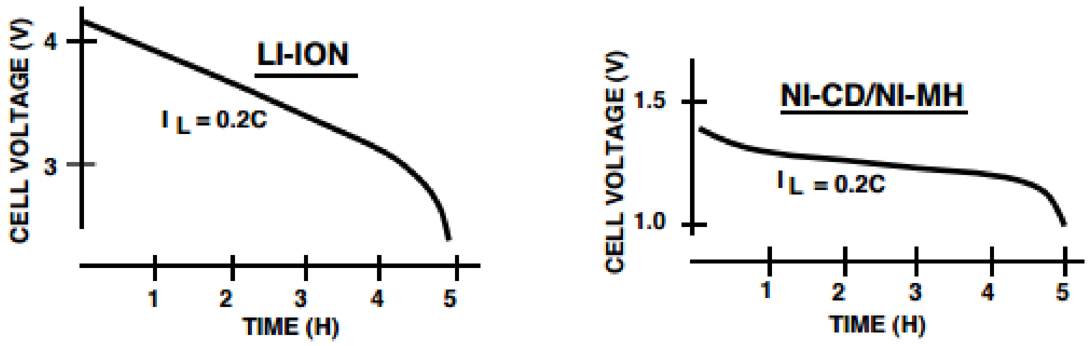


Figure 2.3: Cell discharge curve of the three many battery materials (TI, 2011)

As can be seen from figure 2.3, the Li-ion battery has a considerably higher cell voltage, approximately three times greater. However, the Ni-Cd and Ni-MH batteries have a much flatter discharge curve which closely matches an ideal battery (TI, 2011).

Figure 2.4 is a more detailed diagram of how a battery storage system operates. In this example, the power source is a wind turbine however the general principles still apply.

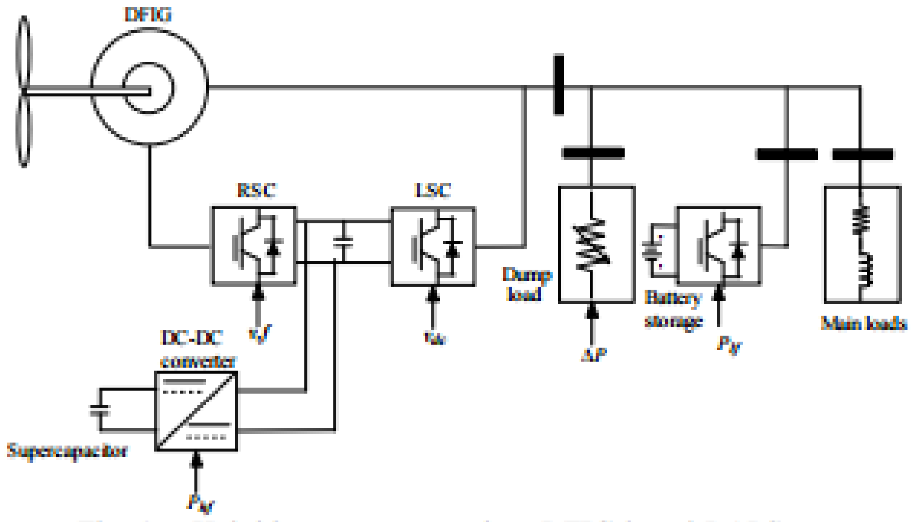


Figure 2.4: Hybrid energy storage in a DFIG based RAPS systems (Mendis, 2012)

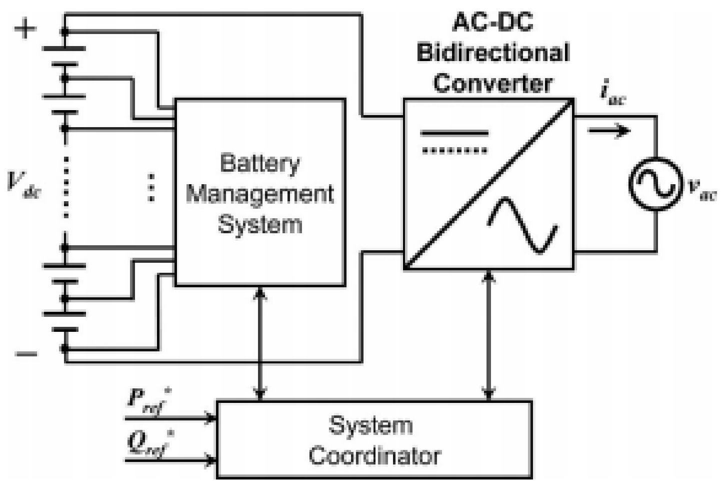


Figure 2.5: Simplified diagram of the lithium-ion energy storage systems (Hao, 2011)

Figure 2.5 demonstrates how a battery DC to AC system needs be designed. As batteries operate in DC and household appliances operate in AC, the battery must be connected to an DC-AC inverter. To enable mains power to charge the battery, the converter must be bi-directional. A bi-directional converter means the bridge of the DC-AC inverter can be controlled to act as a controlled rectifier in the reverse direction to charge the batteries also from mains power is needed. If the batteries are only charged from a PV array a bi-directional converter is not needed however a DC-DC converter with charge controllers if required.

Table 2.2: Comparison of different state of charge estimation schemes (Hao, 2011)

Technique	Summarized Features	Pros	Cons
Discharge	Discharge and measure time to a threshold	Most accurate	Offline & time consuming
Coulomb counting	Counting charges been injected/pumped	Easy	Loss model & need accuracy
Open circuit voltage	VOC-SOC look-up table	Accurate	Time consuming
Artificial network	Adaptive artificial neural network system	Online	Training data needed
Impedance	Impedance of the battery (RC combination)	SOC and SOH	Cost & temp-sensitive
DC resistance	R_{dc}	Easy	Only for low SOC
Kalman filter	Get accurate information out of data using filter	Dynamic	Large computing

As can be seen from the table 2.2, the various methods of measuring the state of charge of a battery has various advantages and disadvantages. For the modelling, the state of charge will be calculated in the program Homer Pro based on the data used from respective datasheets.

2.3 Solar Panels

Photovoltaics have gained considerable popularity due to their benefits. Table 2.3 outlines their main advantages and disadvantages. It must be considered however that not all advantages and disadvantages are equal. Some have greater benefits or issues than others.

Table 2.3: Pros and cons of rooftop solar PV systems (Endeavour Energy Power Quality and Reliability Centre, 2011)

PROS	CONS
Simple – there are no moving parts, no water is required, no regular maintenance is required.	**Variability** – no generation during the evening. Shading from clouds, trees, etc. dramatically reduces output. Power is also unable to be scheduled.
Modular – capacity can be easily increased through the addition of extra panels and inverter capacity.	**Cost** – still higher per kWh than coal and gas.
Long Life – panels typically have a 25 year lifespan. Inverter lifespan is around 10 years.	**Area** – relatively large area needed to generate relatively small amount of power due to low cell efficiencies.
Short Lead Time – systems can be installed very quickly.	**Power Quality Issues** – including steady state voltage rise.
Renewable – effectively infinite energy source.	**Polysilicon** – may become rare or expensive as demand increases.

The average yearly energy yield of a PV array can be estimated from Equation (1).

$$E_{sys} = P_{array\_STC} \times f_{man} \times f_{dirt} \times f_{temp} \times H_{tilt} \times \eta_{pv\_inv} \times \eta_{inv} \times \eta_{inv\_sb} \qquad (1)$$

(Clean Energy Council, 2013)

Where:

- E_{sys} is the average yearly output of the array in Wh
- P_{array_STC} is the rated output of the array under standard conditions in W
- f_{man} is the de-rating factor for the manufacturing tolerance
- f_{dirt} is the de-rating factor due to dirt on the PV array
- H_{tilt} is the yearly irradiation value for the site in kWh/m^2
- η_{pv_inv} is the efficiency of the subsystem between the PV array and the inverter
- η_{inv} is the efficiency of the inverter
- η_{inv_sb} is the efficiency of the subsystem between the inverter and the switchboard

Equation (1) illustrates the maximum power tracking MMP curve that a PV array co-generation inverters use to maximise the annual yield from a PV array. For the modelling in Homer Pro, irradiance profiles are used for Toowoomba which will be used to calculate the annual yield of the selected arrays.

Equation (2) shows how the temperature de-rating factor of a PV array. As arrays heat up, their efficiency decreases. This can cause a balancing act whereby the increase in sunlight which would intuitively equate to more power can heat the array and cause it to become more inefficient. Climate data for Toowoomba is programmed into Homer Pro and is used to calculate the de-rating factor of the array.

$$f_{temp} = 1 + \gamma \times \left(T_{cell_{eff}} - T_{stc}\right) \qquad (2)$$

(Endeavour Energy Power Quality and Reliability Centre, 2011)

Where:

- f_{temp} is the temperature de-rating factor
- γ is the value of power temperature coefficient per C^{O}
- $T_{cell_{eff}}$ is the average daily cell temperature in C^{O}
- T_{stc} is the cell temperature at standard test conditions in C^{O}

Photovoltaics operate in a manner similar to a voltage source and current source as shown in the figures 2.5, 2.6 and 2.7.

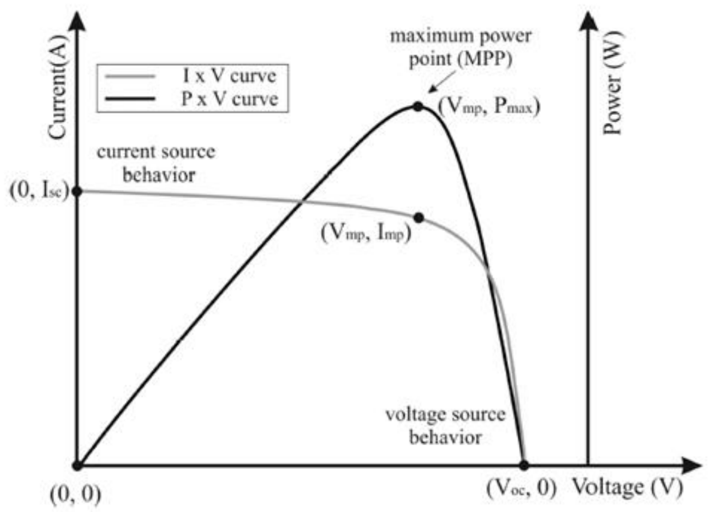


Figure 2.5: Characteristic curves of a solar photovoltaic panel (Cupertino, 2012)

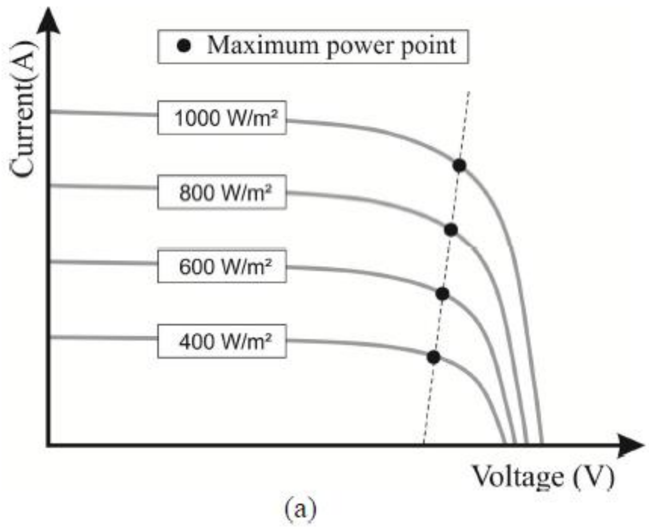


Figure 2.6: Characteristic curves of a solar photovoltaic panel (Cupertino, 2012)

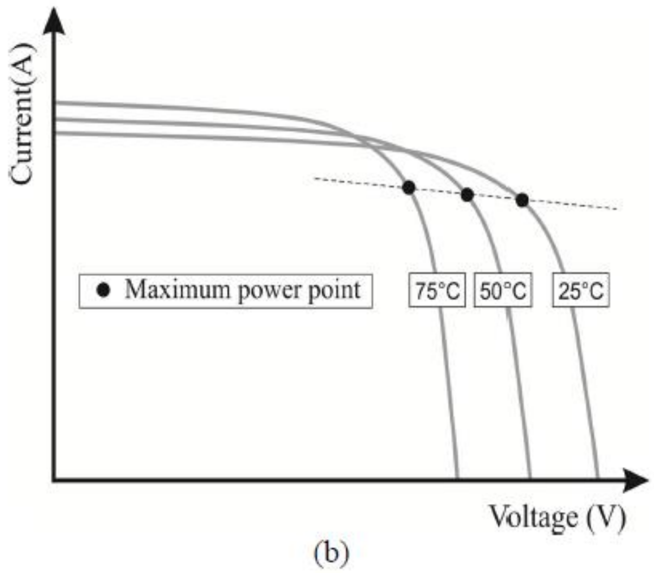


Figure 2.7: Characteristic curves of a solar photovoltaic panel (Cupertino, 2012)

As shown above, figures 2.5 to 2.7 demonstrate the knee curve characteristic of PV array operation. Figure 2.5 shows where the point of maximum power is found from the product of voltage and current. Figure 2.6 demonstrates how enlarging the curve will always yield a larger power and figure 2.7 demonstrates the impact temperature plays on the power output of a PV array. For example, increasing the temperature of a PV cell reduced the maximum power output.

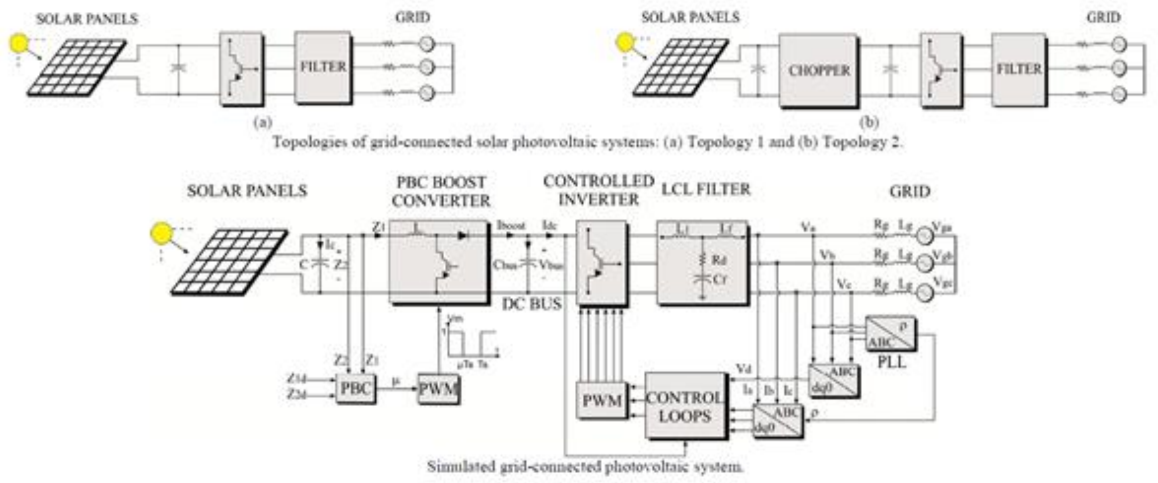


Figure 2.8: Simulated grid-connected photovoltaic system (Cupertino, 2012)

Figure 2.8 shows the two main configurations of inverters. An inverter is needed to convert the DC from the solar panels into AC for use of electrical appliances. For the analysis in Homer Pro, the inverter configuration is taken as strings illustrated in figure 2.9. Figure 2.9 also illustrates the slave inverter system adopted for large PV arrays.

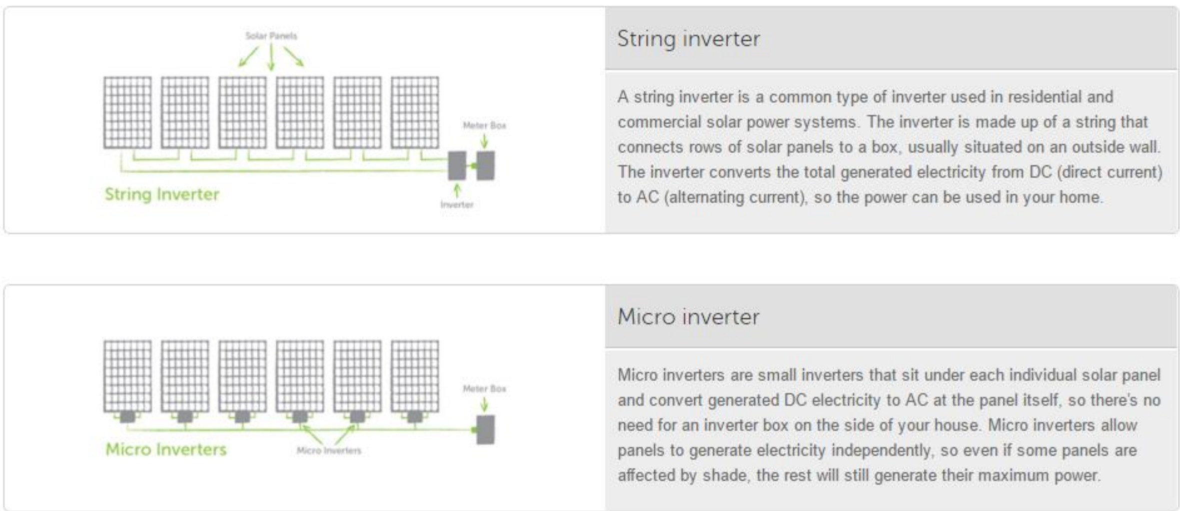


Figure 2.9: Brief description of inverter configurations

2.4 Electricity usage

From Ergon Energy, I was able to receive the load profile data of a Queensland household from the 08th of June 2015 until the 15th of March 2016. From analyses of the data using Matlab, the following data was calculated.

- Mean daily consumption = 10.42Wh
- Median daily consumption = 9.3kWh
- Mode daily consumption = 9.7kWh
- Peak demand = 4.5kW
- Mean daily peak demand = 1.4805kW

According to the Australian Bureau of Statistics (2012) data in table 2.4, on average, an Australian household consumes approximately 19.4kWh of energy per day. Figure 2.10 from AusGrid (2012) similarly confirmed, on average, a Queenslander consumes approximately 20.5kWh of energy per day. For the purposes of determining the optimal battery, the average energy consumption of a Toowoomba resident will be approximated at 20kWh per day. Table 2.5 from Origin Energy outlines the approximate electricity usage of small, average and large households which aligns with the data from AusGrid and the Australian Bureau of Statistics.

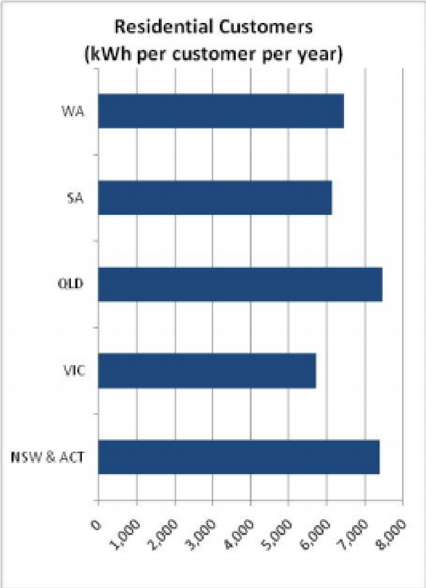


Figure 2.10: Annual consumption of households by state (Ausgrid, 2012)

Table 2.4: Average electricity usage of Australian households (Australian Bureau of Statistics, 2012)

Electricity								
Energy source(s) used in dwelling							Average	Average/day
Electricity only	kWh	138.7	140.8	128.4	137.4	134.3	135.9	19.4
Electricity and mains gas only	kWh	100.9	129.8	103.3	110.0	102.2		
Electricity, mains gas and other sources of energy	kWh	151.2	178.9	136.7	158.3	154.8		
Electricity and LPG/ bottled gas only	kWh	102.4	195.7	93.3	121.4	138.7		
Electricity, LPG/ bottled gas and other sources of energy	kWh	114.7	169.7	140.4	145.4	157.1		
Electricity and other sources of household energy	kWh	126.0	138.5	127.1	132.5	161.4		

Table 2.5: Origin Energy approximations for solar panels for households

	Small household	Average household	Large household
Number of people	1-2 people	2-3 people	4+ people
Average daily usage	5-11 kWh	9-21 kWh	18+ kWh
Approximate power generated	2,049 to 3,212 kWh pa	2,628 to 6,424 kWh pa	5,256 to 8,030 kWh pa
Roof area required	Approx. 16-18m^2	Approx. 18-40m^2	Approx. 40-50m^2
Recommended system	1.5-2kW	2-4kW	4-5kW

From analysing the Ergon Energy load profile data through Matlab, the following electricity usage data was calculated and is shown at the beginning of section 2.4. These values do not match with the data from AusGrid and the Australian Bureau of Statistics which indicates that this household is smaller than average. The values match the usage of a small household as stated by Origin Energy. Therefore, it can be concluded that the load profile data matches what can be assumed to be a small household.

From the comparison to the Origin Energy approximate energy usages, this household would likely be considered small seeing as the mean daily consumption is 10.42kWh and the mean daily peak demand is 1.4805kW.

For the purposes of further analysis, for a middle sized house the daily peak demand will be taken as 3kW from Origin Energy's approximations and the daily consumption will be taken as 15kWh from the Origin Energy approximations and Australian Bureau of Statistics data.

