School of Engineering and Information Technology

ENG470: Engineering Honours Thesis

Photovoltaic Training Facility – Upgrade and Performance Evaluation at Murdoch University

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Abstract

This project focused on upgrading the Photovoltaic Training Facility installed on the rooftop of Murdoch University's School of Engineering and Energy building. This objective included the addition of a new battery and inverter into the system as well as a change in design configuration for optimal efficiency. The project also focused on the improvement of the monitoring, evaluation and documentation aspects of the system's operations.

In order to achieve its objectives, a literature review was first done, which included information on the previous upgrades done in phases to the PV Facility over the years. The literature review also included options for batteries and inverters. The best-suited equipment for the purposes of this project were chosen. Additionally, international standards for system monitoring, analysis and documentation were compared, namely the IEC 61724 Standard and the APVI standard. Then, parameters for monitoring could were chosen, and these included irradiance, ambient air temperature, module temperature, voltage, current and electric power. These parameters' measurement procedures were detailed. Three test methods for evaluation of the PV facility efficiency were discussed: edge seal durability, photovoltaic system performance and energy evaluation. Lastly, the process for documentation via a monitoring log was described.

The methodology for completing the upgrade to the PV Training Facility included five (5) in steps: design configuration, equipment selection, equipment approval, matching PV array and inverter, and design installation. For the battery, the Aqueous Hybrid Ion S30-0080 Battery Stack was chosen, and for the inverters, the Backup Inverter MultiGrid 3000VA and Fronius Galvo 2.0-1 were chosen.

The final design configuration includes two inverters; one multimode inverter connected to the battery storage and the second one is grid-connect inverter connected to the PV array. A total of 22 modules were determined to be needed for the new system, 5 were placed in series and 4 in parallel. Further, the two extra modules need to be removed or disconnected from the array configuration. 4 AHI S30-0080 battery stacks in series were also included in the design. The design operated in 2 ways. Firstly, during normal conditions, the system maintains a charge to the battery unit. Secondly, and during disconnection from the grid, the system is capable of providing the user with an alternate supply of the specified load generated from the PV array and/ or battery. For this reason, an interconnection switching device was also included in the new design since it is more complex than the old one.

The performance was analysed using the APVI standard, by measuring the following parameters: specific array yield, final PV system yield, reference solar yield, array capture losses, performance ratio, array efficiency, PV system efficiency. The inverter efficiency was determined to be approximately 94%. During performance monitoring, it was decided that the PV arrays needed to be cleaned to remove dirt build up on the surfaces. This, as well as shading by trees, created disruptions in the performance analysis.

The project concludes by identifying that a majority of the components in the PV training facility work effectively but there is one inverter that is not operational and that manifests problems in relation to compatibility with the available software. The performance analysis conducted also illustrates that there are arrays that are located in a manner that is not suitable to support data collection for performance analysis – for instance due to shading and irradiance.

Author's Declaration

I, Omar Nasser AL Sidairi, do hereby declare that the current work is an original work product and I conducted all research and writing of the task. Investigation and reporting of findings were attempted to be carried out following Murdoch University standards of research and writing. Furthermore, all the conceptions and relevant sources which have contributed within this report which borrowed from other authors are referenced accordingly, and acknowledged.

I declare that the work I am submitting in this paper is my personal composition and it has not been submitted for assessment in other course.

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Data: 14/07/2019

Signature:

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

A	Ampere
APVI	Australian PV Institute
AC	Alternating Current
ADAM	Advanced Data Acquisition Model
AHI™	Aqueous Hybrid Ion
CEC	Clean Energy Council
DC	Direct Current
E&E	Engineering and Energy Building
EEPV	Engineering and Energy Photovoltaic
IEC	International Electrotechnical Commission
KWp	kilowatt 'peak'
KW	Kilowatt
MPPT	Maximum Power Point Tracker
MMS	Murdoch MET Station
PR	Performance Ratio
PV	Photovoltaic
RTD	Resistance Thermometers
SQL	Structured Query Language

τs	Sample Interval
τr	Recording Interval
VA	Volt Ampere
V	Volt

Chapter 1: Introduction

1.1 Background Information about PV Training Facilities

The Photovoltaic (PV) Training Facility was installed in 2012 on the north-east rooftop of Murdoch University's School of Engineering and Energy building. The facility's main goal is to allow students and researchers to analyse the performance and behaviour of PV technologies and inverter topologies [3]. The PV Training Facility will also contribute in some specialisations at Murdoch University for example, Renewable Energy Engineering (ENG337 and ENG442) and Industrial Computer Systems Engineering. The following Figure 1 adapted from a constructed drawing of E&E Building, which represents a block diagram of the PV facility.

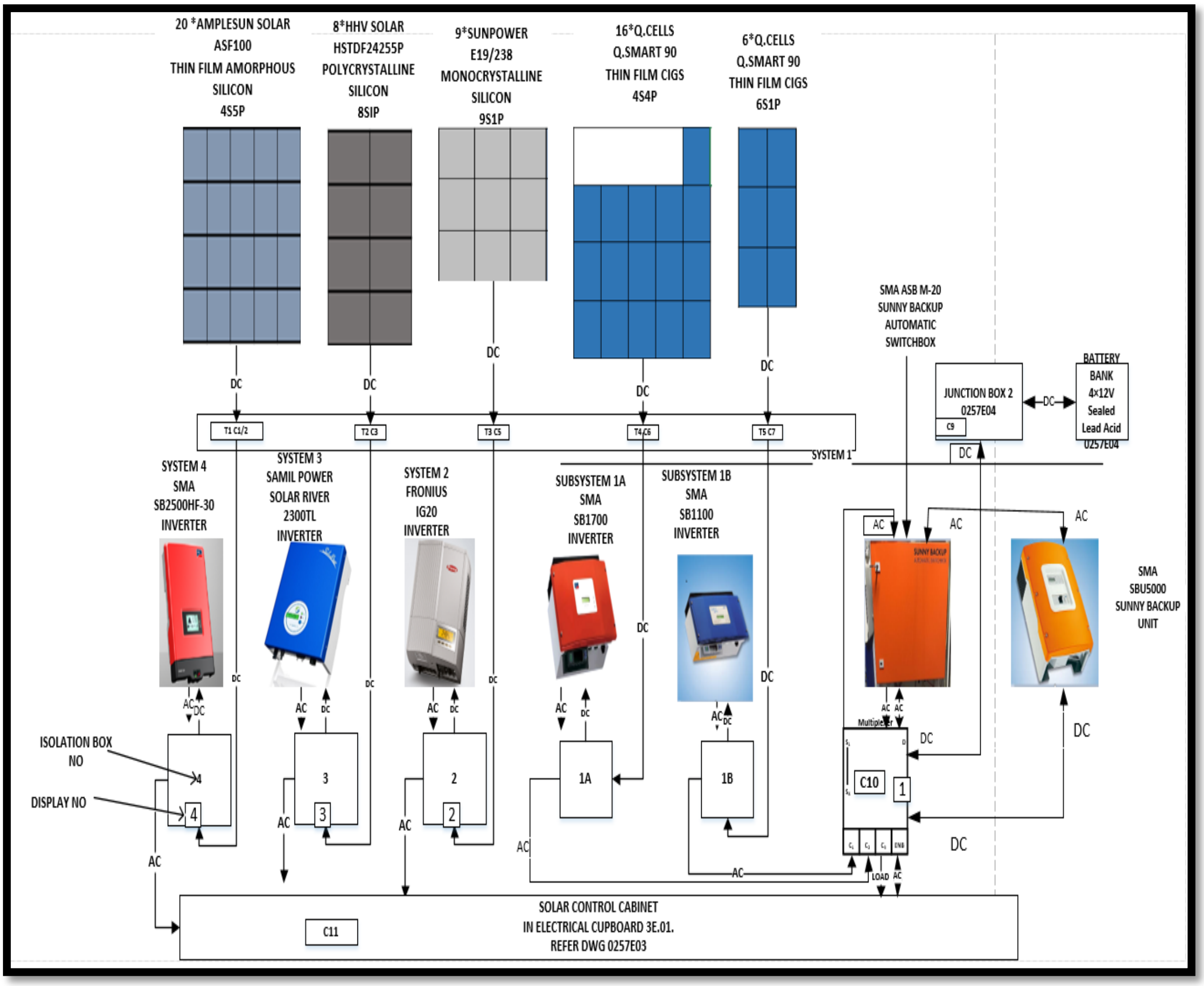

Figure 1: Engineering & Energy Building Solar System Block Diagram [2]

1.2 Aims and Objectives

The main objective of this project is the upgrade system 1(Figure 1) which consists of the multimode inverter system part of the facility, including the evaluation and an investigation of various battery and inverter option .This can be attained through the following specific objectives:

- To check the data requirement for this system to install the new inverter and battery.
- To select and study the best design configuration of grid-connected PV systems with battery storage.
- To calculate the results from matching PV array and Inverter and using it to PV array configuration.
- To determine the required size of the battery by studying the design criteria for sizing the battery bank.

The second objective is monitoring the performance of the system 4(Figure 1), evaluation and documentation. This can be achieved by:

- To study the Australian PV Institute (APVI) system performance monitoring – Guidelines for measurement, data exchange and analysis.
- To obtain the current LabVIEW based monitoring software.
- To determine the performance of the array.

1.3 Significance of the Project

The designed project scope includes the upgrade, design, development and analysis of the PV Training Facility at Murdoch University. In the upgrading system 1, a multimode inverter, grid-connected inverters and battery bank will be replaced. The LabVIEW program will be used for monitoring and analysing the performance of the system 4, which contain SMA SB2500HF-30 inverter and Amplesun Solar ASF100 Thin-Film Amorphous Silicon module.

