Fully Sustainable Energy Module

Stage 1: Source Research and Development

ENG460: Thesis

Prepared for the School of Engineering and Energy, Murdoch University

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Abstract

The rising cost of energy, particularly in the form of electrical power is a concern for business and households predominately in rural regions of Western Australia. The higher ongoing costs due to aging assets and infrastructure make it a genuine expense that almost always has the customer looking for cheaper options. Two particular businesses commissioned a project for developing a renewable approach to help satisfy their demands which due to the size and nature of the operation required a medium scale system that was both economical and environmentally sustainable.

The project purpose was to research and build the first stage or the "source" of a small prototype to address these concerns in the form of a Fully Sustainable Energy Module (FSEM). The objective is to compete or better the average cost per kilowatt hour of the Western Australian electricity suppliers, Horizon Power (HP) and those making up the South West Interconnected System (SWIS). While assessing the design options of the FSEM, various types of software were used extensively to assist in clarifying the optimum designs throughout the project for an initial theoretical approach. Designs such as a custom Parabolic/hyperbolic reflector and Fresnel lens directed to a Concentrator Solar Cell Receiver Assembly (CSCRA), coolant pumping for junction temperature control and simulation of multiple system configurations for electrical power requirements were assessed to maximise energy output per square metre of solar output.

Building a prototype requires a sound knowledge base to ensure that it gives the output expected. Data that can assist inform decisions made to further enhance its operation giving the best possible design for final production. Developing an understanding of a feasibility study on the proof of concept for prototype building is further enhanced by researching the importance and structure of project plans and business expectations. It highlights that the strengths and weakness that need considering and help to show a route to a successful finished product.

Prevalent was the design issue for the parabolic/hyperbolic reflector and the intricacies that exposed the difficulty in getting the system to work efficiently due to very small tolerances in construction. When finally settling with a Fresnel lens type the "source" of the FSEM prototype at the time of publication showed practical results of DC output of cell capacity and consistent hot water set at various temperatures showing solar energy transferred.

Acknowledgements

This project couldn't have been completed without the valuable assistance of certain people. To begin with the gentlemen who assisted me on making the prototype, some well overdue quality father son time with Barry Walsh and the patience and knowledge of Mr John Boullton.

A little unique in its design the thesis sometimes would let my ego get the better of a situation and often confusion would set in, Dr Martin Anda was there to pull me in line and bring things back to perspective. For that I thank you and particularly (I hope) for accepting my colourful personality.

The two proprietors, Mr Douglas Shave and Robert Johnson I appreciate the opportunity you gave me to making an idea slowly come closer to a reality. To the staff of Murdoch University who I managed to corner when you had far better things to do, I appreciate your small doses of wisdom

Finally when I was at my wits end and ranting was common I would like to thank my fellow students, friends and family for digesting it and then standing ready for another serve.

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List of acronyms

ABS - Australian Bureau of Statistics

ASHSC – Arduino Solar Harvester Shield Controller

CPU - Central Processing Units

CPV – Concentrated Photovoltaic

CSP – Concentrated Solar Power

CSCRA – Concentrator Solar Cell Receiver Assembly

DAST - Dual Axis Solar Tracker

DNI - Direct Normal Irradiance

EMF - Electromotive Force

ERA - Economic Regulation Authority

FET - Field-effect transistor

FSEM - Fully Sustainable Energy Module

HOMER – Hybrid Optimisation Model for Electric Renewables

HWS - Hot Water System

HP - Horizon Power

I/O - Input/Output

LRET - Large-scale Renewable Energy Target

M2SP - MICRO® 2 SILVER PVD

NPC – Net Present Cost

NEM - National Electricity Market

NREL – National Renewable Energy Laboratory

O&M – Operation and Maintenance

ORC –Organic Rankine Cycle

RAPS – Remote Area Power Supply

RET - Renewable Energy Target

REC – Renewable Energy Certificate

RTD - Resistance Temperature Detectors

SCA – Solar Cell Aperture

SRES - Small-scale Renewable Energy Scheme

STEM – Short Term Energy Market

STP - Standard Temperature and Pressure

SWIN - South West Interconnected Network

SWIS – South West Interconnected System

VR – Voltage Regulator

WEM - Wholesale Electricity Market

1. Introduction

Attention by the Australian government coupled with greater public interest for increased uses of renewable sources of energy, shows the development of new renewable energy technologies becoming an increasingly popular and feasible form of household and commercial energy supply. The interest also relates to the change in the cost price of energy to households. It is increasing quite dramatically. This problem is considered one of the major contributors to the closure of businesses in Australia according to the Australian Bureau of Statistics (ABS). It also states; (1)

“In the five years to the June quarter in 2012, the ABS Consumer Price Index (CPI) rose by 15% (from 157.5 to 180.4). During the same period, Australia’s retail electricity prices rose by 72%, while the price of gas and other household fuels rose by 45%.”

In 2009 the Australian Government passed a bill to show a commitment to achieving a Renewable Energy Target for 20% of Australia’s electricity coming from renewable sources by 2020. (2) These changes lead to what is now known as the Renewable Energy Target (RET). To assist in achieving these targets required a registry to assist in promoting the desired outcome through Renewable Energy Certificates (REC). The REC Registry is an internet-based registry that supports the Commonwealth Government's Renewable Energy Target (RET). This is achieved with the creation, transfer and surrender of RECs. The make-up of RET consists of two parts being the large-scale Renewable Energy Target (LRET) and the Small-scale Renewable Energy Scheme (SRES)

With so much interest developing with both the public and private sectors the demand for renewable technology is still high. Achieving maximum efficiency from a system design in relation to the cost has in recent time created a greater opportunity due to the fall in price of quality and more efficient components. (3) More recently the concept of cogeneration in the form of Concentrated Heat and Power (CHP) has achieved the level of solar efficiency to 72%. (4) Usually in the form of large output systems 500kW and over, it gives the unique opportunity to build a smaller system to service a household or small commercial requirement, yet ultimately restricted only by the number of modules needed.

The purpose of this project is to design initially through research, a system that trials this opportunity using two different solar concentrator systems and through data analysis, determine each unit's efficiency of useful energy transfer and relating it to the cost of a modular design. The concept to create a modular system appeals as it can have many financial and environmental benefits over the long term through production repeatability and low development cost. To increase effectiveness of the FSEM, it will be designed on the basis of having its energy output provide the dual function of supplying electricity and heated water.

Recent data shows that the average household dedicates 25% of energy consumption to heating water and a further 37% to space heating/cooling depending on location (5).This would imply that the heat generated from the FSEM input, usually considered a by-product of photovoltaic cells, could actually be used to assist these requirements. Contributing directly to the large percentage of consumer electricity usage with its by-product, would allow for other uses of the electricity generated for other consumption requirements or reduce the number of units required for total supply. Using acquired data, research and reporting the objective will help to distinguish if there is a reasonable prospect of thermal transfer being reliable and useful for hot water systems and/or Organic Rankin Cycle (ORC) type regeneration system. (6)

The completed FSEM prototype will be owned and financed by Waldan Technologies P/L, a small research and development company. The product design was developed using a generic process that is a framework for many new product designs (7) and draws on some of my commerce experience from past business operations and includes studies at Murdoch University on the way to finishing a commerce degree. It was acknowledged that a lot of time, effort, and money would be required to achieve the final product and this project/thesis is but a small and very much an initial part of this procedure.

Testing of the prototype has been accepted by two rural proprietors of hotel/motel proprietary limited companies, being the Star and Garter Hotel in Kalgoorlie and the Whitehouse Hotel in Leonora. They have access to either SWIS suppliers or Horizon Power as grid energy suppliers. Should the cost and performance of the FSEM be feasible after testing, further financing for greater development would be injected to increase the probability of the proprietors being independent of the grid. The use of a commercial operation that requires relative measures of both types of output would be beneficial to provide a practical test of the FSEM. The proprietors operations being a combination of motel and hotel require both hot water systems and electricity to drive their operation. Their positions in the Eastern Goldfields of Western Australia make them suitable for the use of solar energy as an alternative source to the grid systems due to relatively high solar concentrations and the associated costs with remoteness.

1.1 Project aims

The project is based on the preliminary development of stage one of a three stage process, FSEM prototype. The stages are based as;

Stage 1 = Source

Stage 2 = Storage (storage of excess energy gathered by the Source, not used for operation)

Stage 3 = Supply (reclaiming the Storage energy for use in operation while the Source is not able)

Stage one (Source) is focused on determining the efficiency of solar energy conversion through a Concentrator Solar Cell Receiver Assembly (CSCRA), to gain both electrical and thermal output (8) which will assist in financial analysis of potential manufacturing. (7) The five main objectivesfor the project were as follows,

1. Design and test efficiency of two different solar concentration systems pre CSCRA.

2. Design and test the efficiency of thermal transfer post CSCRA.

3. Design and fit data logging system to prototype.

4. Review and report on the thermal output and its potential for hot water and/or Organic Rankine Cycle.

5. Financial analysis of source only for prototype expansion to further stages for manufacturing.

Designing the FSEM and trying to minimise its physical footprint and aesthetic appearance (9) are issues taken into account due to the current size of solar panels and thermal systems in the market today. This is directly related to their relatively low efficiency's in relation the kWh per square metre; 15 – 16%, something essentially the FSEM is addressing in its core features (10).

1.2 Thesis outline

1. The structure of this thesis is divided into five sections. Beginning with an introduction, being the drive to explore the need for alternative forms of energy in the market and is briefly highlighted by the relevance of it at this point in time to the community's interests.

2. The second section attempts to bring to light the importance of research and pre-empt results to help guide a practical development for real world operation. From covering the design of a solar concentrator to giving specifications of components as well as demonstrating the importance of software for simulation give highlights for the aspects of research

3. Data logging the performance of the FSEM is important so that adjustments and calculations can be made to reach the goals set out initially in the project plan. The focus will be around taking temperatures ambient and within the FSEM itself as well as measuring the solar radiation and electrical power output all while designing a suitable structure for the processes to take place.

4. Finally to run a cost analysis comparison of remote area application on SWIS and Horizon assets previously captured based on an 8760hr window. The actual working test units are to operate for a satisfactory number of hours to give a good indication of other issues such as

particle interference from dust etc. The cost analysis can then be related to the target efficiencies to determine whether the prototypes can be further researched for production.

5. A conclusion will summarise the findings of the research and briefly discuss the results.

It's important to note that the various design results from the prototype not incorporated into the design report will be supplied as an appendix as they become available. Given the requirement of this thesis, it is implied the results themselves while vital for financial feasibility are not solely the essential aspect. Primarily due to word and time restrictions that are not practical with a project with such a comprehensive variety of topics to cover. It does however endeavour to highlight the ability as stated in the ENG460 study Guide 2013, (11) to

"examine, analyse and report on a design, or research, problem and demonstrate a level of mastery of the subject area."

These are achieved in succession by providing constant overview of the project and where relevant highlighting certain areas to show results, research and understanding to abide by the ENG460 thesis requirements.

2. Background and literature review

2.1 Introduction

The FESM prototype design is essential for various data readings to be taken for analysis of power efficiency through thermal and electrical measurement. It is also intended to highlight the potential factors of modularisation to help in financial analysis of manufacture and power efficiency competitiveness. Analysis of the effective transfer of solar energy from the $1cm^2$ illumination areas will be continuously logged over a determined period of time. The data will indicate through various testing strategies, the best method of transference of heat from the CSCRA. The final transfer of energy in DC electrical and thermal energy output is to be measured and through defining a monitoring system of data logging, which ideally could be remotely portrayed through a web based interface from the remote test units.

Physically designing the major module at $1m^2$ allows for a quick “back of envelope” (12) equation when stating the number of modules required and references in terrestrial solar transmission. A common reference to solar rated (peak) output power is $1kW/m^2$. (13). The module’s physical size also makes an easy reference when determining aesthetics and area consumption. This is important when determining roof space or ground area for design and the number of the modules required. The minor modules are the working aspect of the FSEM and are easily multiplied for simulating the final outputs of the major module. The minor modules are made up of a 333 mm x333mm dimension which allows 9 in a 3 by 3 layout to make the approximate square metre of the major module; the size aligns well with shipping and transportation.

The Australian standard pallet size is 1.165mtrs by 1.165mtrs which allows for a protection boundary for packaging. (14). The size also accommodates for shipping containers which are the most commonly used bulk movement vessel of large order manufacturing. A reinforced understanding of modularisation gained shows the relation to engineering projects and ways it helps with the project design. Strengths are in regards to transportation of unit for the end product, along with control of labour costs and risk mitigation of the construction to name a few. (15)

2.2 Solar Concentration

Solar radiation is the electromagnetic energy of the sun with wavelengths from around 200nm to 2500nm. Split into 3 main types being Ultraviolet, Visible and Infra-Red the bulk of the solar irradiance is spread between a narrow section of the visible and a broad realm of the Infra-Red spectrums and the key is to convert as much as possible.

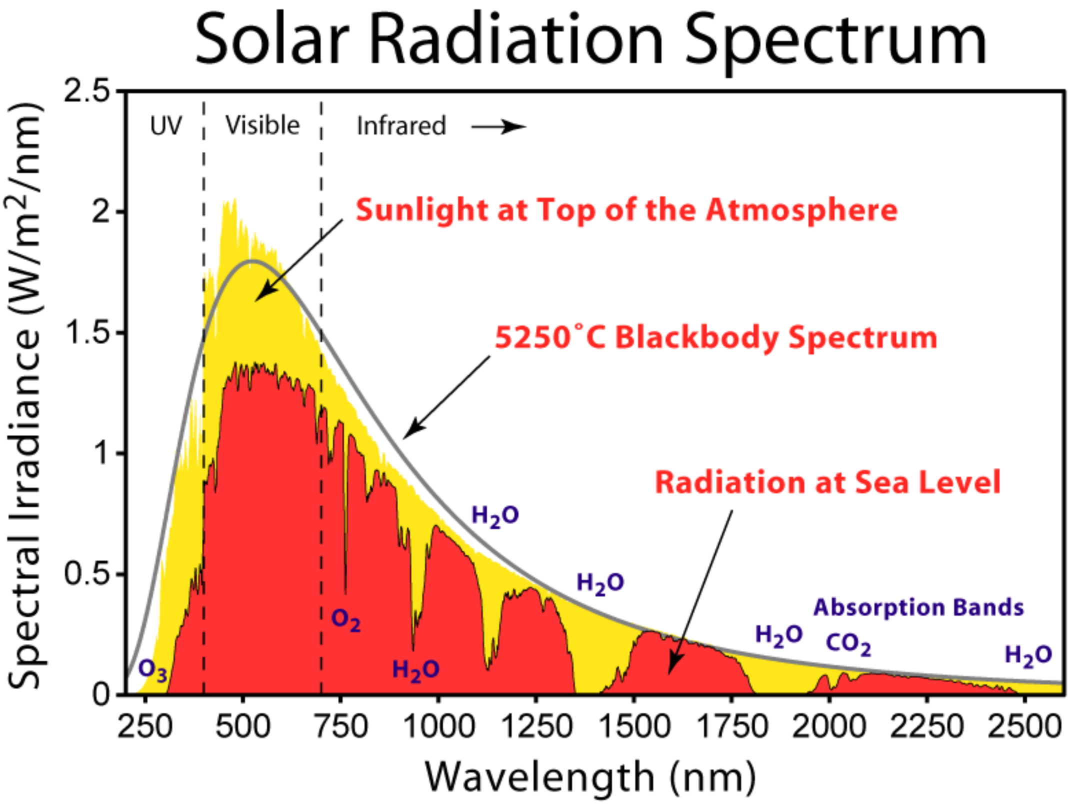


Figure 1: Solar Radiation Spectrum (16)(Image: Wikimedia Commons)

By general design and deployment, solar cells are made up of semiconductor materials being mostly multi or poly crystalline (17) bundled into modules depending on the desired electrical output in Watts per unit. With relatively low average efficiencies based on standard temperature and pressure (STP) an increase in temperature reduces the energy conversion rate even further. It would seem then that concentrating sunlight on to a solar panel to many hundreds of multiples and beyond would not be ideal. However the development of multi-junction solar cells (18) incorporating the ability to receive concentrated sunlight introduces a new opportunity for change.

The common cells used today are mostly single junction cells and cover a small wavelength of the sun. Multi-junction cells by design broaden the cells ability to interact with a greater spread of the suns solar spectrum by layering the cell with two or more junctions (up to 6 is currently being researched) (19).

The junctions are made up of sub-cells that have taken photons with an energy sensitive material grown to suit the band gap. They must be correctly layered or stacked so that all the junctions are transparent to the above junction's energy band gap unless it is the base junction. This section is to explore what becomes a clear advantage of this design. Even at the much higher cost to produce, taking in to account the ability to concentrate sunlight to the CPV the footprint is much smaller and less of CPV is needed. (20)An expected saving in the long term. Figure 2 shows an example of the relationship between solar radiation span and the triple junction cells.

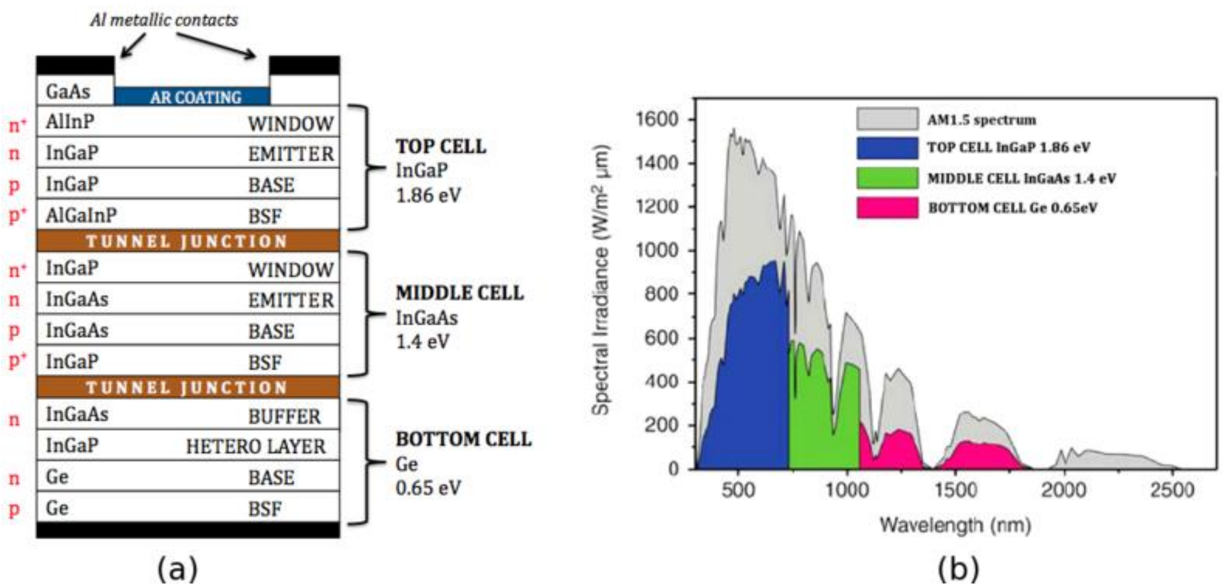


Figure 2: Relationship between T-Junction cells and Spectral Irradiance (21) (Image: Wikimedia Commons)

2.1.1 Concentrator Solar Cell Receiver Assembly

The CSCRA is the heart of the FSEM. It receives solar energy in its concentrated form and then distributes it primarily as electrical energy (DC). The CSCRA is designed for terrestrial use which has a best value of 37% solar to electrical conversion under certain concentrated illumination. The cell is fixed to a receiver assembly made up of an insulated metal substrate with high thermal conductivity. Each CSCRA is tested with a magnification of various suns up to x1150. (22) These efficiencies are achieved by multiplying the number of “suns “through concentration methods as shown in figure 3.

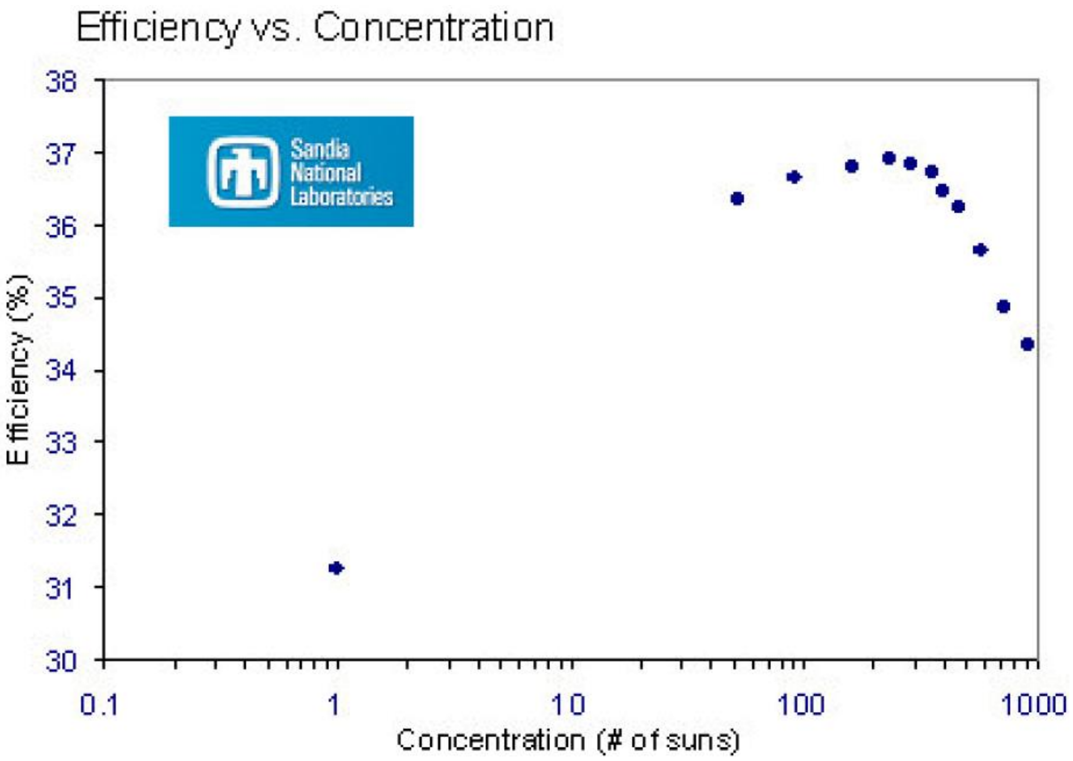


Figure 3: Efficiency vs. Concentration (22)

Increasing the sun concentration amplifies the temperature across the aperture of the photovoltaic cell and reduces the efficiency of the CSCRA. The expected rise in temperature of the CSCRA is to be then transferred to a heat collection unit to be dissipated away from the CSCRA. The need to dissipate the heat energy to maintain its best operating performance is achieved through an electrically inert heat sink at the rear of the unit. Normally the heat dissipation is considered as a problem (23) however it is being used as a positive situation as this heat being concentrated, later discussed is a main factor for the research. Figure 5 shows the compenent make up of the CSCRA and is numbered accordingly.