For further analysis, a large house energy usage will be taken as having a daily peak demand of 5kW and a daily consumption of 20kWh based on the information from Origin Energy and the Australian Bureau of Statistics.

From these approximate values for electricity usage, the load profile data for the small household can be scaled up to be within the ranges as stated by Origin Energy. From this, analysis on can be undertaken on a small, medium and large household.

2.5 Products on the Market

After some initial research of published original equipment manufacturer data, table 2.6 summarises the products currently on the market.

Table 2.6: Preliminary list of available batteries commercially available

Product	Power (kW)	Capacity (kWhr)	Price (AUD)
Tesla PowerWall	3.3	6.4	$17,250
AUO PowerLegato	3	6.5	$12,990
Sunverge SIS 11.6	5	11.6	$19,990
Sunverge SIS 19.4	5	19.4	$24,990
Century Yuasa NP65-12FR	0.078-0.192 per cell	0.78 per cell	$295.10 per cell (Batteries Direct)
Century Yuasa UXH200-6N	0.12-0.24 per cell	1.2 per cell	No price available
Century Yuasa UXH100-12N	0.12-0.24 per cell	1.2 per cell	No price available
Century Yuasa EN160-6	0.096 per cell	0.96 per cell	$693 per cell (1-19 purchased) - $644.49 per cell (20+ purchased) (RS Components)
Century Yuasa EN480-2	0.096 per cell	0.96 per cell	Discontinued (RS Components)
Century Yuasa UXF150-12FR	0.18-0.36 per cell	1.8 per cell	$998.58 per cell (1-19 purchased) - $928.68 per cell (20+ purchased) (RS Components)
Century Yuasa UXL1100-2	0.2 per cell	2 per cell	No price available
Century Yuasa UXL1200S-2	0.2 per cell	2.4 per cell	No price available
Century Yuasa ENERSUN SSR1320-4	0.264-0.452 per cell	5.28 per cell	No price available
Century Yuasa ENERSUN Gel 205	0.198-0.396 per cell	2.472 per cell	No price available

After consultation with the board of standards for battery technologies (Michell Taylor contacted on the 7th of April 2016), the brands suggested include:

- Selectronic MyGrid
- Redback Technologies
- ZEN Energy
- Outback power
- Solax
- AlphaESS
- BYD
- Growatt
- SMA
- Sungrow
- Fronius
- Bosch
- Sunsink
- Goodwe
- Schneider
- Akasol
- Ecoult
- Aquion
- Redflow
- Samsung
- Panasonic
- Toshiba

From the Australian electronics manufacturer Selectronics, tables 2.7 and 2.8 show typical data available for commercial batteries, these being sold with the Selectronics multi-function household inverters.

Table 2.7: Specifications of some Selectronic Batteries

Part number	Suitable inverter	C10 Capacity	C100 Capacity	Max AC coupled PV KACO / Generic [1]	Battery Voltage	Number of battery boxes
MG008024-S6	SPMC240-x.x (3.0 kW) SPMC241-x.x (4.5 kW)	6.2 kWh	8 kWh	4 kW / 3 kW	24 V	1
MG016024-S6		12.5 kWh	16 kWh	6 kW / 3 kW		2
MG016048-S6	SPMC481-x.x (5.0 kW) SPMC482-x.x (7.5 kW)	12.5 kWh	16 kWh	4 kW / 4 kW	48 V	2
MG032048-S6		25.0 kWh	32 kWh	8 kW / 4.5 kW		4
MG040120-S6	SPMC1201-x.x (7.5 kW) SPLC1200-x.x (15.0 kW) SPLC1202-x.x (20.0 kW)	31.2 kWh	40 kWh	8 kW / 5 kW	120 V	5
MG080120-S6		62.4 kWh	80 kWh	10 kW / 5 kW		10

1. Max AC output power from PV grid inverter. KACO is managed AC coupled solar. Generic is unmanaged AC coupled solar

Table 2.8: Specifications of more Selectronic Batteries

					Maximum AC Coupled Solar Allowed			
Part number	Total Battery Capacity	Usable Battery capacity (to 80% DoD)	Battery Voltage Nominal	Suitable SP PRO Single phase	Managed with Selectronic Certified Inverters	Generic AC Coupling	On Grid, Off Grid Generator support	No of Battery Boxes
MGL003024-V12	3.5 kWh	2.80 kWh	24 V	SPMC240	6 kW	3 kW	Yes, On Grid requires additional module.	1
MGL007048-V12	7.0 kWh	5.60 kWh	48 V	SPMC481	10 kW	5 kW		1
MGL014048-V12	14.0 kWh	11.00 kWh	48 V	SPMC481 SPMC482	10 kW 15 kW	5 kW 7.5 kW		2
MGL021048-V12	21.0 kWh	17.00 kWh	48 V	SPMC481 SPMC482	10 kW 15 kW	5 kW 7.5 kW		3
MGL028048-V12	28.0 kWh	22.00 kWh	48 V	SPMC481 SPMC482	10 kW 15 kW	5 kW 7.5 kW		4
MGL018120-V12	18.0 kWh	14.00 kWh	120 V	SPMC1201 SPLC1200	15 kW 30 kW	7.5 kW 15 kW		3
MGL035120-V12	35.0 kWh	28.00 kWh	120 V	SPMC1201 SPLC1200 SPLC1202	15 kW 30 kW 40 kW	7.5 kW 15 kW 20 kW		5
MGL070120-V12	70.0 kWh	56.00 kWh	120 V	SPMC1201 SPLC1200 SPLC1202	15 kW 30 kW 40 kW	7.5 kW 15 kW 20 kW		10

Tables 2.7 and 2.8 illustrate both the difference in capacities of batteries at C(10h) versus C(100h) rates and useable versus total battery capacity. Batteries are very non-linear devices and Homer Pro uses a special algorithm to mimic the individual battery type performance as well as the calculate expected battery life.

Figure 2.11: Redback Technologies battery

Figure 2.11 shows a typical Redback Technologies battery as an alternative to the Selectronics inverters. After further analysis it was decided the batteries more suited to the household are presented in table 2.9.

Table 2.9: Secondary list of available batteries commercially available

Battery	Power Rating (kW)	Capacity (kWh)
Selectronics MG080120-S6	10	80
Selectronics MGL035120-V12	15	28
Selectronics MGL070120-V12	15	56
Redback Smart Hybrid Solar Inverter System	6.21	513
SolaX-BOX	4.6	15
Alpha ESS Storion Powerplug 48V	3.072	2.7
Alpha ESS Storion Powerplug 150V and 450V	3.072	2.7
Alpha ESS Storion-T5	5	16.2
BYD DESS-B08P03A-E	3	8
BYD F12200	2.4	2.56
Sol Distribution SDI ESS 10.8kWh	6.336	10.368

Figures 2.12 and 2.13 show the specifications of a battery and PV array commercially available from EuroSolar.

10kW Storage Ready

Daily Energy Production (approx*)	42kWh
System Peak Power DC	10kW
Number of ZEN 250W Silver Solar Panels	40
Roof Area Required (mtrs sq.)	65.1 sq/m
ZEN Storage Ready Inverter	2 x SR 5TL

*The Average Daily Energy production is based on the Australian average of 4.2 hours of peak sunlight per day and the Solar Panels facing North at a 30 percent incline. Variations to this will have an affect on the energy yield. On a clear day, energy production can be up to 30% higher than these specifications.

SR 5TL

Number of ZEN 250w Silver panels	40
Transformer-less inverter	Yes
Maximum PV power input	4000 W
Maximum current output	25 A
Maximum efficiency	97%
Operating temperatures	-25 up to +60°C
Dimensions - WxHxD (mm)	810x325x222
Weight	< 26.0kg

Figure 2.12: Specifications of a EuroSolar battery storage system

40 x ZEN 250W Silver Solar Panels Specifications

Dimensions (mm)	1640x992x50
Weight	20.21kg
Panel Type	Polycrystalline
Maximum Power Production	250W
Rated Power	±3%
Maximum Power Point Voltage	30.34V
Maximum Power Point Current	8.24A
Open Circuit Voltage (Voc)	37.47V
Short Circuit Voltage (Isc)	8.76A
Maximum System Voltage	DC1000V
Normal Operating Cell Temp.	45.3°C±2°C
TK Isc	0.04% /°C
TK Voc	-0.34% /°C
Connector	MC4

Figure 2.13: Specifications of a EuroSolar solar panel system

After extensive review, the PV arrays commercially available which will be used in the modelling are listed in table 2.10.

Table 2.10: Solar panels for further analysis

Product	Capacity (kW)	Panels	Inverter Capacity (kW)	Energy Output (kWhr/year)	Roof Area Required (m^2)	Cost ($)
EuroSolar 5kW Solar System	5	20 x 250W	5	6,387 – 9,125	36	$3842
EuroSolar 6kW Solar System	6	24 x 250W	5	7,664 – 10,950	43.2	$4300
EuroSolar 10kW Solar System	10	40 x 250W	10	12,774 – 18,250	72	$7680
AGL Solar	2		2			$3200

Finding useful product data and prices for batteries for Homer Pro input was more difficult. After discussions with a project supervisor, I was directed to Rainbow Power Company which has an extensive list of batteries with prices and datasheets. The batteries were ordered from high end to low end and the best batteries were selected. The storage batteries selected for modelling are shown in table 2.11.

Table 2.11: Batteries for further analysis

Product	Capacity (Ahr)	Nominal Voltage (V)	Throughput (kWhr)	Price (AUD)
Trojan T-105	230	6	845	$416.00
Trojan 27TMX	105	12	350	$388.42
Ritar RA12-260D	260	12	1250	$1,020.00
Ritar RA12-100SD	100	12	450	$416.00
Ritar RA12-150D	150	12	675	$616.00

The main benefit from choosing these batteries is that their datasheets are extensive namely they provide the life characteristics of cyclic use which is needed for Homer to calculate the lifetime throughput in kWh.

2.6 Solar levels

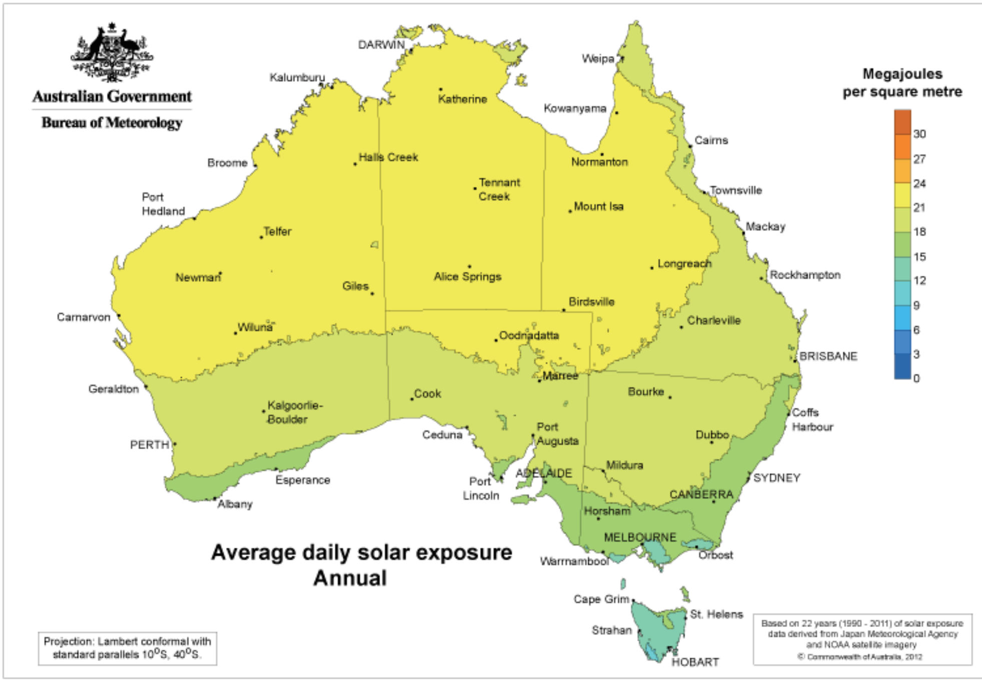


Figure 2.14: Average daily solar exposure (Bureau of Meteorology, 2013)

As can been seen from the figure 2.14, the average daily solar exposure for Toowoomba and the Darling Downs is approximately between 18-21MJ/m^2. This indicates there is sufficient energy available to be harnessed through solar panels as a household power source.

From the NASA global meteorological dataset, Homer Pro is capable of accessing the solar exposure of the Toowoomba region and can also carry out economic analysis. This means that manual cost calculations are not necessary and can be included in the optimisation.

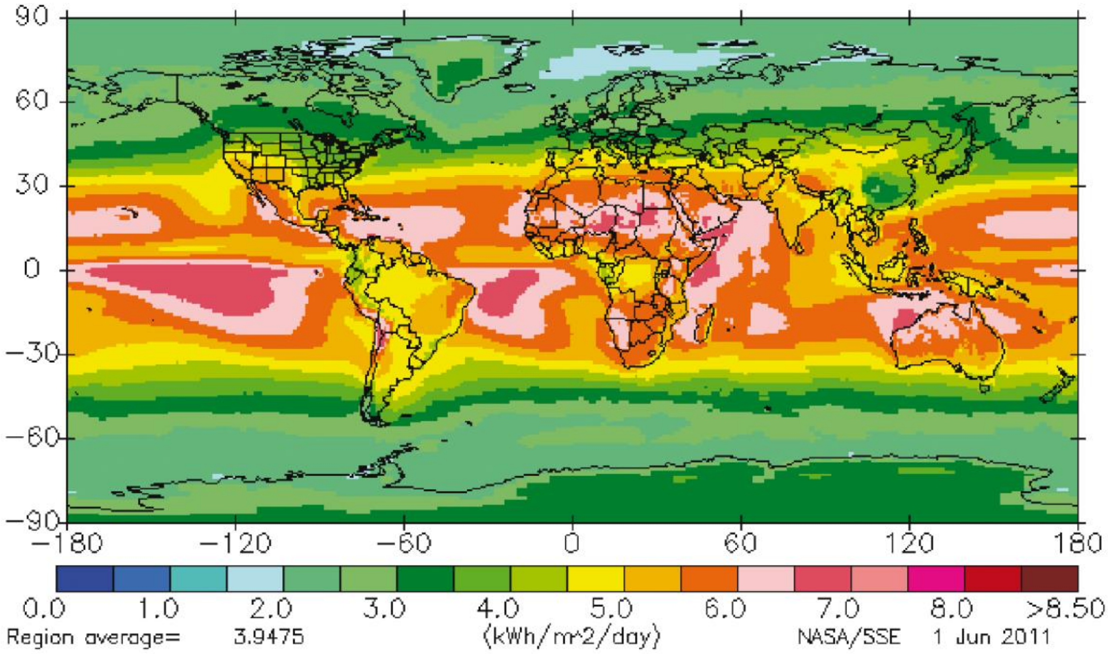


Figure 2.15: Global annual solar irradiance levels (Endeavour Energy Power Quality and Reliability Centre, 2011)

As is shown from figure 2.15, Australia and especially Queensland has some of the highest annual solar irradiance in the world. Having such a high irradiance and a climate with relatively short periods of cloud cover indicates that solar panels are a viable renewable energy resource.

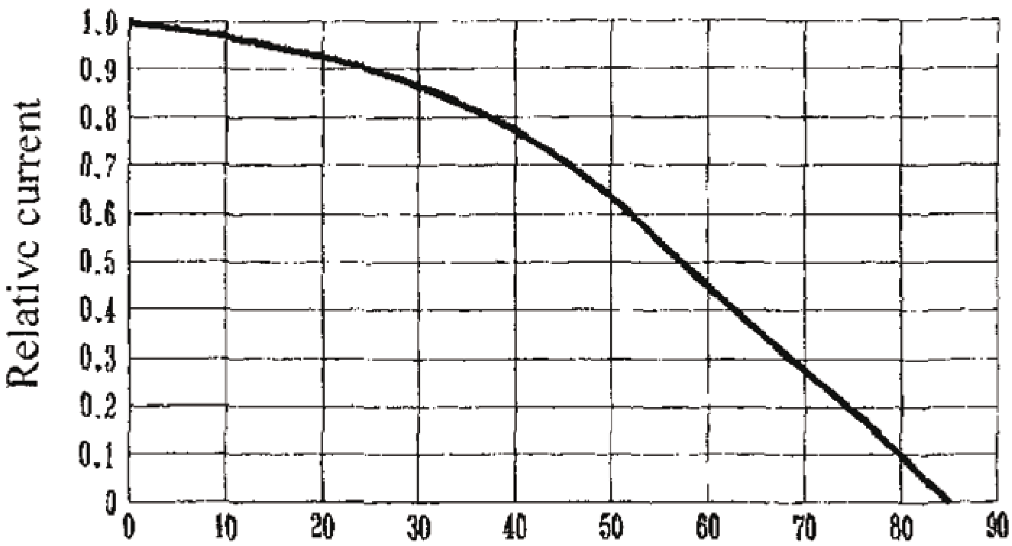


Figure 2.16: Relative current vs angle of solar incidence in degrees (Endeavour Energy Power Quality and Reliability Centre, 2011)

As the sun shifts relative to the PV array, the relative current and thus power changes. Figure 2.16 demonstrates the change in relative current which is dependent upon the angle of incidence. Having the sun directly above the PV array yields the greatest current and therefore power which intuitively makes sense. Homer Pro also allows setup for PV panel orientation to accommodate analysis on non-ideally installed PV arrays.

2.7 Economic Analysis

Economic analysis is one of the main components for optimisation and the return on investment (ROI) is one of the main considerations. The ROI can be calculated from the equation (3) (Kamjoo, 2011).

$$ROI = \frac{TI - TC}{TC} \times 100 \qquad (3)$$

Where *TI* as shown in equation (4) is the total income of the system and takes into consideration the cost of the feed in tariff I_{FIT} and the cost of selling excess power back into the grid $I_{sell\ grid}$. Equation (5) for *TC* is the total cost of the system and takes into consideration the initial capital cost C_{ic}, present value of the replacement cost C_{rep}, the present value of the maintenance cost and the cost of buying power from the grid $C_{buy\ grid}$.

$$TI = I_{FIT} + I_{sell\ grid} \qquad (4)$$

$$TC = C_{IC} + C_{rep} + C_{O\&M} + C_{buy\ grid} \qquad (5)$$

L_P is the lifetime of the product, FIT_{PV} as shown in equation (6) is the feed in tariff of the PV system and $PV_{PV\ load}$ is the generation of the PV system.

$$I_{FIT} = L_P(FIT_{PV} \times PV_{PV\ load}) \qquad (6)$$

Where $T_{sell\ grid}$ is the tariff for selling back into the grid and $PV_{PV\ load}$ is the excess power produced by the PV array after charging. Therefore, the sell to grid current can be calculated from equation (7).

$$I_{sell\ grid} = L_P T_{sell\ grid}(PV_{PV\ excess}) \qquad (7)$$

A_{PV} is the area of the PV array and $C_{unit\ PV}$ is the cost \$/m^2 of the array, N_{batt} is the number of batteries, C_{batt} is the nominal capacity of the batteries in Ah, $C_{unit\ batt}$ is the \$/Ah per battery and C_0 is the constant cost of installation which is taken to be 40% of the cost of the PV array. Therefore, the total cost of a solar array is given by equation (8).

$$C_{IC} = A_{PV} \times C_{unit\ PV} + N_{batt} \times C_{batt} \times C_{unit\ batt} + C_0 \qquad (8)$$

N_{rep} is the number of replacements over the system's life, f is the inflation rate and k_d is the interest rate. Therefore, the economic life of the PV array, the cost of replacing batteries with their shortest cycle lives is given by equation (9).

$$C_{rep} = N_{batt} \times C_{batt} \times C_{unit\ batt} \times \sum_{i=1}^{N_{rep}} \left[\frac{1+f}{1+k_d}\right]^{\frac{N_i}{N_{rep}}+1} \qquad (9)$$

The current inflation rate at the time of printing is 1% while the interest rate is 1.5% (Trading Economics, 2016). However, over the lifetime of the project these values can and will change. Therefore, the default values within Homer Pro will be used in the analysis to determine system capital costs and life costs.

As the location being analysed is in Toowoomba the prices for electricity are available through Ergon Energy. Other electricity retailers are available however Ergon Energy is the most commonly used and therefore the tariff pricing will be based of them. The tariffs used in the Homer Pro analysis are provided in tables 2.12 and 2.13.

Table 2.12: Ergon Energy Tariff 33

	GST incl. from 1 July 2015	GST incl. from 1 July 2016
All usage - cents per kWh	20.759	21.956

Table 2.13: Ergon Energy solar feed in tariff

	Rate from 1 July 2015	Rate from 1 July 2016
All exports - cents per kWh	6.348	7.448

Tariff 33 is the most common tariff customer purchase their energy from and the solar feed in tariff is the price Ergon Energy will purchase electricity for.

Economic data that Homer Pro calculates for the user includes Cost of Electricity (COE), Net Present Cost (NPC), Operating Cost and payback period. The payback period will be calculated by comparing the cost of the system to remaining purely on the grid.

The COE is a measure of the average price of energy for the household. The price is measured in $/kWh.

Net Present Value an economic measure that is the difference between the present value of cash inflows and the present value of cash outflows. NPV is used in capital budgeting to analyse the profitability of a projected investment or project. (Investopedia, 2016)

Net Present Value is calculated using equation 10.