1.3 Thesis Outline

This Thesis report is divided into six chapters which consist of:

- Chapter 1 covers the background information on PV Training Facilities and a description of the research focus. Aims, Objective and significance of the project are also included in this chapter.

- Chapter 2 contains the present literature, an overview of the PV Training Facility and phases of building/upgrading the PV Facility. Specifically, it will consider the review of the inverter, battery concepts and option for upgrade. Finally, this chapter provides system performance monitoring, evaluation and documentation.

- Chapter 3 explore the methodology of the project design. Firstly, design configuration, equipment selection and approval. Then, matching PV array and Inverter, the calculations and results are reviewed. Finally, the design installation.

- Chapter 4 include performance evaluation. In this section, the Australian Technical Guidelines APVI standard is utilised in monitoring as well as analysis of the Photovoltaic System that has been developed. Further, the IEC Standard IEC61724 adaptations are utilized as a reference to the manner in which performance will be evaluated on this project. Information on recording and monitoring intervals is presented in relation to the measured PV data and based on the APVI standard. Parameters (including specific array yield, final PV system yield and array capture losses) are analysed using specific formulas for the individual parameters since each parameter has distinct elements (or components) from it is derived.

- Chapter 5 discusses the results of the design installation. It also provides the performance evaluation results.

- Chapter 6 will conclude the project Thesis and provide some future work suggestions for the PV Training Facility at Murdoch University.

Chapter 2: Literature Review

2.1 Phases of Building/Upgrading the PV Facility

In 2012, the initial design had a rated capacity of 8.2KWp and consisted of four PV arrays. These included the following four types of PV modules: mono-crystalline silicon (SunPower E19), poly-crystalline silicon (HHV), amorphous silicon (AmpleSun) and copper indium gallium selenide thin film (Q.Cells) modules [4]. The following Table 1 is a summary of PV system components and electrical characteristics of the PV modules.

Table 1: Training Facility PV Modules Components and Characteristics [5-7]

PV MODULES				
Electrical Characteristics	Sun power E19/238 Monocrystalline Silicon	HHV Solar HSTDF24255P Polycrystalline Silicon	Amplesun Solar ASF100 Thin Film Amorphous Silicon	Q.Cells Q.SMART 90 Thin Film CIGS
Nominal Power (+5/-3%) P_{nom}	238 W	250 W	100 W	90 W
Voltage (Rated) V_{mpp}	37.3 V	34.5 V	73 V	60.75
Current (Rated) I_{mpp}	4.73 A	7.2 A	1.29 A	1.47
Efficiency η	19.1%	12.65%	6.3 %	11.25 %
Short Circuit Current I_{sc}	6.25 A	7.79 A	1.65 A	1.67 A
Voltage (Open Circuit) V_{oc}	48.5 V	43.3 V	99 V	76.5 V
Maximum System Voltage $V_{max,sys}$	1000 V	_	1000 V	1000 V
Power Temperature Coefficients (P)	-0.38% K	_	-0.20% °C	-0.38 +/- 0.04 %K

The system includes four types of SMA Sunny Boy inverters (SB2500HF, SB1100, SB1700 and SBU5000), one Samil Power SolarRiver 2300 TL inverter and one Fronius IG20 inverter. Other necessary equipment included Lead-acid batteries, current transformer and circuit breakers [4]. The three emergency stop contractors are located in the test area of the solar control cabinet. One contractor is located near isolation box and the other two conductors are near junction boxes JB1 and JB2. To isolate the power system, from the test area for all the systems can be operated by pressing any one of the three emergency stop buttons [8]. The following Table 2 is a summary of PV system inverters Specification and Characteristics.

Table 2: Specification and Characteristics of PV System Inverters [5, 8]

INVERTER MANUFACTURER	SMA	SMA	FRONIUS	SAMIL POWER	SMA
System No.	1A	1B	2	3	4
Model	SB 1700	SB 1100	IG20	Solar River 2300TL	SB2500HF-30
Topology	Low-Frequency Transformer	Low-Frequency Transformer	High-Frequency Transformer	Transformerless	High-Frequency Transformer
Input (DC)					
Max. DC Power	1850 W	1210 W	2150 W	2300 W	2600 W
Max. DC Voltage	400 V	400 V	500 V	550 V	700 V
PV Voltage Range, MPPT	139 V- 320 V	139 V- 320 V	150 V- 400 V	200 V- 500 V	175 V – 560 V/ 530 V
Max. Current	12.6 A	10 A	14.3 A	11 A	15 A
Number of MPP Trackers	1	1	1	1	1
Maximum. No of Strings (Parallel)	2	2	2	2	2
Output (AC)					
Nominal AC Power	1550 W	1000 W	1800 W	2000 W	2500 W
Maximum AC Power	1700 W	1100 W	2000 W	2200 W	2500 W
Max. Current	8.6 A	5.6 A	8.7 A	11 A	14.2 A
Nominal AC Voltage /Range	220 V- 240 V/ 180 V- 260 V	220 V- 240 V/ 180 V- 260 V	180 V – 270 V	230 / 180-270 V	220 V, 230 V, 240 V / 180 V – 280 V
Power Factor (cos)	1	1	1	1	1
AC Connection	Single- Phase	Single-Phase	Single-Phase	Single-Phase	Single-Phase
Efficiency	93.5%	93.0%	94.3%	96.8%	96.3 % / 95.3 %

Since 2012, the facility has been updated to include new monitoring equipment. Part of the physical design of the PV Training Facility was the design and experimental testing of a monitoring system in order to record, store and communicate data related to the PV systems' performance as well as environmental data. The long-term goal of this system is to be able to compare and optimise different inverter topologies and PV technologies under different environmental conditions. The sensors chosen to be included in the monitoring system are pyranometers, anemometers, temperature sensors for both ambient temperature and module temperature, a wind vane and communication interfaces for inverters [3]. The sampling rate, logging intervals and accuracy requirements of these sensors were considered when selecting them.

The pyranometer chosen was an SP Lite Silicon cell pyranometer due to its high accuracy, high stability, fast response, and low-temperature dependency. RTD temperature sensors were chosen since they are highly accurate and stable. RTD PT100 Class A sensors were chosen to monitor the ambient temperature while RTD PT 100 Class B sensors were chosen to monitor module temperature. The wind speed sensor chosen due to its long-term reliability and calibration stability was a #40C anemometer from NRG Systems with an optional meanest calibration. NRG System also manufactured the #200P wind direction vane that was chosen due to its low maintenance and simple design [3].

The data acquisition system was necessary in order to collect the data from the installed sensors. The monitoring platform, LabVIEW, was chosen, and therefore, equipment had to be compatible with this. Advantech Adam RTD I/O modules were chosen due to their low cost, small size and easy to program protocol [3]. They also did not require logging, storage capacity or a microcontroller. There were two additions to the final design: a counter I/O module was added to sample wind speed from the two anemometers, and an analog I/O module was added to sample high-resolution solar radiation [3].

In addition to the sensors and data acquisition system, it was important to choose a communication interface to be able to establish communication between the inverters and the LabVIEW program. The option chosen was the RS 485 interface which was to be used for all the inverters. One advantage of this interface is that the SMA inverters could be connected in series using the same protocol [3]. However, the Samil and Fronius require their own protocols. The initial design of the monitoring system required the above-mentioned changes in order to successfully obtain the desired results and communication pathways.

After the initial designs and installations by Kempin (2012) and Riou (2012), many researchers and students attempted to improvise the existing monitoring system and data acquisition system of the PV Training Facility in 'Phases_of final year industrial computer systems projects.' In 2015 during 'Phase 1', Colson et al. (2015) reviewed and attempted to improve on the design suggested by Riou (*2012). It was discovered that the inverters were not connected to the LabVIEW computer and an incorrect comms card was installed for the Fronius inverter [9]. It was also discovered that sensors were not installed on the solar panels. Thus the data collected with ADAM data acquisition would be simulated data [9]. This phase of the project did not see the successful connection of the inverters.

In 2016, the two major goals were: to set up communication between the inverters and the LabVIEW program in order to monitor real-time data related to power generation, current and voltage, and to install a number of sensors outside the facility in order to monitor basic parameters. In 'Phase 2' of 2016, Augustine et al. (2016) did not focus on the SAMIL inverter since work had been done on this previously. There was successful communication created between 4 SMA inverters and the program, but only data from one of them (SB2500HF-30) was being read. The capture speed of the ADAM modules was improved from a 2.5s interval to a 0.8s interval [10].

In 2016, Augustine et al. (n.d) aimed to fix the problem with other 2 SMA inverters. They discovered a Sunny Explorer software that allows a direct connection from the PC to the inverters via RS485. A program 'Sunny Data Control' was installed as an alternative. The communication cable from the SMA inverter to the computer was changed from 4 to 2 wire. Like in phase 1, no progress was made with communication from the Fronius Inverter. The Samil Inverter connected to proprietary software on the computer but not to the LabVIEW program [10].

In 2016, during 'Phase 3', another project aim was added in addition to the ones from Phase 2 projects. This was to include the transducers in the sensors installation in order to allow values from the inverters to be compared to those from the transducers. There was progress made on the SMA and Fronius Inverters as their official windows interface were located, and communication was established with the LabVIEW program. Ear et Al. (2016) confirmed operations of the ADAM modules but discovered that the wrong type of anemometer was being used and ordered it to be replaced with a module that was supported with a digital output. The EEPV database was set up containing columns for inverters and transducers [11].

In 2017 during 'Phase 3', work was done by Wheat et al. (2017) allowed for successful continuous data processing from the Samil 4 inverter. In order to do this, the group created a two-part LabVIEW program. These two parts are the 'initialization' part and the 'steady state' part. Another focus of phase 3 was the Integra 1430 digital displays, which measure values for voltage, current and power quality of the inverters. The group also managed to achieve successful communication between the computer and the Integra 1540 digital displays, which shows potential for allowing data to be read into the LabVIEW program on the computer. This was done using a converter and software which was available for free download [12].