1. PV cell

Physical size is 10mm x 10mm. Built and designed by EMCORE, the unit is a triple-junction heritage InGaP/InGaAs/Ge solar cell with n-on-p polarity on Germanium substrate and has higher than standard solar cell energy conversion efficiencies. Its enhanced position for activation from solar irradiance is shown in figure 4. (22)

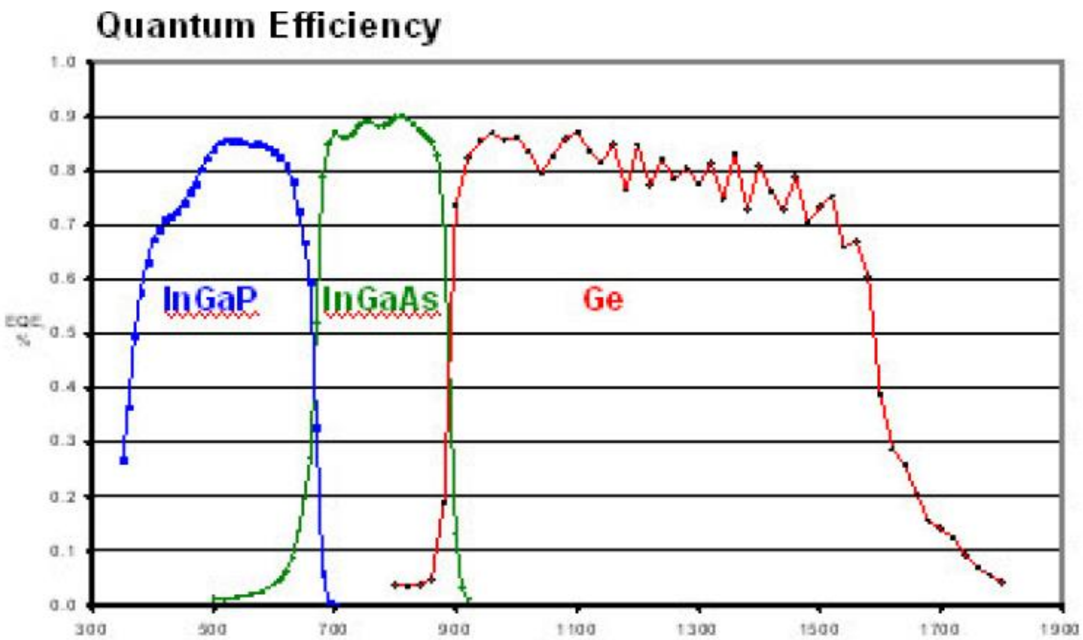


Figure 4: Emcore product statement (22)

2. Diode

A diode uses semiconductor material, usually silicon, with two terminals attached. The function in its simplest form allows electricity to pass in one direction but not the other. With this in mind it prevents back flow of charge into the cell should it be connected to a battery or similar device which could damage the cell. The diode on this particular CRCSA is a bypass diode.

3. Direct Bonded Copper Substrate Panel

The panel is electrically insulated and has very good thermal conductivity properties which make it ideal for transferring heat from the solar cell or aperture to other surroundings.

4. Box receptacle

These receptacles are terminal connections at the end of circuit of the CRCSA for a load to be connected to.

5. *Conformal coating*

A coating applied to dramatically reduce the reflection of the sunlight that lies within the spectral bandwidth of the cell to help as much useful absorption as possible. It is not a perfect system therefore a small amount of solar energy will be reflected away from the CSCRA. The specifications for this are unknown and may be able to be determined after further testing.

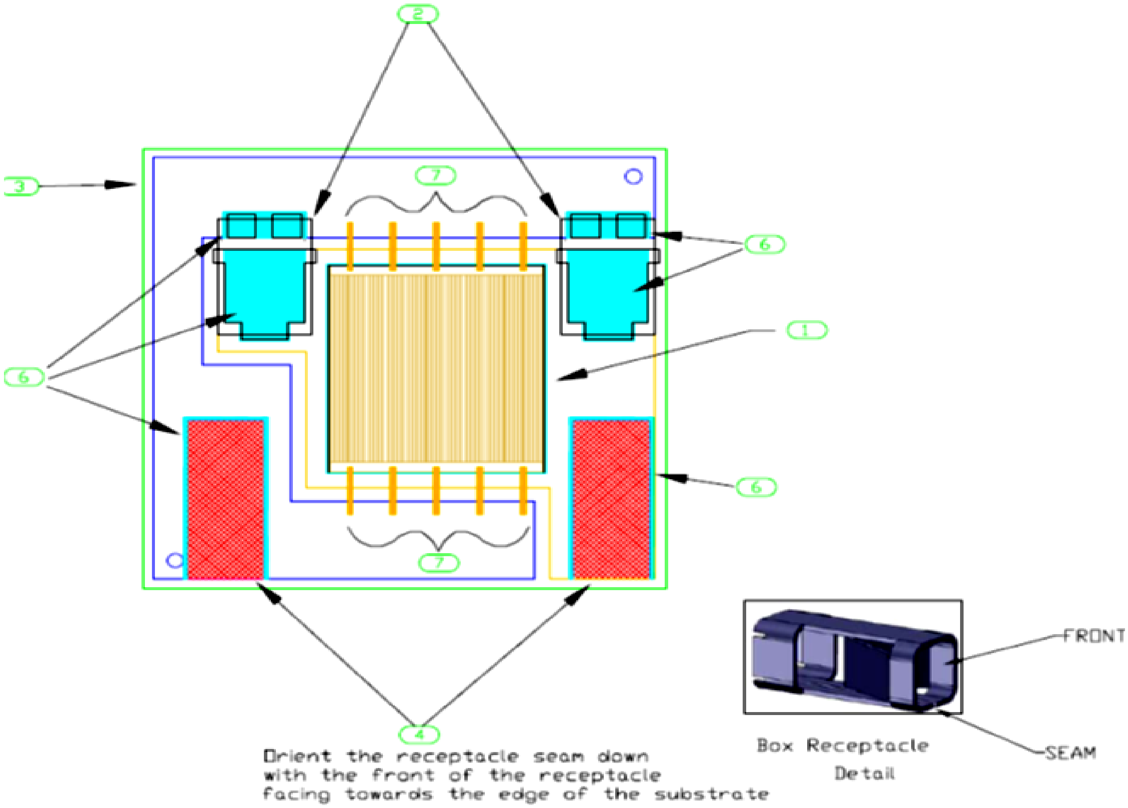


Figure 5: Component makeup of CSCRA (22)

6. *Epoxy Epotek*

An electrical contact glue that has high thermal transfer properties that help transfer heat from the cell quickly so that it does not have time to dissipate into the atmosphere. (24)

7. *Ribbon bonds*

The gold coated ribbons join the positive polarity of the cell to the rest of the receiver assembly. It should be noted that gold is an excellent electrical conductor.

The CSCRA design shown in Figure 6 is made up of components that complement its ability to absorb as much solar energy as possible. It works such intricacies as using a highly thermal electrical contact solution (24) and the application of a multi-layer antireflective coating providing low reflectance across the wavelength range of 0.3 to 1.8µm shown in figure 3.

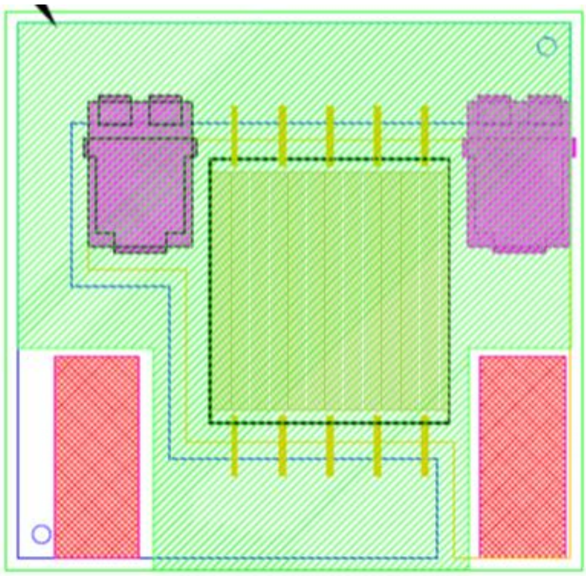


Figure 6: Antireflective covering (22)

2.1.2 Parabolic/hyperbolic reflector

The drive behind the parabolic reflector research is to try developing a more efficient system against the Fresnel lens which is considered “off the shelf” and of a similar physical footprint. The transfer of solar energy in the same footprint creates an opportunity to explore a modular approach in design and being a square shape rather than round allows maximising the footprint of the concentrator.

Upon further investigation it was clear that parabolic dish systems offer the highest potential conversion efficiencies of all the Concentrated Solar Power (CSP) technologies. (25) By necessary design the aperture is always pointed to the sun which has the advantage of avoiding Lamberts cosine law of which systems that don’t follow the suns position may suffer negative effects. The law states that the radiant or luminous intensity that is observed from an ideal diffusely reflecting surface is directly proportional to the cosine angle between the observer’s line of sight and the surface normal (26). With this advantage it is expected that these types of system experience around 20-30% of annual solar to electricity efficiency. The efficiencies are referenced for a single form of generation, being either heat engine or PV and have a low commercial maturity as of 2012. (25)

Further development through Zenith Solar (before it was acquired by the Chinese firm, Suncore Photovoltaic Technology Co) claimed up to 72% efficiency through cogeneration on a large modular system. (4)

The initial concept was first clarified when investigating the concept of dish antenna and optical telescope. The research highlighted the use and the nature of the Cassegrain system. (27) Explanation covers the double reflection of the required waveform of an object generally at a very large distance in relation to the Cassegrain system. By reflecting the objects waveform to a parabolic reflector then onto a smaller hyperbolic reflector the objects waveform can be magnified by manipulating the various physical aspects on the x,y and z plane of the two reflector systems highlighted by figure 7.

Understanding the Cassegrain concept required a series of equations carried out on Microsoft Excel®. (28) The formulas used to design this reflection system were clarified when building the CAD drawings for the engineering of the parabolic pieces and further testing for solar concentration. SolidWorks® was used to design and build the parabolic/hyperbolic shape and convert it to G-code, the primary code for the computer numerical control (CNC) machine to read. When comparing the data between the two, the outcome was the same. It was also reinforced when using Soltrace ray mapping software, it too showed the desired output as per the initial calculations from Excel®.

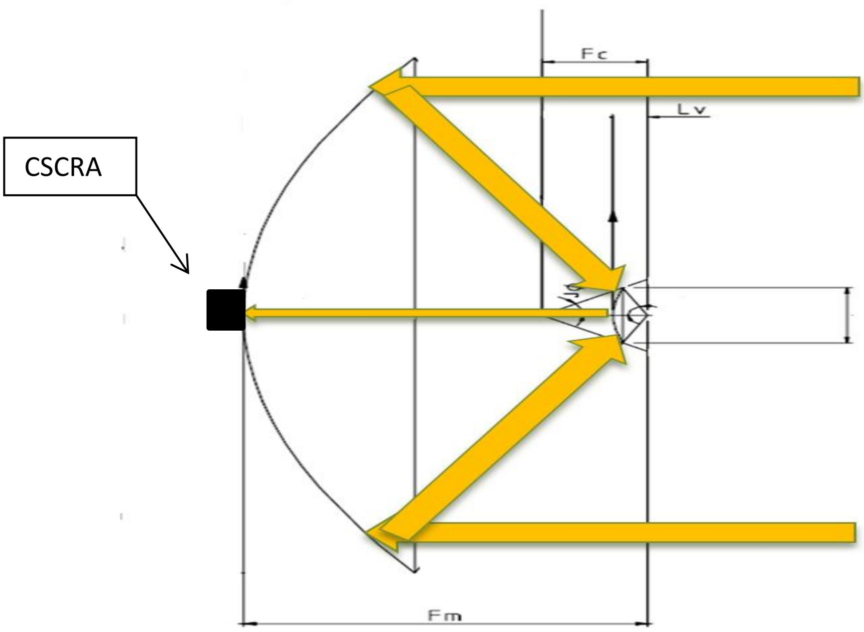


Figure 7: Cassegrain concentration

Essential aspects of data required for creating the Cassegrain reflection system for a square type system shown in Figure 8 are relatively numerous however the more important and relevant points were included here to maintain an understanding of the outputs.

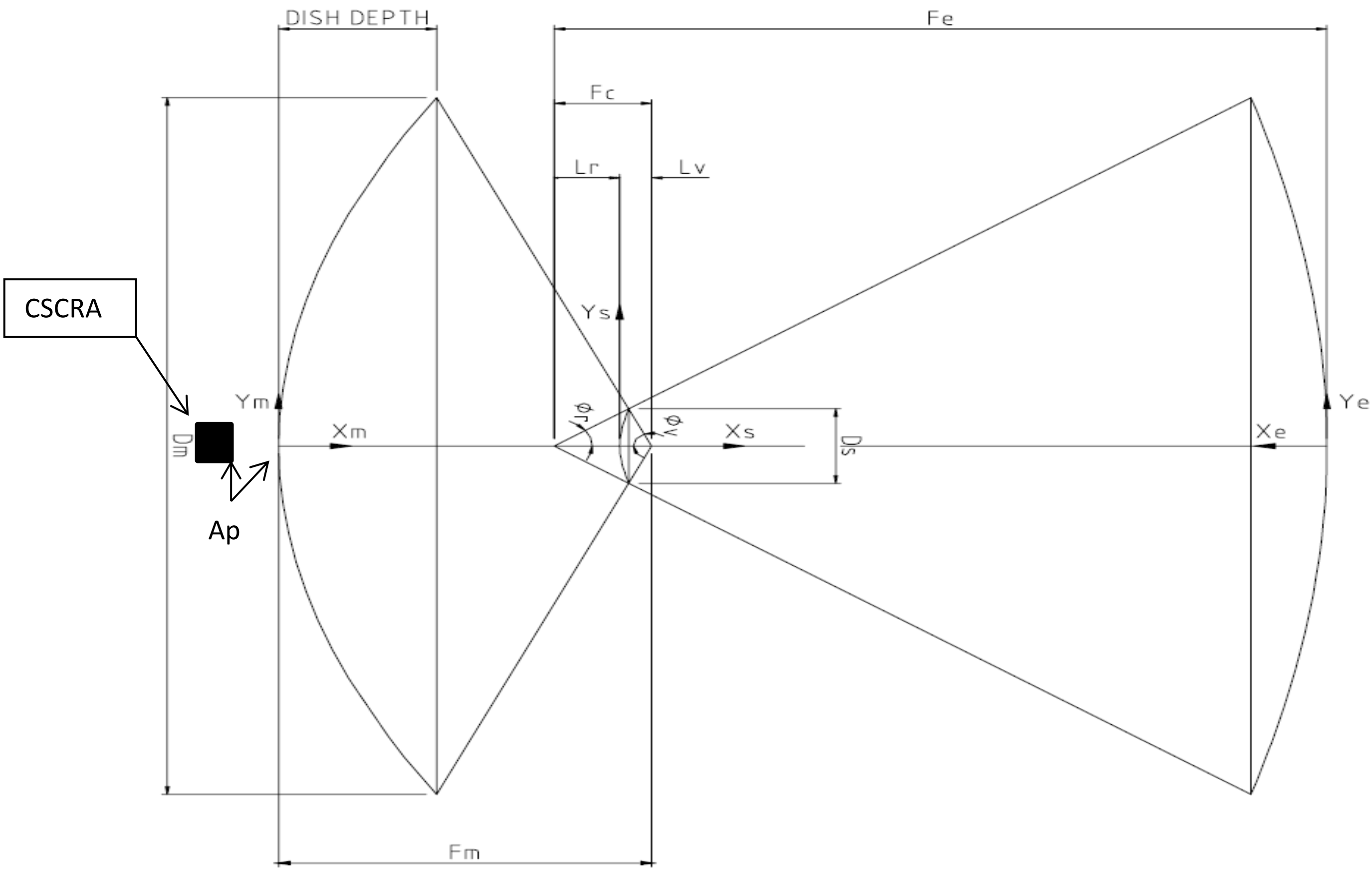


Figure 8: Key elements of equating a Cassegrain type reflection system (28)

Dish Depth 100mm is an arbitrary choice, a round base figure that for conceptual purposes may assist in some type of reference or clarity for future outputs from equations.

Ap - The solar cell aperture (SCA) is set back a distance of 5mm due to a base on the reflector for structural purposes. This constant needs to be considered when making calculations as explained in further reading.

Mr - The design has to be modified to suit a square reflector. This implied that the diameter of the Cassegrain circular reflector was matched as the diagonal of the required square equivalent.

To achieve the magnification of 1000x on a 9 part assembly and including the blockage of the sub reflector creates 1000.34mm leading edge of the x and y axis of the major module.

$$\frac{1000.34mm}{3} = 333.45mm$$

Dm - To achieve this comparison it was considered that if a line is drawn through the centre of a circle then each point at the circumference now represents the end points of a diagonal of a square.

$$\sqrt{(333.45^2 + 333.45^2)} = 471.570mm$$

Sr - Using the basis the design needed to be modified to suit a square reflector, the circular diameter of the sub reflector was matched as the diagonal of the required square equivalent (simular statement to Dm). With a width and length of 11mm and using Pythagoras theory;

$$\sqrt{11^2mm + 11^2mm} = 15.56mm$$

Ds - The spread across the sub-reflector is extremely important in the design as it can change with very small adjustment a lot of the outputs. Again using simular equations as Mr, the diagonal is established with the goal of achieving 1000x Mr in a 2 plane dimension.

Fr The spread across the SCA is extremely important in the design. It is influenced by varying the setting of Fc in its equation and keeping Fm and Ap fixed initially.

$$= (Fc - (Fm + Ap)) \times (\tan \varphi r\ ) \times 2$$

Inputs

5.00	mm	Ap	= Aperture Position in relation to reflector base
11.000	mm	Sr	= SUB REFLECTOR LENGTH/WIDTH
333.450	mm	Mr	= MAIN REFLECTOR LENGTH/WIDTH
100.000	mm	REFLECTOR Depth	

Outputs

471.570	mm	Dm	= EFFECTIVE DIAMETER OF MAIN REFLECTOR (TO EDGE RAYS).
7.778	mm		= HALF DIAGONAL OF SUB REFLECTOR
15.556	mm	Ds	= EFFECTIVE DIAMETER OF SUB REFLECTOR (TO EDGE RAYS).
0.295			F/D Ratio
138.986	mm	Fm	= FOCAL LENGTH OF MAIN DISH.

Table 1: Initial settings

The first table lays out the initial data explained as inputs. Running through the formula developed in Excel gives the expected outputs.

Input

5.000	mm	Ap	= Aperture Position in relation to REFLECTOR base
11.000	mm	Sr	= SUB REFLECTOR LENGTH/WIDTH
333.450	mm	Mr	= MAIN REFLECTOR LENGTH/WIDTH
143.9900	mm	Fc	= DISTANCE BETWEEN FOCI OF SUB REFLECTOR.
100.000	mm	REFLECTOR Depth	

Output

471.570	mm	Dm	= EFFECTIVE DIAMETER OF MAIN REFLECTOR (TO EDGE RAYS).
7.778	mm		= HALF DIAGONAL
0.0004	mm	Fr	= FOCAL DIAGONAL RECREATION ON APETURE
15.556	mm	Ds	= EFFECTIVE DIAMETER OF SUB REFLECTOR (TO EDGE RAYS).
0.295			F/D Ratio
138.986	mm	Fm	= FOCAL LENGTH OF MAIN DISH.
4329.084	mm	Fe	= EQUIVALENT FOCAL LENGTH OF CASSEGRAIN SYSTEM.
4.479	mm	Lv	= DISTANCE FROM VIRTUAL FOCUS (OR MAIN FOCUS) TO SUB.
148.469	mm	Lr	= DISTANCE FROM REAL FOCUS (OR FEED) TO SUB REFLECTOR.
80.611	°	ϕv	= ANGLE BETWEEN AXIS AND EDGE RAY, AT VIRTUAL FOCUS.
3.119		ϕr	= ANGLE BETWEEN AXIS AND EDGE RAY, AT REAL FOCUS.

Table 2: Inclusion of Fc output of Fm

It's important to understand at this point that Fr and Ds must be as close to the same size as possible again for construction and design purposes. This is achieved by using trigonometric inclusions and fixing Fm and varying Fc. To achieve this desired goal Fc will need to be set back beyond the base of the reflector at a great distance to achieve an even spread of the reflected light across the aperture Fr. Figure 9 illustrates and shows how as Fc is extended the angle ϕr gets smaller flattening the hypotenuse and brining the sub reflector (Ds) length and aperture (Fr) length as close to each other as possible.

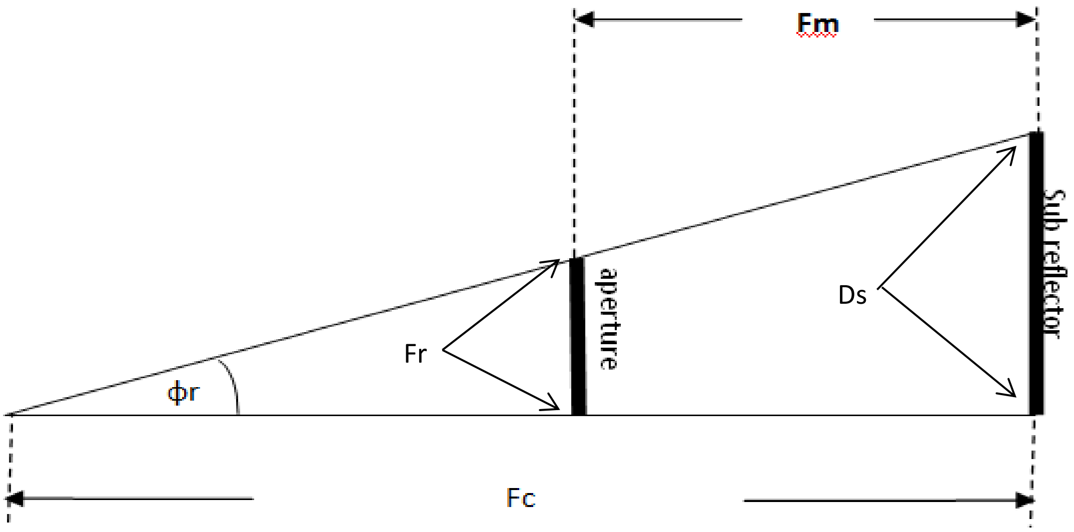


Figure 9: Matching sub reflector size to SCA

Input

5.00	mm	Ap	= Aperture Position in relation to REFLECTOR base
11.00	mm	Sr	= SUB REFLECTO LENGTH/WIDTH
333.45	mm	Mr	= MAIN REFLECTOR LENGTH/WIDTH
40000.00	mm	Fc	= DISTANCE BETWEEN FOCI OF SUB REFLECTOR.
100.00	mm	REFLECTOR Depth	

Output

471.569	mm	Dm	= EFFECTIVE DIAMETER OF MAIN REFLECTOR (TO EDGE RAYS).
7.778	mm		= HALF DIAGONAL
15.542	mm	Fr	= FOCAL DIAGONAL RECREATION ON APETURE
15.556	mm	Ds	= EFFECTIVE DIAMETER OF SUB REFLECTOR (TO EDGE RAYS).
0.295			F/D Ratio
138.986	mm	Fm	= FOCAL LENGTH OF MAIN DISH.
4850142.835	mm	Fe	= EQUIVALENT FOCAL LENGTH OF CASSEGRAIN SYSTEM.
4.585	mm	Lv	= DISTANCE FROM VIRTUAL FOCUS (OR MAIN FOCUS) TO SUB
160004.585	mm	Lr	= DISTANCE FROM REAL FOCUS (OR FEED) TO SUB REFLECTOR.
80.611	°	ϕv	= ANGLE BETWEEN AXIS AND EDGE RAY, AT VIRTUAL FOCUS.
0.003	°	ϕr	= ANGLE BETWEEN AXIS AND EDGE RAY, AT REAL FOCUS.