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0 \qquad (10)$$

Where t is the number of time periods, C_t is the net cash flow during the period t, C_0 is the total initial investment cost and r is the discount rate. Given that NPV is a measure of the profitability of an investment it is desirable to have its value as high as possible.

Net Present Cost (NPC) represent the system's life-cycle cost. NPC combines all the costs and revenues of thee lifetime of the project and presents it in a single lump sum in year-zero dollars. Future cash flows are discounted to year zero using the discount rate. The costs considered may include capital, replacement, operation and maintenance, fuel, electricity and pollutant costs. Revenues that are considered may include selling power into the grid and any salvages that can be recovered at the end of the projects lifetime. NPC costs are represented by a positive value and revenues are represented with a negative value. This is the opposite for NPV and therefore NPC and NPV only differ by the sign (Kayako, 2010).

Operating costs are the expenses associated with the maintenance of a particular investment or business (Investopedia, 2016). For this particular project this includes maintaining and replacing components of the microgrid.

The Operating Cost is calculated from equation 11.

$$Operating\ Cost = Cost\ of\ Goods\ Sold - Operating\ Expenses \qquad (11)$$

The goods sold in this instance is the power back into the grid and the reduction in Cost of Electricity.

The payback period is a measure of the length of time needed to recover the cost of an investment. The payback period of a given investment or project is used as a means of determining whether to undertake the position or project. This is because longer payback periods are typically not desirable for investment positions (Investopedia, 2016). For the project, the payback period will be the time taken in years to recover the expenses associated with the microgrid.

Homer Pro is capable of calculating all of the mentioned economic measures. For the analysis of the results from Homer Pro all will be considered and it is desirable to have a low COE, low NPC, low Operating Cost and low payback period.

Chapter 3 Methodology

3.1 Outline of Methodology

The main components of the project outline for the faculty offer of this project from Assoc Prof Paul Wen is outlined as follows.

- Investigate the existing products, and study how each of the existing products works
- Compare and evaluate their techniques and performance in efficiency and capacity
- Identify the techniques that need to be improved
- Identify the techniques that have the potential to be improved
- Recommend:
  - The best products (value for money)
  - The most sustainable products
  - The ideal system based on the current techniques and products
  - Your vision for the products and markets

For the project the first step undertaken was to determine the minimum requirements of the batteries and solar panels for a household. This was undertaken by analysing load profile data received from Ergon Energy. The data is for a Queensland household in Ergon Energy's jurisdiction. The data was collated from June 2015 to March 2016. The data measured the consumption of the household over a 30-minute period. The data was analysed through Matlab to determine a range of usage values. These were listed in the electricity usage section and were the mean, median and mode daily consumption as well as the peak demand and mean daily peak demand.

The next step of the process was to determine batteries that meet the requirements set in the previous section. This was undertaken by analysing datasheets available for commercial batteries and solar panels online. However, unfortunately a considerable amount of datasheets for batteries did not have the necessary information for analysis in Homer Pro. Another further issue was obtaining datasheets and prices for batteries and solar panels. The data necessary for analysis in

Homer Pro for a battery are nominal voltage, capacity in Ah, lifetime of battery according to depth of discharge (DoD) to find throughput, cost as well as other minor details. Fortunately, all the necessary data for solar arrays were available from the datasheets which were the cost and power rating. As stated in section 2.5, the batteries and PV arrays used in the simulations are shown in tables 3.1 and 3.2.

Table 3.1: Solar panels for further analysis

Product	Capacity (kW)	Panels	Inverter Capacity (kW)	Energy Output (kWhr/year)	Roof Area Required (m^2)	Cost ($)
EuroSolar 5kW Solar System	5	20 x 250W	5	6,387 – 9,125	36	$3842
EuroSolar 6kW Solar System	6	24 x 250W	5	7,664 – 10,950	43.2	$4300
EuroSolar 10kW Solar System	10	40 x 250W	10	12,774 – 18,250	72	$7680
AGL Solar	2		2			$3200

Table 3.2: Batteries for further analysis

Product	Capacity (Ahr)	Nominal Voltage (V)	Throughput (kWhr)	Price (AUD)
Trojan T-105	230	6	845	$416.00
Trojan 27TMX	105	12	350	$388.42
Ritar RA12-260D	260	12	1250	$1,020.00
Ritar RA12-100SD	100	12	450	$416.00
Ritar RA12-150D	150	12	675	$616.00

Figure 3.1 illustrates the data required to input a battery characteristic performance and life into the Homer Pro library.

Figure 3.1: Homer Pro calculating the throughput for the Trojan 27TMX battery

Similarly, figures 3.2 and 3.3 show both the cost inputs for Homer Pro as well as the sensitivity study inputs governed by the “search space”.

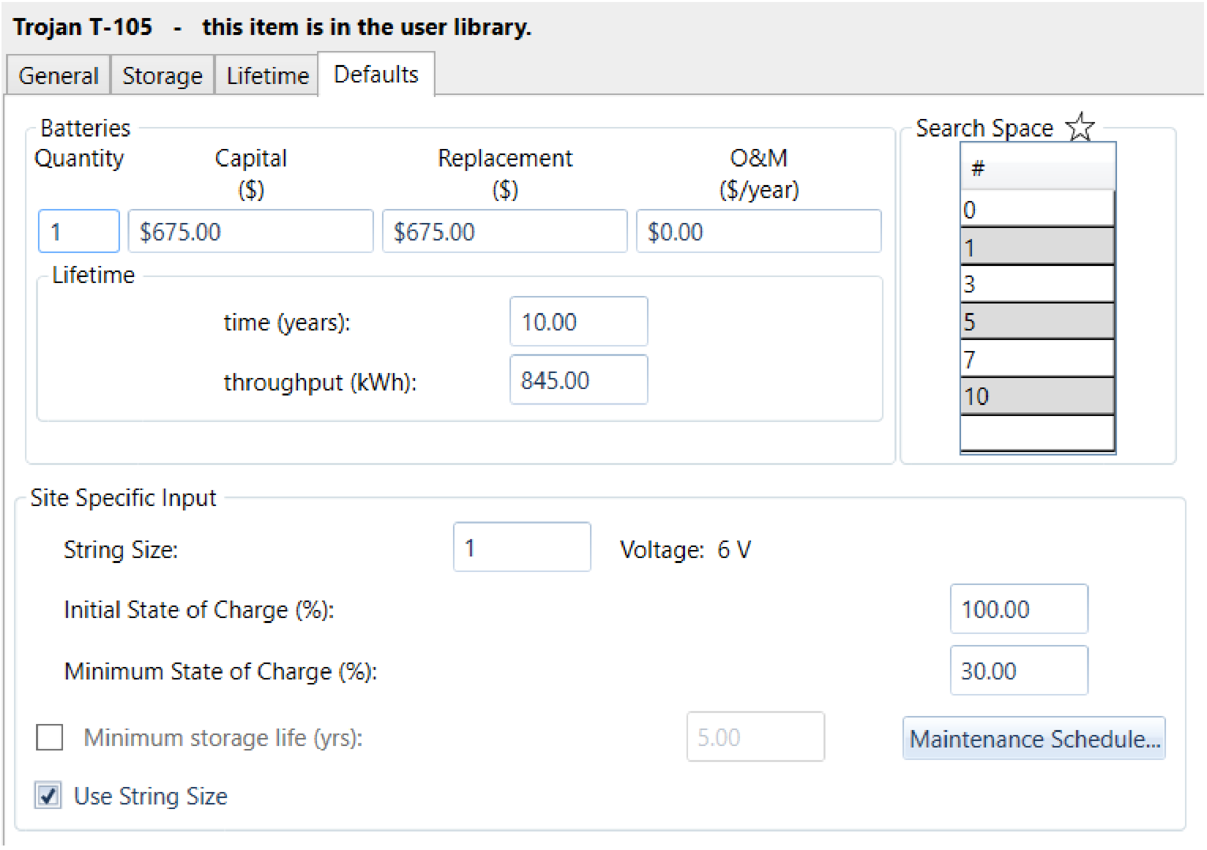


Figure 3.2: Example of some of the inputs for Trojan T-105 battery

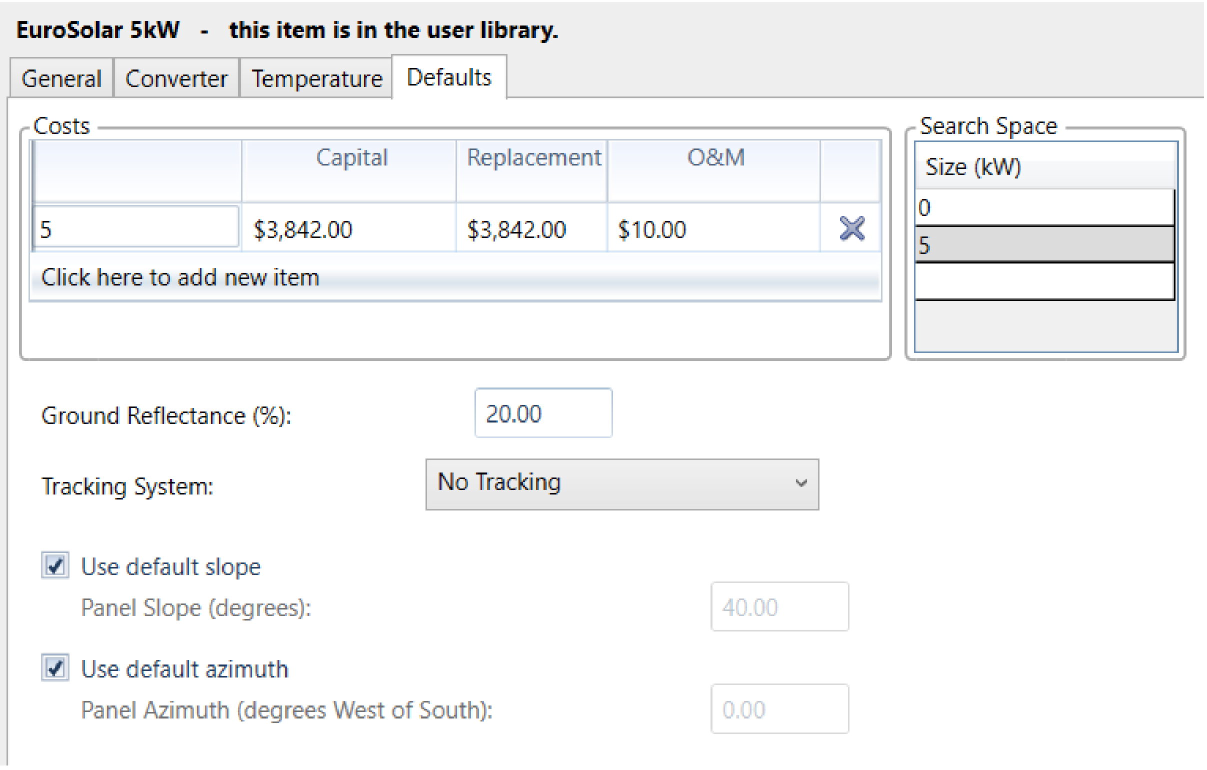


Figure 3.3: Example of some of the inputs for the EuroSolar 5kW array

The next step to be taken is to analyse the data through HOMER Pro. Homer Pro is a software package created by Homer Energy to analyse microgrids and is especially useful for economic analysis undertaken in this project. In Homer Pro, a myriad of factors can be considered and easily adjusted for fast and simple testing and optimisation of a microgrid and can include mains power, solar power and battery storage systems.

In a Homer Pro Project, the microgrid is set up by inputting the sources and loads in the schematic and for this project they included the grid, a PV array, a DC/AC converter, a battery and the electrical load. Homer Pro uses the "search space" of each component in the designed system to check all permutations to find the optimal solution.

For electrical load, the load profile data was deemed to be for a small house and to simulate a medium and large house the loads were doubled and tripled respectively as per the Origin Energy approximations. To input the load profile data from Ergon Energy, the load profile for a week day and a weekend day was required. The first Sunday of every month was chosen to be the weekend load profile and the subsequent Monday was chosen to be the week day load profile for consistency. Homer Pro has inbuilt default irradiation for many locations including Toowoomba. This data is used to calculate the amount of power produced by the PV array. There is also inbuilt default climate data available which is used to calculate the temperature effects on the PV array as differing temperatures affect efficiency.

Figure 3.4 illustrates the Homer Pro GUI to build a model based on load, components, resources and model constraints.

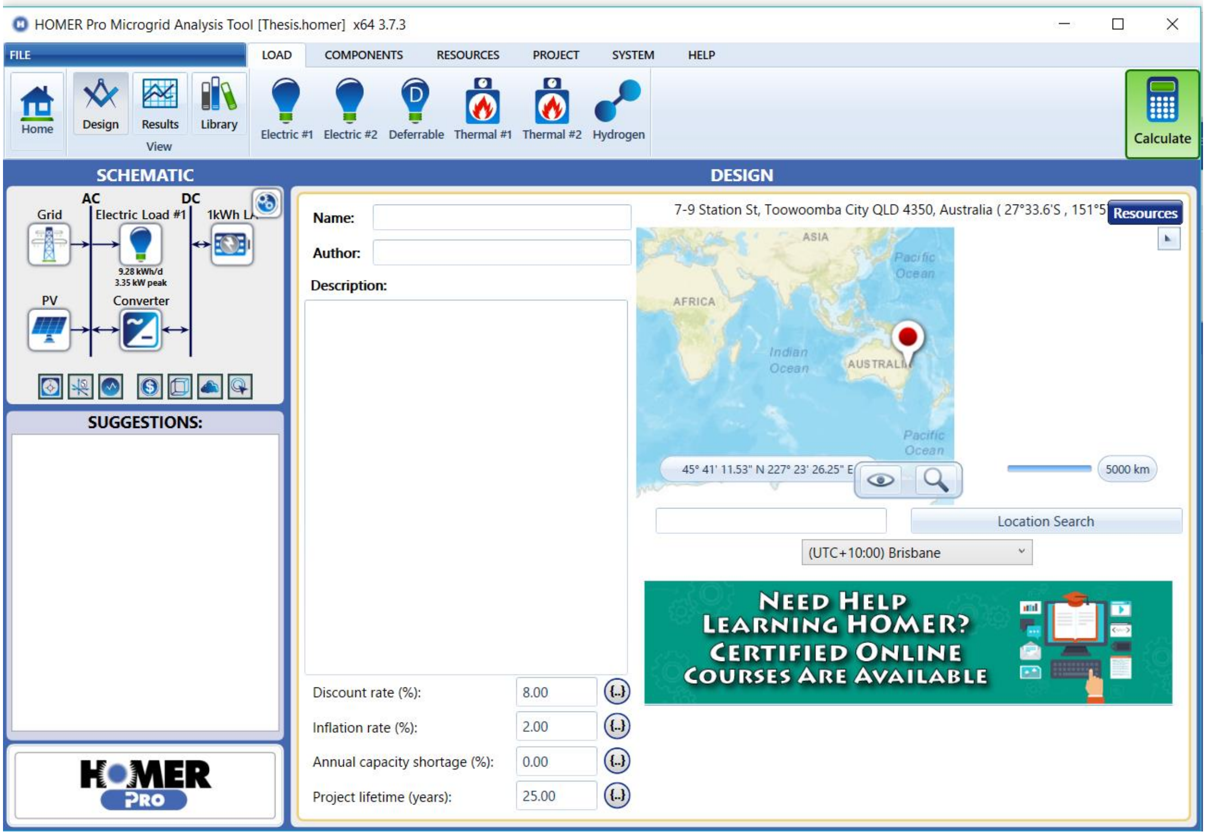


Figure 3.4: Homer Pro interface

The following stage of the project is to analyse the data against determined criteria to evaluate how well each systems works. The criteria will incorporate cost of the system, lifespan, effectiveness and various other considerations. The economic results that Homer Pro can output include Cost of Electricity (COE), Net Present Cost (NPC), Operating Cost, Initial Capital and so on. For the economic analysis, all of these measures will be taken into consideration.

The variables that can be altered in Homer Pro include the components of the microgrid, the tariff pricing, inflation and interest rate and so on. For this project the parameters that will be changed are the components of the microgrid being the battery and PV array as well as the load for a small, medium and large household. The load profiles are based on the Ergon Energy data and scaled according the average usage.

The last step is to make recommendations on which system is the optimal and the cheapest.

3.2 Homer Pro Inputs

This section outlines the exact inputs into Homer Pro for the testing. The inputs for each size house were all very similar except for the load profiles.

Figure 3.5 displays the household PV array and battery model, household load and grid connection. This version of Homer Pro can also compare multiple battery storage types in a single model. In figure 3.5, there are 5 batteries being compared to find the optimal outcome.

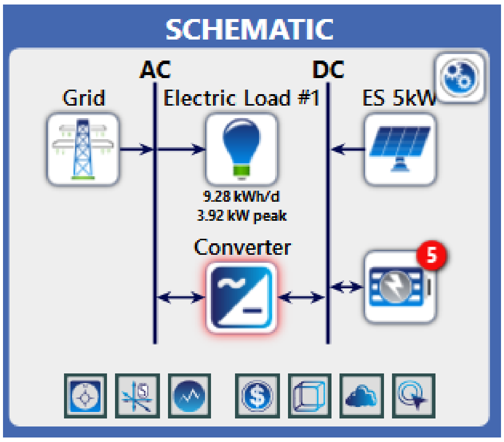


Figure 3.5: Schematic of Architecture in this case for a small household

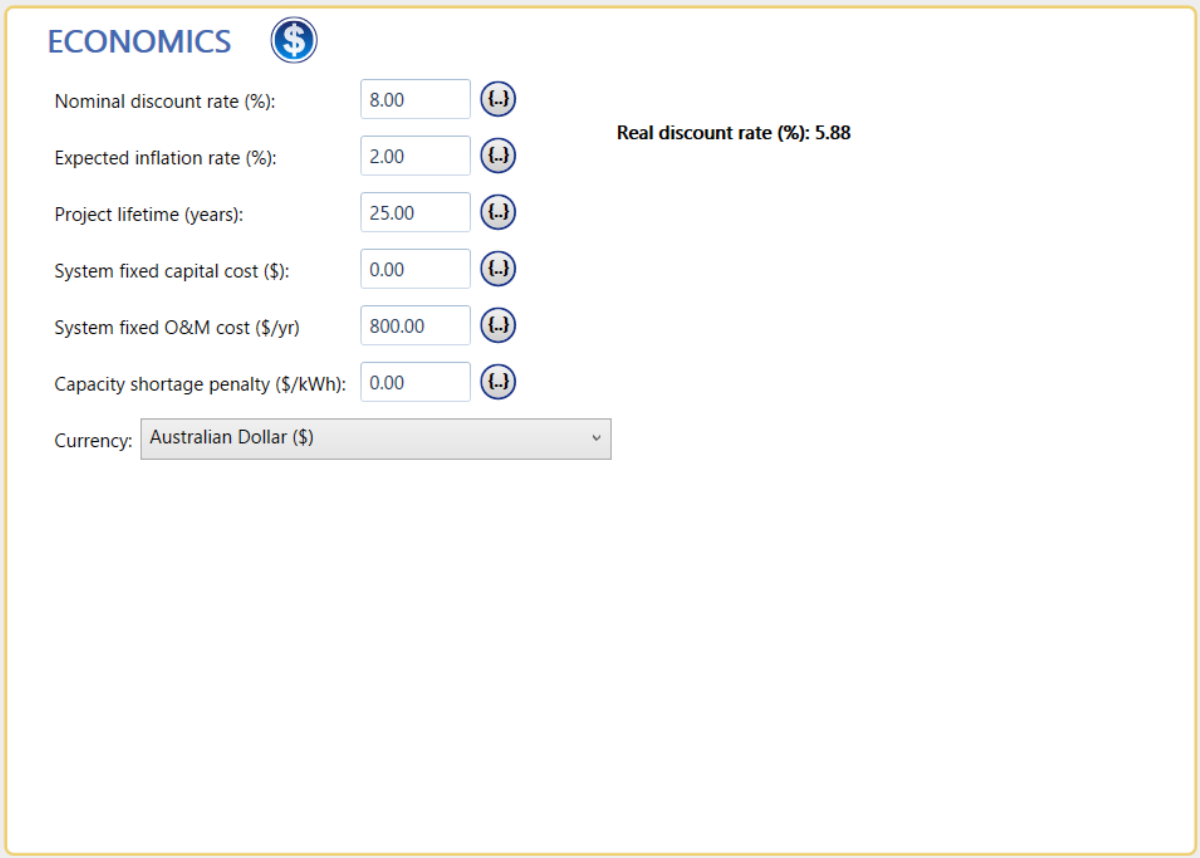


Figure 3.6: Economic inputs in Homer Pro used for the simulations

Figure 3.6 allows economic constraints to be set. The annual system fixed operation and maintenance cost of $800 is present as it is the annual Ergon Energy grid connection cost.