In 2017, during 'Phase 4', Tottman et al. (2017) aimed to log data from the Integra 1540 digital meters and compare them to the inverter logging data. Another objective of this phase was the resolution for the backup system, which was not in operation. The backup unit can provide limited backup power in case of a grid fault. This battery bank comprised of four 12V 105Ah batteries connected in series with an output of 48V and 105Ah capacity. However, it was not providing adequate energy and placed two inverters in an error state, which then impacts the system output. The issue was initially hypothesised to be a battery issue, and it was discovered that there was an overuse of energy. The battery bank was being depleted due to its improper protocols for battery protection level and the wrong battery input parameters in the system. The battery protection parameters were initially set to the default levels. The battery capacity was also recorded incorrectly to 520Ah where it should have been 105Ah. The proper parameters were inputted [13]. There may also have been issues with the switch box leading to the disconnection of the inverter and consequently depletion of the battery.

2.2 Review of Inverter Concepts and Option for Upgrade

The current inverter system, as mentioned previously, comprises of five different types of inverters: 3 types of SMA Sunny Boy inverters (SB2500HF, SB1100 and SB1700), 1 Samil Power SolarRiver 2300 TL inverter and 1 Fronius IG20 inverter. Only System 1 is not operational and required an upgrade-the need to meet new AS4777 requirements. There are also issues with monitoring and documentation capabilities of the system due to the inverters compatibility with available software.

There are several inverter options to consider when choosing the inverters to be used within the PV facility. One possible configuration is the use of two inverters as laid out in Figure 1. This configuration comprises of a grid-connect inverter and a multimodal inverter. The former is connected to the PV array while the latter is connected to the battery. Further, these two inverters are connected, as well as connected to the grid and specified loads through the use of an interconnection switching device [1]. This type of connection provides the system with the functionality similar to that of a grid-connected PV system while also providing, for selected AC loads, a basic ‘backup’ functionality. Some of the functionality that this system would provide is the ability, without the need for the battery to be fully charged, to export any PV generated energy to the grid. Further, the system may also be used to reduce the cost of electricity used as well as also being set up with the potential to provide on-site power to augment and offset peak loads [1].

The system configuration is more complex than the current configuration and thus requires the use of an interconnection switching device; the choice of this device may include either range from the use of a manual change over switch to the use of an automatic device. Functionally, the configuration operates in two main ways; firstly, during normal conditions, the system maintains a charge to the battery unit. Secondly, and during disconnection from the grid, the system is capable of providing the user with an alternate supply of the specified load generated from the PV array and/ or battery. As such, the interconnecting switching device works to manage the various required interconnections, depending on available conditions.

2.2.1 Grid-connected Inverter

This inverter is connected to the interconnection switching device from the AC side as well as being connected to the PV array on the DC side. As such, the inverter will be used to generate a regulated AC from the PV array which is then either fed into the grid or the battery [14].

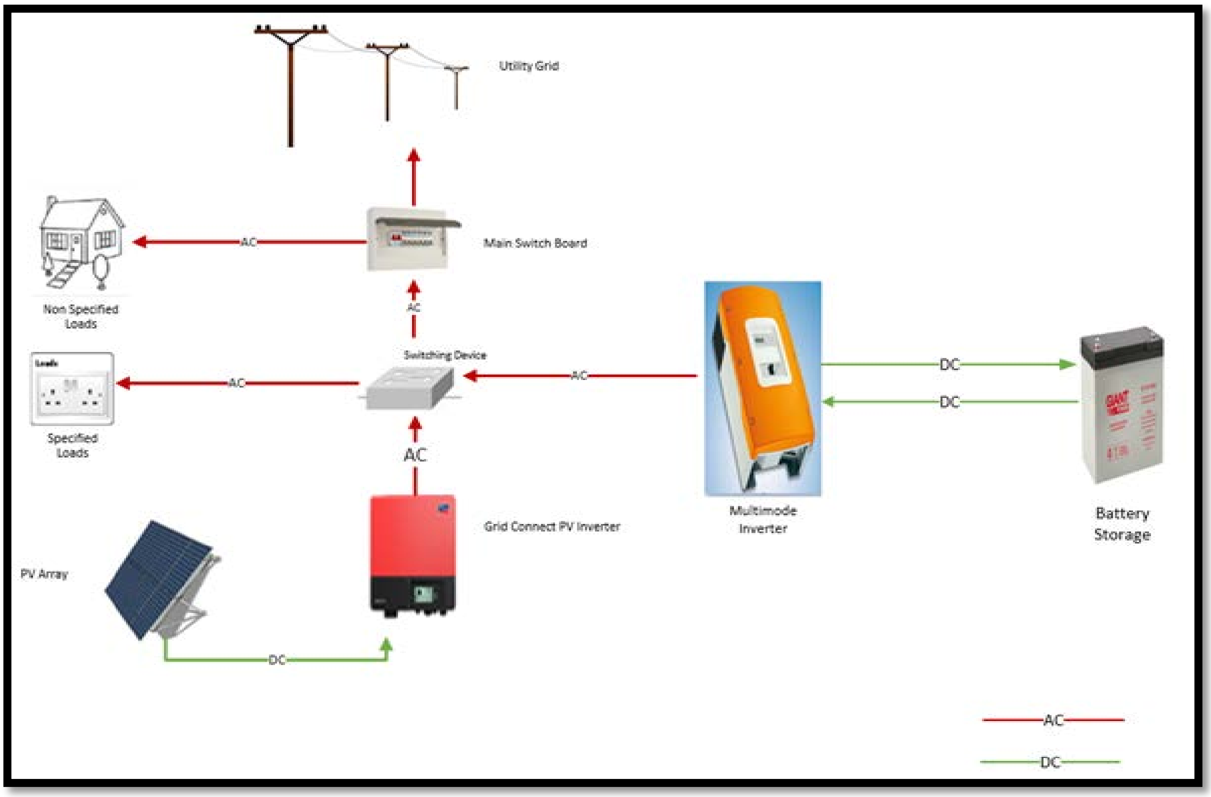

Figure 2: Two Inverters and a Switching Device Configuration [1]

2.2.2 Multimodal Inverter

This inverter is connected with the battery from the DC side as well as also connected to the interconnection switching device. Further, this inverter does not include a solar controller, but has battery charging capabilities [1]. Therefore, in normal grid conditions, the inverter can manage battery charge through the use of the interconnection device. As such, the multimodal inverter will charge the battery by using power from the grid. Should grid conditions be abnormal, the inverter will supply the specified loads through the use of the interconnection device. As such, if the power generated from the PV array is insufficient in supplying the specified loads, the inverter will provide the required power from the battery storage [1]. Further, within abnormal grid conditions, the inverter will charge the battery; if the PV array is generating more than sufficient power to provide an excess of the specified load, the inverter will charge the battery.

With the system set up to offset peak loads, the multimodal inverter (during peak demand times), will supply the specified loads; once the interconnection switching device isolates the system. The inverter will then supply and specified loads. Further, the inverter will also charge the battery should there be excess power generation from the system's PV array. Lastly, the multimodal inverter may also be used to manage the system's PV array output; it does this in the event that the specified power is supplied and the battery at prescribed levels. Accordingly, signals may be sent to the inverter in order to reduce the amount of available PV power generated given that the specified load has been met.

2.2.3 Existing Backup Inverter (Multimodal)

The system 1 shows in Figure 1 above has the SMA Sunny Backup SBU5000 and it's located nearby to the Automatic Switch Box ASB M-20 in the Test Area. This inverter functions as a manager for the system 1, managing all switching operations by the ASB (Automatic Switch Box). If any grid failure, the backup system allows operation of the grid-connected PV 1A and 1B Subsystems. Furthermore, if there is fails on the grid the first response from the backup system will confirm safe disconnection of the PV inverters and any loads. Also, the backup system adjustments to the stand-alone inverter within 20 milliseconds. Further, the battery bank continues to supply the load. The junction box gets mounted under the inverter by utilizing a U-bolt clamp as well as an additional included support plate. It is essential that the junction box be equipped with the needed functionality, protection and safety features (such as grounding and fuses) [29]. The Connections made in the terminals would be solely using copper bus-bar arrangement, and there is a need for suitable cable points in the junction box to be fitted with cable glands that match the recommendable size. Such an arrangement would apply for both outgoing as well as incoming cables. In order to enhance ease of identification, a suggestion made is that the bus-bars should be imprinted with suitable markings. For identification, the cable termination points would have to be fitted with UV resistant cable ferrules [29]. Ensuring precision in the arrangement, ease of identification and functionality among other considerations in relation to the junction box is essential because potential for error that hinders effective functioning of the inverter and eventual effective communication of data during monitoring, evaluation and documentation. It is essential that the modules be in compliance with the requirements outlined in individual equipment standards. For instance, in the case of crystalline PV modules, the requirements to comply with are based on IEC 61215. For type-tested switchgear as well as control gear assembly, the standard used is IEC 60439-1 and the focus are on determination of value factors including short circuit tests, temperature-rise test and the conductor cross-sections [28]. When choosing the arrangement and in establishing the connection between the junction box and related equipment, caution is made with express instructions that it is always essential for the electrical equipment that is arranged in the DC side to accommodate direct voltage as well as current [28].

2.3 Battery Options for Upgrade

At the end of Phase 4 in 2017, which was a project completed by Tottman and others, it was discovered that the backup system was not working properly due to self-discharging and improper operation. This was possibly due to improper user inputs for the battery capacity and the battery capacity levels. Due to this and/or other errors, the batteries now require replacement. As mentioned, the battery bank comprised of four 12V 105Ah sealed lead acid batteries connected in series with an optimal output of 48V and 105Ah capacity [13].