Table 3: Fc introduction

Explaining the importance of Fr highlights a need to place its focal point (Fc) of the sub reflector beyond the base of the main reflector otherwise it will create a hot spot and not spread the concentrated light evenly onto the SCA of the CSCRA as Fr is extremely small. This would have highly concentrated flux intensity. Note the size in ϕr and being a very small angle that in turn shows that the SCA and sub reflector are now a similar size.

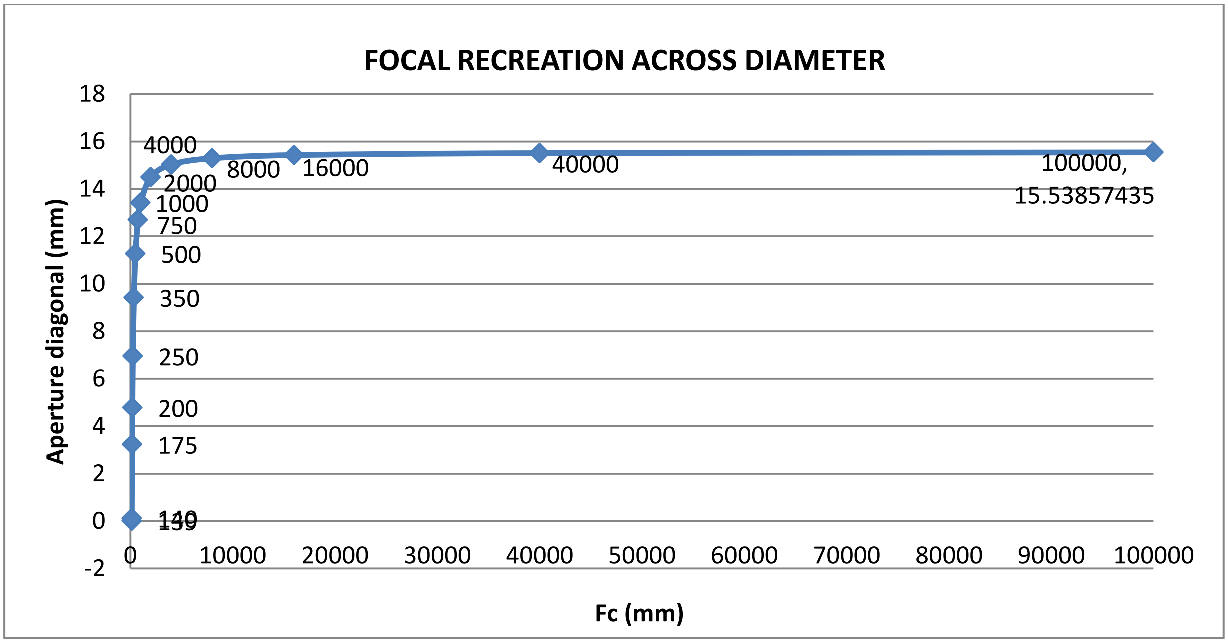


Figure 10: Focal recreation across diameter

By taking various samples of the adjusted Fc, a graph as in figure 10 shows a range from about 16,000mm and beyond will apply very little difference the SCA diameter. From this point it's time to introduce Lv.

Lv is shown in Figure 8 and describes the physical shape of the convex reflector. In summary to achieve the required Fr the shape of the sub reflector will have to change accordingly. Using the same sampled data a graph was created which is shown as figure 11. It presents a potentially large problem. An extremely small change in the Lv of 0.06mm will have a large effect on the focal recreation on the aperture. These changes could vary just on an ambient temperature variation in the field or pressure applied to the unit from wind gust for example. Essentially it would present manufacturing challenges.

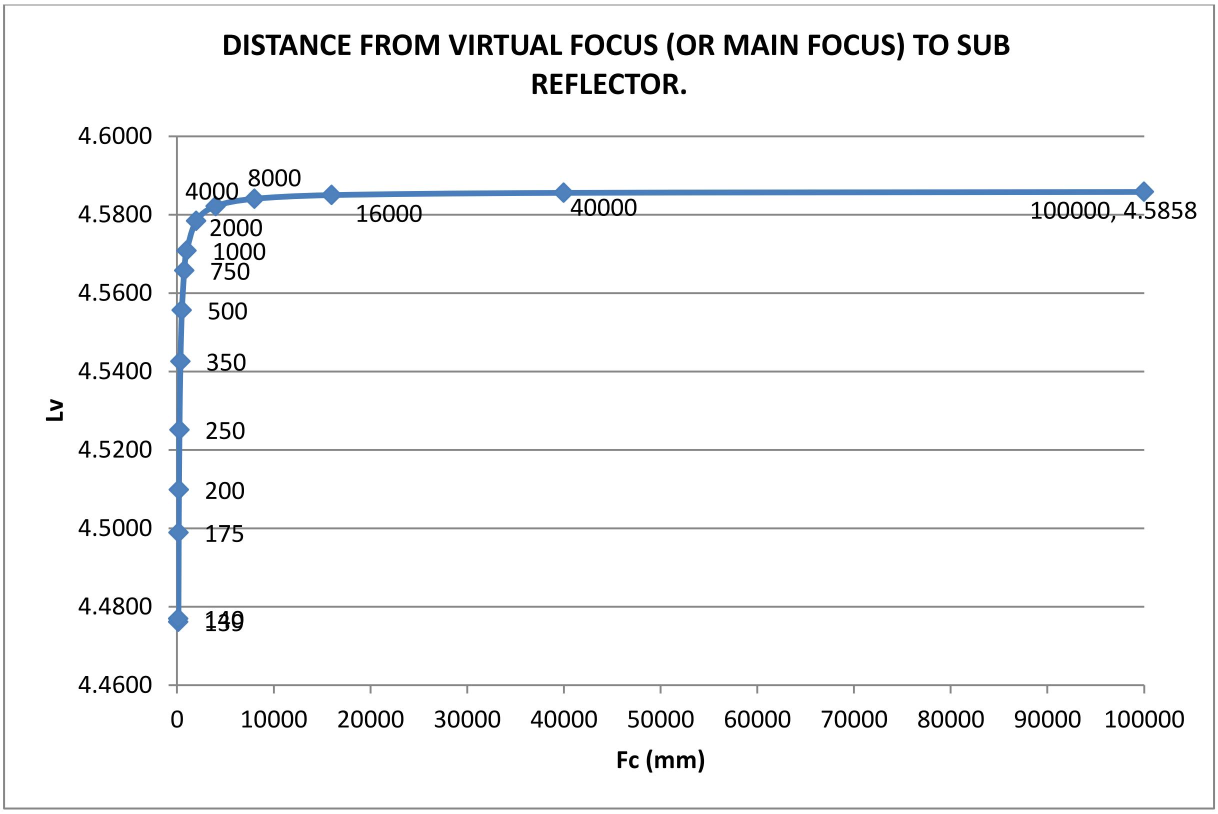


Figure 11: Distance from virtual focus to sub reflector

Parabolic base material

A plastic base is the best option as it is cheaper to manufacture through injection moulding in comparison to metal. The plastic bases should have good rigidity and should be very resilient to environmental conditions. The fact that it is very light in comparison to its size will allow a smaller mechanical effort required to move it when connected to the tracking system.

The base material was initially going to be cut out of a whole block of Ertalon and Nylon 6PLA sheets using a CNC machine. However it was bought to attention by Dotmar that the melting points of these plastics need to be taken into account. It was suggested that Ertalon and Nylon 6PLA sheets be used as it was the most cost efficient to support the reflective material and Ertalon 4.6. High Temperature Nylon Sheet would be used for the base as the heat would be greatest when directed to this area. This implies that base be separated into 2 separate sheets. Figure 17 shows how the base would appear with the lighter aspect of the graphic being the parabolic base material and the darker aspect the parabolic reflective material.

Parabolic reflective material

Applying the reflective material on the parabolic part is very important as it is the one of the main contributions to replicating the theoretical output. (29) The procedure of finding the right part was a process of elimination. After searching locally for reputable companies that claimed extremely high reflective materials for "light tunnels" in the building industry a few were approached. Consultation showed that they all came from one main source and it was settled with a product referenced as 4200AG MICRO 2 SILVER PVD developed by ALANOD Solar in Germany.

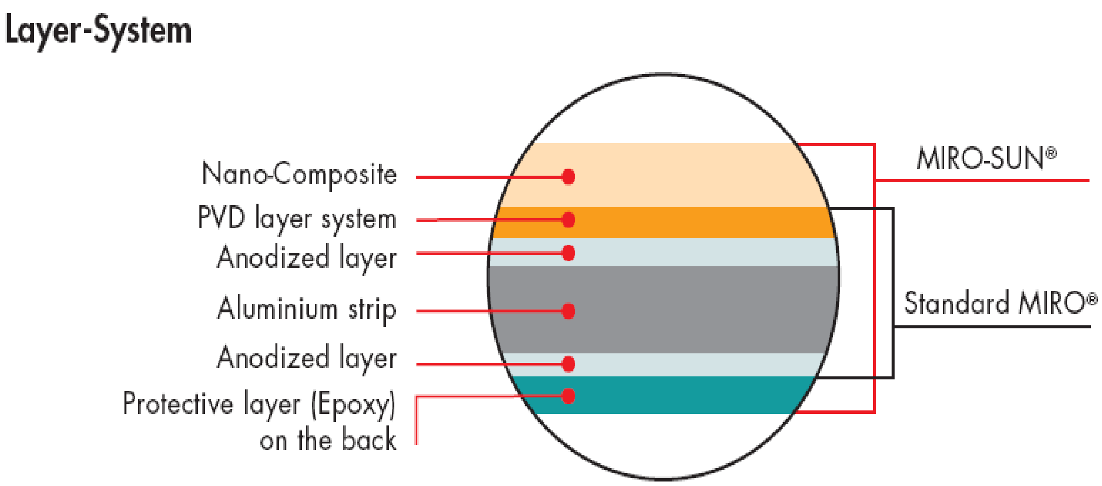


Figure 12: MIRO-SUN makeup (29)

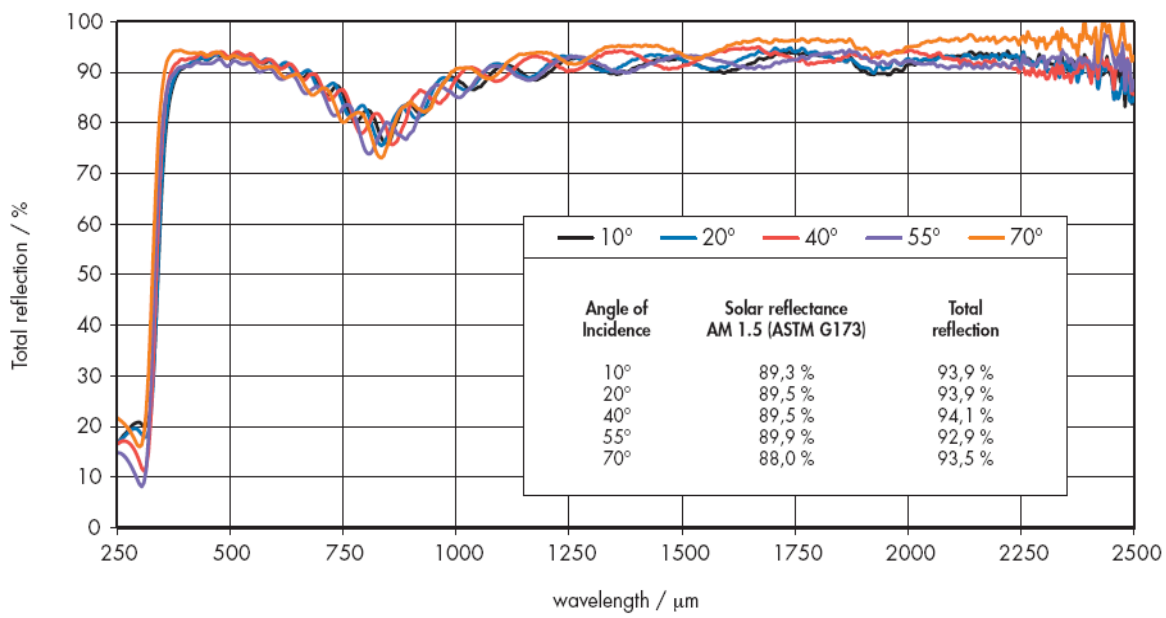


Figure 13: Solar reflectance (29)

PVD is an abbreviation for physical vapour deposition. Among other things, this technique produces reflectivity enhancing oxide layers (PVD coating) on the products as shown in figure 13. As the first company worldwide, ALANOD had developed the necessary systems on an industrial scale to become the market leader in the production of reflectivity enhancing layers in an air-to-air process. Top grade aluminium or pure silver are used as the basis for these layers for a plain white reflection.

Another important aspect of the product is its ability to reflect at different angles and maintain its consistency over various wavelengths. Figure 13 shows the products capabilities to perform well in efficiency given that the CPV is designed operate best between wavelengths of 300-1800nm.

Initially it was claimed that the product only comes rolled and cannot be purchased in flat sheets or pressed. The product was kindly given as a sample supplied direct from Germany as a flat sheet and a resourceful product data sheet. It implied that the product being rolled in one direction along a single axis to make a curved shape is not a particularly challenging issue. As long as it fits within the gauge x 1.5 formula stated by the product data. (29)

This presented another problem with the parabolic base as the design requires the sheet to be pressed along two axes. When consulting the manufacturer it was suggested that it would dramatically reduce the reflectivity by up to 50% if the flat sheet was pressed beyond its specifications as it would stretch and tear the lacquer causing reflectivity issues. At this stage there were no known solutions to this issue and would need to be worked on in the future to be able to make the parabolic system viable.

Hyperbolic base material

Shown in Figure 14 the idea is to either use a complete metal part, or a layered part of metal and high temperature plastic to create the assembly. It is would be expected to be attached to a plate of glass that sits over the whole assembly which acts as both a protection for the CSCRA, a potential mounting medium and a material that is relatively generic .

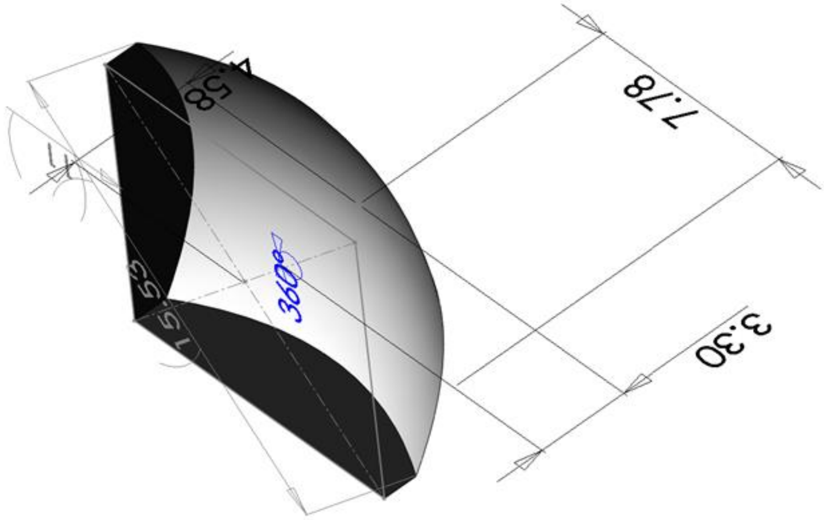


Figure 14: SolidWorks generated hyperbolic sub-reflector

This parts accuracy is vital and as previously discovered in the equations is very susceptible to variations due to the physical environment the whole unit is placed in. It could require different designs to capture all of the reflected light from the base parabola which would need to be further researched. The smallest changes in the hyperbolic Lv as per previous investigations will have a dramatic effect which is not surprising considering it is effectively a theoretical 1000x multiplier.

Facia

The facia will have the dual purpose of protecting the reflective surface and providing a support for placing the hyperbolic base to. The glass needs to have as little interference with the transmission of solar energy through it as possible and strong enough to support the rest of the assembly during heavy environmental conditions.

2.1.3 Fresnel lens

Due to the technical difficulties discovered researching the parabolic/hyperbolic reflector it was decided to use the Fresnel lens type solar concentration for the prototype. Famous for its application for lighthouses, creator Augustin-Jean Fresnel, used an equation that explained when light travels from one medium with a refractive index of n1 into a second medium with refractive of index n2, potentially reflection and refraction of the light will occur. (26)

$$R_s = \left(\frac{n_1 \cos(\theta_1) - n_2 \sqrt{1 - \left(\frac{n_1 \sin(\theta_1)}{n_2}\right)^2}}{n_1 \cos(\theta_1) + n_2 \sqrt{1 - \left(\frac{n_1 \sin(\theta_1)}{n_2}\right)^2}} \right)^2 \qquad T_s = 1 - R_s$$

R_s	reflection coefficient for s-polarized incident light
n_1	index of refraction (first medium)
n_2	index of refraction (second medium)
θ_1	angle of incidence
T_s	transmission coefficient for s-polarized incident light

index of refraction (first medium)	1
index of refraction (second medium)	2
angle of incidence	45°
reflection coefficient for s-polarized incident light	0.2038
transmission coefficient for s-polarized incident light	0.7962

Table 4: Fresnel equation (30)

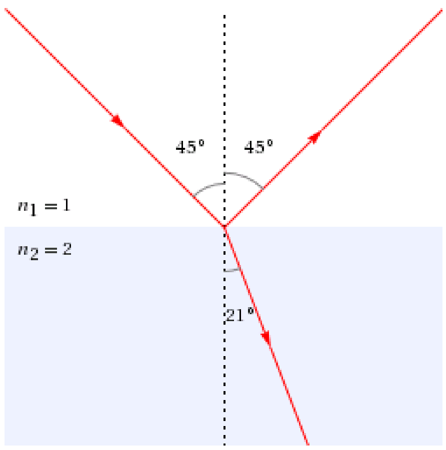


Figure 15: visual display of Fresnel effect

The benefits of this were the ability to make lenses that could be much thinner in production than the conventional spherical plano convex lens with an equivalent output. This gave rise to a cheaper build and less material required.

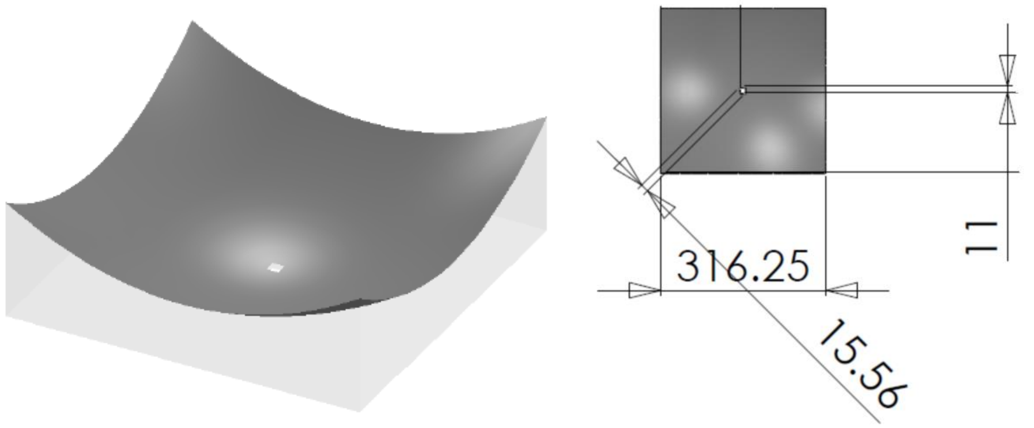
The cost of the lens is fixed per unit of lens which makes them easy to compare with the overall design of the parabolic system. The comparison will involve competing in concentration between the two systems as well as determining the lifespan of the unit. In solar applications a Fresnel lens has a 500:1 ratio (31) and the aim of the parabolic system is to increase to as close to 1000:1. It will be an aspect of cost versus efficiency an important aspect when finalising the final financial feasibility of the FESM.

2.1.4 Design software

SolidWorks

SolidWorks, a 3D design solution from Dassault Systemès is a comprehensive and a full-featured 3D design and analysis package. It allows designers to analyse factors such as stress, flow, mould design, and environmental impact and almost instantly see results of changes to the model. It gives manufacturing companies insight into the overall viability of a product design. (32)

It also allows for easy integration into other software languages that are based on computer aided design (CAD) and in the interest of this project a simple conversion of the 3D designs to G-code. This process not only saves time but can easily be used to reference positions of a 3D models measurements for other software that doesn't integrate such as Soltrace.



Trimetric view Top view

Figure 16: SolidWorks views of parabolic base

Soltrace

Using ray tracing code from National Renewable Energy Laboratory (NREL) provided testing for the theoretical output of the various aspects of thermal power transfer. Soltrace optical geometry modelling set a series of stages that are built with a series of optical features that is not limited by attributes such as and including shape, contour, and optical quality. Such a code has a clear advantage on other code because it is based on the convolution of moments. It replicates the interaction between real photon and which provide accurate results to suit complex systems. (33) The only real disadvantage to this is an expected longer time for processing.

To generate an understanding of the software for testing the theoretical outputs of the parabolic system, a relatively simple model limited with only a reflection from the primary base reflector to the secondary system was used and initially setting a sun position for the process to compute the data of interest.

Setting the optical properties for the system was limited to just using the reflector and not the effects of air for the initial testing. The settings for angle of incidence from specifications data of MICRO® 2 Sun was supplied by data sheet from ALANOD.

Deg	milliradians	Reflectivity
90	1570.796	0.96
70	1221.73	0.915
55	959.9311	0.908
40	698.1317	0.903
10	174.5329	0.884

Table 5: ALANOD specifications

It is important to note that SolTrace is blind to the units of measurement and requires using a consistent set of units throughout the data entry. In addition, within the tracing routine a value of power is applied to each ray and used in subsequent calculations of flux and power on surfaces.

Since the default value associated with power is the user selectable direct normal irradiance (default is 1000 assuming the units are W/m2), a conversion is necessary.

Using millimetres would require a conversion of the Direct Normal Irradiance (DNI) reduced from 1000 using the following

$$\frac{1m^2}{1.0 \times E^6 mm^2} \times \frac{1000W}{1m^2} = 0.001W/mm^2$$

The value of direct normal irradiance (DNI) is set in the Intersections and Flux Maps windows and was set to 0.001.