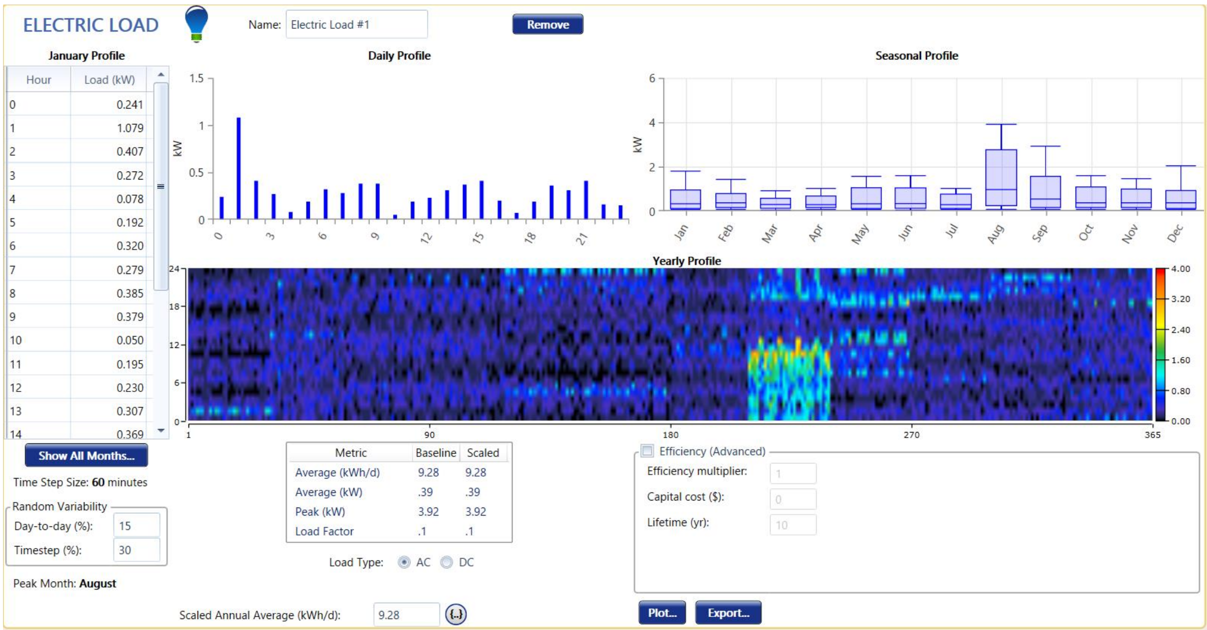


Figure 3.7: Electrical load window for a small household

Figure 3.7 illustrates the small household load profile window

Hour	January	February	March	April	May	June	July	August	September	October	November	December
0	0.241	0.390	0.146	0.146	0.144	0.144	0.387	1.015	0.310	0.323	0.427	0.663
1	1.079	0.452	0.156	0.156	0.345	0.345	0.373	1.003	0.356	0.402	0.326	0.388
2	0.407	0.428	0.314	0.314	0.312	0.312	0.164	1.257	0.188	0.320	0.116	0.227
3	0.272	0.454	0.384	0.384	0.425	0.425	0.157	1.135	0.122	0.164	0.209	0.465
4	0.078	0.272	0.384	0.384	0.840	0.840	0.381	1.000	0.274	0.163	0.273	0.493
5	0.192	0.206	0.384	0.384	0.295	0.295	0.302	1.051	0.355	0.314	0.375	0.342
6	0.320	0.205	0.169	0.169	0.279	0.279	0.176	1.131	0.358	0.384	0.365	0.112
7	0.279	0.336	0.126	0.126	0.086	0.086	0.202	1.297	0.947	0.274	0.208	0.231
8	0.385	0.410	0.165	0.165	0.101	0.101	0.373	1.545	0.558	0.181	0.155	0.428
9	0.379	0.443	0.264	0.264	0.169	0.169	0.264	1.744	0.582	0.170	0.367	0.467
10	0.050	0.433	0.396	0.396	0.346	0.346	0.648	2.217	0.526	0.390	0.485	0.448
11	0.195	0.267	0.368	0.368	0.337	0.337	0.592	0.965	0.336	0.395	0.262	0.295
12	0.230	0.398	0.394	0.394	0.134	0.134	0.372	0.296	1.334	0.229	0.240	0.276
13	0.307	0.707	0.293	0.293	0.147	0.147	0.195	0.494	1.167	0.190	0.323	0.412
14	0.369	0.332	0.162	0.162	0.378	0.378	0.173	0.247	0.581	0.317	0.397	0.509
15	0.405	0.399	0.169	0.169	0.340	0.340	0.336	0.274	0.269	0.415	0.514	0.359
16	0.202	0.455	0.166	0.166	0.187	0.187	0.396	0.390	0.111	0.301	0.281	0.386
17	0.067	0.405	0.407	0.407	0.272	0.272	0.182	0.439	0.378	0.181	0.262	0.288
18	0.194	0.280	0.386	0.386	0.389	0.389	0.166	0.303	1.103	0.252	0.224	0.289
19	0.364	0.180	0.383	0.383	0.438	0.438	0.177	0.927	0.804	1.155	0.344	0.371
20	0.312	0.192	0.337	0.337	0.284	0.284	0.363	0.821	0.556	0.731	0.812	0.434
21	0.405	0.286	0.137	0.137	0.625	0.625	0.383	0.558	0.319	0.481	0.441	0.512
22	0.155	0.454	0.145	0.145	0.355	0.355	0.253	0.315	0.446	0.260	0.987	0.251
23	0.147	0.429	0.170	0.170	1.014	1.014	0.173	0.369	1.110	0.324	0.257	0.186

Figure 3.8: Load profile data for a weekday for a small household

Hour	January	February	March	April	May	June	July	August	September	October	November	December
0	0.415	0.221	0.368	0.368	0.183	0.183	0.177	0.736	0.262	0.301	0.223	0.131
1	0.326	0.212	0.146	0.146	0.083	0.083	0.163	0.330	0.366	0.145	0.410	0.440
2	0.236	0.230	0.166	0.166	0.153	0.153	0.280	0.178	0.307	0.194	0.365	0.364
3	0.191	0.305	0.137	0.137	0.307	0.307	0.397	0.819	0.140	0.368	0.204	0.403
4	0.189	0.426	0.304	0.304	0.464	0.464	0.337	1.161	0.135	0.286	0.184	0.165
5	0.191	0.426	0.415	0.415	0.734	0.734	0.189	1.256	0.225	0.126	0.328	0.237
6	0.392	0.387	0.379	0.379	0.084	0.084	0.163	0.978	0.365	0.770	0.360	0.222
7	0.390	0.724	0.361	0.361	0.175	0.175	0.164	1.062	0.274	0.682	0.216	0.459
8	0.217	0.457	0.193	0.193	0.433	0.433	0.400	1.189	0.240	0.270	0.187	0.354
9	0.195	0.187	0.141	0.141	0.301	0.301	0.378	0.960	0.361	0.123	0.250	0.213
10	0.191	0.305	0.156	0.156	0.131	0.131	0.245	2.161	1.073	0.119	0.371	0.232
11	0.291	0.422	0.270	0.270	0.140	0.140	0.166	2.177	0.444	0.338	0.579	0.280
12	0.410	0.363	0.400	0.400	0.333	0.333	0.163	2.403	0.318	0.333	0.212	0.367
13	0.265	0.381	0.396	0.396	0.365	0.365	0.774	0.291	0.117	0.165	0.251	0.462
14	0.388	0.267	0.381	0.381	0.194	0.194	0.769	0.341	0.186	0.142	0.318	0.339
15	0.227	0.206	0.302	0.302	0.148	0.148	0.300	0.477	0.388	0.398	0.449	0.224
16	0.191	0.143	0.185	0.185	0.330	0.330	0.193	0.408	0.506	0.468	0.246	0.126
17	0.216	0.385	0.136	0.136	0.356	0.356	0.176	0.210	0.463	0.329	0.203	0.425
18	0.424	0.437	0.168	0.168	0.166	0.166	0.245	0.374	1.667	0.557	0.149	1.273
19	0.414	0.492	0.403	0.403	0.217	0.217	0.402	1.511	1.198	0.857	0.429	0.461
20	0.310	0.410	0.366	0.366	0.733	0.733	0.384	1.241	0.485	0.403	0.404	0.369
21	0.183	0.642	0.618	0.618	0.387	0.387	0.164	1.125	0.438	0.343	0.698	0.392
22	0.194	0.202	0.739	0.739	0.196	0.196	0.169	1.268	0.205	0.174	0.560	0.348
23	0.191	0.270	0.179	0.179	0.148	0.148	0.209	1.285	0.160	0.176	0.196	0.632

Figure 3.9: Load profile data for a weekend day for a small household

Figures 3.8 and 3.9 show the data input for the load profile for the small household. The load profiles for the medium and large households are similar except the values are doubled and tripled respectively as per the approximate energy usage outlined by the Australian Bureau of Statistics and Origin Energy. Data for the months of April and May were not available therefore the data for March and June were used instead for the missing months.

After initial testing it was found that the batteries were not operating as intended. Their annual throughput, which is the amount of energy they transfer in a year, was only approximately 4-12kWh which is exceedingly low. This problem was being caused by the solar panels selling as much power as possible and not charging the batteries. To rectify this issue, alterations in the cost of electricity were made to ensure that the PV arrays would charge the battery first and once the batteries are fully charged then sell power to the grid. The alterations are shown in the following figures.

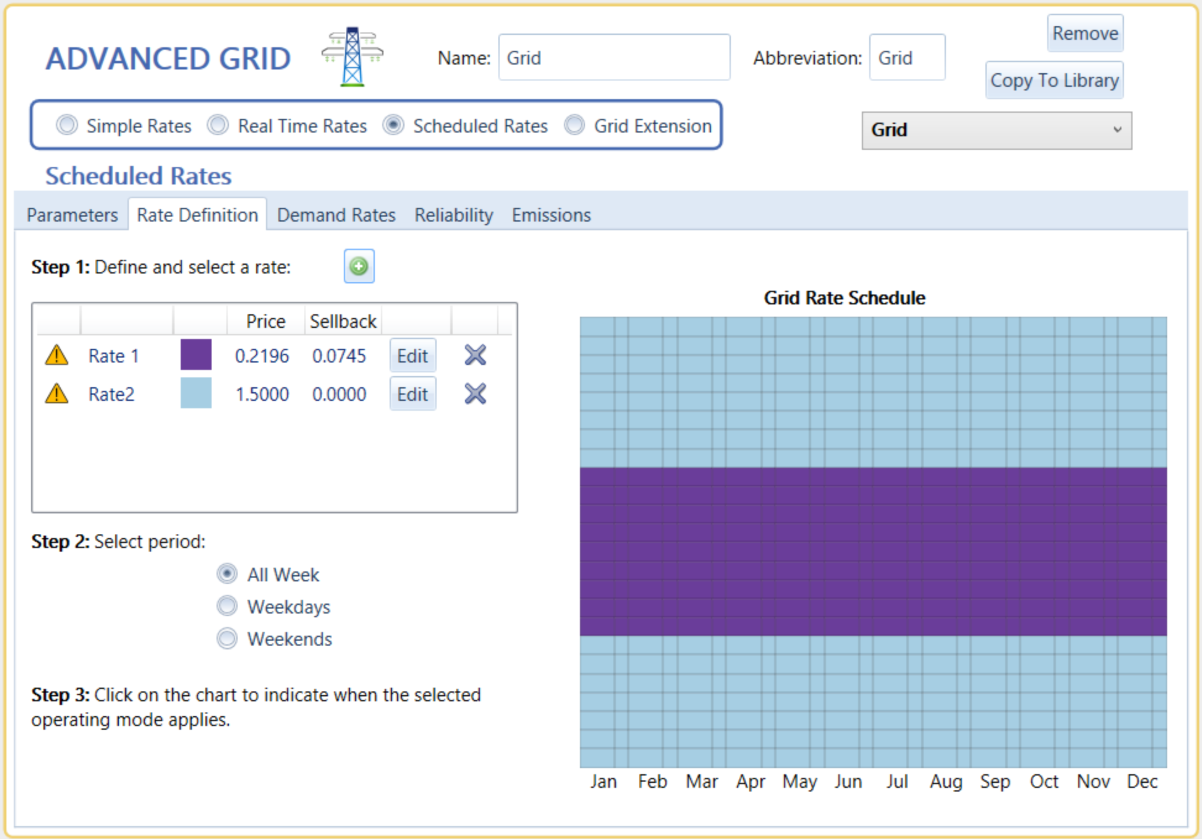


Figure 3.10: Rate definition input into Homer Pro to ensure that the batteries would charge

By including this change the percentage of energy that came from renewable resources increased to above 90% in many tests. A main objective of the project is to maximise the renewable fraction of energy consumed to be as high as possible and this alteration was necessary to achieve this.

Figures 3.10 to 3.13 show the inputs into Homer Pro for the PV arrays used in the simulations. For the intensions of the simulations a wide range of PV array sizes were used to see the effects the power output a PV array will have on the optimal solution. The annual maintenance cost of $10 is assigned to the PV arrays assuming that the owner is able to clean the panels and the associated costs would be for cleaning equipment and materials.