Kempin, in his initial report in 2012, did a lot of thorough research on the battery bank. The battery bank had to be in accordance with the standards set out by Invitation To Offer (ITO), which required the battery bank to supply 100Ah [4]. This size 100 Ah was chosen as small as possible foreseeing that the battery bank may be replaced in future and a large battery bank is expensive. This capacity will be sought in the replacement. The bank must also comply with Australian standards, a lot of which dealt with the construction of the enclosure and other accessories. As these are related to the battery technology, they may change when replacement of batteries. In Kempin's paper, he credited a 2011 semester 1 ENG421 student project report for the following specifications: the battery bank should comprise of two to four strings of batteries depending on the make and model of the battery [4]. None of the previous work states any specifications for the voltage so a combination of either two 12V 100Ah batteries or four 12V 100Ah batteries will still satisfy the 100Ah requirement, while having different voltage outputs [4].

No specific battery type was specified in earlier reports than Kempin's. Battery efficiency is an important aspect of choosing a battery type but it is not a linear quantity, and it depends on a number of factors, including temperature, rate of charge, rate of discharge and depth of discharge or state of charge [4]. Stevens and Corey investigated the effect of lead-acid battery efficiency on PV system design. It is important to note that the usable battery capacity of lead-acid batteries decreases each day when the battery is partially charged for several consecutive cycles. This can occur for one of many reasons including battery inefficiencies, electrolyte stratification, and sulphate build-up during these partial charges. This can have an impact on the operation of a PV system and should be taken into consideration when making battery choices [15].

Lead acid batteries are known to have a general efficiency of between 85 and 95% at 22 degrees Celsius [4]. Lead acid batteries were preferred due to their availability and price in line with their efficiency. Batteries were replaced ,, and the necessary precautions like proper ventilation, chemical hazard safety, including permission from building management, were taken into consideration for battery enclosure to ensure this efficiency in the current set-up. Going forward, six types of batteries will be compared based on the factors above in order to determine which type is best suited to be used in the battery bank. These are: nickel cadmium batteries, nickel metal hydride batteries, lithium ion batteries, sodium sulphur batteries, zinc bromine flow batteries, and the currently used sealed lead acid batteries.

2.3.1 Nickel Cadmium Battery

There are many advantages associated with the nickel-cadmium battery, including its long life cycle, even at deep discharge and its ability to charge very fast [16]. They can also be overcharged continuously without affecting its capacity or efficiency at all. However, this battery is very sensitive to temperature, which affects its battery life and cycles [17]. It works best in temperatures from 0 to 45 degrees Celsius for charge and -20 to 65 degrees Celsius for discharge [16]. It does not work very well at low temperatures, and it can also get damaged at high temperatures [17].

2.3.2 Nickel Metal Hydride Battery

This battery is very similar to the nickel-cadmium battery in many ways. For instance, like the nickel-cadmium battery, this battery is also sensitive to temperature and works best under the similar temperature conditions. Like Nickel Cadmium, this battery is very sensitive to the high and low temperatures. However, this battery does have some advantages over the nickel-cadmium battery and is often used as its replacement. Firstly, it has less of a memory effect when quick charging is used, but this memory effect begins to show up if the battery is not frequently discharged [17]. It also has a higher energy density than the nickel-cadmium battery, and it uses metals that are less toxic [16]. The downside is that the battery has a much shorter life cycle and will need replacing much more often than a nickel cadmium battery [17].

2.3.3 Lithium-Ion battery

This type of battery has many advantages, such prolonged high cycle and low maintenance [16]. It is also made from the lightest material, and therefore the batteries are light [17]. However, it does require protection circuits to ensure that it is not over charged or discharged too much [16]. This will add extra cost to the system. Additionally, it is sensitive to temperature, and it works best in temperatures from 0 to 45 degrees Celsius for charge and -20 to 60 degrees Celsius for discharge, making it a little more sensitive than the nickel counterparts [16].

2.3.4 Sodium Sulphur Battery

This type of battery is non-toxic and inexpensive since sodium is easy to find [17]. It is also low maintenance, high power and has a high energy density, which may be of particular use in this environment [17]. However, they operate at high temperatures (270 degrees Celsius) relative to the environment in which the PV facility operates. Therefore, in order to use this battery, energy may have to be applied, thus making it inefficient. This is not suitable for small scale applications due to the high operating temperature.

2.3.5 Zinc Bromine Flow Battery

This type of battery runs on an external fuel source, but it is charged and discharged like a battery [17]. One major advantage of this battery is that can be fully discharged without affecting battery life [17]. It also a high energy density and high overall efficiency. However, these batteries can be bulky and more suitable for large scale operations. In this situation, this is not a problem due to the fact that the battery will remain stationary.

2.3.6 Sealed Lead Acid Battery

This type of battery is able to deliver power very quickly and is also very cost efficient for its ability [17]. However, its life cycle is limited to a couple of hundred, meaning it requires frequent replacement. Like many of the others, this battery is sensitive to temperature, and it works best in temperatures from-20 to 50 degrees Celsius for charge and discharge [16]. These batteries cannot be stored in temperatures that are too cold or too hot, or it loses its efficiency. Another downside of these batteries is that they are heavy [17]. However, since in this case, the battery is staying in one area, this does not pose a problem.

The following Table 1 is a summary of comparisons of important battery parameters:

Table 3: Comparison of Different Battery Parameters [17]

Type of Battery	Specific Energy (Wh/kg)	Specific Power (W/kg)	Cell Voltage (V)	Cycles	Depth of Discharge	Efficiency
Nickel Cadmium	30 – 60	80 – 150	1.2	1K – 50K	60 – 80%	60 – 70%
Nickel Metal Hydride	60 - 80	200 – 300	1.2	300 – 600	-	-
Lithium Ion	80 – 180	200– 1000	3.05	3000	100%	90%
Sodium Sulphur	150 – 240	230	2.71	2.5K – 40K	100%	86% - 89%
Zinc Bromine	65 – 85	90 – 110	1.8	2000	100%	75 – 85%
Lead Acid	30 - 50	150 - 400	2.1	250 - 1000	20 -80%	75 - 85%

After careful research and comparison of all six types of batteries, while considering the specific conditions of the already-built enclosure, it was determined that the best type of battery to be used in the battery bank for the PV facility would be the lithium-ion battery. This battery has-high specific energy relative to the current led acid battery, a longer life cycle, a good second option due to its cost efficiency and thus, the operations can continue efficiently if the lead-acid batteries are kept and replaced regularly.

2.4 System Performance Monitoring, Evaluation and Documentation

2.4.1 Photovoltaic Standards

Due to the different system across a range of technologies and climates, many standard has been put in place to give recommendations, guidelines for monitoring and analysis of the performance and reliability of Photovoltaic (PV) systems in Australia. These standards include IEC 61724 and APVI standards.

2.4.1.1 IEC 61724 Standard

IEC 61724 is an international standard drafted by the International Electrotechnical Commission (IEC)

Which is a worldwide organisation that gives recommendations to describes general guidelines for the monitoring and analysis of the electrical performance of PV systems. Further, the IEC 61724 standard does not include a description for the components performance, but focusing on evaluating the system performance of the array. In addition, the standard include the exchange of monitoring data between organisations to describe a file format to be used [18].

2.4.1.2 APVI Standard

APVI refers to Australian PV Institute and gives guidelines to provide recommendations for PV system performance monitoring and analysing. The standard guidelines was developed from IEC 61724 standard with adaptions for the requirements needs in Australia [19].

2.4.2 Monitoring

There are several real-time monitoring methods that may be used to monitor system performance - via the system's data acquisition software [18]. Further, any parasitic draw down of power from the plant from any all ancillary systems that are not part of student research projects to test and measure PV technologies and inverter topologies shall not be considered as part of the various measured parameters [20].

2.4.3 Measurement of Irradiance

Irradiance data will be recorded (the plane of the array) and will be used in the performance analysis of the system. Further, in order to permit comparisons with other, standard meteorological data from other locations, pyranometer shall be used to measure in-plane irradiance [18].

2.4.4 Measurement of Ambient Air Temperature

Typically, module output power will reduce with increases in module temperature – as such and when integrated onto an area exposed to the elements (such as a roof). Therefore, representative ambient air temperature (which represents array conditions) shall be measured with the use of temperature sensors that are placed under solar radiation shields [18].

2.4.5 Measurement of Module temperature

Through the use of sensors that are typically located on the back of modules, PV module temperature may be measured. This may take place by measuring locations that are representative of the sensors located on the modules. Further, steps and special care will be taken to ensure that the sensor on the back of the module does not affect the temperature of the sensor at the front of the cell [18].

2.4.6 Measurement of Voltage and Current

Through the use of either A.C or D.C measurements, voltage and current parameters may be assessed. Further, the accuracy of the voltage and current sensors should be better than 1% of the available reading, including signal conditioning [18]. However, it may not be necessary to continuously monitor AC voltage and current for every perceived situation.

2.4.7 Measurement of Electrical Power

Either D.C, A.C or both may be used as electrical power parameters; D.C may either be measured through the use of a power sensor (recommended) or through the use of real-time calculations based on current quantities and sampled voltage. If calculated, these should be based on sampled voltage and current quantities, rather than through the use of average voltage [18]. Further, it is recommended to use a D.C wattmeter in order to accurately measure it as a result of stand-alone inverters; these may reasonably have large amounts of A.C ripples impresses upon it, and as such, the use of a wattmeter would yield more accurate results. The measurement of A.C power shall be performed with the use of a power sensor as these are accurate in their accounting of harmonic distortion and power factor. Further, in order to avoid sampling errors, the system may make use of an integrating power sensor may be used (such as a KWh meter).