After accessing ray tracing of the Fc using SolTrace and consulting ALANOD it was decided to readjust to the dish depth from the parabolic equation form 100mm to 46.21mm. This has various advantages in lowering the cost of the base material and reducing the angle of reflection of the incident rays. It also allowed for the manipulating of the MICRO® 2 Sun reflective sheets to be cold pressed without affecting the reflectance.

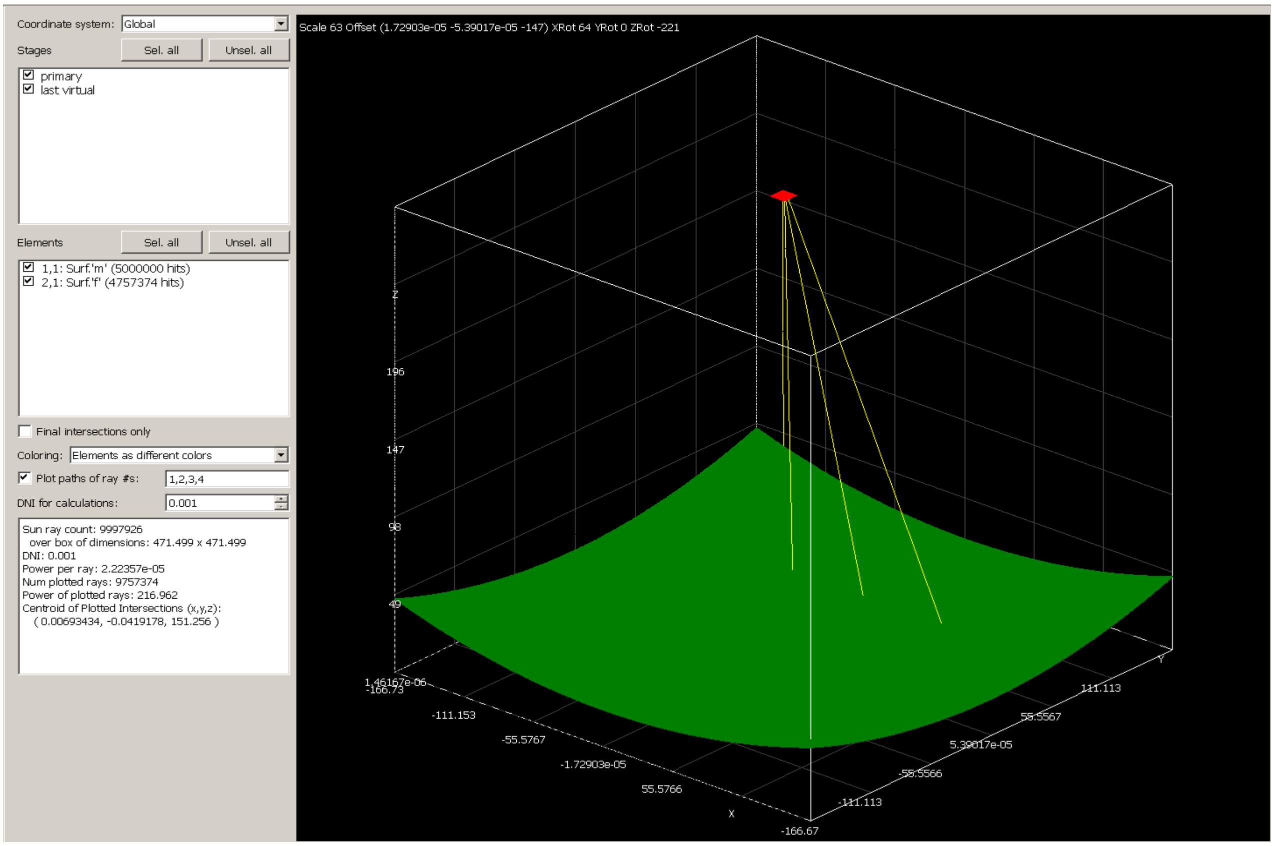


Figure 17: SolTrace output

Figure 18 shows the output incorporating the 2 stages; the Primary Reflector position (primary) and the Sub reflector position (last virtual). The green section is the contact point on the primary made by 5million rays traced. The red section is the end point of the traced rays that actually reaches the last virtual stage. The 4 yellow lines show the first 4 plots of the 5 million and the route they take from stages; fixed sun to primary and finish on the last virtual. The data shows that of 5 million hits on the primary, 4.8 million made it to the last virtual or more precisely 95.14%

The following contour plot from SolTrace of the positions of the x, y and z planes show an image that creates a very intense point of contact if it were the SCA.   The flux decrease is more important than the power loss however because the spread of the flux needs to be uniform to prevent potentially overheating and destroying the aperture of the CSCRA which the case would be such as in figure

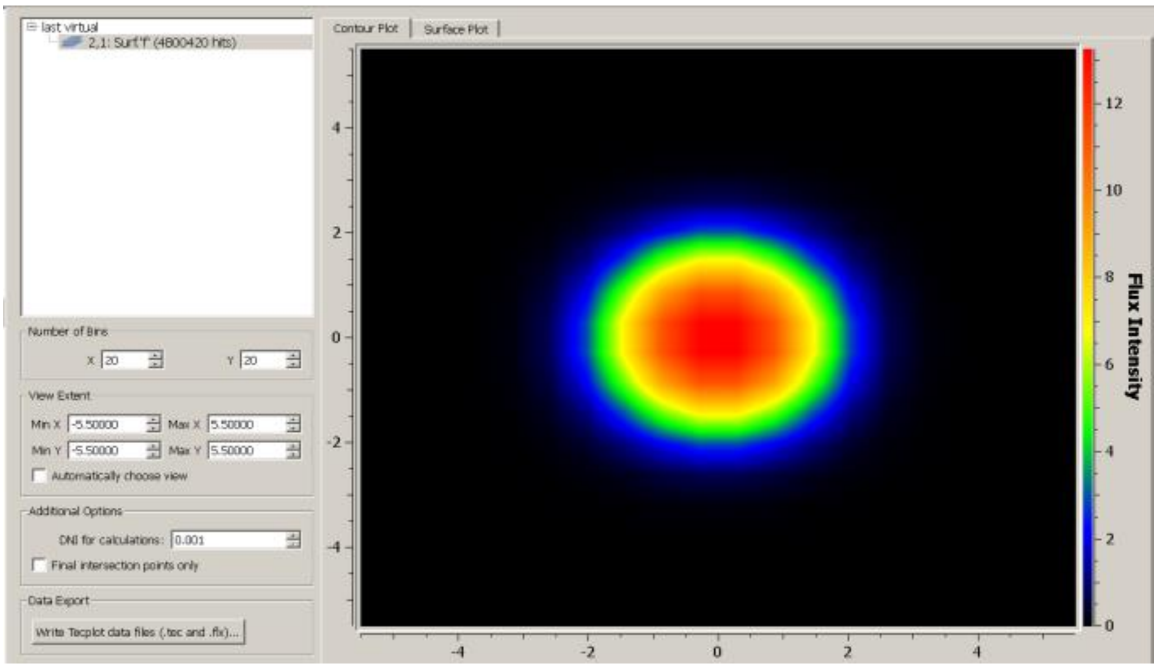


Figure 18: Highly concentrated positioning

Primary Reflector position (x,y,z) x = -166.73 to 166.73(mm);y = -166.72 to 166.72(mm); z=0mm

Sub reflector position (x,y,z) x = -5.5 to 5.5(mm);y= -5.5 to 5.5(mm) z=300mm

The output on figure 20 shows a relatively good spread across the 5mm x 5mm sub reflector position considering that it grabbed 95.14%. This spread is achieved by moving the sub reflector down from its 300mm focal point as shown in figure 18 to 294mm. This also decreased the flux intensity from the pinpoint output on the right from 13.24 to 2.524, a decrease of 10.72. It also created a drop in power from 106.66 to 105.78W, a decrease of 0.88W.

Figure21 gives a 3D surface plot of the flux spread across the aperture. The output of this system shows 105.78W of solar energy. When the efficiency of the CSRCA is specified to be approximately 34.1% at 1000 suns (16), then the theoretical electrical output should be 105.75W ×34.1%=36.1W when DNI = 1kW/m2

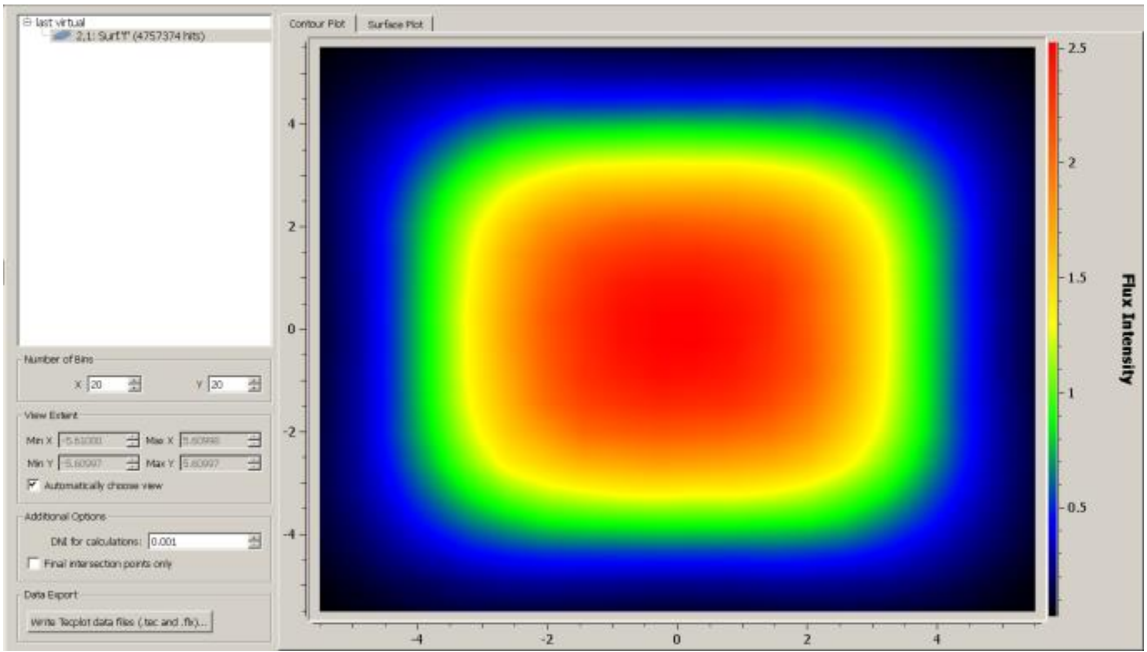


Figure 19: SolTrace showing even spread

Primary Reflector position (x,y,z) x = -166.73 to 166.73(mm);y = -166.72 to 166.72(mm); z=0mm

Sub reflector position (x,y,z) x = -5.5 to 5.5(mm);y= -5.5 to 5.5(mm) z=294mm

Data from desired output
Sun ray count: 9997926, over box of dimensions: 471.5 x 471.5
Power per ray: 2.22e-05
Peak flux: 2.52
Peak flux uncertainty: +/- 0.539 %
Min flux: 0.0267
Sigma flux: 0.756
Avg. flux: 0.874

Avg. flux uncertainty: +/- 0.0319 %
Uniformity: 0.86
Power of plotted rays: 105.78

Table 6: SolTrace final data

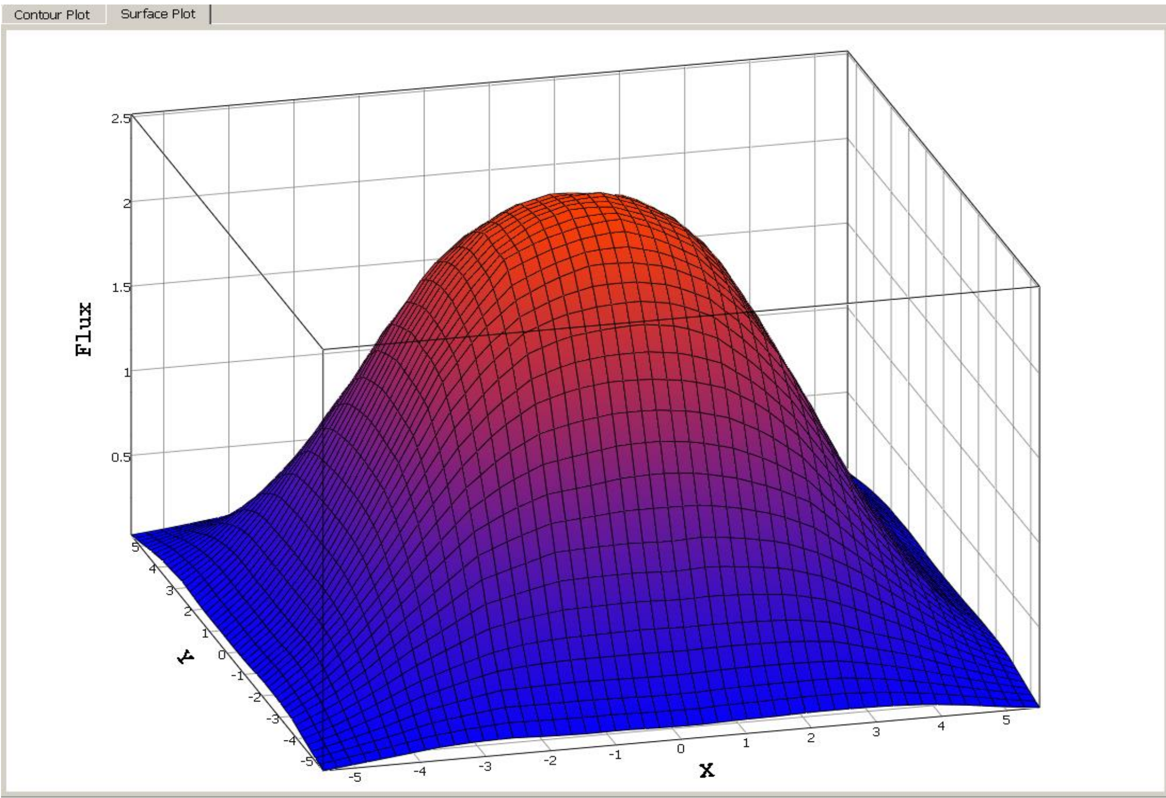


Figure 20: 3D surface plot

2.3 Tracking system

In general with any solar tracking system, the main concern for a designer is how to design a system which will continue tracking reliably and accurately over a long period of time. The various methods to track the suns path each having its own engineering issues for reliability and accuracy gives a lot to consider when considering this issue.

The issues with dual axis system over long term is mainly due to the increase in components to operate and control the horizontal and vertical motion, the efficiency of the motor, gears and actuator will decrease unless constant maintenance is upheld. Again one engineering issue is regular calibration every few years. Calibration involves comparing their response to reference values on relatively clear skies and assigning a value which relates the output of our device to the radiation absorbed.

Therefore, no matter how finely designed and manufactured a tracker may be, over a very long period, perhaps even years, minute errors will have a very large impact. To ensure that the reliability and accuracy of a dual axis tracking dish focusing it towards the CSCRA remains and doesn't decrease dramatically over a long period of time, constant maintenance must be under taken. This includes calibrations of the component and instruments comparing it to the reference data when the equipment was tested in ideal conditions.

The tracking system is vital in physically maintaining the FSEM in the best possible position in relation to the sun for maximum concentration. However even though concentration itself will be enhanced it isn't crucial for testing the ratio of solar output to FSEM energy conversion as a pyanometer attached to the tracker at exactly the same line of the solar concentrators essentially provides a basis regardless of position to the sun. That is to say the test is to monitor the ratio of the conversion from solar to electrical/heat not necessarily the maximum solar penetration to the FSEM. The penetration can be provided by the Bureau of Meteorology (BOM) and the ratio applied to test suitability. However on the financial feasibility aspect it would be very important for final production of a unit as it would be essential to minimising unnecessary units required to cater for energy needs by customers. The Solar Tracking Strategies (STS) project aims to find and analyse different tracking strategies for solar energy harnessing devices. (34) For testing purposes, a high-precision, low-cost table-top solar positioning device was designed and produced making it highly relevant to this project.

2.3.1 Sun Position

The main aim of solar tracking is to decrease the angle of incident. The smaller the angle of incident, the more solar energy can be extracted from the sun. If the slope of a surface is zero, its angle of incident will be about 90 degree as the sun rises, it will be more or less 0 degree when the sun reaches its meridian and 90 degree again when it sets. This means, that without aligning the tracking system towards the sun, a lot of energy is wasted during mornings and evenings. But as the sun does not only change its position depending on the time of the day but also depending on the time of the year and the location, this aspect needs to be considered as well as shown in figure 22. The sun-path diagram for Perth shows the seasonal effects as well as the diurnal changes quite well.

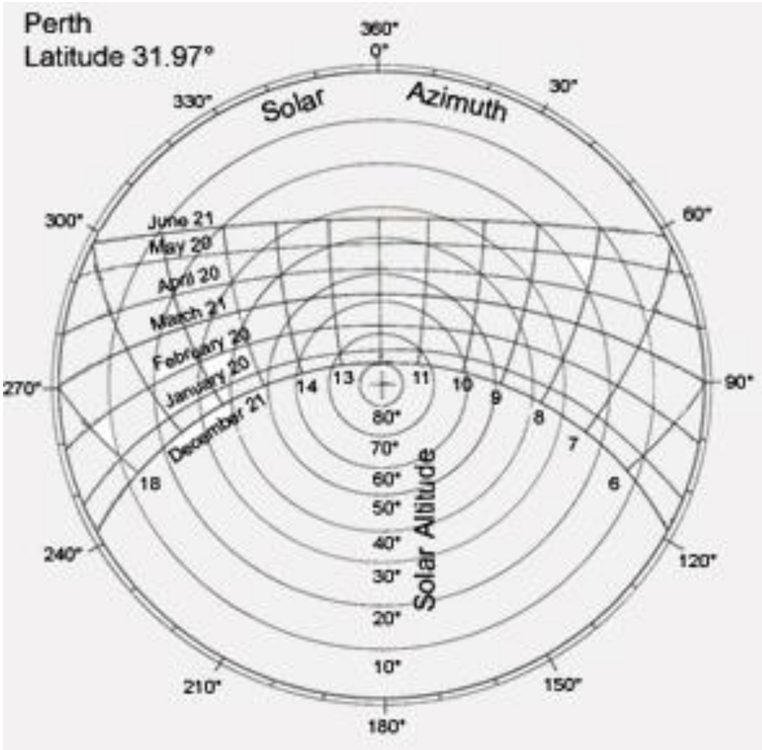


Figure 21: Perth's solar position over the year (35)

2.3.2 Active Tracking

Active tracking systems use electronic componentry to try and set the position of the sun based on the brightest point in the sky. Depending on the design, the restrictions are based on the complexity of the sensors and positioning in relation to the structure. This system is constantly searching for the ideal point which presents a major flaw. It is using energy in sometimes unwanted movements which equates to mechanical wear and excessive power consumption. The advantages are relatively low complexity, small build time and a relatively low cost system.

2.3.3 Passive Tracking

Passive tracking uses astronomical algorithms to find its position by first querying the time and topocentric position of the system, then relating that back to the algorithm and using the mechanical drive to set the system in the new position. The systems flaws are found in the feedback loop when checking errors and how well the algorithm adjusts to suit. Essentially the precision is only limited to the mechanical equipment in the design should the algorithm be capable. It requires more equipment in the use of programmable controllers; however this is not a problem as the controller is already on-board dealing with data acquisition and other control procedures. With this in mind this system seems the best option. It gives a very good insight to the movement of the sun and its characteristics as well as the most accurate system to generate the highest concentration of solar energy for the future development of the FSEM.

2.4 Thermal Transfer

The heat build-up on the aperture of the CSCRA is essentially designed to be transferred via a coolant from the base of the aperture to a heat exchanger for a hot water system and/or provide the heat to operate a Rankin cycle system (36).The process required various equations to be analysed and converted. Simulink helped gain an insight into what sort of pump capacity would be required and the storage mass for the heated fluid. Using outputs from SolTrace of a multiple of 1000 suns and subtracting the CSCRA's conversion efficiency of a minor module, a simple fixed input of heat energy from the unit could be determined as;

$$105.748\text{W} - 36.1\text{W} = 69.6\text{W}$$

This sum of 69.6W will be used as the benchmark for the DNI of a minor module unit under investigation and all variations in modelling will be based from this measurement. It is somewhat a theoretical system as it does not take into account the thermal energy that is lost into the ambient surrounding away from the CRCSA.

2.4.1 Heat Transfer

Heat transfer relates to the generation, exchange, use and conversion of thermal energy and heat between physical systems and is an aspect of thermal dynamics. (37) Of the main forms of heat transfer explored so far, thermal radiation heat transfer has been already used in the transfer of energy from the sun. Heat transfer using conduction and convection will be explored to assist in designing the transfer of thermal energy from the CSCRA to the Hot Water System (HWS). To clarify this, a basic assessment of each of the form of heat transfer is as follows.

Conductive Heat Transfer

The Conductive Heat Transfer represents a heat transfer by conduction between two layers of the same material. The transfer is governed by the Fourier law and is described with the following equation: (38)

Equation 1: $$Q_{conductive} = k_d \times \frac{A}{D}(T_A - T_B)$$

Where

$Q = heat\ flow$

$k_d = Material\ thermal\ conductivity$ coefficient

$A = Area\ normal\ to\ the\ heat\ flow\ direction$

$D = Distance\ between\ layers$

$T_A \& T_B = Temperature\ of\ the\ bodies$

Convective Heat Transfer

The Convective Heat Transfer represents a heat transfer by convection between two bodies by means of fluid motion. The transfer is governed by the Newton law of cooling and is in its simplest from described with the following equation: (38)

Equation 2: $$Q_{convective} = k_v \times A(T_A - T_B)$$

Where

$Q = heat\ flow$

$k_v = Convection\ heat\ transfer\ coefficent$

$A = Surface\ Area$

$T_A \& T_B = Temperature\ of\ the\ bodies$

CSCRA (conduction) → Heat exchanger (convection) → Coolant (convection) → Heat exchanger (conduction) → HWS.

Heat Exchanger

Efficiency being the key, heat exchangers are designed to maximize the surface area of the wall between two mediums, while minimizing resistance to medium flowing through the exchanger. The performance of the exchanger can also be affected by corrugations in one or both directions and/or the addition of fins, which increase surface area and may channel medium flow or induce turbulence. This turbulence is desired to increase the mixing of the medium so that the heat is transferred more effectively however not at the cost of restricting flow. The medium used in the prototype is expected to be a fluid to solid where the highest heat transfer coefficients are reasonably possible.

This is a similar principle used in current high end computer systems used by operators such as “gamers”. The gamers “overclock” the central processing units (CPU) beyond manufacturer’s specifications. This causes the CPU to make calculations at higher speeds than the physical make-up of the CPU allows and causes it to overheat to the point of destruction if not for the aftermarket cooling systems being fitted. Using this readily available, relatively inexpensive system that is similar in overall size as the model, it was decided to use this component analyse and work into the design.