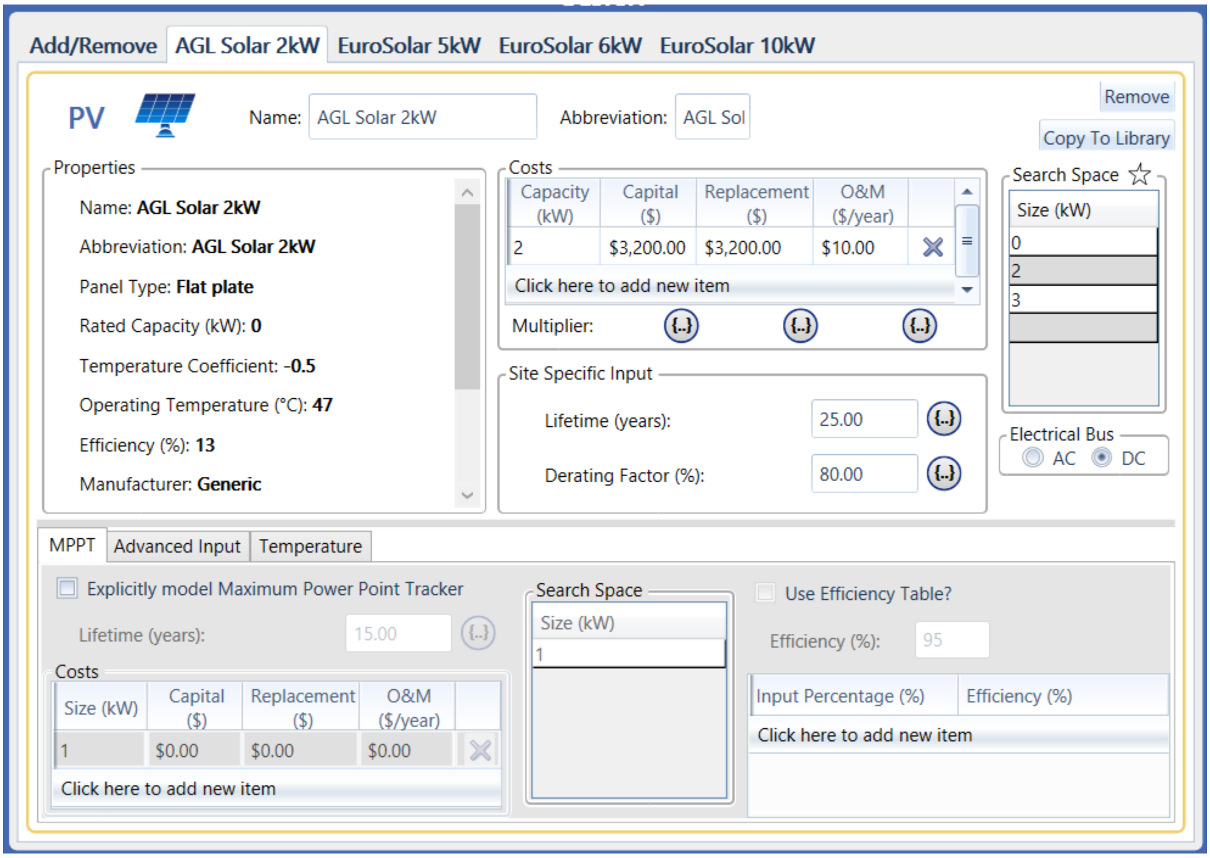


Figure 3.11: Homer Pro input for the AGL Solar 2kW PV array

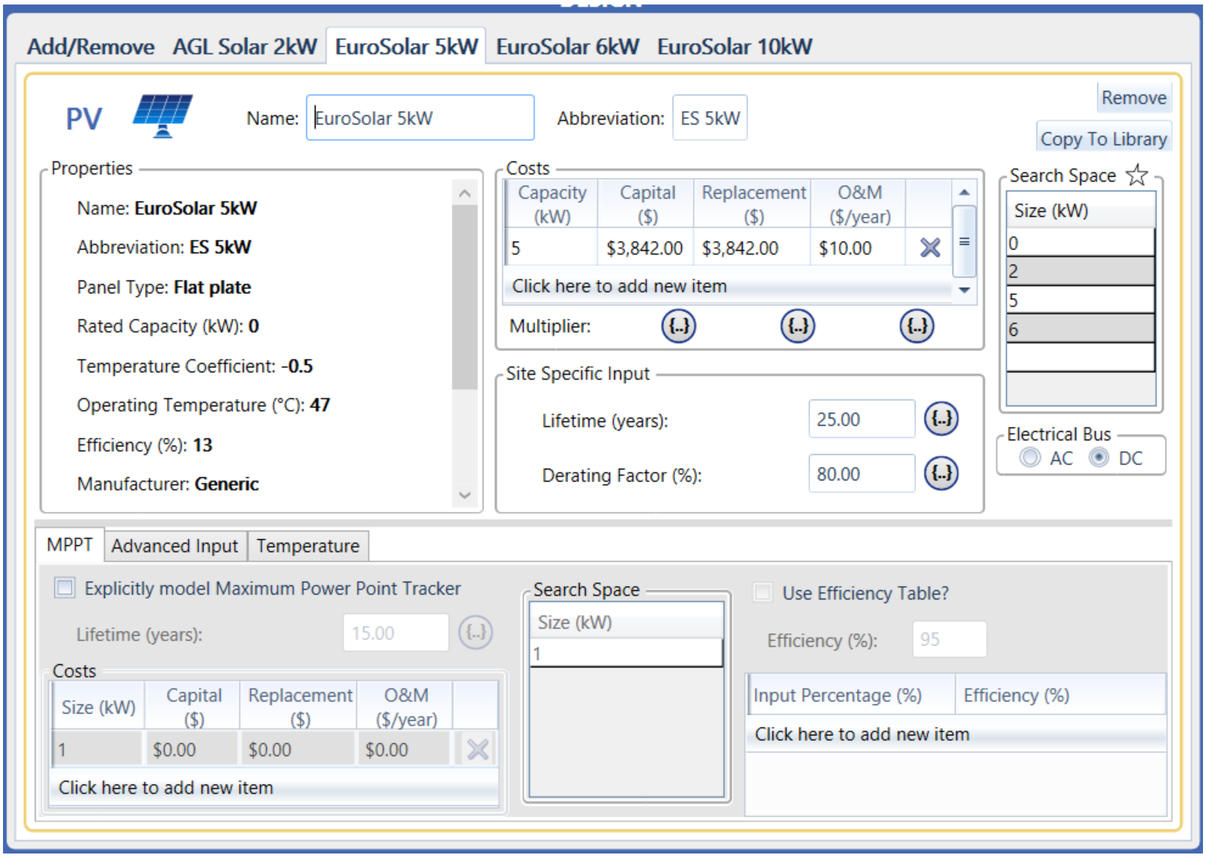


Figure 3.12: Homer Pro input for the EuroSolar 5kW PV array

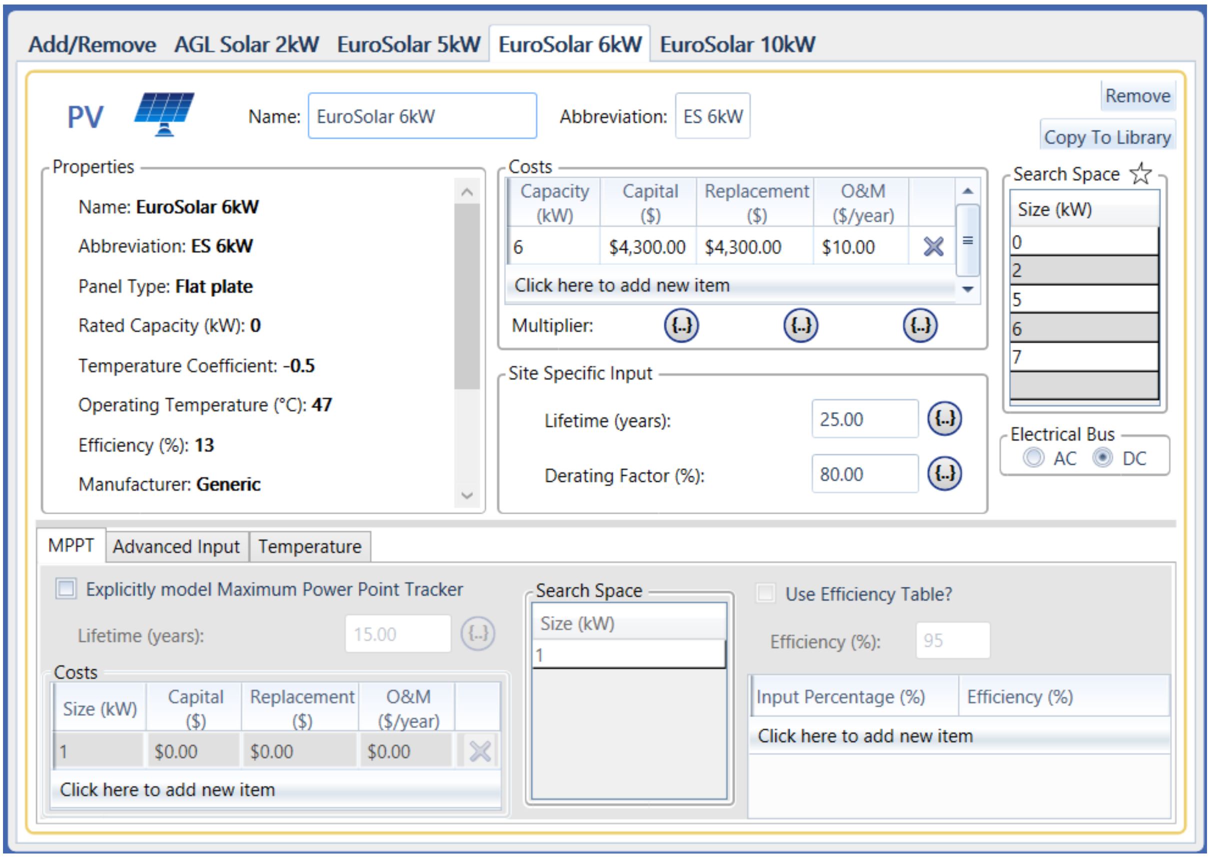


Figure 3.13: Homer Pro input for the EuroSolar 6kW PV array

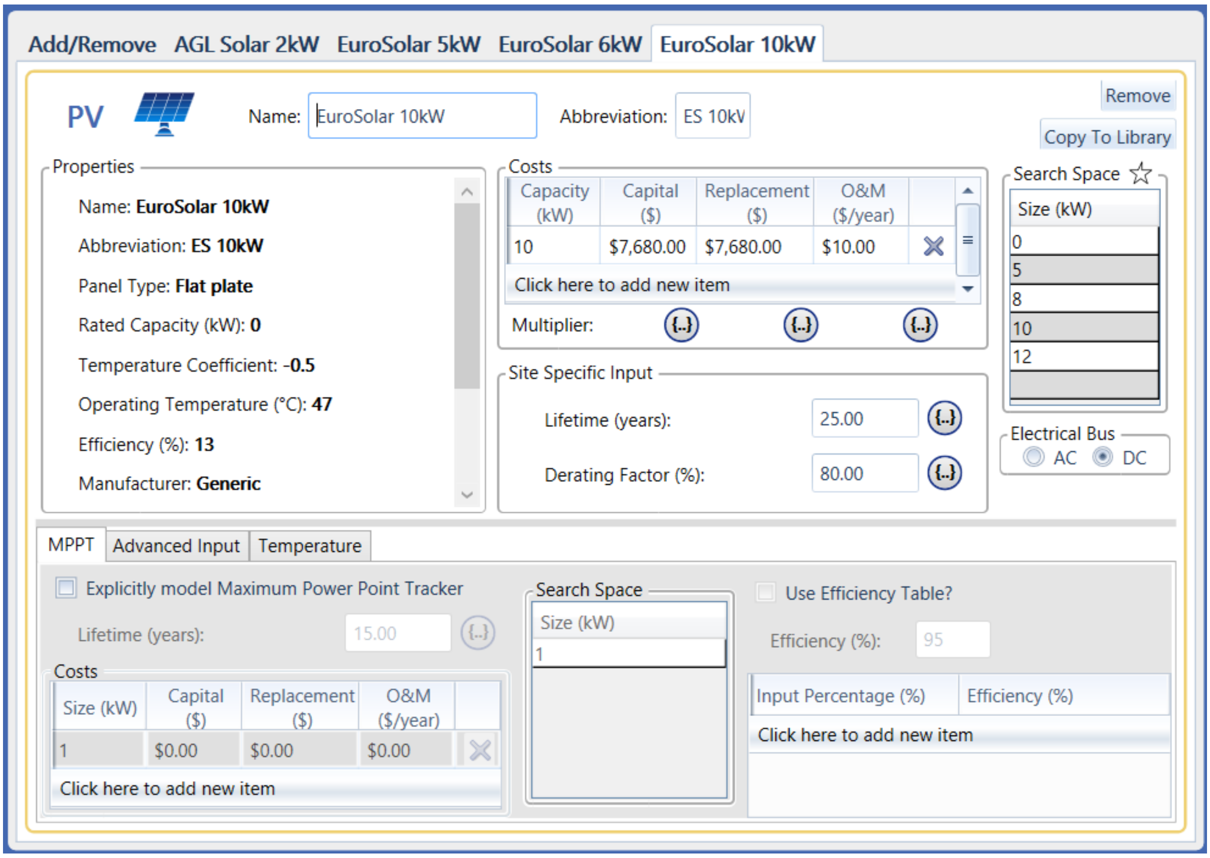


Figure 3.14: Homer Pro input for the EuroSolar 10kW PV array

Figure 3.14 to 3.18 show the inputs into Homer Pro for the batteries used in the simulations. These batteries were used in the simulations because access to datasheets and prices were available.

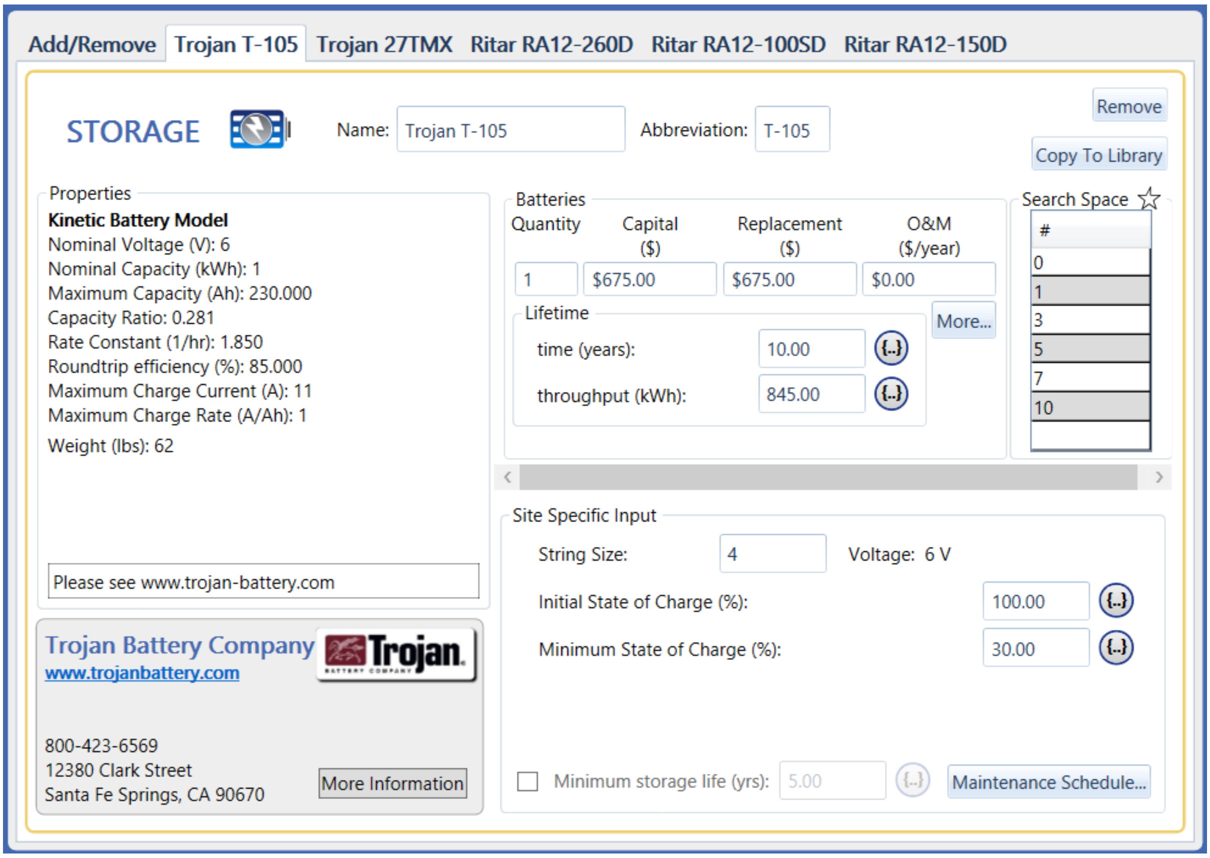


Figure 3.15: Homer Pro input for the Trojan T-105 battery

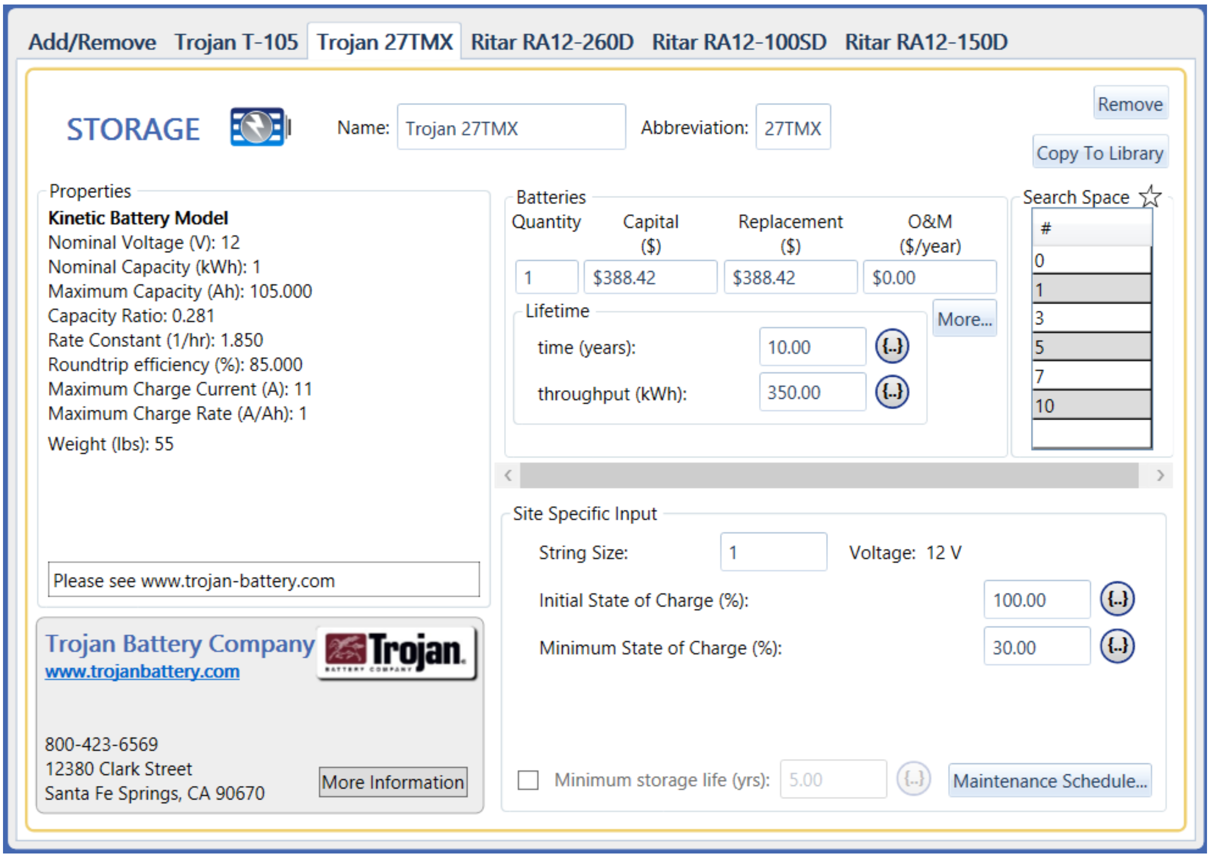


Figure 3.16: Homer Pro input for the Trojan 27TMX battery

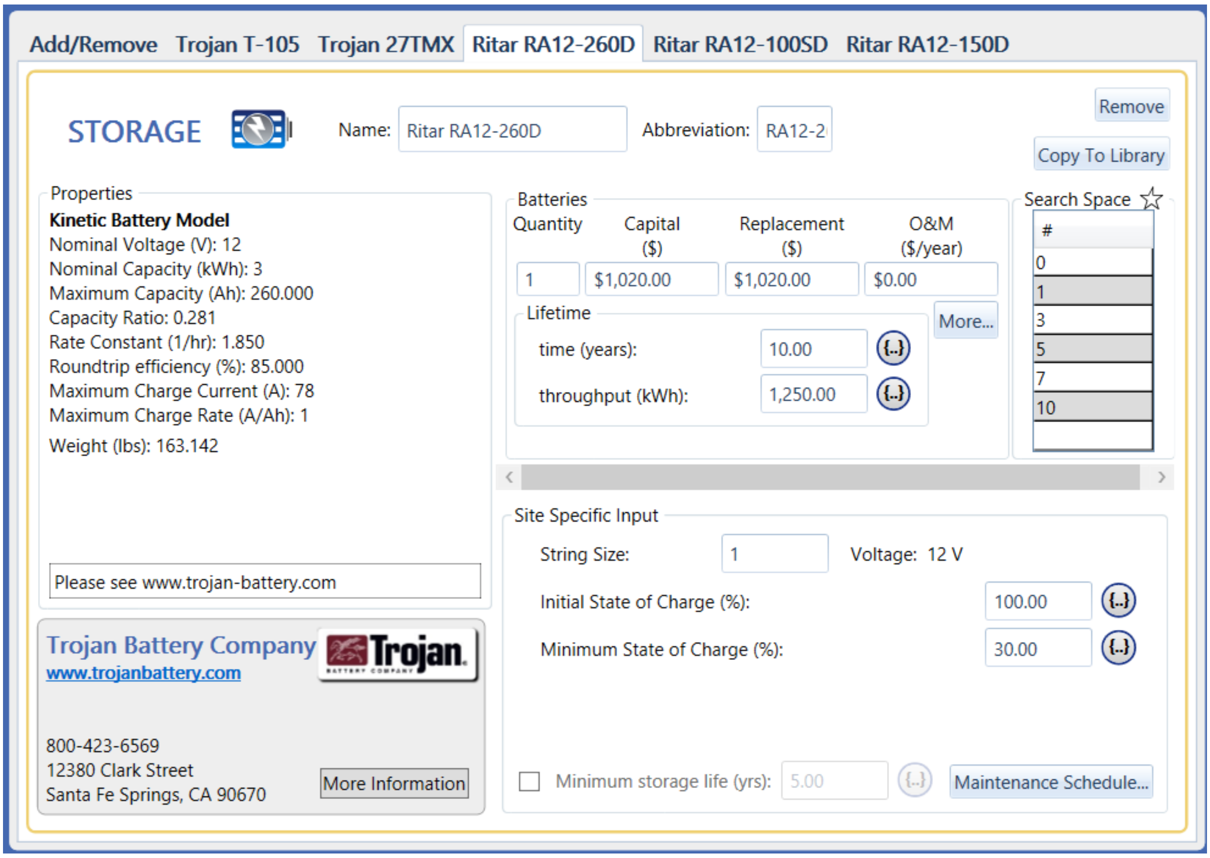


Figure 3.17: Homer Pro input for the Ritar RA12-260D battery

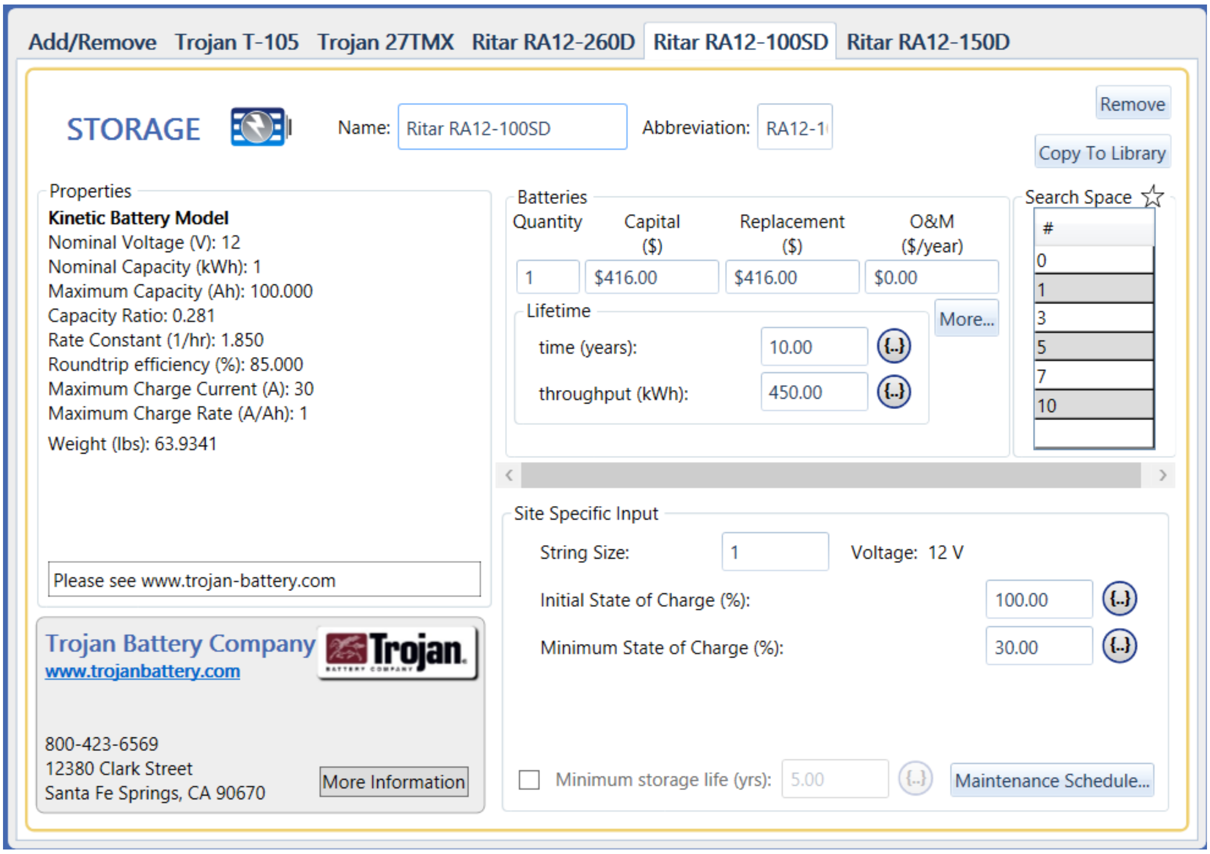


Figure 3.18: Homer Pro input for the Ritar RA12-100SD battery

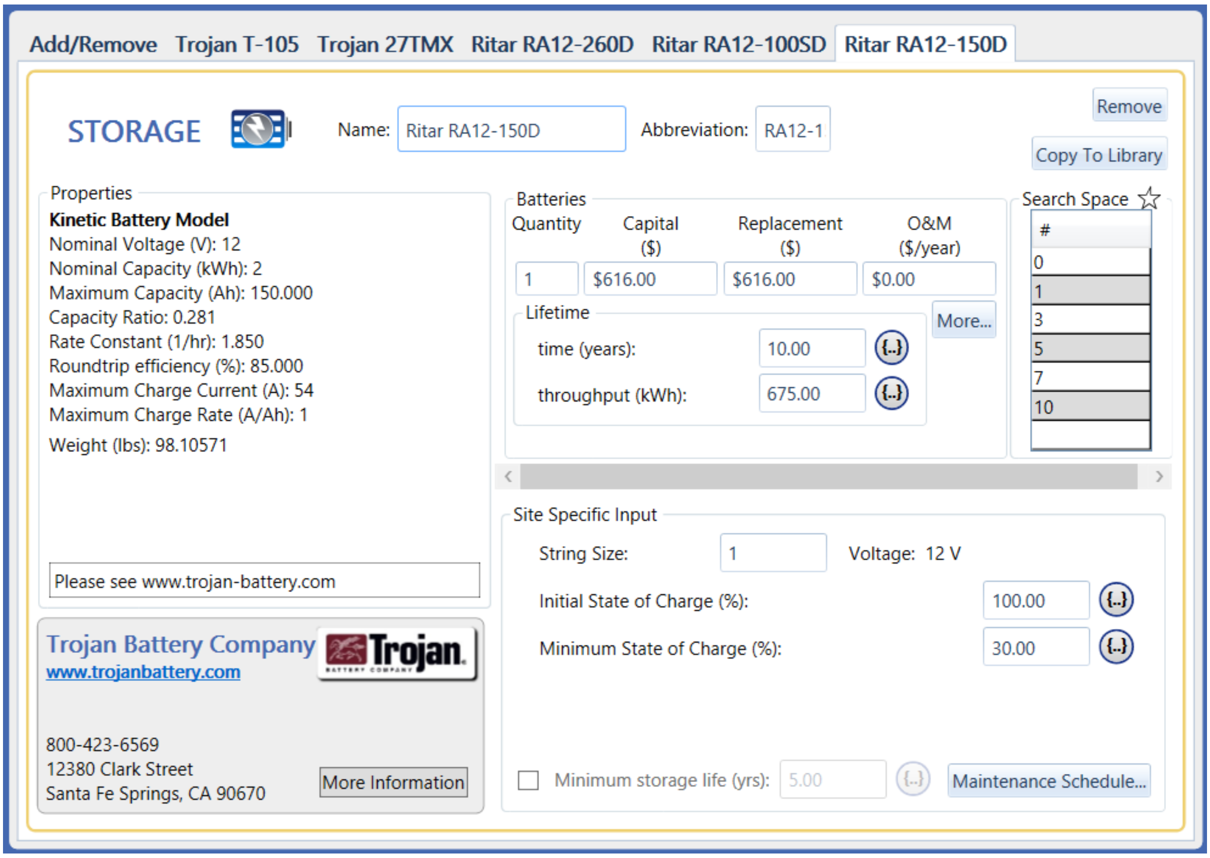


Figure 3.19: Homer Pro input for the Ritar RA12-150D battery

For the Ritar T-105, the nominal voltage of the battery is 6V however it is standard for a converter to have a 12V or 24V input. Due to this, the string size had to be increased to accommodate. The rest of the batteries have a nominal voltage of 12V so this issue was not present for the other batteries.