2.4.8 Data Acquisition System

In order to effectively monitor the system will require the use of an automatic data acquisition system – the method of system calibration shall determine the actual total accuracy of the further, the monitoring system to be used for the PV facility should be based on commercially available software and hardware, both of which should be properly documented with complete user manuals, with readily available and effective technical support [18].

The data acquisition system may be checked through the use of the following:

- Checking input signals, some of which may include irradiance, ambient temperature and voltage, power and current for every component of the PV plant;
- Checking for a linear response; and
- Checking for stability, integration, zero value integrals and integrating intervals.

2.4.9 Sampling Interval

Parameters shall have a time constant for recording intervals that are either 1 minute shorter between samples; parameters with a requirement for longer/ larger time constants may use an arbitrary sample of between 1 and 10 minutes [18].

2.4.10 Data Processing Operation

All of the data from the system (based on individual measured parameters) shall be aggregated into time-weighted averages.

2.4.11Recording Interval

All of the data processed, each by parameter, will be recorded at hourly intervals, with shorter (more frequent) recordings implemented where they may be required [18].

2.4.12 Monitoring Period

The monitoring period to be determined should be sufficient enough to provide operational data that will reflect ambient conditions and load.

2.4.13 Evaluation

There are several specific test methods that may be used to evaluate the performance of the PV facility, according to the Joint Research Centre (JRC):

- Edge-seal durability guideline. This standard is a measurement of the various materials that are used in the manufacture of photovoltaic modules, specifically, the durability rating of the edge seals used within PV modules [20];
- Photovoltaic system performance. This standard is used to define the procedure that is used to measure and analyse the specific power production of a specific PV system – this is intended to measure the quality of system performance. The IEC TS 61724-2 standard may be used to compare the actual power produced against what is expected, especially on sunny days [20]; and
- Energy evaluation. This procedure may be used to measure energy conversion efficiency – these may include measuring dynamic energy conversion efficiency– which act to anticipate the actual quantity of energy that is produced by the PV system.

2.4.14 Documentation

This will be handled through the maintenance of a monitoring log; the log will be maintained and kept with the intention of recording all unusual events, failures, accidents, faults or component changes. Further, the log shall also include various other comments that may be considered useful in the interpretation and evaluation of data – these may include factors such as weather, as well as any changes made to the data acquisition system, sensor calibration, load, sensor within the system or general system operation [18]. Finally, any system maintenance shall be explicitly documented; these may include changes made to the array tilt angle, any module changes, or cleaning of soiled array surfaces.

Chapter 3: System Design

3. Methodology

This chapter covers and discussed the methodology for upgrading system 1(Figure 1), which consists of the backup inverter system part of the facility. Figure 3 below shows the methodology used to complete this design. The flow chart shows the design outlines for all the procedures starting from the design configuration and ending with design Installation.

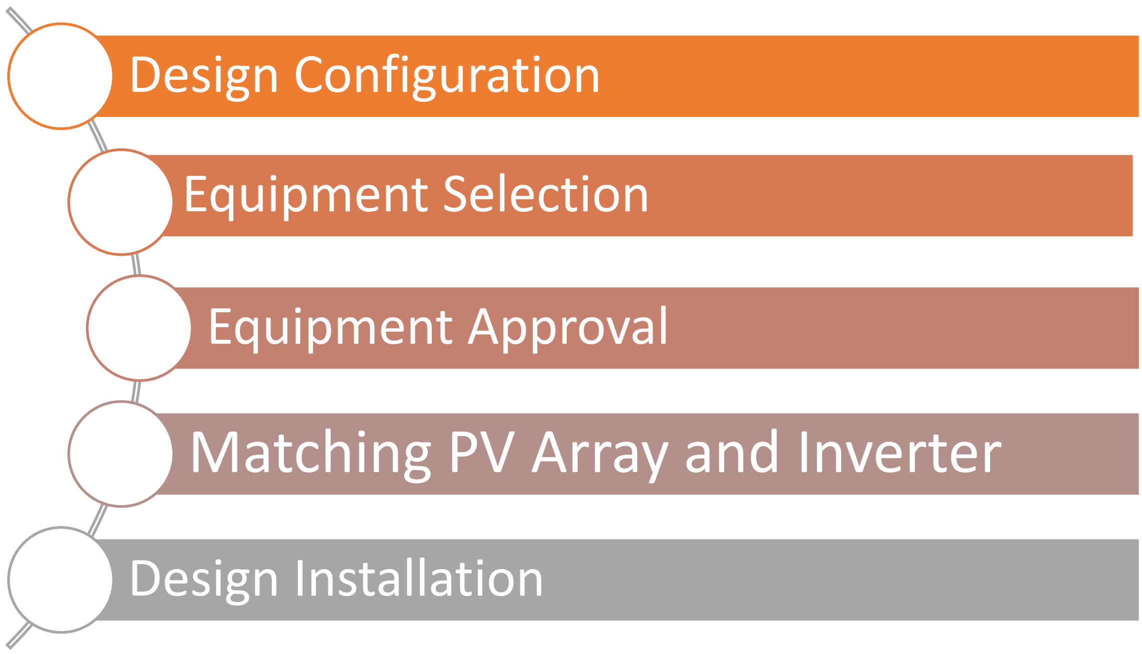

Figure 3: Design Procedures Flowchart

3.1 Design Configuration

There are several different possible configurations that can be used to connect the PV systems with battery storage and grid. The configuration in Figure 4 has been selected to upgrade the current design [21]. This includes two inverters; one multimode inverter connected to the battery storage, and the second one is grid-connect inverter connected to the PV array.

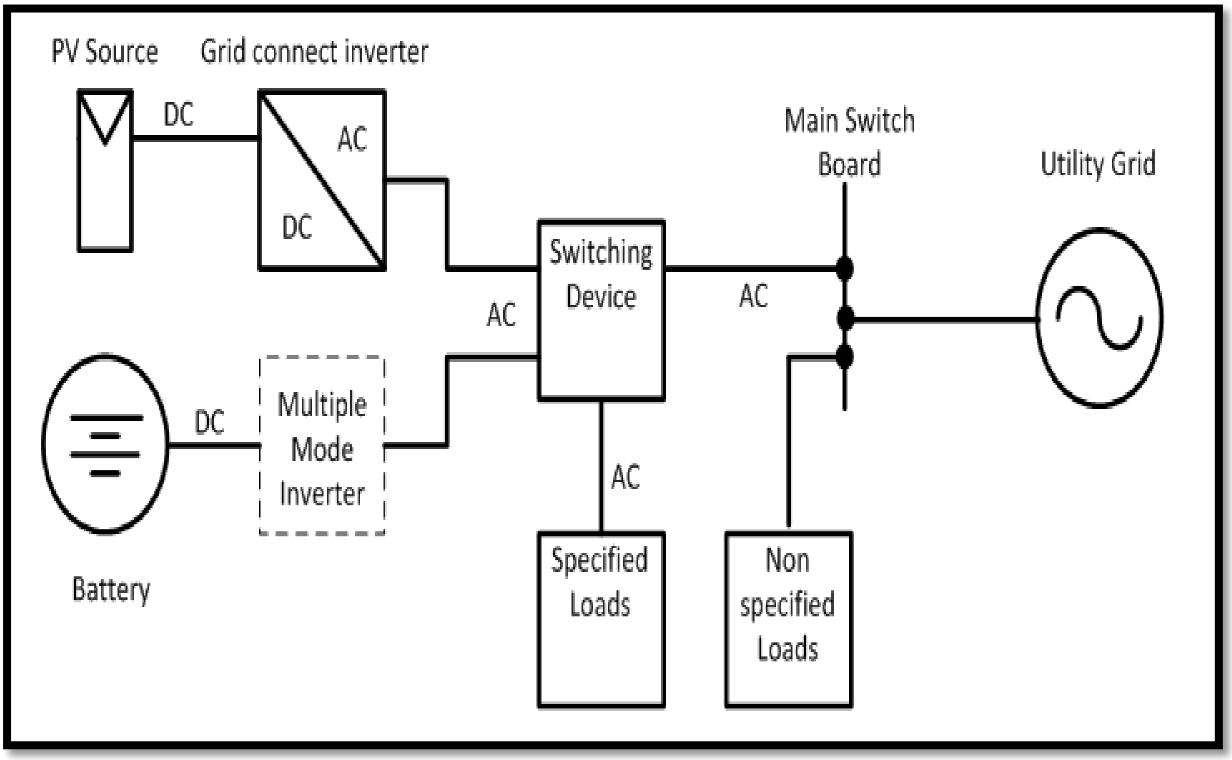

Figure 4: Two Inverters with Interconnection Switching Device [21]

3.2 Equipment Selection

There are four systems, as shown in Figure 1 above and Appendix A. This project will focus on System 1. This system previously included the following equipment: copper indium gallium selenide thin film (Q.Cells) PV modules, two types of SMA Sunny Boy inverters (SB1100 and SB1700), backup inverter SMA SBU5000, Automatic Switch Box SMA ASB M-20 and Sealed Lead acid battery. The main aim is to upgrade this system by replacing some equipment but keeping the same PV modules in a reconfigured array. The following components are proposed for the new system:

- Existing solar PV array (Q.CELLS 90 Thin Film).
- One single phase grid connect PV inverter Fronius Galvo 2.0-1.

- MultiGrid 3000VA Inverter (Backup System) and associated with Color-Control-GX-EN.
- Battery Bank S30-0080 Battery Stack from Aquion Energy 48 V to supply 100Ah.

Figure 5 below illustrates the system 1 configuration.