Pump Specifications

The ideal pumping system is a dosing type pump which is commonly called a peristaltic pump. It is a positive displacement pump that works by a rotating mechanism which compresses a tube creating a fluid locking effect and draws the fluid around until it exits the pump as in figure 16. It has the advantages of being very accurate, no fluid interaction with moving pump system, very low maintenance and no need for valves. It is useful in this case as its displacement can be very small and accurate and coupled with a variable speed motor can maintain a simple low rotation pumping system.

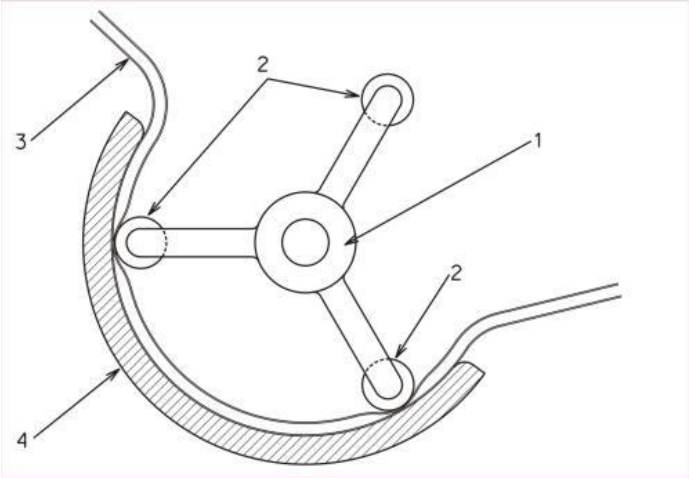


Figure 22: Peristaltic pump operation (39) (Image: Wikimedia Commons)

2.3.2 Simulation

Simulink® creates model-based design and multi-domain simulation in a block diagram environment. Its function includes support for automatic code generation, system-level design, simulation as well and continuous verification and testing of embedded systems. (38)

This model was designed using 2 sub-systems that allow for the movement of a fluid through the heat exchanger and accounts for the loss or gain of heat through ambient air temperature to the mass of the heat exchanger. The model showed the effects on the pump speed in relation to changing ambient air temperature and a varying solar power to try recreating a more realistic power supply. It was initially modelled over a 10 hour day to see if the fundamentals of heat transfer, pump speed and displacement coincided respectably.

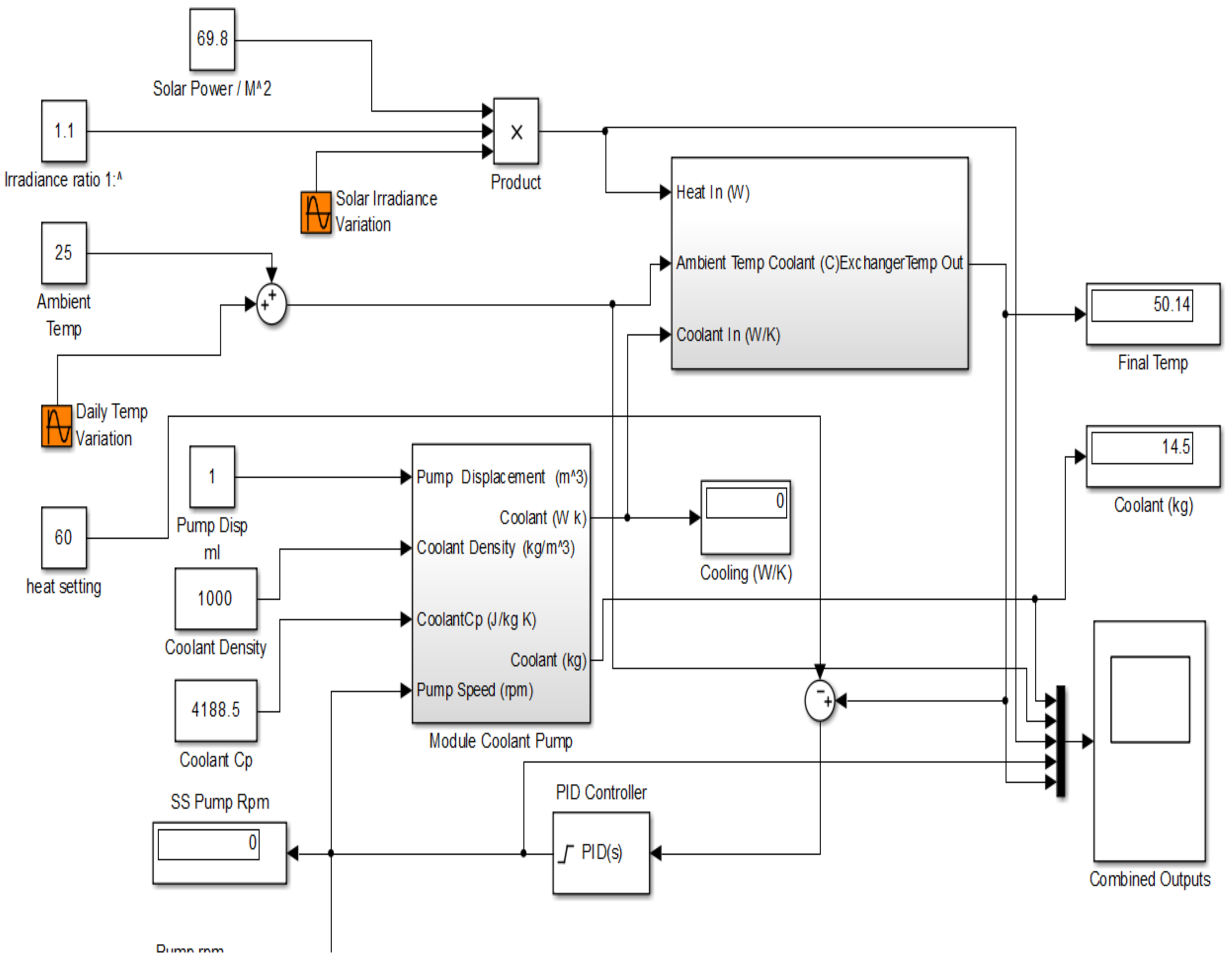


Figure 23: Simulink model

Input Data	
Outside ambient temp	25°C +/- 8°C
Peak input power (initially turned off for the first 60 seconds.)	69.6 W
Variation DNI x (bright cloudless sky)	1.2
Pump displacement	1ml/rev
Heat exchanger initial temp (To show the rise in temperature associated with ambient temperature)	0°C
Output temperature required	60°C
Exchanger Heat Transfer Coefficient (high-density copper)	400 W/m^{2}K
Water block mass	0.11 (kg)
Aperture Surface =	6.25E-04 (m^2)

Table 7: Input data

Figure 24 is an image of the model design to be run for 10hrs or 36000 seconds. A variation in the temperature and solar irradiance was fitted to simulate a change over the day.

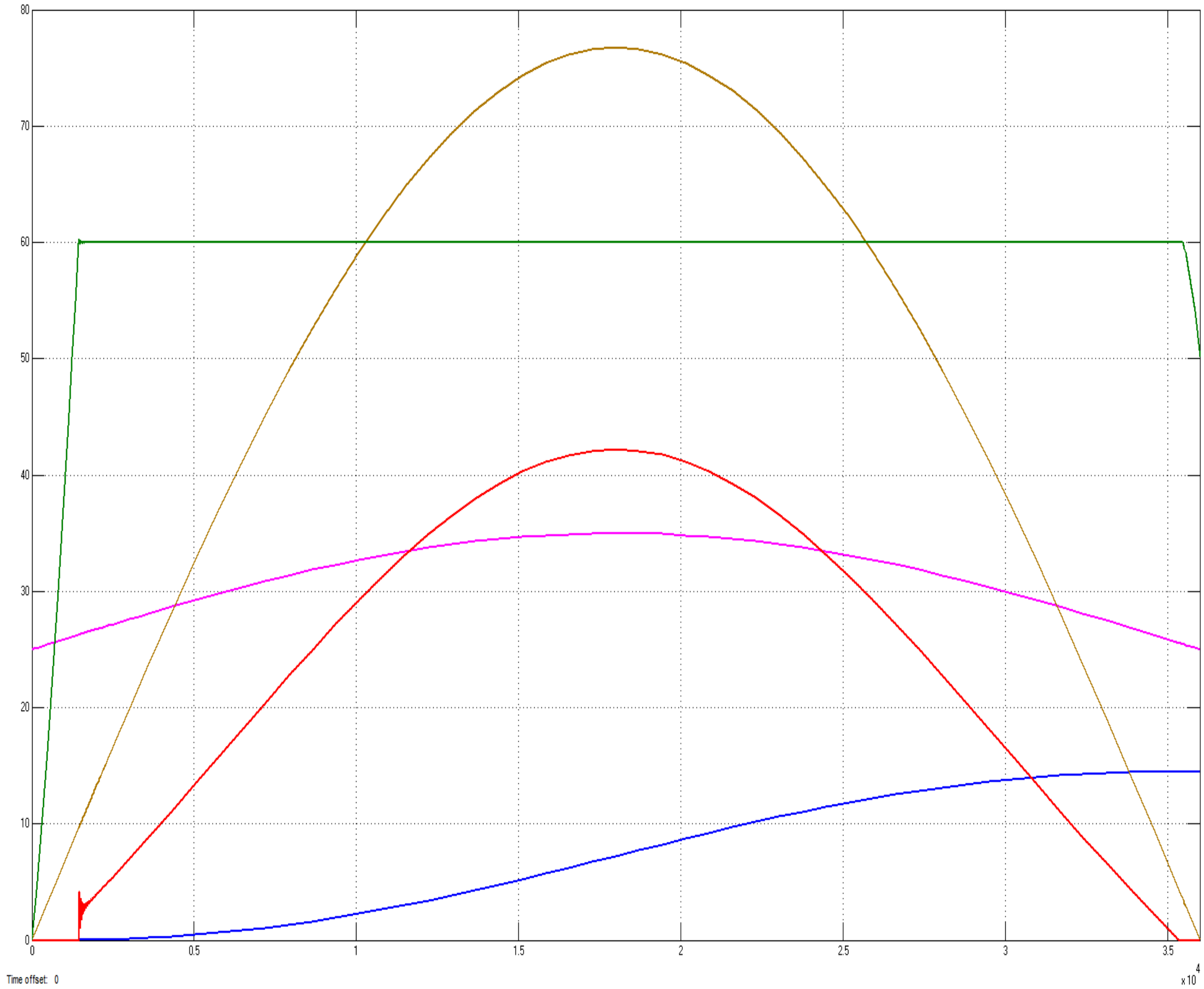


Figure 24: Simulink 10hr Output

Yellow = solar irradiance (watts)
Green = output temperature (deg C)
Red = speed of pump (rpm)
Purple = ambient temperature (deg C)
Blue = acquired coolant kg

Table 8: figure 25 legend

The outputs shown on figure 26 clearly show the heat exchanger temperature maintaining 60°C and the pump varying its speed to match the changing ambient temperature over the 10 hr. period

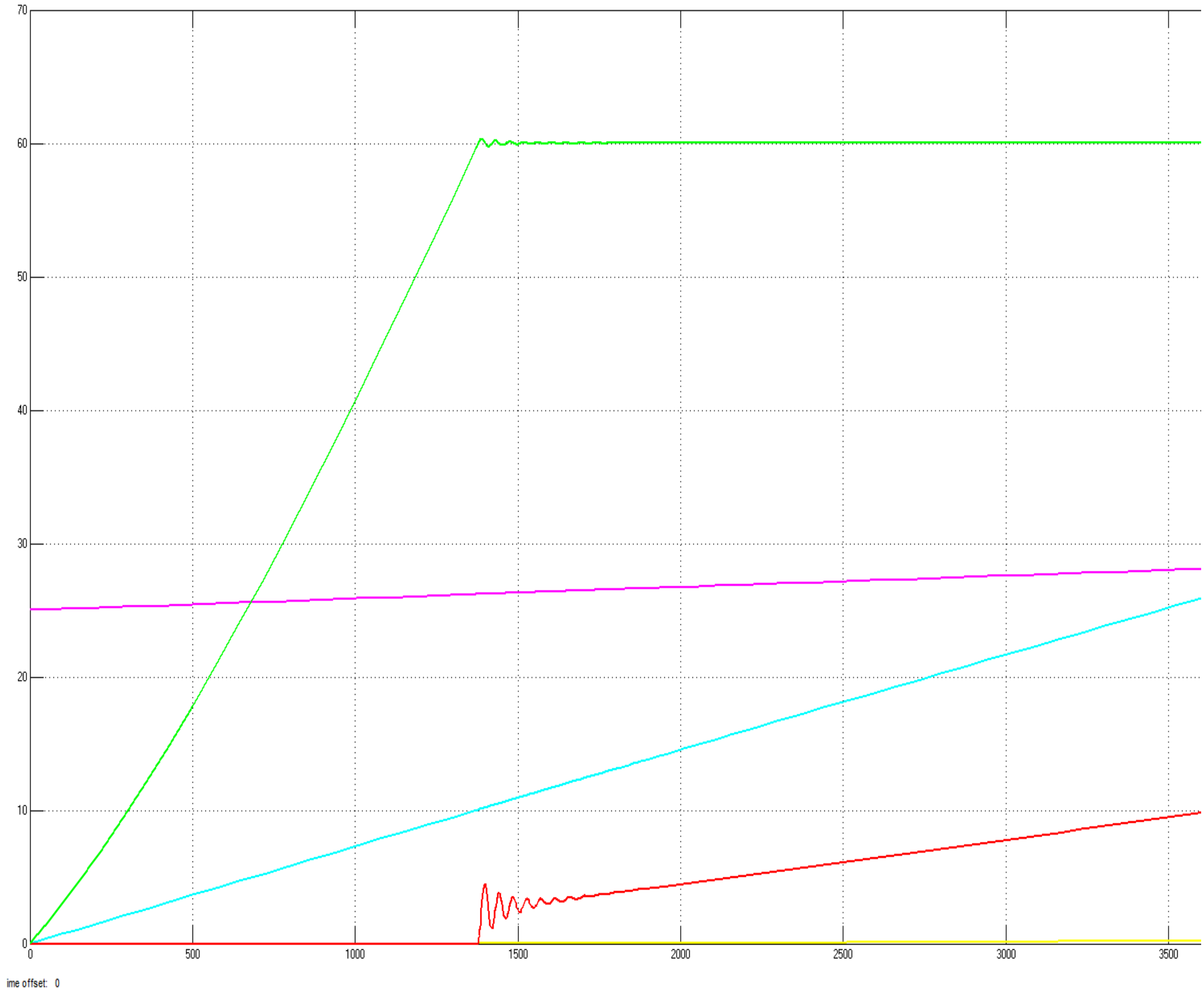


Figure 25: Simulink output 3600secs (1 hr)

Cyan = solar irradiance (watts)
Green = output temperature (deg C)
Red = speed of pump (rpm)
Purple = ambient temperature (deg C)
Yellow = acquired coolant kg

Table 9: Figure 26 legend

Taking a view of the first 3600 seconds or hour of the system shows in figure 26 some interesting characteristics of the system and helps to confirm some expectations. Using the inputs at t = 0s the aperture power is off and the heat exchanger is heating up at ambient temperature. Once the aperture power is turned on at t = 60s, the heat exchanger heats up till it reaches the desired temperature of 60°C and the pump starts at just before 1500s. The two oscillate until they reach steady state.

The overall output expects to generate at least 14.5kgs of water to 60°C. This is assuming ideal conditions and that none of the heat is lost to the atmosphere. The model is based on the minor model and when considering that it represents 9 per square metre, simple addition would give an expected 130.5 litres.

2.3.3 Organic Rankine Cycle system (ORC)

There was been quite a lot of research on the ORC of late and to pin an exact efficiency really comes down to the type of working fluid used and the variation in the expanders(turbine section). (40) Its two main advantages are the simplicity of the components and their availability. The working fluid, usually an organic component, is better adapted than water to lower heat source temperatures. Unlike with traditional power cycles, local and small scale power generation is made possible by this technology which would greatly suit the smaller footprint of the FSEM design. These units are known for the operation with lower temperatures to generate electricity and have greatly increased in popularity in the past decade. They are often applied to many different fields such as biological waste heat, engine exhaust gases, solar thermal power, domestic boilers, etc. (40)

Blue = solar irradiance (watts)
Green = output temperature (deg C)
Red = speed of pump (rpm)
Pink= ambient temperature (deg C)
Yellow = acquired coolant kg

Table 10: Figure 27 legend

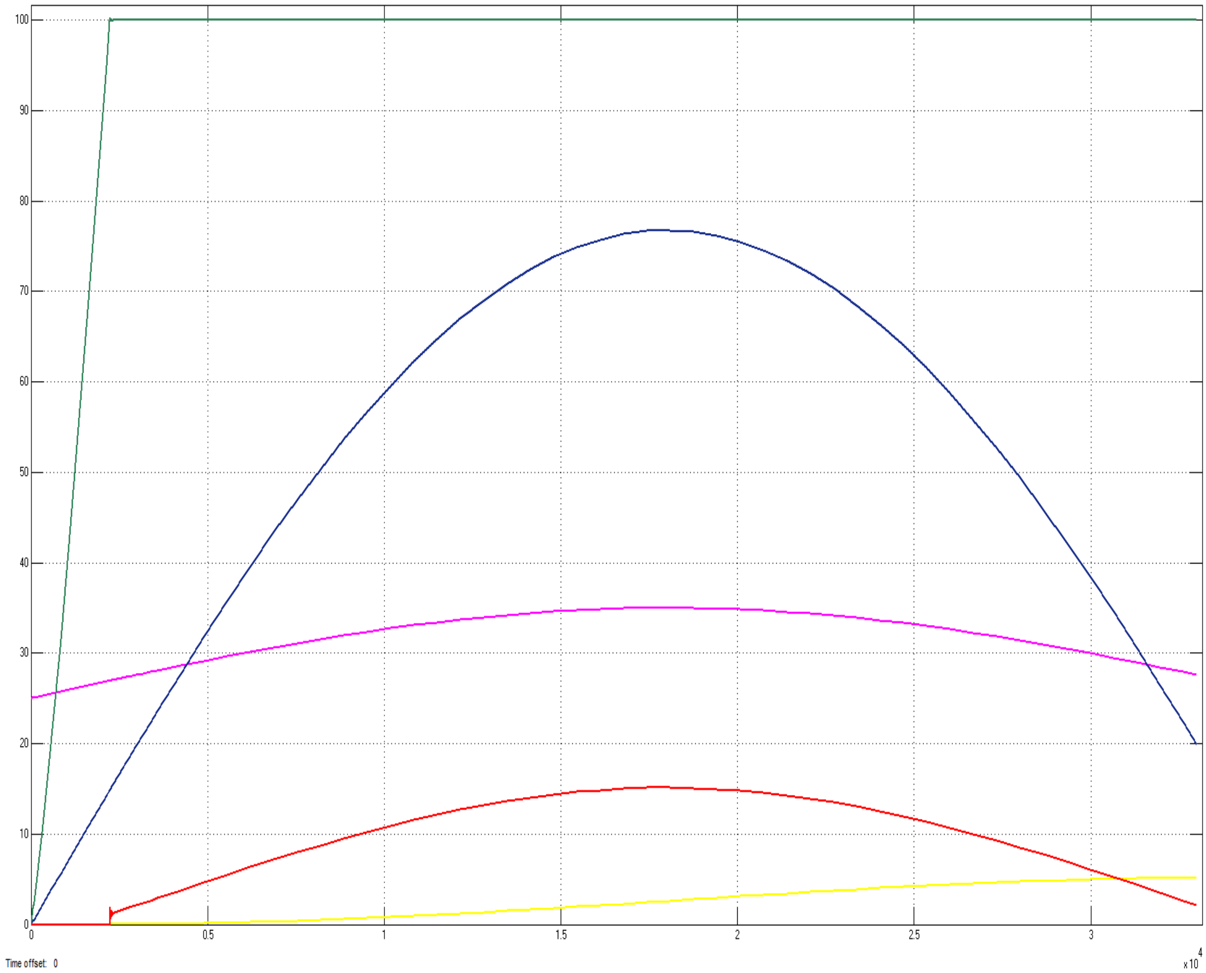


Figure 26: 10hors with fluid output set to 100°C

Having around 60% of the energy from the FSEM expelled as thermal energy it is worth considering the option of an ORC to supplement the FSEM. It would not at this stage be considered an integral part until there is enough “spare” thermal energy to warrant it as it is more satisfactory to supply the required hot water.

If it were to be considered however the ideal case would be to supply the working fluid with around 100°C (depending on its evaporation rate) from the solar concentrator to the evaporator side of the turbine. When the turbine converts the thermal energy to mechanical to drive a DC motor the exhaust on the condenser side could be further cooled to preheat the inlet water preheated into the hot water exchanger and keep the cycle running such as in Figure 28. A Simulink model with a minor module being used and the desired temperature set to a 100°C output shows approximately 3x less working fluid (water) produced.