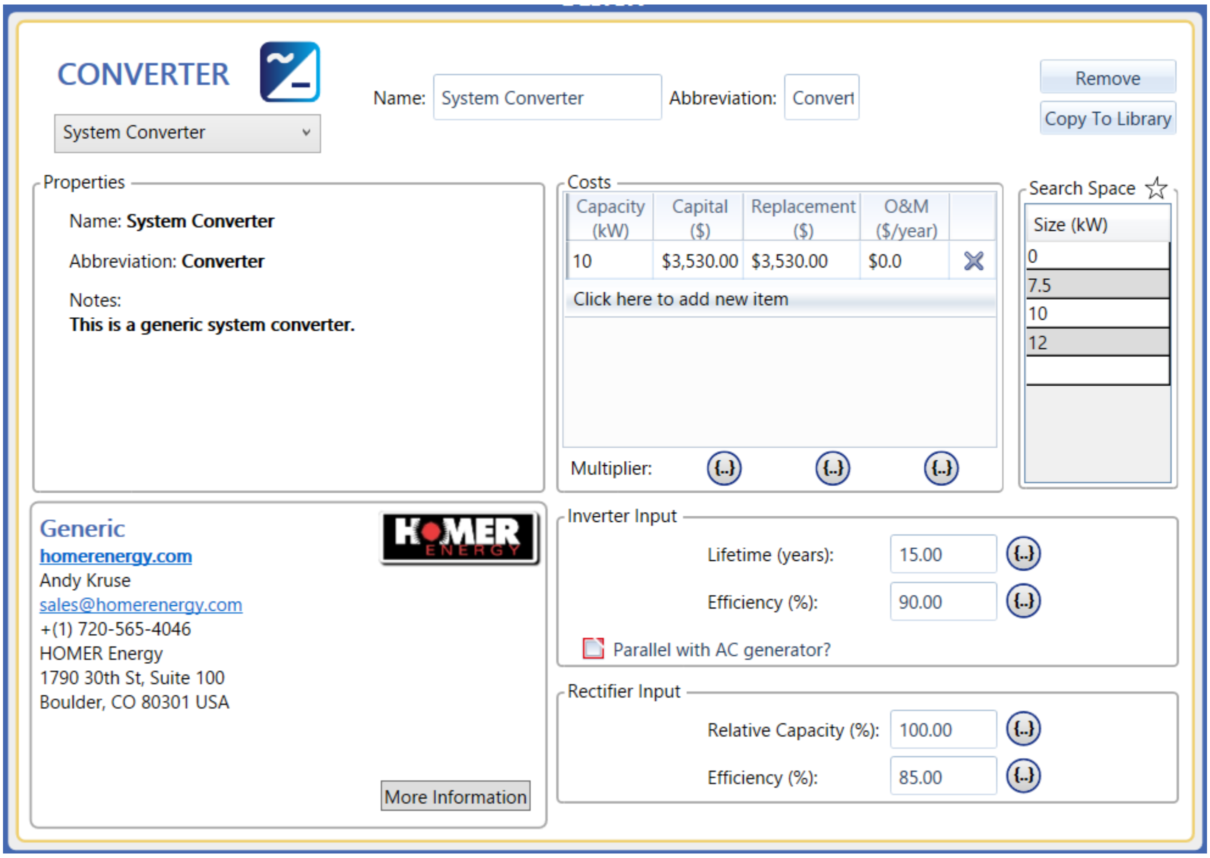
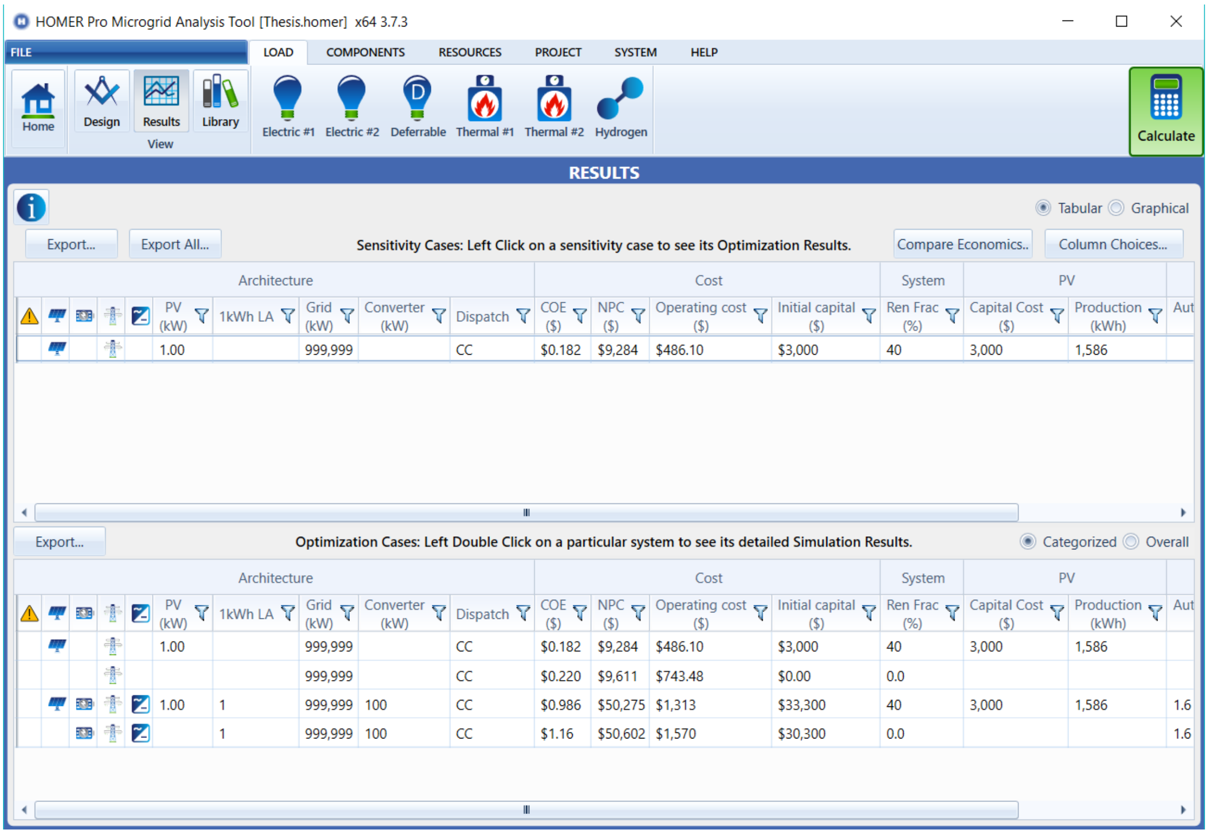


Figure 3.20: Homer Pro input for the AC/DC converter

For the purposes of the research, the main scope focuses on the battery and PV component of the microgrid. The converter is an integral component however for the simulations are typical converter will be used to ensure that the results are consistent throughout. The option of having the converter operate in parallel with the AC generator was not considered because when it was the batteries would not operate and would have annual throughputs of 0kWh.

Chapter 4 Testing and Evaluation

The testing undertaken for the project was completed using Homer Pro. A number of constraints were kept constant throughout the testing such as the cost of selling electricity back into the grid as well as the current inflation and interest rates.



PV (kW)	1kWh LA	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	PV Capital Cost ($)	PV Production (kWh)	Aut
1.00		999,999		CC	$0.182	$9,284	$486.10	$3,000	40	3,000	1,586	

PV (kW)	1kWh LA	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	PV Capital Cost ($)	PV Production (kWh)	Aut
1.00		999,999		CC	$0.182	$9,284	$486.10	$3,000	40	3,000	1,586	
		999,999		CC	$0.220	$9,611	$743.48	$0.00	0.0			
1.00	1	999,999	100	CC	$0.986	$50,275	$1,313	$33,300	40	3,000	1,586	1.6
	1	999,999	100	CC	$1.16	$50,602	$1,570	$30,300	0.0			1.6

Figure 4.1: Homer Pro Results interface which displays the outcomes from optimising the possible configurations

4.1 Preliminary Testing

To develop experience with Homer Pro, initial preliminary tests were undertaken with a generic 1kW PV array and 1kWh Lead Acid battery. The load profiles received from Ergon Energy were loaded into Homer Pro and result was that the most cost effective configuration would be to power the residence only from the grid and the PV array. The PV array only system had the lowest Cost of Electricity (COE), lowest Net Present Cost (NPC) and lowest operating Cost as shown in Figure 4.2.

PV (kW)	1kWh LA	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)
1.00		999,999		CC	$0.182	$9,284	$486.10	$3,000
		999,999		CC	$0.220	$9,611	$743.48	$0.00
1.00	1	999,999	100	CC	$0.986	$50,275	$1,313	$33,300
	1	999,999	100	CC	$1.16	$50,602	$1,570	$30,300

Figure 4.2: Homer Pro output from optimising the microgrid configuration for the Preliminary Test

Sections 4.2 to 4.4 detail the Homer Pro output solutions for small, medium and large household energy demands. It also provides the outputs of different PV array “search space” sensitivity studies to determine the optimal size. Sections 4.6 and 4.7 detail the Homer Pro results for altering the load profile of a medium household by shifting the evening load and hot water peak to determine whether a PV array only microgrid would be a more cost effective system than staying purely on the grid.

4.2 Small House Testing

Tables 4.1 to 4.4 show the outputs from Homer Pro for a microgrid for the small household with varying PV arrays. Each table analyses the same batteries and for each table the PV array changes. The architecture section outlines the components of each system, the cost outlines the economic outputs for each system and the system Ren Frac(%) outlines the percentage of electricity used that came from renewable resources.

Table 4.1: Homer Pro output for a small household with 2kW AGL array

Architecture									Cost				System
AGL Solar 2kW (kW)	T-105	27TMX	RA12-260D	RA12-100SD	RA12-150D	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
3			5			999999	2	CC	0.782319	45033.67	2663.131	10606	89.39703
3	12					999999	2	CC	0.792053	46408.22	2537.395	13606	87.50306
3					7	999999	2	CC	0.816551	47560.2	2919.524	9818	88.43314
3				10		999999	2	CC	0.818435	47859.12	2954.405	9666	88.1168
3		7				999999	2	CC	0.865283	52446.91	3420.763	8224.94	85.00697
3						999999	2	CC	0.675933	53917.77	3744.862	5506	62.56323
						999999		CC	1.26345	55307.88	4278.307	0	5.88E-13
		1				999999	2	CC	1.300458	56927.9	4318.964	1094.42	0.02160221
				1		999999	2	CC	1.301586	56977.26	4320.649	1122	0.02050006
					1	999999	2	CC	1.309488	57323.2	4331.938	1322	0.03085103
			1			999999	2	CC	1.325425	58020.85	4354.653	1726	0.05349181
	4					999999	2	CC	1.392493	60956.75	4451.802	3406	0.09467998

Table 4.2: Homer Pro output for a small household with 5kW EuroSolar array

Architecture									Cost				System
ES 5kW (kW)	T-105	27TMX	RA12-260D	RA12-100SD	RA12-150D	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
6			5			999999	5	CC	0.369753	40300.64	2229.758	11475.4	97.57893
6	12					999999	2	CC	0.445154	41440.24	2167.767	13416.4	94.98901
6					7	999999	5	CC	0.389875	42792.74	2483.489	10687.4	96.98746
6				10		999999	5	CC	0.39213	43115.3	2520.198	10535.4	96.84451
6		7				999999	5	CC	0.429335	47739.62	2989.382	9094.34	95.05493
6						999999	5	CC	0.377311	48946.01	3293.023	6375.4	79.6949
						999999		CC	1.26345	55307.88	4278.307	0	5.88E-13
		1				999999	2	CC	1.300458	56927.9	4318.964	1094.42	0.021602
				1		999999	2	CC	1.301586	56977.26	4320.649	1122	0.0205
					1	999999	2	CC	1.309488	57323.2	4331.938	1322	0.030851
			1			999999	2	CC	1.325425	58020.85	4354.653	1726	0.053492
	4					999999	2	CC	1.392493	60956.75	4451.802	3406	0.09468

Table 4.3: Homer Pro output for a small household with 6kW EuroSolar array

Architecture									Cost				System
ES 6kW (kW)	T-105	27TMX	RA12-260D	RA12-100SD	RA12-150D	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
7			5			999999	5	CC	0.307553	39007.29	2098.286	11881.67	98.20817
7	12					999999	5	CC	0.320038	40291.5	1965.562	14881.67	97.45728
7					7	999999	5	CC	0.325517	41528.41	2354.261	11093.67	97.71764
7				10		999999	5	CC	0.327494	41859.45	2391.625	10941.67	97.55113
7		7				999999	5	CC	0.362276	46526.69	2864.13	9500.606	96.06209
7						999999	5	CC	0.325648	47711.87	3166.13	6781.667	82.33209
						999999		CC	1.26345	55307.88	4278.307	0	5.88E-13
		1				999999	2	CC	1.300458	56927.9	4318.964	1094.42	0.021602
				1		999999	2	CC	1.301586	56977.26	4320.649	1122	0.0205
					1	999999	2	CC	1.309488	57323.2	4331.938	1322	0.030851
			1			999999	2	CC	1.325425	58020.85	4354.653	1726	0.053492
	4					999999	2	CC	1.392493	60956.75	4451.802	3406	0.09468

Table 4.4: Homer Pro output for a small household with 10kW EuroSolar array

Architecture									Cost				System
ES 10kW (kW)	T-105	27TMX	RA12-260D	RA12-100SD	RA12-150D	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
12			5			999999	7.5	CC	0.173549	37100.95	1557.72	16963.5	99.3463
12	12					999999	6	CC	0.190665	38454.86	1471.347	19434	98.91451
12					7	999999	7.5	CC	0.185038	39704.3	1820.055	16175.5	99.00615
12				10		999999	7.5	CC	0.186064	39949.87	1850.809	16023.5	98.95267
12		7				999999	7.5	CC	0.20943	44695.04	2329.341	14582.44	98.09333
12						999999	7.5	CC	0.199904	45772.81	2623.033	11863.5	89.29921
						999999		CC	1.26345	55307.88	4278.307	0	5.88E-13
		1				999999	2	CC	1.300458	56927.9	4318.964	1094.42	0.021602
				1		999999	2	CC	1.301586	56977.26	4320.649	1122	0.0205
					1	999999	2	CC	1.309488	57323.2	4331.938	1322	0.030851
			1			999999	2	CC	1.325425	58020.85	4354.653	1726	0.053492
	4					999999	2	CC	1.392493	60956.75	4451.802	3406	0.09468

Table 4.5: Optimal solutions for a small household as calculated from Homer Pro. The highlighted solution is the overall optimal choice.

Architecture									Cost				System
Solar Array (kW)	T-105	27TMX	RA12-260D	RA12-100SD	RA12-150D	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
2			5			999999	2	CC	0.782319	45033.67	2663.131	10606	89.39703
5			5			999999	5	CC	0.369753	40300.64	2229.758	11475.4	97.57893
6			5			999999	5	CC	0.307553	39007.29	2098.286	11881.67	98.20817
10			5			999999	7.5	CC	0.173549	37100.95	1557.72	16963.5	99.3463

Table 4.5 outlines the optimal solution for each PV array system for the small household. The highlighted row shows the overall optimal system. The system with a 10kW EuroSolar PV array and 5 Ritar RA12-100SD batteries has the lowest cost of electricity, net present cost, operating cost and highest renewables fraction.

4.3 Medium House Testing

Tables 4.6 to 4.9 show the outputs from Homer Pro for a microgrid for the medium household with varying PV arrays. Each table analyses the same batteries and for each table the PV array changes.

Table 4.6: Homer Pro output for a medium household with 2kW AGL array

Architecture									Cost				System
AGL Solar 2kW (kW)	T-105	27TMX	RA12-260D	RA12-100SD	RA12-150D	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
3			5			999999	7.5	CC	1.027328	90296.41	6014.219	12547.5	57.73174
3					7	999999	7.5	CC	1.045197	93470.61	6320.712	11759.5	56.71502
3	12					999999	7.5	CC	1.000406	93511.47	6030.854	15547.5	54.22464
3				10		999999	7.5	CC	1.043979	93933.75	6368.296	11607.5	56.37429
3		7				999999	7.5	CC	1.048944	99218.16	6888.541	10166.44	53.25942
						999999		CC	1.145798	100346.3	7762.229	0	2.55E-13
3						999999	7.5	CC	0.899951	101174.8	7250.216	7447.5	40.07837
		1				999999	7.5	CC	1.194102	104576.7	7854.621	3035.92	0.010716
				1		999999	7.5	CC	1.194665	104626	7856.305	3063.5	0.010175
					1	999999	7.5	CC	1.198617	104972.1	7867.603	3263.5	0.015254
			1			999999	7.5	CC	1.20658	105669.5	7890.302	3667.5	0.026735
	4					999999	7.5	CC	1.240106	108605.7	7987.471	5347.5	0.047129

Table 4.7: Homer Pro output for a medium household with 5kW EuroSolar array

Architecture									Cost				System
ES 5kW (kW)	T-105	27TMX	RA12-260D	RA12-100SD	RA12-150D	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
6			7			999999	7.5	CC	0.648822	75880.53	4755.951	14397.9	88.22594
6	20					999999	7.5	CC	0.661737	79035.43	4508.022	20757.9	86.19898
6					10	999999	7.5	CC	0.679224	81409.78	5259.47	13417.9	86.31233
6				10		999999	7.5	CC	0.645326	84218.13	5631.417	11417.9	80.16705
6		7				999999	7.5	CC	0.657431	91069.45	6272.868	9976.84	75.44467
6						999999	7.5	CC	0.587769	93779.95	6692.86	7257.9	62.75787
						999999		CC	1.145798	100346.3	7762.229	0	2.55E-13
		1				999999	7.5	CC	1.194102	104576.7	7854.621	3035.92	0.010716
				1		999999	7.5	CC	1.194665	104626	7856.305	3063.5	0.010175
					1	999999	7.5	CC	1.198617	104972.1	7867.603	3263.5	0.015254
			1			999999	7.5	CC	1.20658	105669.5	7890.302	3667.5	0.026735
	4					999999	7.5	CC	1.240106	108605.7	7987.471	5347.5	0.047129

Table 4.8: Homer Pro output for a medium household with 6kW EuroSolar array

Architecture									Cost				System
ES 6kW (kW)	T-105	27TMX	RA12-260D	RA12-100SD	RA12-150D	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
7			7			999999	7.5	CC	0.555649	73885.58	4570.206	14804.17	91.37913
7	20					999999	7.5	CC	0.569231	76806.73	4304.196	21164.17	89.71569
7					10	999999	7.5	CC	0.583698	79484.45	5079.11	13824.17	89.50536
7				10		999999	7.5	CC	0.560384	82299.72	5451.592	11824.17	83.82909
7		10				999999	7.5	CC	0.613947	89151.66	6002.955	11548.37	84.09917
7						999999	7.5	CC	0.522258	91869.23	6513.631	7664.167	67.24205
						999999		CC	1.145798	100346.3	7762.229	0	2.55E-13
		1				999999	7.5	CC	1.194102	104576.7	7854.621	3035.92	0.010716
				1		999999	7.5	CC	1.194665	104626	7856.305	3063.5	0.010175
					1	999999	7.5	CC	1.198617	104972.1	7867.603	3263.5	0.015254
			1			999999	7.5	CC	1.20658	105669.5	7890.302	3667.5	0.026735
	4					999999	7.5	CC	1.240106	108605.7	7987.471	5347.5	0.047129

Table 4.9: Homer Pro output for a medium household with 10kW EuroSolar array

Architecture									Cost				System
ES 10kW (kW)	T-105	27TMX	RA12-260D	RA12-100SD	RA12-150D	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
12			7			999999	7.5	CC	0.311261	68393.74	3820.551	19003.5	96.79269
12	20					999999	7.5	CC	0.324959	70953.15	3526.559	25363.5	96.1386
12					10	999999	7.5	CC	0.331885	73897.62	4322.107	18023.5	95.66336
12				10		999999	7.5	CC	0.328449	76526.28	4680.155	16023.5	91.84106
12		10				999999	7.5	CC	0.365551	83742.23	5259.675	15747.7	92.10857
12						999999	7.5	CC	0.33493	86171.34	5748.037	11863.5	79.6582
						999999		CC	1.145798	100346.3	7762.229	0	2.55E-13
		1				999999	7.5	CC	1.194102	104576.7	7854.621	3035.92	0.010716
				1		999999	7.5	CC	1.194665	104626	7856.305	3063.5	0.010175
					1	999999	7.5	CC	1.198617	104972.1	7867.603	3263.5	0.015254
			1			999999	7.5	CC	1.20658	105669.5	7890.302	3667.5	0.026735
	4					999999	7.5	CC	1.240106	108605.7	7987.471	5347.5	0.047129

Table 4.10: Optimal solutions for a medium household as calculated from Homer Pro. The highlighted solution is the overall optimal choice.