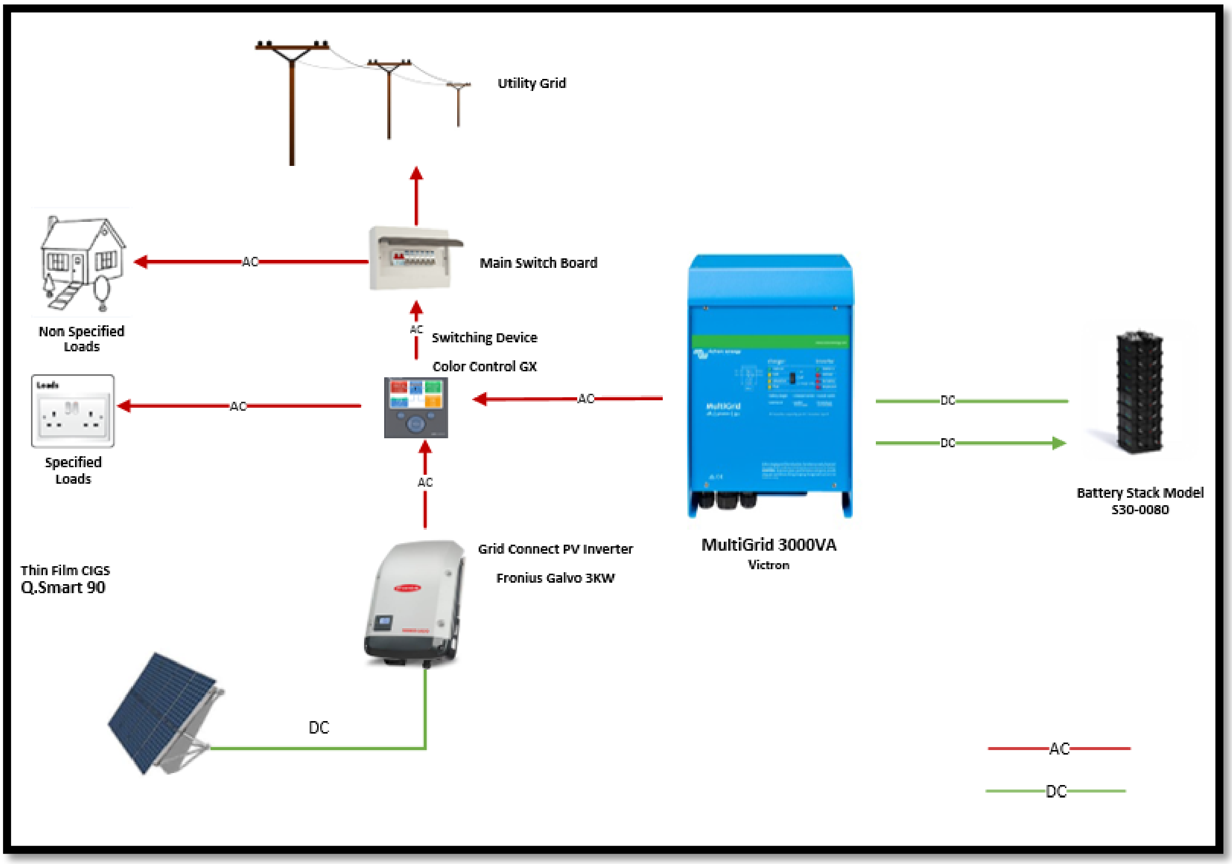

Figure 5: Grid-connected PV systems with battery storage – System Configurations [Author]

3.2.1 PV Arrays (Q. CELLS 90 Thin Film)

In system 1 at PV Training Facility (Figure 1), the Q.CELLS 90 Thin Film modules are used. There are 22 of these modules to form one array. The shading and high temperature have less impact on the performance of these PV Modules. As a result, from matching PV array with inverter, it has been confirmed with project supervisor Dr Martina Calais that the configuration for this design should include 20 panels; 5 in series and 4 in parallel with two extra panels need to be removed. The PV module mechanical specification and key electrical characteristics are listed in Table 1 below. Detail informational sheet of the Q.CELLS 90 Thin Film modules is included in the Appendix G.

Table 4: Q.CELLS 90 Thin Film Electrical and Mechanical Specifications Summary [6]

System No	1
Module	Q.Smart 90
Make	Q.Cells
Module Type	Thin film CIGS
No. of Modules	22
Configuration	5 series and 4 Parallel
Functional Earth Required	Yes (negative)
PV Array Power (W)	1980
Electrical Specification	
Nominal Power (P_{nom})	90 W
Rated Voltage(V_{mpp})	59.2 V
Rated Current (I_{mpp})	1.52 A
Open Circuit Voltage (V_{oc})	75.1 V
Short Circuit Current (I_{sc})	1.69 A
Temperature Coeffi cient of VOC (%K)	− 0.30 ± 0.04
Efficiency (η)	11.8 %
Mechanical Specification	
Width	636 (+1/-0.5) mm
Length	1196 (+1/-0.5) mm
Height	36 mm
Weight	14.5 kg
Cell Type	CIGC [Cu(in, Ga) Se_2]
Front Cover	4 mm tempered low iron glass
Back Cover	3 mm float glass
Junction box	Protection class IP 65, with 1 bypass diode (3 A) 66 x 54 x 15 mm^3
Connector	MC4

The PV module (Q.Cells Q.Smart 90 thin film CIGS) in this system requires the negative functional earthing, to prevent module damage and reduced output [8]. In order to use that, insert the grounding fuse on the back of the grid connect inverter and set the code “22742” on the inverter setting (grounding setting) then select negative grounding. The following Figure 4 shows the fuse location and installation.

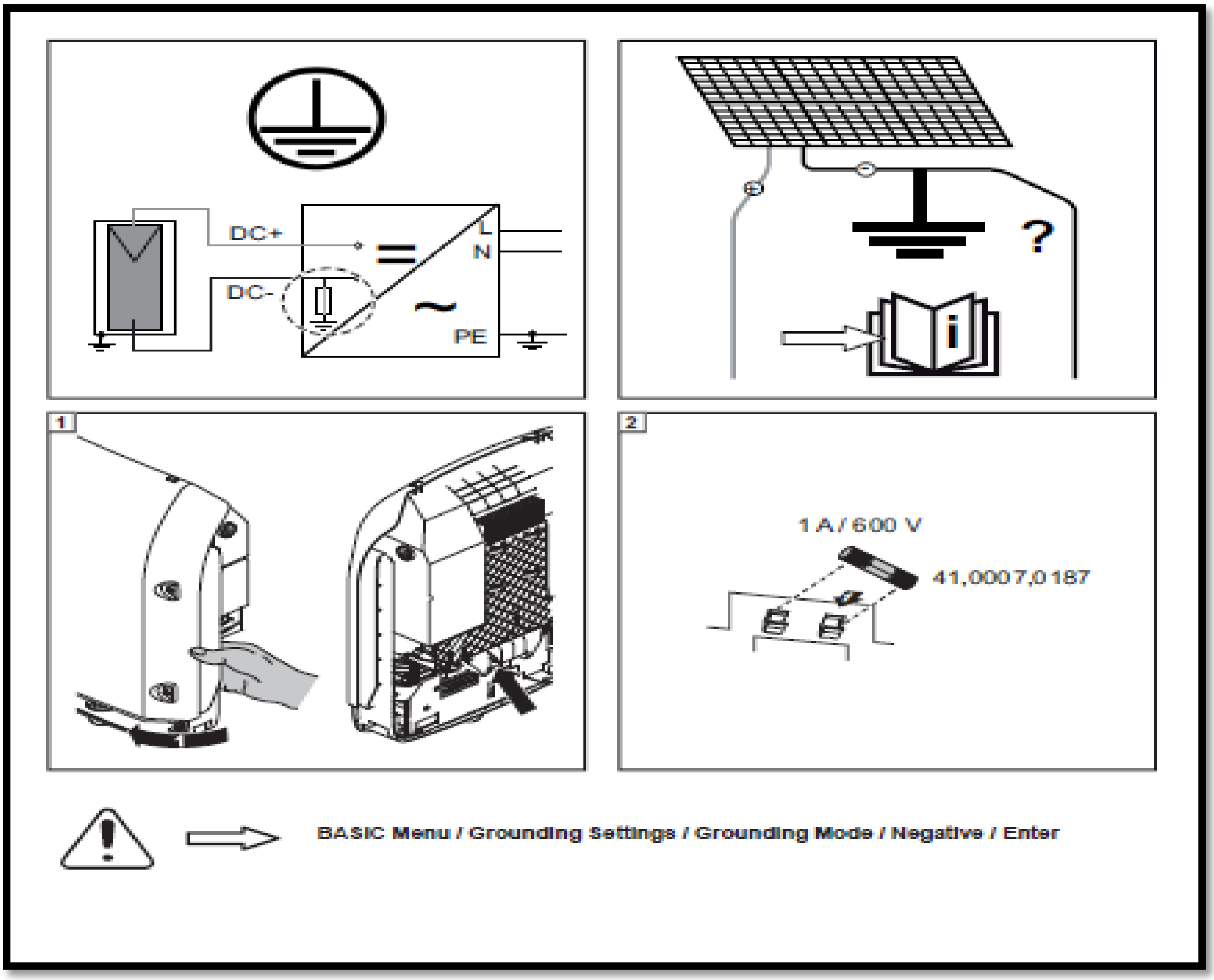

Figure 5: Functional Earthing Installation [6]

3.2.2 Inverters

3.2.2.1 Grid Connect Inverter (Fronius Galvo 2.0-1)

This inverter is connected to the interconnection switching device from the AC side and connected to the PV array on the DC side. As such, the inverter will be used to generate a regulated AC from the PV array which is then either fed into the grid or into the battery. In this design, Fronius Galvo 2.0-1 have been used, which is compatible with backup system inverter and battery as have been discussed and confirmed with Fronius Company. The efficiency curve shows in Figure 7 for the Fronius Galvo 2.0-1 inverter at 165 VDC, 330 VDC and 440 VDC. The efficiency curve shows that the efficiency of the inverter increases sharply at low standardised output power ratio. The efficiency increased sharply from 89% to 96% for 0.05 to 0.3 ratio of power output and then in steady position and drops slowly. Also, it shows that inverter efficiency is better at higher DC voltage (330/440 VDC) as compared to low DC voltage of 165 VDC [22].