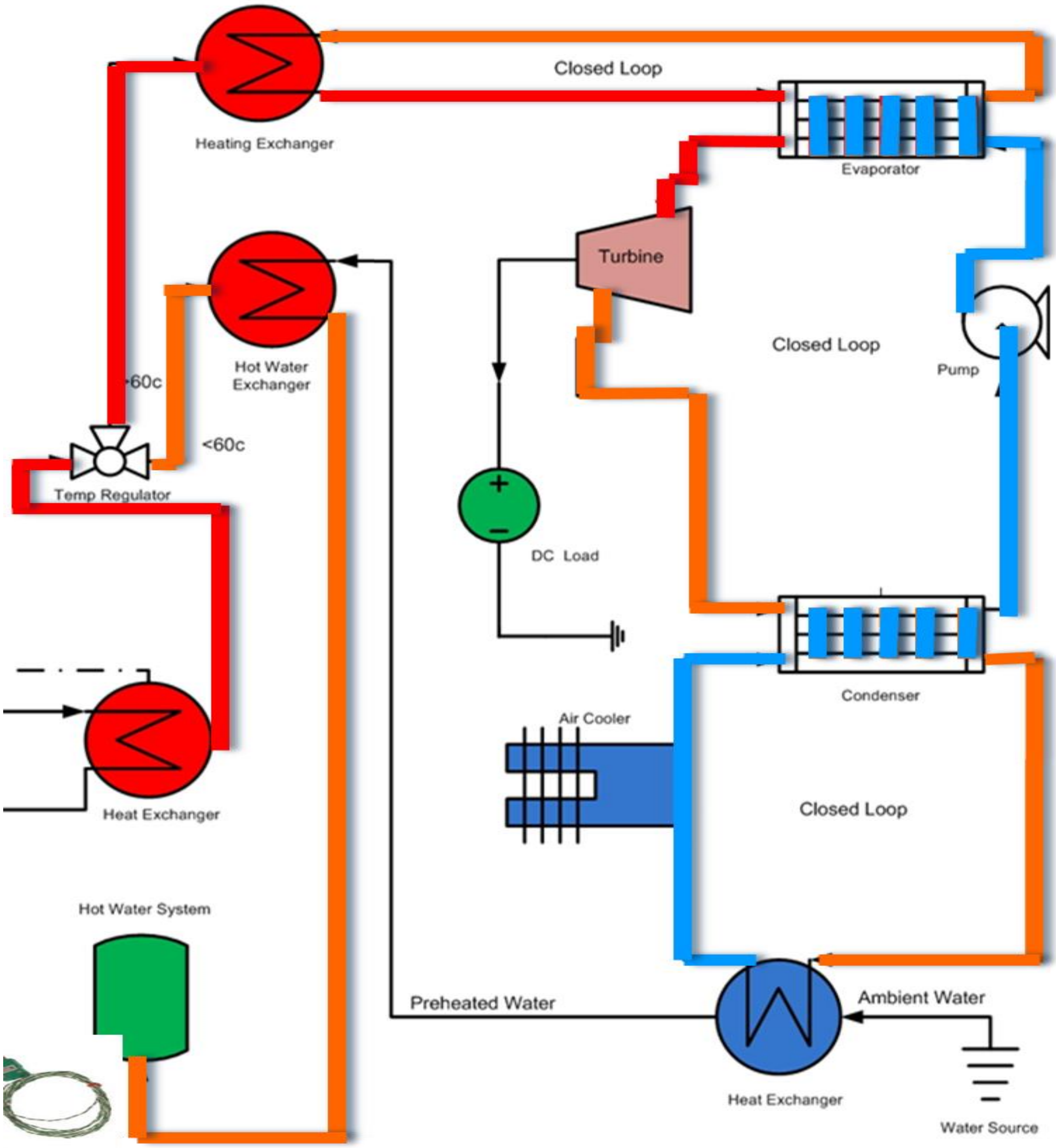


Figure 27: ORC incorporated into hot water system

However with further research a better working fluid could be used if it remains a closed system between the evaporator and the condenser to help with better efficiencies. (6) For this small type of module the iTmini Figure29 shows a delta T of a minimum 65 C for the machine to work using R134a working fluid. (36) The delta T relates to the change in temperature from the hot side of the turbine to the cold side. The unit has a capacity of 1kW and is something that could be attached to supplement the FSEM as a separate power system if it weren't being used to supplement hot water. It would also need the coolant temperature set to about 100°C similar to Figure 27.

Figure28: iTmini 1 kW capacity (36)

2.5 Data Acquisition

To determine the efficiency of the FSEM in operating conditions various parameters of the FSEM need to be assessed within the prototype's operating system. The measurement and observation of these parameters will not only assist in determining efficiency and energy transfer but also bring to light short comings and areas where the system can be improved. It is important to monitor as many parameters as reasonably possible which in turn separate the reference parameters of the system apart for individual analysis. The individual parts can then to be grouped together to sum a component and finally the sum of components to show the FSEM source efficiency.

2.5.1 Data Logger and Controller

Use of a data logging system is required to gather information about the performance of the FSEM. Initially the idea was to take data for analysis only; however it rapidly became clear that there would be a need for automatic adjustment within the FSEM to maximise the performance of the unit. The data not only gives feedback of what is taking place within the FSEM but is necessary to assist in live adjustments through the feedback to the FSEM like pump speed and tracker position for example. It would require a number the electrical input/output (I/O) readings to monitor and give feedback.

The ideal controller would require a unit that is cost effective, programmable and capable of many functions. Particularly for remote positioning, the controller requires the ability to send data via the web and store on a database ready for extraction and presentation through a web based output for mobility and remote access.

2.5.2 Sensors

A sensor is an object that measures a physical quantity that is converted to a signal that can be registered by an observer for a response or further processing. Early in history sensors were restricted to mostly nature when requiring a response to stimuli. Engineering developments have throughout history; evolved sensors from chemical and mechanical to the more recently and commonly used electrical outputs. While all sensors technically have an effect on the object they are taking measurement of, the quality of the sensor is based on the slight effect that it has. (41)

Focussing on the electrical input/output (I/O) for the purpose of testing there are two main types being analogue and digital. Analogue sensors relate to continuous measurements where digital is more accustomed to discrete measurements matched with time increments. Sensors sometimes need other signal convertors to translate into a common output so that it can be incorporated into a common display of results. To increase precision, more than 1 minor module of the same type will be tested for data to increase the spread. This will be stated as" multiple sensors" where each sensor function is described.

Solar Irradiance

Single sensor - Pyrheliometers / Pyranometers are generally all sensors that are made up of a type thermopile which is an electronic device that converts thermal energy into electrical energy. Given a 180 degree field-of-view assists for measuring the hemispheric solar radiation and address a previously mentioned a cosine-weighting function. Some of these types of these sensors use a small PV as a sensor to provide a predetermined reference voltage. Really depending on the device and model it is made up of either one or two transparent glass domes that are designed to protect the sensor from thermal effects. Desiccant is placed inside the sensor to remove moisture from between the glass domes to prevent interference as shown in Figure30.

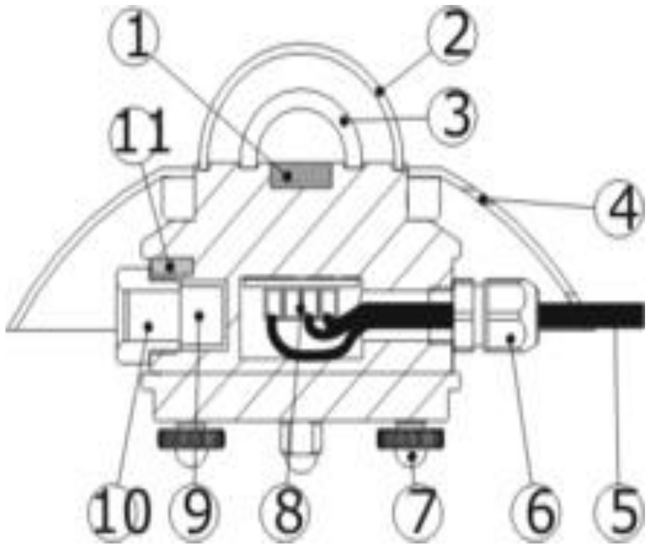


Figure29: Working parts (Image: Wikimedia Commons)

Significant aspects of the sensor are as follows. (1) Sensor, (2, 3) glass domes, (5) output cable (9) desiccant. Measurement is kilowatt per square meter and is a usually an analogue reading due to a small voltage output determining the measured reading. From this data output, the total efficiency of the unit as well as many smaller level equations are derived.

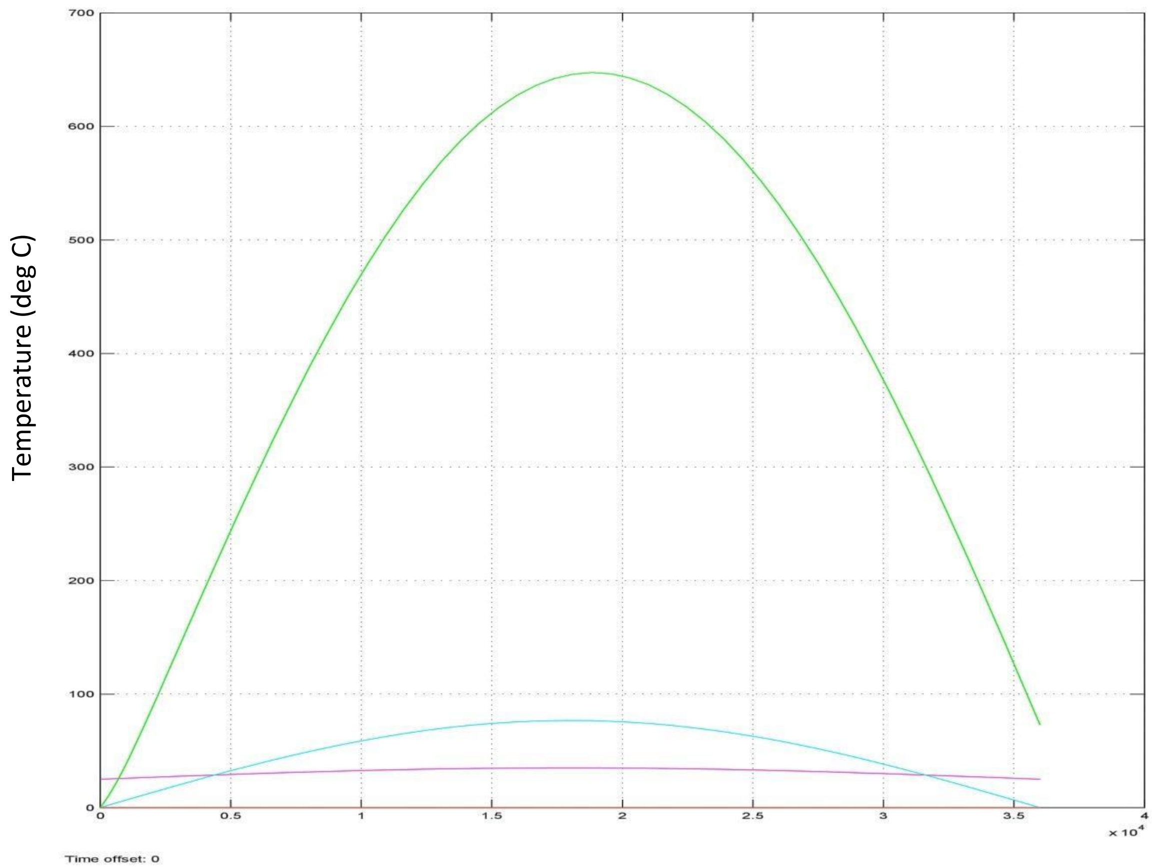
Temperature – ambient

Single sensor - For the best part, the ambient temperature is a reference point for deriving temperature changes in heat energy transfer. It also is an indicator for any variations in temperature that can be placed back on the environment that cannot be controlled. Variation in temperature will be relatively slow and will not require as precise logging. This would be suitable for a Resistance Temperature Detector (RTD) as they use the change in electrical resistance of metals with temperature as an output. The cheaper versions are made of copper and nickel and can be used up to 150°C. Platinum can be used to reach variations of -220 to 750°C but are obviously more expensive.

Temperature – concentrated

Multiple sensors - Measuring temperatures that have been manipulated by solar concentration will require sensors with far greater capabilities than those of the ambient temperature. Simulations with Simulink the temperature at the SCA after the concentrator and assuming the pump was not moving any coolant through the heat exchanger showed the temperature was extremely high, approximately 650°C in ideal conditions.

Cyan = solar irradiance (watts)
Green = output temperature (deg C)
Red = speed of pump (rpm)
Pink = ambient temperature (deg C)



Time (seconds)

Figure30: Coolant not supplied

Thermocouples as a sensor option are a good way of dealing with this variety of temperature measurement. The cost of thermocouples is lower than platinum RTDs and their response time is roughly 5x quicker. (41) A thermocouple operate by forming two wires of different metals or alloys together and fusing one of the ends of each which is known as the measuring junction. When a temperature differential occurs between the measuring junction and the reference junction that is at one of the free ends then a thermoelectric voltage known as the Seebeck effect occurs. It can be mathematically explained as

$$U_0 = f[(t_m - t_c) - (t_r - t_c)]$$

Where

U_0 = thermoelectric voltage

t_m = measurement temperature

t_c = temperature of connection point

t_r = temperature of reference element

The front side of the CSCRA needs be monitored to see how much heat is generated on its surface. To be used as a reference it will help to access to see how much solar energy is lost through any glass cover medium, reflective surface or magnifying mediums from the base measurement of solar irradiance. The ideal situation would be to use an infrared type of temperature sensor. This would prevent any interaction with the SCA and hindrance of the concentrated solar irradiation for a better measurement. The way this sensor works is by measuring the infrared radiation emitted from the object. The temperature of the object is calculated by the distance the sensor is from the point required to measure. That is to say if the sensor is 10cms from the object it will take an average measurement across a 10cm diameter and register it.

Voltage

The voltages will be measured to show when the CSCRA has reached it optimum specified level. The voltage shouldn't change much once a optimum amount of solar energy is provided and should around 2.5 V depending on load and according to Figure32 of the specifications.

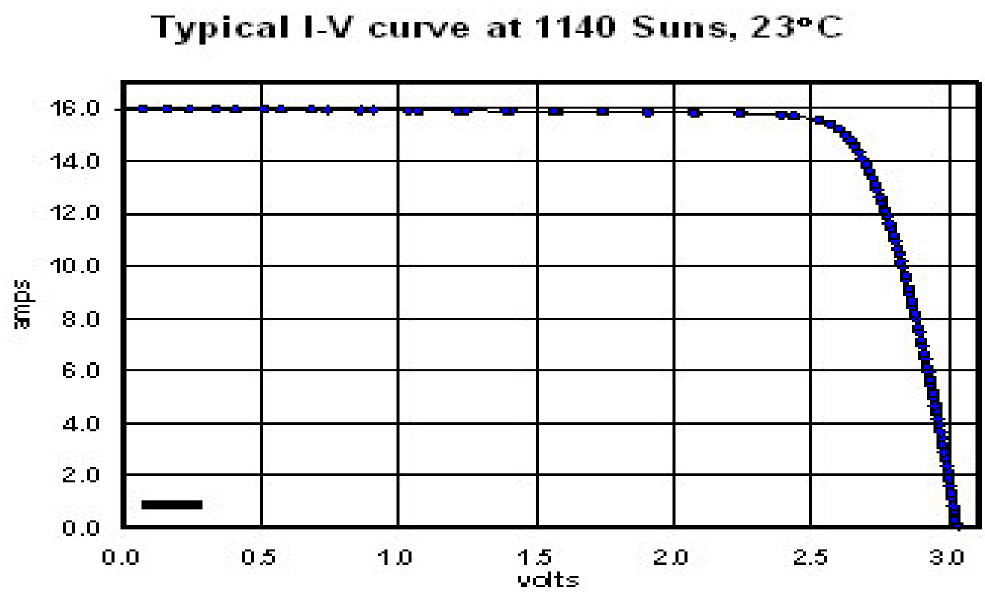


Figure31 Typical I-V Curve (22)

Current

The CSCRA will be connected to a load so that the current can be determined and with the combination of voltage be equated to provide the power output from the CSRA.

Rear side (Temp)

The rear side of the CSCRA is to be monitored to give data on the difference between the front side and the rear side. When aligned on a time basis should show the delay as well as loss to the atmosphere. It also stands as a reference to the front side of the heat exchanger.

3. Prototype design

3.1 Introduction

The design of the prototype essentially was based on the research from section 2 which helped to build a core construction route. Most of the components from this point are off the shelf and specifications are relatively easily accessed should further knowledge be required. This section goes through the key components that made up the prototype with a small explanation of each one's basic purpose.

3.2 Concentrated Solar

As the main input component in the system it is expected that the CSCRA have a majority positive or high gain of energy transfer. The expected breakdown in summary,

- Very High Gain

  Approx. 37% electrical conversion through semiconductor

  Excellent heat transfer through to the heat exchanger

- Very Low Loss

  Reflection of aperture

  Heat loss to atmosphere

It is important to be able to track these changes as the overall results will require solid measurements to prevent amplification of errors throughout the prototype.

3.2.1 Fresnel lens

The Fresnel lens is the key medium for concentration due to the difficulty of getting quality machining of the parabolic design to specification and not damaging the reflective sheets. Relying on the Fresnel lens gave some form of consistency with measurements in the form of creating a decent ratio of total input to output efficiency which can illustrate the concept. While the expected output from the Fresnel is a lot less than the parabolic concentrator it certainly not to be underestimated. On initial testing it went above the measuring capacity of the infrared sensor by reaching over 300 deg C. Positioning the CSCRA will require it be placed on a modified ceramic tile capable of high temperature In case of misalignment or focal overlap.

This also highlights many safety issues attached to the testing of the unit. When the unit is potentially operational a job hazard assessment will be required to highlight dangers for any working on the prototype. It also brings attention the need for an emergency position should the system lose control of the objective and a safety position is required forcing the concentrator to remove its access to sunlight. Achieving this position shall be set into the tracking controller through programming the controller should this eventuate.

3.2.2 Parabolic reflector

A version of the parabolic design will be trialled without using its full potential. Utilising the blocks machined for pressing the M2SP to the required shape Mylar highly reflective film will be fitted to try and replicate the design. It is not expected to reflect as well as the M2SP even though the reflective Mylar has highly reflective qualities itself and is under normal conditions very resilient to normal ambient conditions (42). The problem chiefly lies in the ability to attach it to the moulding block and making sure that it follows correctly the contours without getting air pockets and the film folding over itself. The reflective aspect of Mylar actually requires careful handing as it creases very easily which would cause issues with correct reflection.

3.3 Tracking system

Designing a tracking system requires care in the development of the system to minimise energy dependence yet also keeping the build costs down. The use of a brightest light seeking system which is the cheaper option has the motors always active which make it more energy demanding. The controller used in this prototype uses a preconceived algorithm of the suns exact position in relation to the tracking systems longitude and latitude and date/time previously discussed in section 2. The tracker is made up of a holding structure, motors and gearboxes all need to be capable of a certain degree of strength to handle various environmental aspects of wind dust etc.

3.3.1 Position Controller

The Arduino Solar Harvester Shield Controller (ASHSC) was developed by Gabriel Miller. The ASHSC has been trialled over time with a multitude of users and through a large amount of testing finally was able to reach a level of commercialisation. It has the ability to simultaneously connect to 16 individual trackers all from the single shield. The hardware is controlled by the EtherMega with the ASHCA and requires a number of programs to be down loaded and data initially entered. Once completed a small power supply is required to keep the EtherMega operational and simultaneously supplies power to the ASHCA.

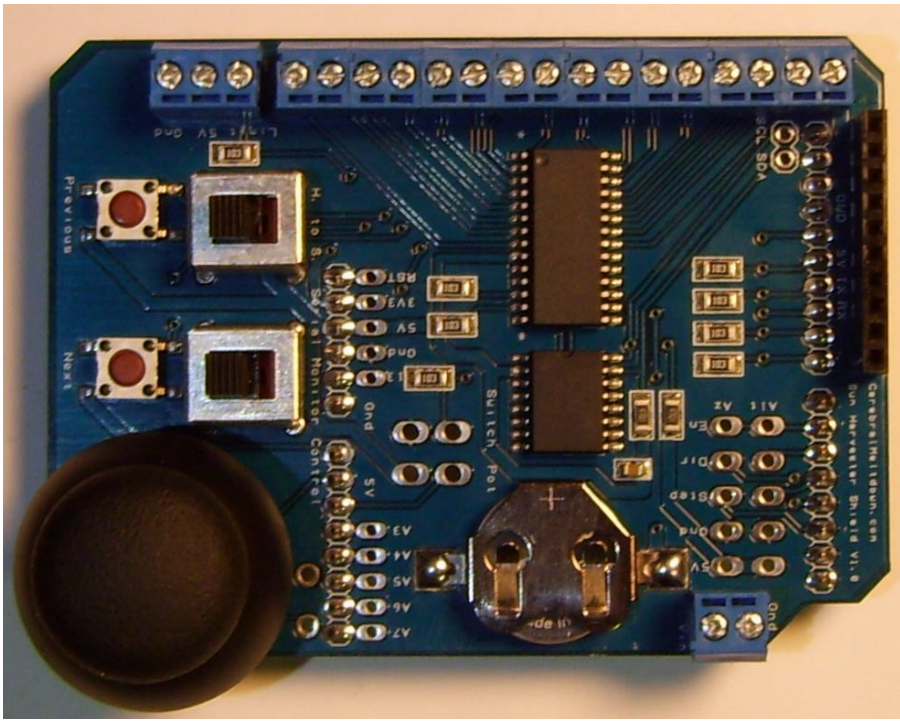


Figure32: ASHSC

At this point a sound knowledge of programming Arduino was required. The choice was to work with the Arduino hardware and its equivalents using its Arduino programming language. (43) The products help and open source section is limited only by its community and the tutorials attached to them making it very resourceful. The vast community of Arduino enthusiasts includes groups that are region specific groups and contains support through special interest groups. The community itself is as much the key as the programming language as it provides a large supply of assistance both in programing and project assistance.

3.3.2 Holding Structure

Building the holding structure was a case of finding material that was relatively hard wearing so that it can withstand a fairly strong wind and other weather conditions if need be. It was taken into account what aspect of the prototype would have the greatest wind thrust and so it was decided to build the solar concentrator in a height direction rather than in a width direction as the drive section of elevation would be much stronger than the azimuth through design of the gearbox.

Base

The base is made up of a modified laptop safe. It has very good strength characteristics and even when the hole was drilled to make way for the azimuth shaft it easily maintained structural integrity. Having a door attached to it from the side that was very secure, plays it role very well for protecting and holding other components like the controller and pumping equipment. Having pre drilled holes for attaching to a floor or wall gave the opportunity for easy access for cables and hoses that could easily be sealed with rubber grommets.

Azimuth

The baseplate for the azimuth was designed as a circular 4mm thick plate cut into a circular shape to remove any sharp corners and potential safety issues. Two holes had to be drilled as close to a central position on the plate as possible to prevent eccentricity when turning. To assist in maintaining the central position the plate was placed but not fixed to a heavy duty rubber/composite 6 kg base used for holding bollards in place for road works. Not being fixed directly to the metal base allows for a small degree of movement to compensate such as in bearing/ coupling structures and accommodate both angular and parallel misalignment. (44) The 305mm diameter circular swivel assembly from Bunning's provided the assistance in the form of a ball race. The ball bearing rollers are suitable for loads up to 300kg which is suffice for the smaller version of the prototype testing. The ball race is bolted directly to the top of the safe and assists in the ease of turning of the base plate.

Elevation

The building of the elevation structure was less complex than the azimuth because of the choice of gearbox and it far less requirement of freedom of movement. The structure was designed using 3 stainless steel heavy duty hinges that were connected in a triangle layout to allow for a continuous change in angle suitable for a linear actuator. It also allows the motor to pass through the centre of the main structure to reduce overall size. The final position for fixing the CSCRA test unit is to a pole that can have the units attached by U-bolt and allows a greater freedom of movement.

3.3.3 Gearboxes

By using a gearbox in the design means simply gaining a mechanical advantage of increased torque at the cost of rpm. Solar tracking systems move very slowly so it is in the best interest of design to take advantage of this. The two types of movement azimuth and elevation both through holding structure design were set up with different types of gearbox.

Rotational

The rotational motion of the tracking system was designed with the turning of the azimuth in mind with a full 360 ° movement. It seemed the best method as it gave a greater degree of movement on a much smaller footprint than the linear actuator type of gearbox. A wiper motor from a Scania truck was the used which internally was made up of a worm type gear box. Being a reduction type of gearbox it assisted in torque multiplying and through the worm design actually has braking capacity as the teeth on the worm wheel cannot move the worm shaft in most cases. Ideal for holding position for long periods of time if needed and reducing load on the stepper motor and enabling the controller to but it into rest position.