Architecture									Cost				System
Solar Array (kW)	T-105	27TMX	RA12-260D	RA12-100SD	RA12-150D	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
2			5			999999	7.5	CC	1.027328	90296.41	6014.219	12547.5	57.73174
5			7			999999	7.5	CC	0.648822	75880.53	4755.951	14397.9	88.22594
6			7			999999	7.5	CC	0.555649	73885.58	4570.206	14804.17	91.37913
10			7			999999	7.5	CC	0.311261	68393.74	3820.551	19003.5	96.79269

Table 4.10 outlines the optimal solution for each PV array system for the medium household. The highlighted row shows the overall optimal system. The system with a 10kW EuroSolar PV array and 7 Ritar RA12-100SD batteries has the lowest cost of electricity, net present cost, operating cost and highest renewables fraction.

4.4 Large House Testing

Tables 4.11 to 4.14 show the outputs from Homer Pro for a microgrid for the large household with varying PV arrays. Each table analyses the same batteries and for each table the PV array changes.

Table 4.11: Homer Pro output for a large household with 2kW AGL array

Architecture									Cost				System
AGL Solar 2kW (kW)	T-105	27TMX	RA12-260D	RA12-100SD	RA12-150D	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
3			5			999999	7.5	CC	1.036968	136409.1	9581.239	12547.5	38.81667
3					7	999999	7.5	CC	1.054264	139076.8	9848.548	11759.5	38.29614
3	12					999999	7.5	CC	1.035442	139179.5	9563.478	15547.5	36.96938
3				10		999999	7.5	CC	1.055277	139388.9	9884.451	11607.5	38.12132
3		7				999999	7.5	CC	1.071519	144204.5	10368.43	10166.44	36.28086
						999999		CC	1.105831	145364.9	11244.61	0	1.78E-13
3						999999	7.5	CC	0.991425	146887.6	10786.3	7447.5	25.47306
		1				999999	7.5	CC	1.138016	149595.6	11337.04	3035.92	0.006922
				1		999999	7.5	CC	1.138391	149645	11338.72	3063.5	0.006567
					1	999999	7.5	CC	1.141021	149990.6	11349.99	3263.5	0.010168
			1			999999	7.5	CC	1.14633	150688.5	11372.72	3667.5	0.017595
	4					999999	7.5	CC	1.168667	153624.9	11469.9	5347.5	0.031067

Table 4.12: Homer Pro output for a large household with 5kW EuroSolar array

Architecture									Cost				System
ES 5kW (kW)	T-105	27TMX	RA12-260D	RA12-100SD	RA12-150D	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
6			10			999999	7.5	CC	0.844395	115197.8	7560.611	17457.9	74.14851
6	40					999999	7.5	CC	0.891242	120882	6700.75	34257.9	74.30716
6					10	999999	7.5	CC	0.82665	124588.9	8599.562	13417.9	67.80524
6				10		999999	7.5	CC	0.780027	128063.4	9023.043	11417.9	62.73478
6		7				999999	7.5	CC	0.784042	134841.1	9658.797	9976.84	59.73556
6						999999	7.5	CC	0.721907	138240.5	10132.07	7257.9	50.11784
						999999		CC	1.105831	145364.9	11244.61	0	1.78E-13
		1				999999	7.5	CC	1.138016	149595.6	11337.04	3035.92	0.006922
				1		999999	7.5	CC	1.138391	149645	11338.72	3063.5	0.006567
					1	999999	7.5	CC	1.141021	149990.6	11349.99	3263.5	0.010168
			1			999999	7.5	CC	1.14633	150688.5	11372.72	3667.5	0.017595
	4					999999	7.5	CC	1.168667	153624.9	11469.9	5347.5	0.031067

Table 4.13: Homer Pro output for a large household with 6kW EuroSolar array

Architecture									Cost				System
ES 6kW (kW)	T-105	27TMX	RA12-260D	RA12-100SD	RA12-150D	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
7			10			999999	7.5	CC	0.75506	111042.1	7207.724	17864.17	80.74884
7	40					999999	7.5	CC	0.802355	116274.8	6312.937	34664.17	81.45917
7					10	999999	7.5	CC	0.740175	122021.1	8369.509	13824.17	72.97366
7				10		999999	7.5	CC	0.70047	125790.8	8815.82	11824.17	67.65246
7		10				999999	7.5	CC	0.745654	132770.5	9377.064	11548.37	67.66511
7						999999	7.5	CC	0.657378	136250.7	9946.73	7664.167	55.12219
						999999		CC	1.105831	145364.9	11244.61	0	1.78E-13
		1				999999	7.5	CC	1.138016	149595.6	11337.04	3035.92	0.006922
				1		999999	7.5	CC	1.138391	149645	11338.72	3063.5	0.006567
					1	999999	7.5	CC	1.141021	149990.6	11349.99	3263.5	0.010168
			1			999999	7.5	CC	1.14633	150688.5	11372.72	3667.5	0.017595
	4					999999	7.5	CC	1.168667	153624.9	11469.9	5347.5	0.031067

Table 4.14: Homer Pro output for a large household with 10kW EuroSolar array

Architecture									Cost				System
ES 10kW (kW)	T-105	27TMX	RA12-260D	RA12-100SD	RA12-150D	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
12			10			999999	7.5	CC	0.451052	102281.3	6205.198	22063.5	92.34354
12	28					999999	7.5	CC	0.465191	106202	5835.499	30763.5	90.87891
12					10	999999	7.5	CC	0.464023	114046.5	7427.796	18023.5	85.86731
12				10		999999	7.5	CC	0.451561	118440.5	7922.407	16023.5	80.96949
12		7				999999	7.5	CC	0.468346	125456.8	8576.615	14582.44	78.17272
12						999999	7.5	CC	0.453218	129909.5	9131.372	11863.5	70.29064
						999999		CC	1.105831	145364.9	11244.61	0	1.78E-13
		1				999999	7.5	CC	1.138016	149595.6	11337.04	3035.92	0.006922
				1		999999	7.5	CC	1.138391	149645	11338.72	3063.5	0.006567
					1	999999	7.5	CC	1.141021	149990.6	11349.99	3263.5	0.010168
			1			999999	7.5	CC	1.14633	150688.5	11372.72	3667.5	0.017595
	4					999999	7.5	CC	1.168667	153624.9	11469.9	5347.5	0.031067

Table 4.15: Optimal solutions for a large household as calculated from Homer Pro. The highlighted solution is the overall optimal choice.

Architecture									Cost				System
Solar Array (kW)	T-105	27TMX	RA12-260D	RA12-100SD	RA12-150D	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
2			5			999999	7.5	CC	1.036968	136409.1	9581.239	12547.5	38.81667
5			10			999999	7.5	CC	0.844395	115197.8	7560.611	17457.9	74.14851
6			10			999999	7.5	CC	0.75506	111042.1	7207.724	17864.17	80.74884
10			10			999999	7.5	CC	0.451052	102281.3	6205.198	22063.5	92.34354

Table 4.15 outlines the optimal solution for each PV array system for the large household. The highlighted row shows the overall optimal system. The system with a 10kW EuroSolar PV array and 10 Ritar RA12-100SD batteries has the lowest cost of electricity, net present cost, operating cost and highest renewables fraction.

4.5 Analysis of Results

A clear observation is that for all sized households choosing the highest powered solar system was the most economically sound decision. This would be due to being able to sell more power back to the grid which more than offsets the higher initial capital.

A noticeable occurrence from the results that Homer Pro gave was that the optimal system is always with a PV array and a battery when basing the results on the lowest Net Present Cost. The subsequent better options are those that include a PV array. Due to this it is clear that the PV array has a greater impact on the system being economically sound than the batteries do. Therefore, the payback periods calculated in the following tables will be for the overall optimal as calculated by Homer Pro, as well as using only 1 battery and only considering the PV array.

The payback period of the systems was calculated using equation 12.

$$Cost\ of\ System = \sum_{i=1}^{n} Initial\ Capital \times (1 + interest\ rate) - kWh\ not\ bought \times \frac{\$0.22}{kWh} - kWh\ sold \times \frac{\$0.0745}{kWh} + Annual\ maintenance\ cost \quad (12)$$

The interest rate used in the calculations was 5.88% which is the real discount rate used in the calculations within Homer Pro.

The cost of maintenance and replacement was calculated from the Homer Pro simulations and factors in the cost of cleaning the PV arrays and the replacement of the batteries and converter. The system's annual fixed operation and maintenance cost of $800 factors is the connection fee of Ergon Energy and as all the systems have a grid connection they would all be affected by this cost. As such, this cost is not considered in the payback period because it is present in all cases.

The results of the payback periods investigated are summarised in tables 4.19 to 4.27.

Table 4.16: Table representing payback period of the optimal system for the small household with a 10kW EuroSolar PV array and 5 Ritar RA12-260D batteries.

Year	Cost of System	Cost of maintenance and replacement
0	$ 16,963.50	$ 10.00
1	$ 16,270.07	$ 10.00
2	$ 15,535.87	$ 10.00
3	$ 14,758.50	$ 10.00
4	$ 19,035.42	$ 5,110.00
5	$ 18,463.82	$ 10.00
6	$ 17,858.61	$ 10.00
7	$ 22,317.82	$ 5,110.00
8	$ 21,939.22	$ 10.00
9	$ 21,538.37	$ 10.00
10	$ 26,213.95	$ 5,110.00
11	$ 26,064.44	$ 10.00
12	$ 25,906.15	$ 10.00
13	$ 30,838.55	$ 5,110.00
14	$ 30,960.98	$ 10.00
15	$ 33,738.10	$ 2,657.50
16	$ 39,131.02	$ 5,110.00
17	$ 39,741.05	$ 10.00
18	$ 40,386.94	$ 10.00
19	$ 46,170.81	$ 5,110.00
20	$ 47,194.77	$ 10.00
21	$ 48,278.94	$ 10.00
22	$ 54,526.87	$ 5,110.00
23	$ 56,042.16	$ 10.00
24	$ 57,646.56	$ 10.00
25	$ 64,445.30	$ 5,110.00

As there will not be a payback period for the optimal small household microgrid since the cost of the system is increasing, the cost of the system with one Ritar RA12-260D battery is shown in table 4.17.

Table 4.17: Table representing payback period of the optimal system for the small household with a 10kW EuroSolar PV array and 1 Ritar RA12-260D batteries.

Year	Cost of System	Cost of maintenance and replacement
0	$ 16,963.50	$ 10.00
1	$ 16,449.31	$ 10.00
2	$ 16,924.89	$ 1,030.00
3	$ 16,408.43	$ 10.00
4	$ 16,881.61	$ 1,030.00
5	$ 17,382.60	$ 1,030.00
6	$ 16,893.06	$ 10.00
7	$ 17,394.73	$ 1,030.00
8	$ 16,905.90	$ 10.00
9	$ 17,408.32	$ 1,030.00
10	$ 17,940.29	$ 1,030.00
11	$ 17,483.54	$ 10.00
12	$ 18,019.93	$ 1,030.00
13	$ 17,567.86	$ 10.00
14	$ 18,109.21	$ 1,030.00
15	$ 21,329.89	$ 3,677.50
16	$ 21,072.45	$ 10.00
17	$ 21,819.86	$ 1,030.00
18	$ 22,611.23	$ 1,030.00
19	$ 22,429.13	$ 10.00
20	$ 23,256.32	$ 1,030.00
21	$ 23,112.15	$ 10.00
22	$ 23,979.50	$ 1,030.00
23	$ 24,897.86	$ 1,030.00
24	$ 24,850.21	$ 10.00
25	$ 25,819.76	$ 1,030.00

Tables 4.16 and 4.17 show that including batteries in the microgrid will never have a payback period.

Table 4.18: Table representing payback period of the optimal system for just a PV array for the small household.

Year	Cost of System	Cost of maintenance and replacement
0	$ 11,863.50	$ 10.00
1	$ 11,175.72	$ 10.00
2	$ 10,447.50	$ 10.00
3	$ 9,676.46	$ 10.00
4	$ 8,860.08	$ 10.00
5	$ 7,995.70	$ 10.00
6	$ 7,080.50	$ 10.00
7	$ 6,111.48	$ 10.00
8	$ 5,085.48	$ 10.00
9	$ 3,999.15	$ 10.00
10	$ 2,848.95	$ 10.00
11	$ 1,631.12	$ 10.00
12	$ 341.67	$ 10.00
13	-$ 1,023.59	$ 10.00
14	-$ 2,469.13	$ 10.00
15	-$ 1,352.17	$ 2,657.50
16	-$ 2,817.03	$ 10.00
17	-$ 4,368.02	$ 10.00
18	-$ 6,010.22	$ 10.00
19	-$ 7,748.97	$ 10.00
20	-$ 9,589.96	$ 10.00
21	-$ 11,539.21	$ 10.00
22	-$ 13,603.06	$ 10.00
23	-$ 15,788.28	$ 10.00
24	-$ 18,101.98	$ 10.00
25	-$ 20,551.73	$ 10.00

From the calculations for the payback periods for the systems for a small household, only the system with just the PV array had a payback period within the 25-year project life.

Table 4.19: Table representing payback period of the optimal system for the medium household with a 10kW EuroSolar PV array and 7 Ritar RA12-260D batteries.

Year	Cost of System	Cost of maintenance and replacement
0	$ 19,003.50	$ 10.00
1	$ 17,998.80	$ 10.00
2	$ 16,935.02	$ 10.00
3	$ 22,948.69	$ 7,150.00
4	$ 22,175.97	$ 10.00
5	$ 28,497.81	$ 7,150.00
6	$ 28,051.37	$ 10.00
7	$ 34,718.68	$ 7,150.00
8	$ 34,638.03	$ 10.00
9	$ 41,692.64	$ 7,150.00
10	$ 42,022.06	$ 10.00
11	$ 49,510.85	$ 7,150.00
12	$ 50,299.98	$ 10.00
13	$ 51,135.52	$ 10.00
14	$ 59,160.18	$ 7,150.00
15	$ 63,164.19	$ 2,657.50
16	$ 71,896.13	$ 7,150.00
17	$ 74,001.52	$ 10.00
18	$ 83,370.70	$ 7,150.00
19	$ 86,150.79	$ 10.00
20	$ 96,234.35	$ 7,150.00
21	$ 99,770.82	$ 10.00
22	$ 110,655.24	$ 7,150.00
23	$ 115,039.66	$ 10.00
24	$ 119,681.89	$ 10.00
25	$ 131,737.07	$ 7,150.00

As there will not be a payback period for the optimal medium household microgrid since the cost of the system is increasing, the cost of the system with one Ritar RA12-260D battery is shown in table 4.20.

Table 4.20: Table representing payback period of the optimal system for the medium household with a 10kW EuroSolar PV array and 1 Ritar RA12-260D batteries.

Year	Cost of System	Cost of maintenance and replacement
0	$ 19,003.50	$ 10.00
1	$ 18,409.01	$ 10.00
2	$ 18,799.55	$ 1,030.00
3	$ 18,193.07	$ 10.00
4	$ 18,570.92	$ 1,030.00
5	$ 17,950.99	$ 10.00
6	$ 18,314.61	$ 1,030.00
7	$ 18,699.61	$ 1,030.00
8	$ 18,087.24	$ 10.00
9	$ 18,458.87	$ 1,030.00
10	$ 17,832.35	$ 10.00
11	$ 18,188.99	$ 1,030.00
12	$ 18,566.61	$ 1,030.00
13	$ 17,946.42	$ 10.00
14	$ 18,309.77	$ 1,030.00
15	$ 20,321.99	$ 2,657.50
16	$ 20,825.02	$ 1,030.00
17	$ 21,357.63	$ 1,030.00
18	$ 20,901.56	$ 10.00
19	$ 21,438.67	$ 1,030.00
20	$ 20,987.36	$ 10.00
21	$ 21,529.52	$ 1,030.00
22	$ 22,103.55	$ 1,030.00
23	$ 21,691.34	$ 10.00
24	$ 22,274.89	$ 1,030.00
25	$ 21,872.75	$ 10.00

Table 4.21: Table denoting payback period of the optimal PV only system for the medium household.

Year	Cost of System	Cost of maintenance and replacement
0	$ 11,863.50	$ 10.00
1	$ 10,993.28	$ 10.00
2	$ 10,071.89	$ 10.00
3	$ 9,096.32	$ 10.00
4	$ 8,063.39	$ 10.00
5	$ 6,969.72	$ 10.00
6	$ 5,811.74	$ 10.00
7	$ 4,585.68	$ 10.00
8	$ 3,287.52	$ 10.00
9	$ 1,913.03	$ 10.00
10	$ 457.72	$ 10.00
11	-$ 1,083.16	$ 10.00
12	-$ 2,714.64	$ 10.00
13	-$ 4,442.06	$ 10.00
14	-$ 6,271.05	$ 10.00
15	-$ 5,560.08	$ 2,657.50
16	-$ 7,454.81	$ 10.00
17	-$ 9,460.95	$ 10.00
18	-$ 11,585.05	$ 10.00
19	-$ 13,834.05	$ 10.00
20	-$ 16,215.28	$ 10.00
21	-$ 18,736.54	$ 10.00
22	-$ 21,406.04	$ 10.00
23	-$ 24,232.51	$ 10.00
24	-$ 27,225.18	$ 10.00
25	-$ 30,393.81	$ 10.00

From the calculations for the payback periods for the systems for a medium household, only the system with just the PV array had a payback period within the 25-year project life.

Table 4.22: Table representing payback period of the optimal system for the large household with a 10kW EuroSolar PV array and 10 Ritar RA12-260D batteries.

Year	Cost of System	Cost of maintenance and replacement
0	$ 22,063.50	$ 10.00
1	$ 20,864.16	$ 10.00
2	$ 19,594.31	$ 10.00
3	$ 28,449.79	$ 10,210.00
4	$ 27,625.96	$ 10.00
5	$ 36,953.70	$ 10,210.00
6	$ 36,629.91	$ 10.00
7	$ 46,487.08	$ 10,210.00
8	$ 46,723.85	$ 10.00
9	$ 57,174.55	$ 10,210.00
10	$ 58,039.74	$ 10.00
11	$ 69,155.81	$ 10,210.00
12	$ 70,725.50	$ 10.00
13	$ 82,587.49	$ 10,210.00
14	$ 84,946.97	$ 10.00
15	$ 101,881.18	$ 14,446.00
16	$ 105,375.12	$ 10.00
17	$ 109,074.51	$ 10.00
18	$ 123,191.42	$ 10,210.00
19	$ 127,938.41	$ 10.00
20	$ 143,164.52	$ 10,210.00
21	$ 149,085.93	$ 10.00
22	$ 165,555.51	$ 10,210.00
23	$ 172,793.50	$ 10.00
24	$ 190,657.09	$ 10,210.00
25	$ 199,371.06	$ 10.00

As there will not be a payback period for the optimal large household microgrid since the cost of the system is increasing, the cost of the system with one Ritar RA12-260D battery is shown in table 4.23.

Table 4.23: Table representing payback period of the optimal system for the large household with a 10kW EuroSolar PV array and 1 Ritar RA12-260D batteries.

Year	Cost of System	Cost of maintenance and replacement
0	$ 22,063.50	$ 10.00
1	$ 21,518.47	$ 10.00
2	$ 21,961.38	$ 1,030.00
3	$ 21,410.35	$ 10.00
4	$ 21,846.91	$ 1,030.00
5	$ 21,289.14	$ 10.00
6	$ 21,718.57	$ 1,030.00
7	$ 21,153.25	$ 10.00
8	$ 21,574.70	$ 1,030.00
9	$ 22,020.92	$ 1,030.00
10	$ 21,473.38	$ 10.00
11	$ 21,913.65	$ 1,030.00
12	$ 21,359.80	$ 10.00
13	$ 21,793.39	$ 1,030.00
14	$ 21,232.48	$ 10.00
15	$ 24,306.08	$ 3,677.50
16	$ 24,912.91	$ 1,030.00
17	$ 24,535.42	$ 10.00
18	$ 25,155.73	$ 1,030.00
19	$ 24,792.52	$ 10.00
20	$ 25,427.96	$ 1,030.00
21	$ 25,080.75	$ 10.00
22	$ 25,733.13	$ 1,030.00
23	$ 26,423.87	$ 1,030.00
24	$ 26,135.23	$ 10.00
25	$ 26,849.61	$ 1,030.00

Table 4.24: Table denoting payback period of the optimal PV only system for the large household.