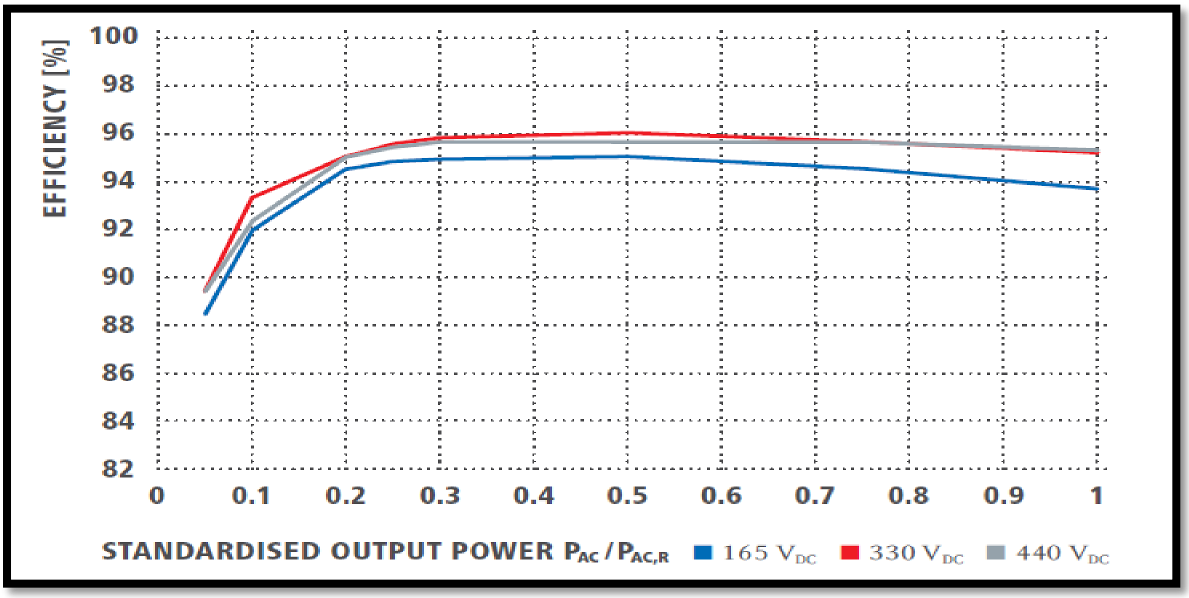

Figure 6: FRONIUS GALVO 3.1-1 Power and Voltage Efficiency Curve [22]

The inverter has a maximum AC power output of 2 KW, and maximum DC input is 4KWp at 420 V_{max} and 17.8 A_{max}. However, there is one maximum power point tracker (MPPT) in this inverter. The following Table 2 is a specification and characteristics for Fronius Galvo inverter, with more detailed and key technical information in the Appendix B.

Table 5: Fronius Galvo 2.0-1 key Electrical Characteristics Summary [22]

Manufacturer	**Fronius**
Model	Fronius Galvo 2.0-1
Topology	Transformer (High Frequency)
Input (DC)	
Maximum DC input power	4 KWp
Maximum DC input voltage	420 V
Maximum input current	17.8 A
PV voltage range	120-420 V
Number of MPP trackers	1
Output (AC)	
AC nominal output Power ($P_{AC\ nom}$)	2000 W
AC Max.output power ($P_{AC\ max}$)	2000 VA
Nominal output current ($I_{AC\ nom}$)	8.7 A
AC voltage range (U_{min} –U_{max})	180-270 V
Frequency (f_r)	50/60 Hz
Power factor (cos $\phi_{ac,r}$)	0.85-1 ind/cap
EFFICIENCY	
Max.efficiency (PV-grid)	96.0%
European efficiency (ηEU)	94.9%

3.2.2.1 Backup Inverter (MultiGrid 3000VA).

This inverter is connected with the battery from DC side as well as also connected to the interconnection switching device (Color Control GX)[23]. Further, in normal grid conditions, the inverter is able to manage battery charge through the use of the interconnection device. As such, the multimodal inverter will charge the battery by using power from the grid. Should grid conditions be abnormal, the inverter will supply the specified loads through the use of the interconnection device. As such, if the power generated from the PV array is insufficient in supplying the specified loads, the inverter will provide the required power from the battery storage. Further, within abnormal grid conditions, the inverter will charge the battery; if the PV array is generating more than sufficient power to provide an excess of the specified load, the inverter will charge the battery.

With the system set up in order to offset peak loads, the multimodal inverter (during peak demand times), will supply the specified loads; once the interconnection switching device isolates the system. The inverter will then supply specified loads. Further, the inverter will also charge the battery, should there be excess power generation from the system's PV array. Lastly, the multimodal inverter may also be used to manage the system's PV array output. It does this in the event that the specified power is supplied and the battery is at prescribed levels. Accordingly, signals may be sent to the inverter in order to reduce the amount of available PV power generated given that the specified load has been met.

3.3 Battery Bank

3.3.1 Battery Selecting and Sizing

After selecting the battery technology will be use in this project which is S30-0080 Battery Stack, and it must also comply with Australian Standards [24]. Therefore, the cost and sizing of the battery must be considered. Murdoch University got an offer from Aquion Energy Company to support the University with a number of batteries required for free of charge. However, there are a design criteria for sizing the battery bank, these can be explained with the following criteria [1]:

- Size of the specified loads that must be powered during cut-off from the grid.
- How long of disconnections from the grid and the length of backup time required.
- Frequency of disconnections from the grid.
- The load assessment must be provided.

The following calculation is to size the minimum capacity of the battery bank required, based on the energy to be supplied during disconnections from the grid. Further, the total DC energy that must be supplied by the battery bank during a disconnection from the grid can be determined by the following equation[1]:

$$ETOT - GD = \frac{EAC}{\eta\ inv \times \eta\ cable \times \eta\ temp} \tag{1}$$

Where:

EAC = total AC energy to be supplied by the system, Watt-hours.

ηinv = inverter efficiency, dimensionless.

ηcable = cables from the battery to the specified load's efficiency, dimensionless.

ηtemp = derated capacity of the battery, dimensionless.

Then, apply the result from equation 1 to determine the battery capacity using the following equation[1]:

$$\mathrm{Cx} = \frac{\mathrm{ETOT-GD}}{\mathrm{VDC \times DODMAX}} \qquad (2)$$

Where:

Cx = battery capacity and x is a specified discharge rate, Ampere-hours.

ETOT-GD = Total energy must supply the specified load/s by the battery bank during a failure from the grid, Watt- hours.

VDC = battery bank nominal voltage, Volt.

DODMAX = maximum depth of discharge.

3.3.2 S30-0080 Battery Stack

The S30-0080 Battery Stack from Aquion Energy Company is a 2 KWh system at 48V nominal voltage. Further, the battery stack can be connected in parallel or series for different type of system configurations. This is made up of clean saltwater batteries which use Aquion's proprietary Aqueous Hybrid Ion (AHI™) technology [25]. Furthermore, the most important features for this battery is low environmental footprint, less maintenance, non-flammable, non-explosive, and non-corrosive. It has very high cycle life of 3000 cycles and 100% usable discharge depth. The physical characteristics for this battery are, height 935 mm, width 330 mm and weight 118 kg (260lbs). This project will use two S30-0080 Battery Stacks and must be charged and discharged with no more than current 17 A, 48 V nominal voltage and 680 W continuous power. Table 3 shows characteristics, operation and performance of S30-0080 Battery stack.

Table 6: Characteristics, Operation & Performance of S30-0080 Battery stack [25].

Voltage Range	40 to 57.6 V
Nominal Voltage	48 V
Continuous Power	680 W
Peak Power	800 W
Continuous Current	17 A
Operating Temperature	-5°C to 40°C ambient
Depth of Discharge	100 %
Weight	118 Kg
Cycle Life	3000 cycles
Round Trip Efficiency	> 90%

3.3 Equipment Approval

3.3.1 Inverter Approval

The Backup Inverter MultiGrid 3000VA and Fronius Galvo 2.0-1 have been verified that with Clean Energy Council (CEC) list [26]. Furthermore, both inverters have been checked that they are compliant with AS 3100, AS 4777.2 and AS 4777.3 [4].

3.3.2 PV Module Approval

The Q.CELLS 90 Thin film modules which have be used in this design was approved and listed by Clean Energy Council (CEC). Further, these listed modules confirm that is compliant with AS 5033, IEC 61730, and IEC 61646 [4].

3.3.3 Battery Bank Approval

The AHI S30-0080 Battery Stacks are Cradle to Cradle Certified TM Bronze products which is an institute for assesses and certifies products like a battery for material health. Furthermore, it has a 5-year warranty, plus 3-year prorated [25].

3.3.4 Inverters, Modules and Battery Compatibility

As been discussed and confirmed with inverters companies Victron Energy for the (MultiGrid-3000VA) backup inverter and with Fronius Company for (Fronius Galvo 2.0-1) are compatible with each other. Further, the Aquion Energy confirmed the compatibility of the battery bank (S30-0080 Battery Stack) which have been used in this design with backup inverter (MultiGrid-3000VA).

3.4 Matching PV Array and Inverter

The Clean Energy Council (CEC) guidelines (CEC 2013) have been followed to match the PV array power output to the inverter's power rating using the data shows on the Tables 4 and 5 above. In order, to select and configure a suitable PV array by matching the grid-connected inverter (Fronius Galvo 2.0-1) with Q.SMART 90 PV module.