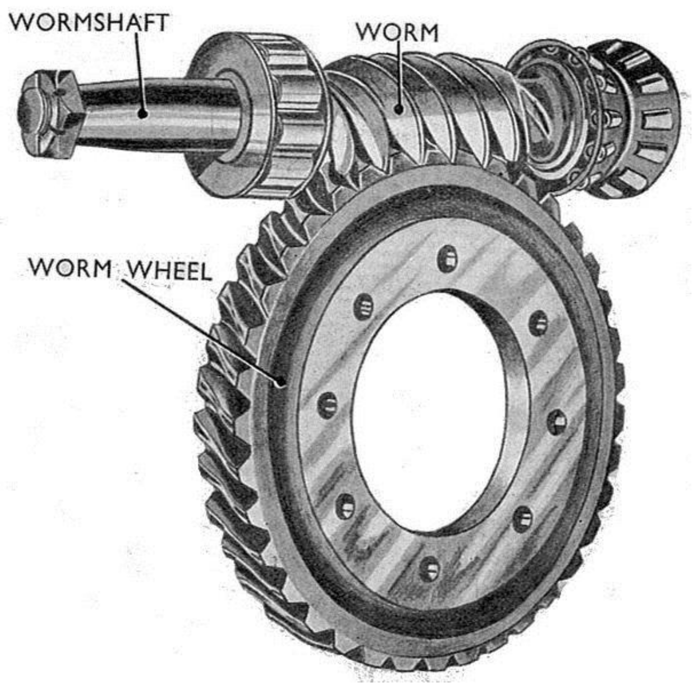


Figure33: Worm drive (45) (Image: Wikimedia Commons)

The stepper motor is attached to the worm shaft which allows for the worm wheel to turn a shaft connected to the baseplate in the previously mentioned azimuth aspect of the holding structure to move the concentrator to the desired azimuth position.

Linear actuator

One of the many rules of geometry states that if a triangles length increases or decreases only one side, that the internal angles of the three sides will also increase or decrease proportional to maintain 180 deg. (46) Using this basis a linear actuator is a device that pushes and pulls to create the movement that is required to changes these angles and therefore change the position of the solar array to the desired point. There are several ways of achieving this. This linear application is the basic make-up of the tip–tilt dual axis tracker; the concentrator sits atop a pole firmly fixed vertically to the baseplate. The tilt action is achieved by the linear actuator. The stepper motor rotary motion can be converted to linear motion through a lead screw drive system. The pitch, of the lead screw amounts to a linear distance travelled during a revolution of the screw. If the lead travels over one revolution 25mm with 200 full steps every revolution, then mathematically it can be said that there is 0.125mm per step. A greater resolution is possible if the stepper motor drive system is in micro stepping mode. (47) The gear mechanism acts as a brake when not operational which like the rotational choice of gearbox helps to reduce the effort of the stepper motor when in rest position.

3.3.4 Motors

With highly accurate and repeatable positioning it is an obvious choice to use a stepper motor. Using an electronic controller discussed further, electrical pulses are sent to the motor windings causing the shaft to turn either direction in multiples of a step angle as per the motors specifications. (48) The stepper motor also possesses the advantage of being controlled accurately in an open loop system. This means that there is no feedback information required to determine position. The position is tracked by the input step pulses. This is a desired of method of control as it reduces cost by removing the need for sensing and feedback devices. (49)

STEPPING MOTORS TYPE 60BYGH303-13								
SPECIFICATIONS								
PHASE	STEP ANGLE	CONNECTION STYLE	CURRENT	RESISTANCE	INDUCTANCE	HOLDING TORQUE	CLASS OF INSULATION	WEIGHT
	DEG/STEP		A	ohms±10%	mH±20%	N.m		Kg
2	1.8	parallel	2.8	1.5	7.5	3.1	B	1.4
2		series	1.4	6.0	30	3.1		
4		unipolar	2	3.0	7.5	2.2		

Table 11: 60BYGH303-13 specifications

The stepper motor comes in three basic types. In order of complexity it starts with the variable – reluctance, permanent magnet type and the Hybrid. The Hybrid 60BYGH303-13 is the one chosen for this concept as it harnesses the best qualities of the other two types at the only disadvantage of cost. They are constructed with a permanent magnet rotor, multi-toothed, stator poles. The

60BYGH303-13 motor has 200 rotor teeth which allow it to rotate at 1.80°step angles. It can run in either bipolar or unipolar mode depending on its application. It develops its torque from 3 main factors being the step rate, the drive current and the type of motor.

$H = \frac{N\,x\,i}{l}$ (49)

N = number of winding turns

i = current

H = Magnetic field intensity

l = Magnetic flux path length

By changing the wiring layout, the stepper motor can have very different torque rating regardless of the frame size of the motor. The two ways considered to connect the hybrid type stepper motor is in series or in parallel. High inductance occurs in a series connection and provides a greater torque at low speeds. Lower inductance occurs in a parallel connection which results in increased torque at faster speeds. Considering the stepper motor will not be involved in any high speed situations it would be the best to operate in a series type of arrangement.

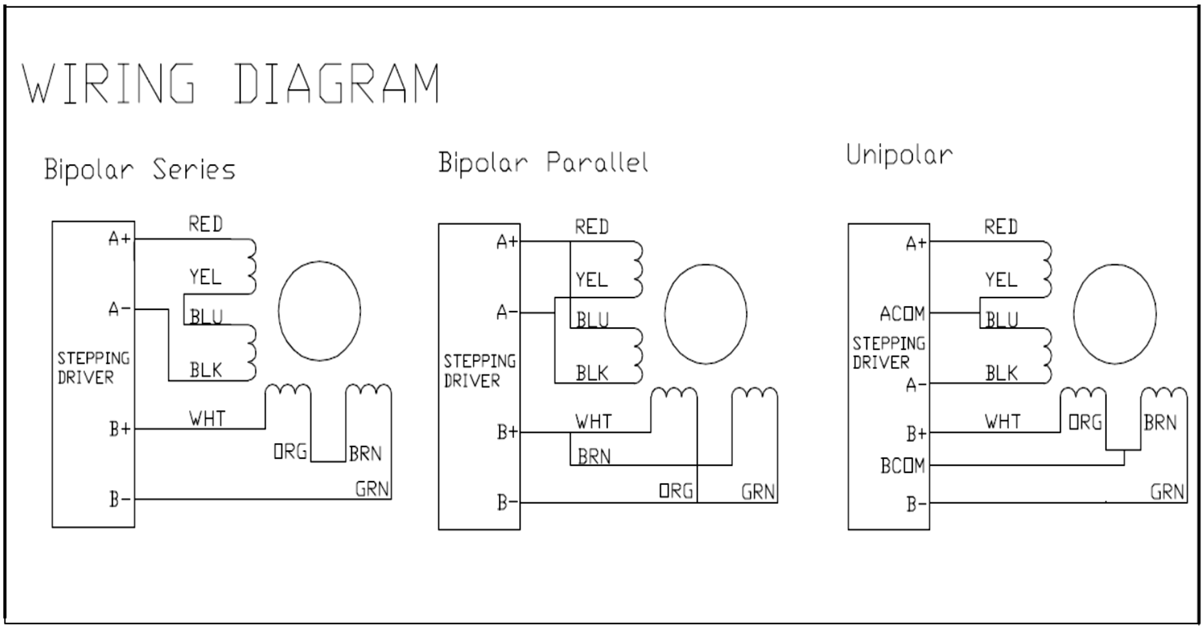


Figure34: 60BYGH303-13 wiring diagram

Motor Driver

The driver converts the controller signals into power which in turn is necessary to energise the motor. Even though there are many unique drivers, with different ratings in current and amperage, they are not all suitable to run all motor types. Designing the 60BYGH303-13 motion control system, the process for driver selection was important particularly its capability of "step modes". The step modes include Full, Half and Microstep. The CW230 2-Phase Micro stepping motor driver has stepper motor drives with switch selectable capabilities and is shown in Figure36.

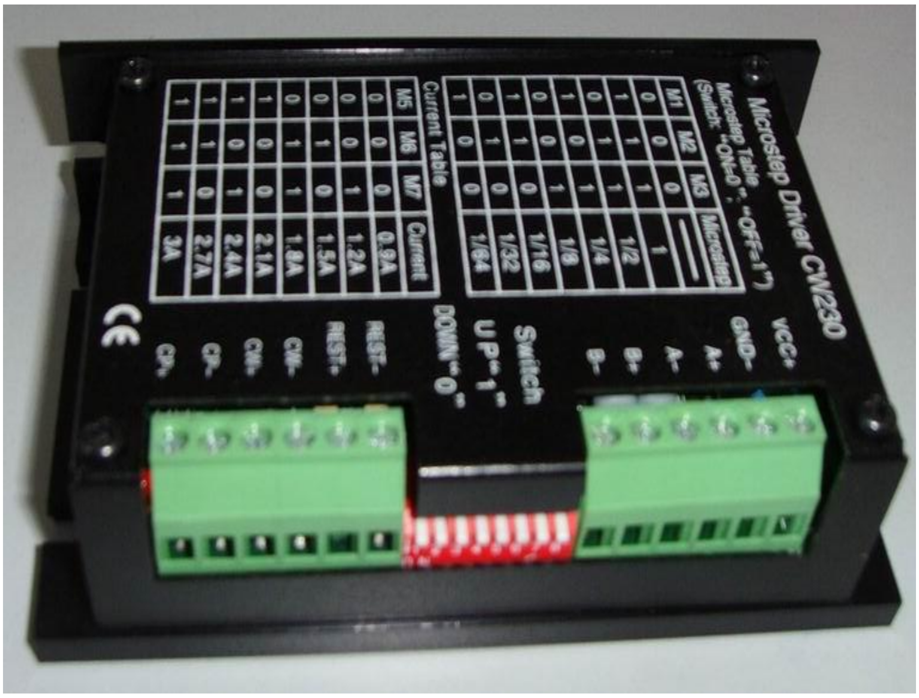


Figure35: CW230 2-Phase Micro stepping motor driver

FULL STEP

The 60BYGH303-13 stepping motor has 200 rotor teeth, which equate to 200 full steps per revolution of the motor shaft. Dividing the 200 steps into the 360° of rotation equals a 1.8° full step angle. The 60BYGH303-13 in full step mode would be achieved by having both windings energised and at the same instant reversing the current alternately which equates to one digital pulse from the driver equalling one step. (47)

HALF STEP

The step mode generates a change of 400 steps per revolution that the step motor is rotating. The step mode causes one winding to be energized and then two windings are energized alternately, causing the rotor to rotate at half the distance, or 0.9°. Approximately 30% of torque is removed however it produces a smoother motion compared to full-step mode.

MICROSTEP

When accurate positioning and smoother motion applications are required over a broad range of speeds micro stepping is the latest development. Similar to half-step mode, microstepping is affected by approximately 30% less torque than full-step mode.

Depending on the application and torque requirements which in this case require slow speed and high torque, the step settings need to be carefully chosen. To illustrate the point and analysing the rotational gearbox the following details can be determined.

Step angle = 1.8°

Gear reduction = 50:1

$$\frac{1.8^\circ}{50} = 0.036^\circ$$

The step angle is actually converted to 0.036°per step. So it will be the best option to keep the stepper from going into any mode other than full step, as it will provide maximum torque and with the angular position is still high precision.

3.4 Thermal transfer

The transfer of heat from out of the CRSCA is considered the activity that will result in the greatest energy loss in the system. Heat that can be >3 multiples higher than ambient temperature will be transferred and the opportunity to lose it will need careful monitoring to mitigate for energy loss or at the least measure it for further research.

Situations will be present where this just cannotbe avoided. For example the pumping mechanism will not be able to be effectively insulated to prevent heat escape. However the lines that feed and extract the coolant from the heat exchanger should be insulated as they provide a large potential surface area due to the design of piping systems which ironically enough are used in heat exchangers to transfer heat between two mediums.

3.4.1 Heat Exchanger

The chosen heat exchanger for this project is the CHC-125. It is designed to provide high efficiency liquid cooling for heat sources up to approximately 175W. This easily covers the theoretical 106W expected average per minor module. It is made out of a solid high-density copper cold plate, brass top, and anti-corrosive nickel plating. The CHC-125 also has 360-degree rotational sockets; enabling the use of 1/4 BSPP threaded fittings of any diameter and type. It is advised to use coolants to prevent biological growth and issues that pertain from mixed metals. On that note certain metals can't be used together as they will interact, similar to a battery and create corrosion within the unit.

Figure36: CHC-125

3.4.2 Pump

To control the speed of each pump to match the varying temperature a small variable speed dc motor circuit was designed to be controlled by the EtherMega as shown in Figure 40. Combining knowledge from various electrical power units over the course of university study and specifications by manufacturers, the circuit was developed using an N-MOSFET module which gives the ability to switch high-current loads using a small microcontroller.

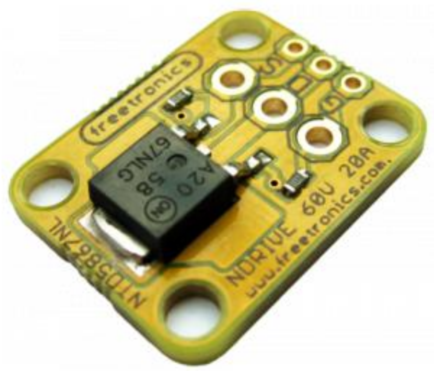


Figure37: Ndrive from Feetronics (50)

Figure38: peristaltic pump (51)

The power provided to the pump has to overcome the inertia of pump mechanism as well as try and simulate the pump speed control system researched in the Simulink model. The controller would receive temperature readings as analogRead() code giving values between 0 and 1023 in 10 bit. It would then have to then activate the Ndrive through analogWrite() code with values between 0 and 255 or 8 bit to adjust the voltage at the gate. So a code was written to proportionally scale back the reading from analogRead() by dividing it by 4 before it can be used to set the motor speed through the analogueWrite() code.

The actual pump capacity as seen in Figure39 as a peristaltic dosing type of pump, has a capacity of 500mls per minute which would be enough if fitted to each minor module to cater for the Simulink model. (51)

3.4.3 Storage

Using expected capacity modelled by Simulink and multiplying it by 4 (the expected size of the prototype), an ample 2 x 100 litre containers will be used to simulate the hot water storage systems. The ideal situation would be to use containers that are insulated to reduce the amount of heat transfer from the hot water lost to the atmosphere.

The idea will be to pump from container 1 through the heat exchanger into container 2 over the course of the day. Tank 2 will then cool during the day and night before transferring back into tank 1 to repeat the cycle.

3.5 Data Acquisition

The idea for this prototype was to use a device that could both collect data analyse it and then make informed decisions based on this data to then make the appropriate changes to the system constantly. Such devises in the past have been expensive. However with the development of low cost equipment it seems these devices play a part in the overall cheaper component statement made prior.

3.5.1 Data Logging/Controller

Freetronics supply a cheaper and more option orientated Arduino clone of the Mega 2560 known as the EtherMega. Being a powerful and fully programmable board it has 16 analogue Input/Output (I/O) and 54 digital. With a very accurate and capable internal clock for timing of I/O data it conveniently matched with more than enough I/O to spare for data logging.

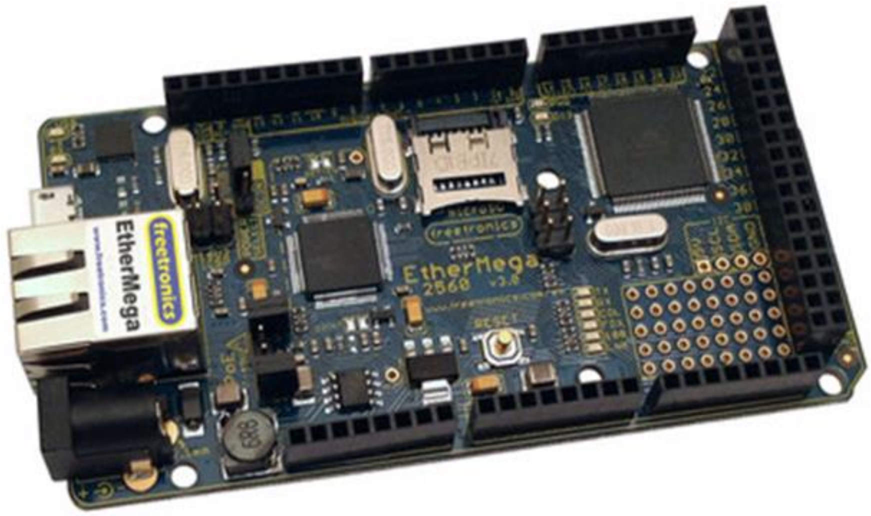


Figure39: EtherMega (50)

3.5.2 Sensors

The energy input to the FSEM is made up of the Concentrated Photovoltaic (CPV) and heat exchanger components which in sum are expected to be positive gain which need to be maximised and the losses minimised. It also has a negative component being the dual axis tracking system. The Dual Axis Solar Tracker (DAST) can only have a negative effect on total efficiency as it is a power draw due to its mechanical and electrical operation.

Solar radiation-ambient

This sensor was kindly loaned by Murdoch University and mounted on the DAST creating the reference output for the multiple minor modules. It was initially a concern as to what sort of accurate readings the unit would have as the sensor was basically a polycrystalline cell that was calibrated against another more sensitive unit. The fact that the bandwidth of the solar spectrum was quite limited as mentioned in earlier research lent its self to not having very accurate readings across the complete spectrum. I was assured that would be ok during clear and near perfect conditions.

Temperature – ambient

This DS18B20-based 1-wire bus temperature sensor module is easy to connect and use 0.5°C accuracy and fast response. It has the following specifications which make it ideal for measuring ambient temperature.

- -55 to +125°C temperature range
- +/-0.5°C accuracy
- Selectable 9 or 12 bit precision
- Arduino compatible library and examples support
- Unique device ID coded into every sensor
- Two sets of header connections to allow easy daisy-chaining
- Dimensions: 23(W) x 16(H) x 6(D)mm

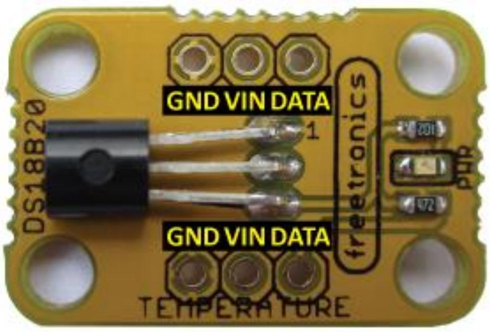


Figure40: Temperature sensor (50)

Temperature - SCA

Using an Infra-red device will prevent physical blockage to the apertures solar input from the concentration sources. The reflector system will have it sit at the bottom of the parabolic dish looking up at the aperture. The Fresnel system will be on an opposite corner, on the diagonal looking down to the aperture.

Figure41: Infra-red temperature sensor (50)

Temperature - exchanger inlet/Exchanger outlet

Wire Type K Thermocouple. It requires further hardware to convert its signal through amplification so that the controller can read it and output a satisfactory response. The thermocouple measurement range sits from below minus 40°C to over 250°C.

Figure42: Wire type K thermocouple

4. Financial feasibility

4.1 Introduction

A feasibility study is designed to both rationally and to objectively determine the strengths and weaknesses of a proposed venture or an existing business. It should expose threats and opportunities current in the environment, the resources needed to convey through, and finally the visions for success. The two key criteria to evaluate feasibility are cost required and value to be attained

To initiate a well-designed feasibility study the following should be considered; (52)

- historical background of the business or project
- comprehensive description of the product or service
- financial and accounting statements
- operations and management details
- Policies and marketing research
- Tax obligations.
- legal requirements

Normally feasibility studies will lead project implementation and technical development.

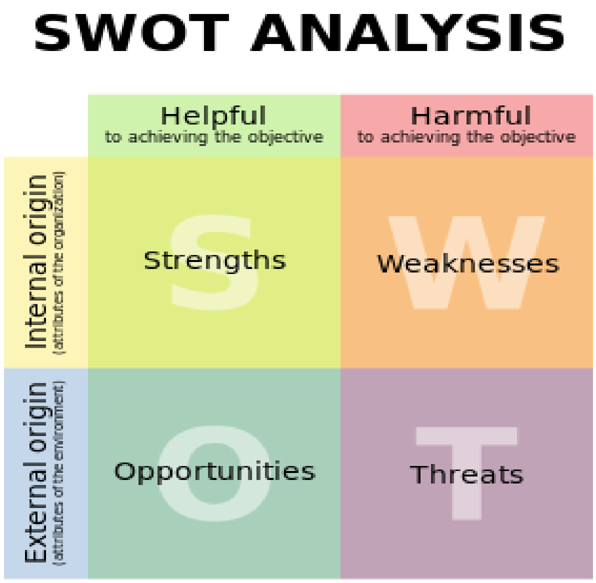


Figure43: Swot analysis (52) (Image: Wikimedia Commons)

A feasibility study gauges the project's probability of being successful; this is strong reasoning for obtaining assumed objectivity as it is a significant factor in the integrity of the study for prospective investors and lending institutions. The study must therefore be conducted with an unbiased objective, approach, to provide the relevant information to which decisions can be determined.

4.1.1 Proof of concept

Feasibility of a new type of product in engineering and technology with regards to a rough prototype of a novel idea is often assembled as a "proof of concept". Furthermore to apply a patent application can demand a demonstration to show that there is functionality before being processed. (53) The Australian government has a proof of concept for innovative ideas that are partial reality but just need extra assistance to turn to prototype and help to enter the market. The financial incentives 50:50 match if successful include the potential to provide case managers and networks to help promote the proof of concept. The applications again highlight the importance of a well-structured feasibility study. (54)

4.2 Governance

The concept of governance is to highlight the fact that there are many rules and regulations that are associated with being an energy provider should the venture become successful. These could be considered as threats to the development of a prototype in the guise of additional costs to maintain the standards required.

4.2.1 Economic Regulation Authority

The Economic Regulation Authority (ERA) ensures that Western Australian consumers are getting quality services in economic services for a fair price. The object of the ERA is to maintain a fair commercial environment that is competitive and efficient. This applies especially where a business may operate as a natural monopoly. It is achieved by regulation of third party contact to gas, rail infrastructure and electricity. It is monitored through controlling licenses for gas, water service and providers of electricity. Surveillance of wholesale electricity market in WA's and undertaking inquiries on a wide range of economic issues are also part of the ERA's agenda. (55)

4.2.2 Wholesale Electricity Market (WEM)

On 21 September2006 the government of the day decided to commence the Wholesale Electricity Market (WEM) in Western Australia for the South West interconnected system of (SWIS) following a reform of the state's electricity industry. Initiated in 2001, the electricity reform process comprised disaggregating Western Power Corporation the state-owned and run body into four separate entities. The intentions of WEM are to generate competition and develop private investment and allow wholesale purchasers of electricity (such as retailers) and generators more flexibility for the procurement of electricity. (56)

4.2.3 Design and compliance obligations

Attention needs to be directed to the various standards and legal requirements so that specifications do not conflict with Australian/New Zealand Standards and the implementation of any relevant legal framework. To give a demonstration of requirements the following is extracted and condensed from the handbook, Solar & Heat Pump Hot Water Systems (57)

- **Water connections**

All water supply connections in solar hot water systems must be made by an installer holding the relevant state or territory plumbing licence.