Year	Cost of System	Cost of maintenance and replacement
0	$ 11,863.50	$ 10.00
1	$ 10,888.85	$ 10.00
2	$ 9,856.90	$ 10.00
3	$ 8,764.26	$ 10.00
4	$ 7,607.38	$ 10.00
5	$ 6,382.47	$ 10.00
6	$ 5,085.54	$ 10.00
7	$ 3,712.34	$ 10.00
8	$ 2,258.41	$ 10.00
9	$ 718.98	$ 10.00
10	-$ 910.96	$ 10.00
11	-$ 2,636.75	$ 10.00
12	-$ 4,464.01	$ 10.00
13	-$ 6,398.72	$ 10.00
14	-$ 8,447.18	$ 10.00
15	-$ 7,968.60	$ 2,657.50
16	-$ 10,109.37	$ 10.00
17	-$ 12,376.03	$ 10.00
18	-$ 14,775.96	$ 10.00
19	-$ 17,317.00	$ 10.00
20	-$ 20,007.47	$ 10.00
21	-$ 22,856.13	$ 10.00
22	-$ 25,872.29	$ 10.00
23	-$ 29,065.80	$ 10.00
24	-$ 32,447.09	$ 10.00
25	-$ 36,027.20	$ 10.00

From the calculations for the payback periods for the systems for a large household, only the system with just the PV array had a payback period within the 25-year project life.

4.6 Load Shifting from Evening Peak

To determine if a PV array alone is the optimal microgrid system further tests were undertaken. For the evening load shifting tests, load shifting was undertaken whereby the peak load from 6pm-8pm was added to the load from 11am-1pm. Many customers demand a lot of power in the peak periods to either heat or cool their homes therefore this cooling or heating could take place in the middle of the day when the PV arrays are producing most of their power. Due to the increase in power in the middle of the day for heating or cooling the demand from 6pm-12am was halved to reflect the reduction in demand.

Table 4.25 outlines the results from Homer Pro for the shifting the evening peak.

Table 4.25: Results from load shifting the evening peak of a medium household for a microgrid with only a PV array

Architecture							Cost				System
AGL Solar 2kW (kW)	ES 5kW (kW)	ES 6kW (kW)	ES 10kW (kW)	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
			12	999999	7.5	CC	0.077744	19931.37	624.085	11863.5	83.72073
		7		999999	7.5	CC	0.14074	23885.05	1254.756	7664.167	70.83802
	6			999999	7.5	CC	0.166093	25372.21	1401.221	7257.9	65.73383
3				999999	7.5	CC	0.30258	32277.47	1920.707	7447.5	37.07766

Table 4.26: Result from remaining purely on the grid for a medium household

Architecture		Cost				System	Grid	
Grid (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Energy Purchased (kWh)	Energy Sold (kWh)
999999	CC	0.33765	29570.57	2287.413	0	2.66E-13	6774.518	0

From comparison between the costs of electricity for table 4.25 for the evening peak shifted and table 4.26 for the grid only connection it can be seen that installing a PV array will lower the cost of electricity. Having a 10kW EuroSolar PV array yields the lowest cost of electricity, net present cost, operating cost and highest renewable fraction which matches the results from Section 4.3. These results further support the data that shows the largest PV array is the optimal microgrid.

4.7 Hot water Peak Shifting

The peak demand for the household is often caused by heating the hot water system. This peak occurs at variable times during the day. The load profile data for a medium household was altered to have the peak during the middle of the day at 12pm and the previous peak during the day is halved. This was undertaken to represent the hot water system being heated when the power output of the PV array is at its greatest. The previous peak is halved to represent not needing to heat the hot water at that time.

Table 4.27 outlines the results from Homer Pro for the shifting the hot water peak demands.

Table 4.27: Results from load shifting the hot water system of a medium household for a microgrid with only a PV array

Architecture							Cost				System
AGL Solar 2kW (kW)	ES 5kW (kW)	ES 6kW (kW)	ES 10kW (kW)	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
			12	999999	7.5	CC	0.079222	21028.13	708.9245	11863.5	81.33067
		7		999999	7.5	CC	0.138564	24664.48	1315.049	7664.167	68.7624
	6			999999	7.5	CC	0.162238	26068.39	1455.074	7257.9	63.93297
3				999999	7.5	CC	0.288185	32308.08	1923.075	7447.5	38.58207

From comparison between the costs of electricity for table 4.27 for the hot water peak and table 4.26 for the grid only connection it can be seen that installing a PV array will lower the cost of electricity. Having a 10kW EuroSolar PV array yields the lowest cost of electricity, net present cost, operating cost and highest renewable fraction which matches the results from Section 4.3. These results further support the data that shows the largest PV array is the optimal microgrid.

Chapter 5 Benefits Analysis

From the tables shown in Chapter 4 it is clear that the optimal solution for all sized households is to purchase as large a PV array as possible and not include batteries. All of the scenarios that Homer Pro output that included PV arrays were also the better options. For a small household, the optimal battery scenario was to purchase a 10kW EuroSolar PV array. For the medium household, the optimal battery scenario was to purchase a 10kW EuroSolar PV array. For the large household, the optimal battery scenario was to purchase a 10kW EuroSolar PV array. From these results, it is clear that the optimal battery to purchase is the RA12-260D model and the optimal PV array is the 10kW EuroSolar system. The Ritar RA12-260D battery has the greatest storage capacity of all the batteries.

When considering the payback period for just a PV array system and a system that has both a PV array and batteries, the system with just the PV arrays always has a shorter payback period. The larger household had a shorter payback period than the smaller households. This is likely due to the the PV array lowering the cost of electricity and not just selling. Three units of electricity (each kWh) sold almost equates to not purchasing one. Due to this, the larger households had a greater potential to save money. Including batteries increases the payback period for all the households resulted in payback periods over the total project lifetime of 25 years.

Some of the tests had renewable fractions at 98-99%. This indicates that there is a possibility of some households going off grid. However, it must be considered that real life electricity usage is variable and Homer Pro is a computer program which means that the data it presents is theoretical however not entirely possible practically.

To determine if having only a PV array is a better solution than only staying on the grid sections 4.6 and 4.7 studied the effects of changing the load profile of a medium household and comparing to staying only on the grid. Section 4.6 shifted the evening peak demand and section 4.7 shifted the hot water system peak. From the results, it was found that installing any of the PV arrays will yield a lower cost of electricity than remaining purely on the grid. It was also found that as the output power of the PV arrays increased the cost of electricity, net present cost and operating cost lowered. This shows that having the highest powered PV array is the optimal microgrid.

From the results it is possible to make a potential generalisation that the optimal configuration of a solar powered battery storage system would be to include the highest powered PV array and the highest capacity battery. However, economic considerations would need to be taken into consideration and further testing and future work would need to be conducted before this generalisation could be made.

A main reason for the increase in interest for renewable energy resources and storage has come about through greater awareness of environmental impacts. More and more people are wanting to lower their carbon emissions and a common means it to use clean renewable resources instead of the power generated from coal. An environmental consideration that must be taken into account is the production and disposal of the equipment used for a microgrid. The production process of acquiring the materials and manufacturing of PV arrays and batteries has an impact on the environment as does their disposal. A considerable amount of batteries are made with toxic chemicals which could potentially have a greater impact on the environment than the carbon they reduce. When making any decision for environmental reasons all impacts must be considered.

Chapter 6 Conclusions

6.1 Summary of Outcomes

The recommended microgrid for a small household in the Toowoomba region is to have a 10kW EuroSolar PV array. This system will have a payback period of between 12 and 13 years and will yield a renewable fraction of energy consumption of 89.3%.

The recommended microgrid for a medium household in the Toowoomba region is to have a 10kW EuroSolar PV array. This system will have a payback period of between 10 and 11 years and will yield a renewable fraction of energy consumption of 79.7%

The recommended microgrid for a large household in the Toowoomba region is to have a 10kW EuroSolar PV array. This system will have a payback period of between 9 and 10 years and will yield a renewable fraction of energy consumption of 70.3%.

Considering all the optimal solutions, it is recommended that for households of any size to install only a PV array. The optimal PV array and battery in all instances was the most powerful and the highest capacity respectively that were considered.

A possible generalisation that could be made is that the optimal solar powered battery storage system configuration would be comprised of the highest powered PV array available. Further work would need to be undertaken to determine the validity of such a generalisation.

Having just a PV array is a more economical option than remaining purely on the grid as found in sections 4.6 and 4.7. The PV array will offset the power taken from the grid and sell power back which results in a lower cost of electricity than being purely off the grid.

6.2 Academic Contribution

The research question that this project aims to achieve is to develop methods to evaluate the considerations for designing solar powered battery storage systems as well as to help consumers make educated decisions regarding solar panels and battery storage systems. Many people do not have an extensive knowledge on renewable energy resources and a lot of contradicting facts become wide spread. To this end, it is hoped that knowledge can be spread and consumers can make an informed decision about how they chose the components of microgrids.

The research project found that for a household microgrid, the optimal system is to only have a high powered PV array and to not include batteries. It was also found that including PV arrays is a more economical option than remaining purely on the grid.

6.3 Future Work

Future work that is recommended is to do similar tests with different PV arrays and batteries to determine the validity of the generalisation that the optimal microgrid configuration consists of the highest PV array only.

Possible future work that is recommended is to investigate the environmental impacts PV arrays and batteries have from their acquisition, production and disposal. One of the main causes that has driven their increase in interest is environmental purposes therefore the environmental impacts that are created by the microgrid components should be studied to see if overall their usage will help the environment from reduced carbon emissions.

For all of the final decided systems the optimal cases were to only have a PV array. Possible future work could be to determine how much cheaper batteries would need to become before they are economically viable. In the calculations for the payback periods, the batteries would need to be replaced before the system was paid off so other future work could be to determine how much greater battery throughput would need to increase by before batteries could be economically sound.

For the analysis and results the price of electricity to buy and sell, interest rate and electricity usage are considered to be constant over the entire 25-year project lifetime. A possible future work could be to vary these inputs to determine the impacts they have on deciding the optimal solution.

Homer Pro has inbuilt default climate and solar irradiance data for many places. These were considered in the analysis and optimisation. However, it must be noted that the weather is always variable and thus would impact on the calculations. Further work in this area could be to manually change the climate data used to determine the impacts the changes would have on the optimal solution.

6.4 Evaluation of Aims and Objectives

The aims and objectives of the project were to design an optimal solar powered battery storage system for a small, medium and large house in Toowoomba, QLD. To this end I believe I have achieved this aim having sought out real load profile data from an Ergon Energy household and analysed it through Matlab. From the data calculated by Matlab, PV arrays and batteries that met the requirements were researched and collated. The necessary data for the microgrids and its components were input into Homer Pro and various scenarios were calculated. The lowest Net Present Cost for each scenario was calculated as the optimal and the payback periods were calculated. Given this I believe that I have achieved the aims and objectives outlined at the beginning of the project. It was also found that having a microgrid with only a PV array is more economical than remaining purely on the grid.

6.5 Professional Reflection

A possible improvement to the study that could have happened was to use load profile data from more Ergon Energy customers especially those that would be considered medium and large. Unfortunately, it was very difficult to obtain the data I did have and thus I had to scale the data I had to artificially have a load profile for a medium and large household.

Size of households change with time for example families get larger and smaller and people move. These changes would greatly affect the calculations. The calculations assume that the load profiles stay constant throughout the lifetime of the project however changes in the number of the residents and electricity usage would definitely change over a 25-year period.

Chapter 7 Appendix

Appendix 1: Project Specifications

ENG4111/4112 Research Project

Project Specifications

For: Steven Shephard

Title: Home based solar power generation, storage and localised energy grids

Major: Electrical and Electronic Engineering

Enrolment: ENG4111 – On campus S1, 2016
ENG4112 – On campus S2, 2016

Project Aim: To design an optimal and most cost effect solar power home battery storage system

Programme: Issue A, 16th of March 2016

1. Research background information on high capacity batteries and solar panels
2. Collate data on batteries and solar panels
3. Research and understand all relevant standards for batteries and solar panels
4. Collate costs for various batteries and solar panels
5. Collate data for home energy usage and demand
6. Create model of home battery storage system
7. Simulate model to analyse operation
8. Optimise system design
9. Evaluate optimal system

If time and resources permit:

10. Evaluate and compare actual performance to collected data

Appendix 2: Risk Assessment

Control Methods

Note: Highest score in any risk category takes precedence over lower scores in other categories for multiple risks

25: Extreme risk
Must refer to USQ Manager Audit & Risk for clearance to proceed.

15-20: High risk
Use appropriate procurement documentation, as a minimum Full Offer process. Possible refer to Audit and Risk

8-12: Moderate risk
Use appropriate procurement documentation, must use Special Conditions of Contract for acquisitions under $100k

1-6: Low risk
Manage by routine procedures/processes (dependent on value of procurement)

Figure 7.1: Control Methods to reduce risk (USQ, 2012)

Table 7.1: Table to determine severity of risk (USQ, 2012)

Likelihood – Numerical:	Historical:				Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
>1 in 10	Is expected to occur in most circumstances	>	Almost Certain	5	5	10	15	20	25
1 in 10 - 100	Will probably occur	>	Likely	4	4	8	12	16	20
1 in 100 – 1,000	Might occur at some time in the future	>	Possible	3	3	6	9	12	15
1 in 1,000 – 10,000	Could occur but doubtful	>	Unlikely	2	2	4	6	8	10
1 in 10,000 – 100,000	May occur but only in exceptional circumstances	>	Rare	1	1	2	3	4	5

Green: Low Risk Yellow: Moderate Risk Red: High Risk

Table 7.2: Potential consequences of the risks

	Consequence					Rating
People	First aid	Injury requiring medical attention	Single person injury requiring hospitalisation	Multiple person injuries requiring medical attention or hospitalisation	Death or multiple life threatening injuries.	
Infrastructure	Minor damage not requiring repair (superficial)	Minor damage requiring attention to reduce potential major damage (such as rust or rot)	Damage requiring major repair to make serviceable	Damage requiring major immediate repair so as to not prohibit continued operations	Damage requiring immediate repair so as to prevent potential life threatening hazards	
Operational	Minor disruption to operations lasting less than 3 hours	Disruption to operations lasting up to 6 hours	Disruption to operations lasting up to 24 hours	Disruption to operations lasting up to 3 days	Disruption to operations lasting up to 1 week	
Reputation	Minor unsubstantiated negative publicity or damage to reputation to an insignificant audience	Minor negative publicity or damage to reputation to an insignificant audience	Negative publicity or damage to reputation to a specific audience which may not have sufficient long-term or community effects	Negative publicity or damage to reputation from a national perspective, industry perspective or community welfare perspective	Sustained negative publicity or damage to reputation from a national perspective, industry perspective or from the community welfare perspective	

For this project, all of it was be undertaken using simulations on a computer. Due to this there are little to no hazards present, no more than for any other university work undertaken. A non-safety risk that need to be assessed is loss of data or technical issues. As this project will primarily be undertaken through software any data loss or technical issue could be catastrophic yet rare. For example, if all the data I have collated is corrupted I will have lost all my progress as well as if computer programs are no longer available then progress will seize. To mitigate the chance of data loss I will ensure that all necessary files are stored in multiple locations for back up. To mitigate the possibility of technical issues like not being able to use some programs I will endeavour to ensure that I can use as many programs on my personal computer to minimise the need to use university computers. As the risk was deemed rare and catastrophic it is deemed low risk.

Appendix 3: Project Timeline

Table 7.3: Gantt Chart of progress

Steven Shephard	Semester 1																	Holidays		Semester 2															
# 0061046511					Recess											Exams															Recess				
Activity	Week																																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1. Start up phase																																			
Resource Check	■																																		
Conduct Literature Review		■	■	■	■	■																													
Collate Data for Batteries			■	■	■	■	■																												
Collate Data for Solar Panels				■	■	■	■	■																											
Collate Costs								■	■																										
ENG4903 Seminars										■	■	■																							
Review 1										■																									
2. Research phase																																			
Prelimainary Anaylsis of Data													■	■	■																				
Compare Results																	■	■																	
3. Data analysis phase																																			
Analyse Data																	■	■	■	■															
Conduct Simulations																					■	■	■	■											
Further Analysis of Data																																			
Review 2																■																			
4. Write up phase																																			
Prepare Dissertation Draft						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							
Review 3																													■						
ENG4903 Seminar																														■					
Finalise Dissertation																															■	■	■	■	■

Appendix 4: References

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Appendix 5: Matlab script analysing Load Profile Data

```
%-----------------------------------------------------------------------
% Steven Shephard 0061046511
% This MATLAB script is used to help analyse the load profile data of a
% Toowoomba household. The analysis includes calculating the average load
% profile, the daily consumption and a histogram of the daily consumptions
%-----------------------------------------------------------------------

clear;
clc;
close all;

values = csvread('11-04-2016_EM1000_31001415.csv');
```

```
data = values(3:end);

number_of_days = floor(length(data)/48);

data_length = 1:number_of_days;

day = 0:0.5:23.5;

entries = length(day);

interval = 0.5; % Interval between samples

first_10_days = zeros(length(day),10);

%------ This it to show profiles for day 1 and 2----------
% days_1 = data(1:entries);

% figure()
% plot(day,days_1)
%
% days_2 = data(length(day)+1:entries*2);
%
% figure()
% plot(day,days_2)
%--------------------------------------------------------------

%------ This is to find load profiles of the first 10 days------

for digits = 0:9

count = digits;

time_frame = count*entries+1;

days_ = data(time_frame:time_frame+(entries-1));

first_10_days(:,digits+1) = days_;
```

```
% This is to plot the result
% figure()
% plot(day,days_)

end

%---------------------------------------------------------------

%--------- Checks to see if total consumption is correct -------

days_1 = data(1:entries);
Consumption_day_1 = sum(days_1);

days_2 = data(entries+1:2*entries);
Consumption_day_2 = sum(days_2);

%------ This it to calculate load profiles for everyday ----------
consumption = zeros(number_of_days,1);
demand_divide = zeros(number_of_days,1);
demand_diff = zeros(number_of_days,1);
for digits = 0:number_of_days-1

count = digits;
% Calculates the timeframe values for the day
time_frame = count*entries+1;
% Extracts data for particular day
days_ = data(time_frame:time_frame+(entries-1));
% Stores daily consumption
consumption(digits+1) = sum(days_);

%consumption(digits+1);

% Possible method of calculating peak demand however calculates negative
% power
%Y = diff(days_)/interval;
%demand_diff(digits+1) = max(Y);

% Find peak demand of particular day
```

```
demand_divide(digits+1) = max(days_/interval);

%Z = cumtrapz(days_);
%peak = max(Z);
%demand(digits+1) = peak;

% This is to plot the result
% figure()
% plot(day,days_)

end
%-----------------------------------------------------------------



%-------- This is to find the average values --------------------
storage = zeros(entries,1);
average_storage = zeros(number_of_days,1);

for a = 1:entries
for b = 0:number_of_days-1
average_storage(b+1) = data(b*entries+a);
end
%average_storage;
storage(a) = mean(average_storage);
end

%-------------------------------------------------------------------

%----------------- Plots --=--------------------------------------

% Extracts data for first day
days_1 = data(1:entries);
% Consumption_day_1 = sum(days_1) % Calculates consumption of the first day

% Plots load profile of the first day
figure()
plot(day,days_1),title('Day 1'), xlabel('time (hrs)'),ylabel('Consumption
(kWh)')
```

```
% Plots the average load profile
figure()
plot(day,storage),title('Average Load Profile'), xlabel('time
(hrs)'),ylabel('Consumption (kWh)')

% Plots the total consumption of every day
figure()
plot(data_length,consumption),title('Daily Total Consumption'),
xlabel('Days (08/06/15 - 15/03/16) (Beginning of Winter to Early
Autumn)'),ylabel('Consumption (kWh)')

% Plots the peak demand of every day dividing by time interval
figure()
plot(data_length,demand_divide),title('Daily Peak Demand'), xlabel('Days
(08/06/15 - 15/03/16) (Beginning of Winter to Early
Autumn)'),ylabel('Demand (kW)')

disp('The mean daily peak demand in kW is');
Mean_daily_demand = mean(demand_divide)

disp('The median daily peak demand in kW is');
Median_daily_demand = median(demand_divide)

disp('The mode daily peak demand in kW is');
Mode_daily_demand = mode(demand_divide)

% Possible method of finding peak demand however calculates negative power
% Plots the peak demand of every day by appriximate derivative
%figure()
%plot(data_length,demand_diff),title('Daily Peak Demand'), xlabel('Days
(08/06/15 - 15/03/16) (Beginning of Winter to Early
Autumn)'),ylabel('Demand (kW)')



% Creates histogram of the daily total consumption
nbins = 200;
figure()
hist(consumption,nbins),title('Histrogram of the daily consumptions'),
xlabel('Consumption (kWh)'), ylabel('Frequency')
```

```
% Finds average daily consumption
mean_daily_consumption = mean(consumption);
median_daily_consumption = median(consumption);
mode_daily_consumption = mode(consumption);

% Creates ordered list to determine total consumption of any given day
ordered_consumption = [(data_length)',consumption];


% Creates ordered list to determine peak demand of any given day
ordered_demand_divide = [(data_length)',demand_divide];
max_demand = max(demand_divide);
%ordered_demand_diff = [(data_length)',demand_diff]

% Plots the load profiles for the first week
figure()
plot(day,first_10_days(:,1),day,first_10_days(:,2),day,first_10_days(:,3),.
..
day,first_10_days(:,4),day,first_10_days(:,5),day,first_10_days(:,6),day,fi
rst_10_days(:,7)),...
title('Load Profiles of first 5 days'), xlabel('time (hrs)'),...
ylabel('Consumption (kWh)'),...
legend('Monday 8/6/15','Tuesday 9/6/15','Wednesday 10/6/15','Thursday
11/6/15','Friday 12/6/15','Saturday 13/6/15','Sunday 14/6/15')
```