- **Gas connections**

Where the system is connected to a gas booster, all gas connections must be made by an installer holding the relevant state or territory gas-fitting licence.

- **Electrical connections**

Where the system is connected to an electronic controller or general power outlet, all electrical connections must be made by a person holding the relevant state or territory electrical licence.

- **Compliance certificate**

Requirements for plumbers to provide a certificate of compliance to the authority with jurisdiction over the installation of water heaters and to the householder will vary across states and territories.

- **WaterMark compliance**

The WaterMark is a statement of certification of compliance with required specifications and Standards. The compliance is in accordance with MP 52–2005 (Manual of authorization procedures for plumbing and drainage products.

4.3 Business development

To enhance sales and business development, it is often beneficial to allow a prospective customer to receive a potential end product to trial. This use of proof-of-concept helps to suggest overall direction, to isolate technical issues, and to establish viability, whilst providing feedback for market direction, budgeting and other forms of the decision-making processes. In this situation, the proof of concept will need constant hands on support to assist in technical shortfalls, enhance consumer optimism and to make sure that the potential long term customer is making the effort to maximise the prototype potential.

A SWOT analysis threat that needs special attention is the knowledge of the competition when piecing together is part of the feasibility study. Based initially in Western Australia it gives the advantage of having access to the competition. Primarily due to a lot of the competitors being actually government operated entities. The clear advantage is that access to operations and cost is relatively freely distributed for public scrutiny.

4.3.1 Western Power

Western Australian State Government owns the Western Power owned corporation. Its purpose is connecting people through electricity and enhances the fact that that it is done safely, affordably and reliably. Western Power is responsible building, maintaining and operating the electricity network in the south west corner of Western Australia as shown in Figure45. Western Power forms a large majority of the South West Interconnected Network (SWIN), which together with all of the electricity generators comprises the South West Interconnected System (SWIS).

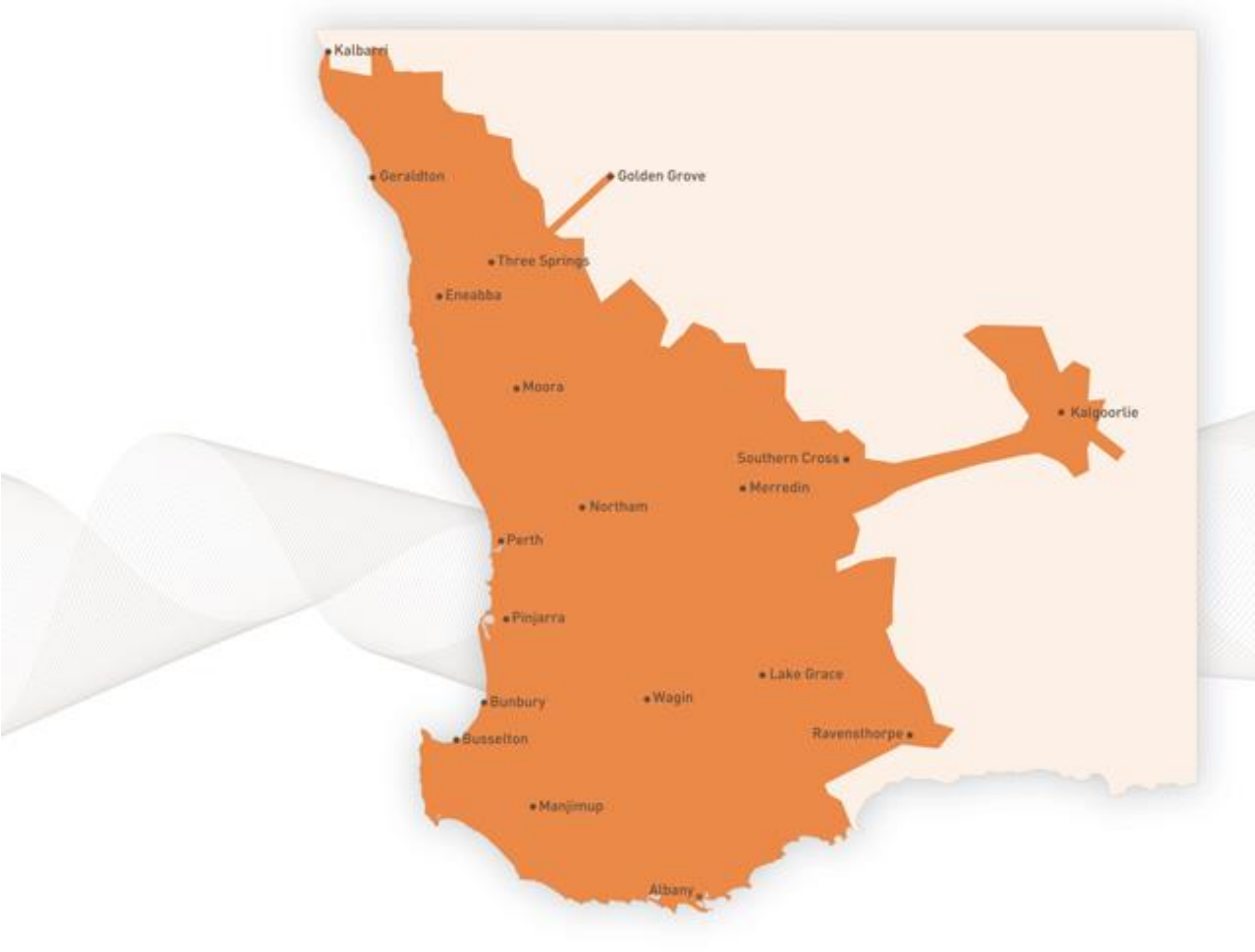


Figure44: SWIS layout permitted Use of copyright Material according to Western Powers terms and Conditions

261,000 square kilometres is the total area the SWIN covers. The National Electricity Market (NEM) which is made up of a series of interconnected networks, covers all other major Australian urban areas, the SWIN however is a self-contained network that is isolated from others. This issue with is that consumers electricity within the SWIS at all times must be delivered by the SWIS. It cannot rely on any support or reserve. (58)

4.3.2 Horizon Power

Horizon Power is also State Government-owned Corporation with a commercially-focused attitude that tries to provide reliable power to approximately 10,000 businesses and 100,000 residents, which includes major industry and mining, across remote and regional Western Australia. Horizon Power is unique in that it is responsible for all aspects of power supply. Horizon Power 45,164 customer connections as of June 2013 spans in the Pilbara, Gascoyne, Mid-West, Kimberley and southern Goldfields regions. An of area of 2.3 million square kilometres has the Horizon Power service dispersed all over it. As shown in Figures. (59)

Figure45: Horizon Power services permitted Use of Copyright Material according to Horizon Power terms and conditions

4.3.3 Star and Garter Hotel

Being positioned in Kalgoorlie WA gives this e establishment the unique advantage of being on the SWIS network therefore having bargaining ability for the best supplier that uses it. It also is in an area that has a good daily solar irradiance. (60)

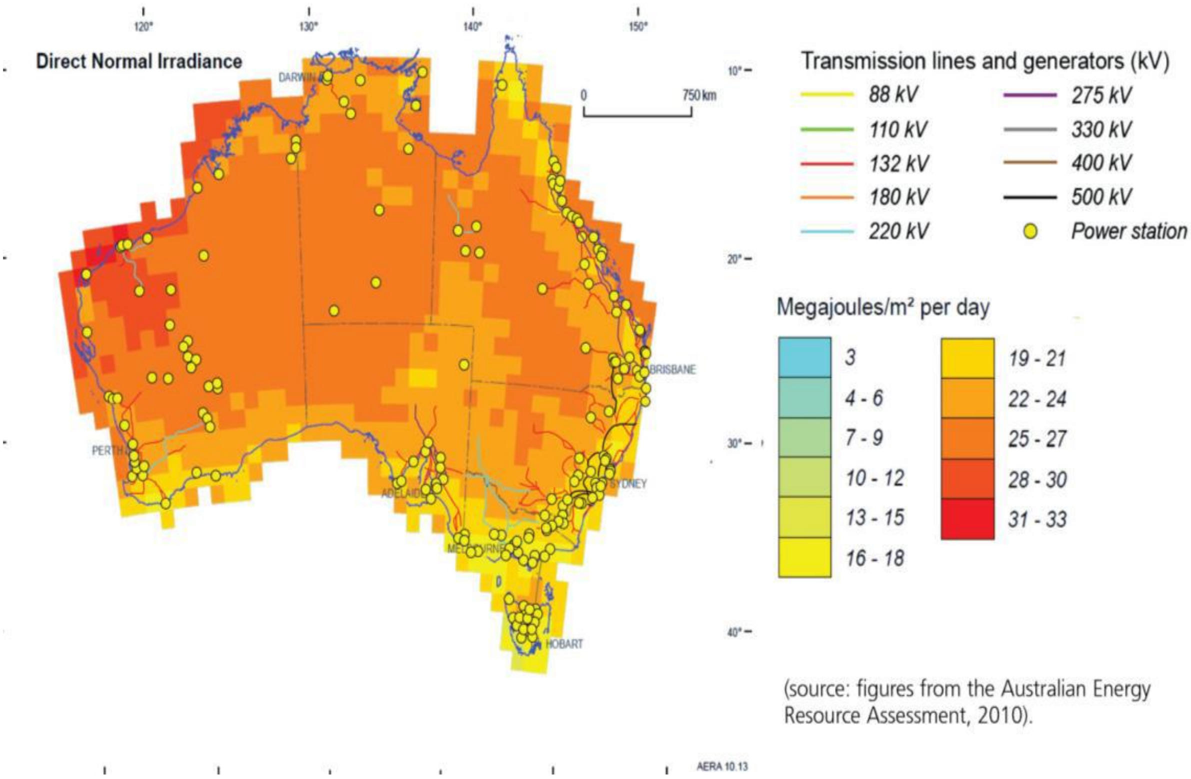


Figure46: DNI and transmission lines (provided under a Creative Commons Attribution 3.0 Australia licence)

A feasibility study was carried out on this location as it has the competitiveness of being on the SWIS system and a good source of solar energy. The proprietor has agreed with providing the necessary information to assist in developing the required inputs as well as potential positioning for a prototype.

The hotel has four individual land lots that make up two Taverns and a total of 59 motel type units. It is a fairly good representation of a large residential living type of arrangement where the customers are predominately mine workers. It is expected to follow similar trends with eating time, showering, entertaining etc. These aspects are expected to be portrayed in the peaks and troughs of the daily energy consumption.

4.3.4 Whitehouse Hotel

Being positioned in Leonora WA restricts this business from any form of bargaining for energy supplier. Fixed to the Horizon provider, Leonora is powered by Horizon Power and is supplied by gas power generators that were opened in January of 2000. (61) This type of power supply while being cheaper than a diesel powered version causes the utility rate to be higher where there is no off-peak option such as when connect to the SWIS system.

4.4 Homer 2.81

Homer is an acronym for Hybrid Optimisation Model for Electric Renewables. The reason that I chose HOMER to run simulations is because it has a variety of different energy systems of which an operator can compare the results and get a realistic projection of their capital and operating expenses. It has the advantage of other systems by simultaneously running configurations simultaneously and ranking them accordingly. (62) This is extremely useful for tweaking various outputs and inputs of the configuration without too much effort.

The original design started where the storage system was actually a battery that was converted to simulate fuel cells. Recently however the system has been updated due to Homer 2.81 being available and a far more realistic version of the storage system was portrayed.

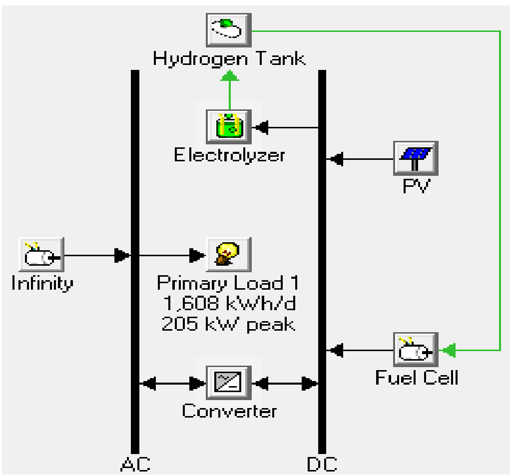


Figure47: Opening screen

The opening screen is set up as in Figure48 and the operator begins adding the required inputs and outputs as a particular element based on the specifications of each element. Each element can be manipulated individually and has degrees of variance to help the model be more fluid and realistic in its results. The following inputs and outputs are a quick summary of how the configuration was designed.

4.4.1 Primary Load Inputs

The design of the primary load was supplied by the Star and Garters electricity supplier at the time. Initially the data was supplied in 30min increments over a 365 day period that had to be reconfigured to make 8760hrs. After loading in to Homer it gave an overall view of electricity consumption for the year as shown in Figure49

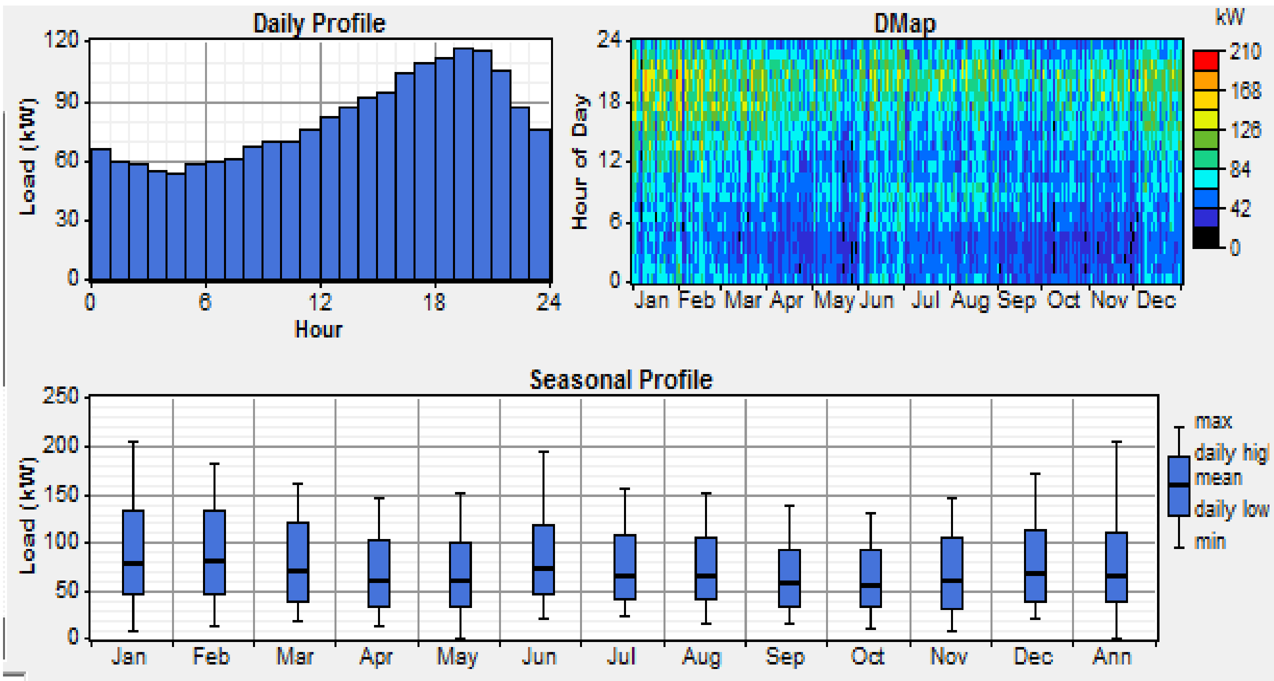


Figure48: Load profile

This aligns to what was expected as it shows most of the energy consumption towards the end of the day due to the expectation of people coming home for the day after work and using hot water systems to shower, using cooking apparatus as well as lighting and televisions etc.

4.4.2 PV

The data to create this input was designed to try and replicate a CPV with cogeneration capabilities in this case the FSEM's CSCRA and its heat exchanger. Homer does not address this situation so to try and compromise an assumption was made that 25% of energy consumption is put to heating water and a further 37% to space heating/cooling (5). To account for this cost variation per kWh for the PV, it was decreased by an over compensated 30%. The extra energy generated out of the PV did not consider a timing when reflecting on daylight hours to use for heating.

4.4.3 ORC - Infinity

Again as there is no thermal output benefit that can be directly attributed to the FSEM's cogeneration system, the timing aspect of the FSEM was incorporated into a generator so that it can be applied to the primary load. By designing a generator that runs on a fuel (diesel) that costs nothing allows for the remaining heat power to be used. Assuming the FSEM will take some time to actually warm up the generator was set to only be allowed on after 12pm. There is a physical cost attached to each kW that the generator produces to incorporate a potential heat engine like an ORC.

4.4.4 Fuel Cell

The basis of this system is to simulate a hydrogen fuel cell system by manipulating a generator to give a similar an output. Using the 59% peak efficiency (63) for a 1kW as in the Horizon fuel cell, a generator was designed by varying the slope (kg/hr/kW output) allowed to gain the same efficiency to be reached. The basic running system of the unit is the same as a generator that would be set to follow the just enough to meet the load.

4.4.5 Convertor

The convertor was a standard DC - AC unit that was selected from a large variety of products giving it fairly common inputs for generating its efficiency and cost.

4.4.6 Hydrogen Tank/Electrolyser

These two components which are not actually part of this study are separated for the functionality of Homer. However they are currently under design and to be part of the structural aspect of the modular system as a combined unit. They have incorporated a cost that has been shared amongst other units to help spread the real overall cost to help make the system more realistic.

4.4.7 Sensitivity Results

The sensitivity results show a more realistic outcome of the system than previously used. It has a higher NPC however is more realistic in line with the requirements of a feasibility expectation. The outputs also determine various shortages that could be experienced to make the system more economically viable. They are displayed in table 11 for illustrative purposes

Max. Cap. Shortage (%)	PV (kW)	DGen (kW)	FuelC (kW)	Conv. (kW)	Elec. (kW)	H2 Tank (kg)	Efficiency Measures	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	DGen (hrs)	FuelC (hrs)
0.5	375	150	150	140	325	400	No	$ 636,321	11,068	$ 744,984	0.130	0.73	0.01	60,162	1,750	3,626
1.0	375	150	150	120	300	350	No	$ 622,351	10,593	$ 726,356	0.127	0.71	0.01	64,059	1,847	3,608
3.0	425	150	90	100	350	300	No	$ 554,630	11,183	$ 664,421	0.117	0.73	0.03	56,267	1,488	4,176
5.0	375	150	90	80	300	275	No	$ 513,547	9,715	$ 608,932	0.108	0.61	0.05	85,992	2,458	3,939

Table 12: Sensitivity output.

4.5 Future work

Although some intricate research into the development of the FSEM prototype has been carried out there are considerable amounts of additional research that should be carried out to further develop the FSEM prototype. Primarily the stage 2 and 3 discussed in 1.1 the Project aim need more research carried out to become more realistic and assist in the decision for getting it closer to production capacity.

4.5.1 Homer model discrepancies

It must be acknowledged that this model is by no means entirely accurate. It is more to demonstrate the ability to work different systems and provide a rough guide to assist in determining whether further research is a viable option in the future. There are short comings in this design that must be clarified to highlight this point. As the development of the other stages of the system are realised especially in the form of mass production, then more accurate conclusions can be drawn and input data becomes more relevant.

4.5.2 Additional revenue streams for FSEM

No additional revenue streams were identified for the islanded HOMER case. While mentioned earlier it would be advised to investigate further the full benefit of the RECs. It would be an idea to investigate whether or not a collection of more than If these additional revenue streams result in a large reduction of the NPC of the islanded option, it will be necessary to re-evaluate whether the grid connected option is still the optimum solution.

4.5.3 Excess Electricity

According to HOMER all simulations will generate a considerable amount of excess electricity that the system cannot use simply because of the nature of renewable energy generation and not necessarily requiring the storage or not capable for later use. It could then be considered for sending back to the grid or selling to nearby operations.

4.5.4 Regulatory governance

It was mentioned that part of feasibility study certain regulations will need to be adhered to. It would be essential to research this further to understand completely all of the aspects of regulatory governance and try to determine the advantages and disadvantages.

4.5.5 Software simulations

Simulink and SolTrace are only responsible for the information that is entered. To generate a more reasonable process, greater extensions of the software should be encouraged to instigate more realistic approaches. For example in the Simulink model the inclusion of variations of real data rather than just a simple cosine wave would be more effective in data output. Soltrace could have been better utilised by designing a Fresnel equivalent to determine outcomes.

4.5.6 Cassegrain reflector

Adjustments to the original design should be investigated to try and make it a reality through higher end engineering practises. . Most common in the parabolic design it took a longer than reasonable amount of time to finally understand the desired product only to find the supplier wasn't capable of producing the product. Various other methods were suggested however it is not expected to get the same quality.

Restriction related to time and money prevented further investigation at this level. It would be useful to further investigate as it is the source that is a key part of the prototype considering the rest of the prototype is controlled by it.

5. Conclusion

Using various types of specialised software, a design for a solar concentrator was completed showing the process of manufacturing to be more difficult for the parabolic/hyperbolic design than first thought. Primarily due to limitations of the approached suppliers and the amount of time that was allocated to resolving the issue, it was suggested to be investigated at a later date and given more time.

Using the data collected from the theoretical version, the efficiency of the systems heat transfer after the CSCRA was further tested with Simulink and SolTrace to give an indication of what to expect once the prototype was developed. The outlook was positive with an expected greater than 130 litre output at 60 °C for hot water and a greater than 100°C for running an ORC type heat pump. It would be required that the results be corroborated with the prototype to clarify and to help support the efficiencies acquired.

Due to issues with the parabolic/hyperbolic system, the Fresnel lens was used to check to see if the data from the software simulations would correlate in a “real world” scenario through a prototype design. The prototype is a dual tracking system that is controlled by a programmed Ardunio unit which acts as both controller and data acquisition. It is in its final stages of being completed and the comparisons when the experimental results from the prototype will be added as appendices in the near future when requested.

Using the acquired data an ORC system was investigated but deemed unsuitable at this point focusing on the use of heated water solely. It was considered that it would be a better option as the consistency of the heat output may not be enough to warrant the cost of the plant until a larger capacity prototype was built.

To replicate the prototype to a larger system, research and knowledge was gained about feasibility studies and the pitfalls that need to be avoided. Special mention was made to the regulations of the energy industry. The system was then put through a HOMER 2.81 optimization to see how it would perform with some real life data. The outcome was positive by being very competitive of the cost of current energy suppliers to the commercial entities that were simulated. However the whole system depends on the development of the remaining aspects of the fully completed prototype and the source (stage 1) is only the collection of solar energy. Although positive, this development should go further to include the storage (stage 2) and the supply (stage 3) aspects with more research in the future.

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7. Appendices

Appendices are to be added as results become available.