The following steps have been done to complete this matching [26]:

Firstly, matching array to voltage window of selected inverter,

1. Fronius Galvo 2.0-1 inverter has been chosen with input voltage window:
   a. V_{invmax} = 420V
   b. VinvmaxMPP = 420 V
   c. Vinvmin = 120V

Where:

Vi_{nvmax} = Maximum inverter DC input voltage, volts

$V_{invmaxMPP}$ = Maximum Power Point inverter DC input voltage, volts

V_{invmin} = Minimum inverter DC voltage, volts

2. Adjust the suggested safety margin for the lower end input voltage, because the operation at lower irradiances and the MPP moving to lower voltages. The suggested safety margin is (1.1 * Vinvmin).

Vinvmin * 1.1 = 120V * 1.10 = 132V

3. Select a minimum cell operating temperature for the location (5°C in this case), get the maximum number of modules in series. Then calculate maximum open circuit voltage (Vocmax) for the module using the following equation:

$$V\max\_oc = Voc\_stc + \gamma v(T\min cell\_eff - 25) \tag{3}$$

= 75.1+-0.2253(5-25)

= 79.606 V

Where:

V_{max_oc} = Maximum open circuit voltage, volts

V_{oc_stc} = Open Circuit Voltage at STC, volts

γ_v = Voltage temperature co-efficient, volts per degree Celsius (V/C)

$T_{mincell.eff}$ = Minimum daily cell temperature (5°C in this case), in degrees Celsius (°C)

T_{stc} = Cell temperature at standard test conditions (25°C), measured in degrees Celsius.

4. The maximum number of modules in series

$$Nmax = \frac{Vinvmax}{V\max\_oc} \quad (4)$$

= 420/79.606 = 5.27 ……… Round Down 5

It's important to check if the Vmaxmpp are within the operating window:

Vmax_mpp = Vmpp_stc +Yv (T min cell_eff - 25)

=59.2 + (-0.2253) (5 – 25)

= 63.706

Number of modules (5) * Vmax_mpp = 318.53 < 420 (PV voltage range)

5. The minimum number of modules using the maximum cell temperature (70°C in this case, then determine the minimum module operating voltage for the inverter.

$$V_{min\_mpp} = V_{mpp\_stc} + \gamma v(T_{\max cell.eff} - 25)$$

$$V_{\min-mpp-inv} = V_{min\_mpp} \times \left[1 - \frac{VoltDrop\%}{100}\right] \quad (5,6)$$

Vmin-mpp=inv = [59.2 + (-0.2253) (70-25)]*[1-0.03] = 47.58

Where:

V_{min_mpp} = Minimum Power Point inverter voltage, volts

V_{mpp_stc} = Maximum Power Point Voltage at STC, volts

$T_{maxcell.eff}$ = Maximum daily cell temperature (70°C in this case), in degrees Celsius (°C)

Voltage Drop = 3%

6. The minimum number of modules in series

$$Nmin = \frac{Vinvmin}{Vmpmin} \tag{7}$$

= 132/54.556 = 2.4 ……..Round-Up 3

To summarie the above, there are 5 PV modules as a minimum in series and 3 as a maximum in series.

7. The total number of modules required:

Power Required = 2000W

$$Nmod = \frac{Preq}{Prated} \tag{8}$$

= 2000/90 = 22.22

3.5 Result and Discussion

The configuration used in the assessment of the system one was obtained from ENG442 Renewable Energy Systems Engineering unit, which is a fourth-year unit in Renewable Energy Engineering major at Murdoch University. The configuration in Figure 8 has been selected to upgrade the current design. This includes two inverters; one multimode inverter connected to the battery storage, and the second one is grid-connect inverter connected to the PV array. Furthermore, these two inverters are connected to each other and also connected to the grid and specified loads through the use of an interconnection switching device. This type of connection provides the system with the functionality similar to that of a grid-connected PV system while also providing a basic 'backup' functionality for selected AC loads. Some of the functionality that this system would provide is the ability to export any PV generated energy to the grid without the need for the battery to be fully charged. Further, the system can be set up with the potential to provide on-site power to augment and offset peak loads, which in turn will reduce the cost of electricity.

The system configuration is more complex than the current configuration and thus requires the use of an interconnection switching device. The choice of this device may include either range from the use of a manual change over switch to the use of an automatic device. Functionally, the configuration operates in two main ways; firstly, during normal conditions, the system maintains a charge to the battery unit. Secondly, and during disconnection from the grid, the system is capable of providing the user with an alternate supply of the specified load generated from the PV array and battery. As such, the interconnecting switching device works to manage the various required interconnections, depending on available conditions. The final configuration for the proposed design is shown in Figure 8 below.

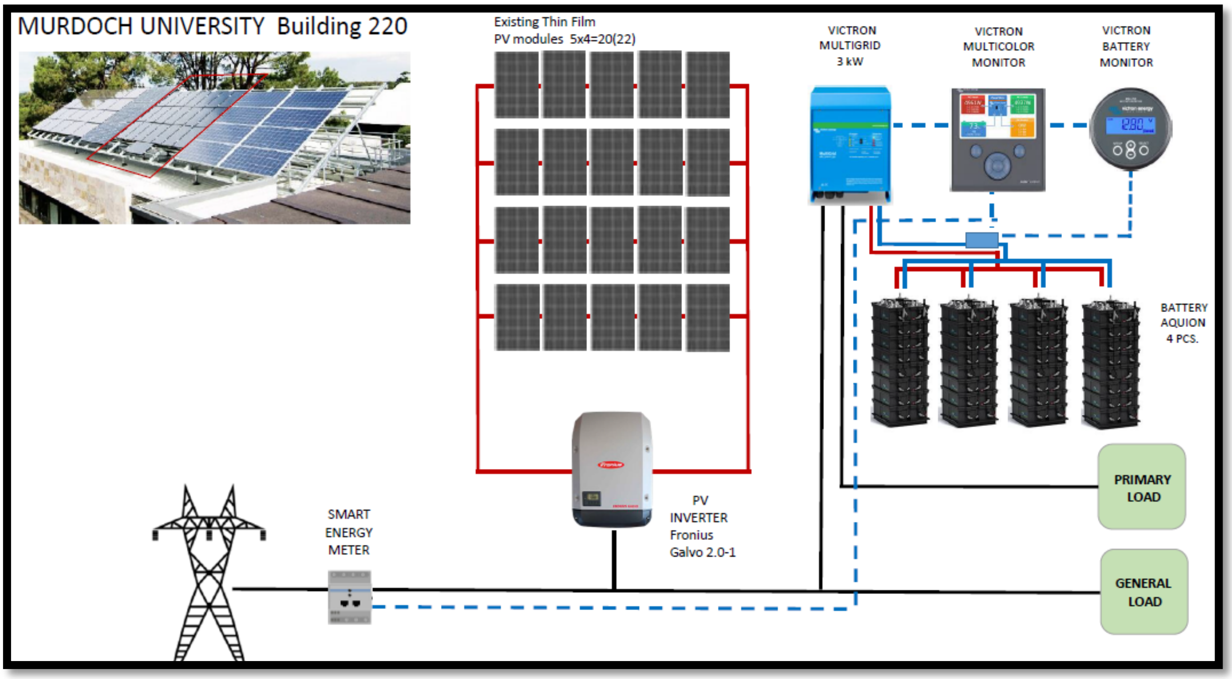

Figure 7: Two Inverters and a Switching Device Final Configuration [Aquion Energy].

The result from matching the grid-connected inverter (Fronius Galvo 2.0-1) with Q.SMART 90 PV module has been calculated. The maximum number of modules in series after rounded down was 5 modules. Further, the maximum power point voltage (Vmax_mpp) was within the operating window with around 318.53V less than 420 (PV voltage range). The minimum number of modules in series after rounded up was 3 modules. Based on the result was obtained, the total number of modules for the new system is required 22 modules. The new configuration for this design will be 5 modules in series and 4 in parallel with a total of 20 modules after removing 2 modules from the old design.

Both inverters Fronius Galvo 2.0-1 and MultiGrid 3000VA Inverter (Backup System) which have been used in the project were checked and listed on Clean Energy Council (CEC) and compatible with each other. As a recommendation from Q.Cells manufacture's that the modules should be grounded, the grid-connected inverter Fronius Galvo 2.0-1 came with grounding kits, which comply with the manufacturer’s recommendation. However, in this project, the backup inverter which has been chosen in the design it may change for the same features inverter. Further, the recommendation from the installer to use Selectronic SP Pro SPMC481 in place to MultiGrid 3000VA Inverter.

Battery Bank S30-0080, 10 batteries stacks from Aquion Energy (donated) and 4 stacks are going use. Approved from Murdoch University Facility Management about the equipment weight and ventilation. There is a plane to use the other 6 stacks for new project in Renewable Energy Power System Training Facility (REPS) in the future. However, the 4 stacks connected in series to provide 100Ah at 48 VDC. The batteries are connected to the backup inverter (Victron MultiGrid 3000VA) via Victron multicolour monitor which connected from Victron battery monitor and feed-through terminals in system 1.

Supply and install Solar PV System to existing Q Cell Panels 90W thin film on existing roof frame plus rewire panels to new lay out, disconnect of old equipment as per schedule (Disconnect old SMA Synny Boys x2 with old Sunny Boy Storage) adapt old installation to new Selectronic charge inverter with a new Fronius 2KW Galvo (negative earth) as a Ac Coupled Inverter with a 4 Stack Aquion Battery Bank plus Back up/Emergency Power set up as a Power Points as old was. Table 7 shows the supplier quotation for solar system with battery inverter and battery bank Aquion.

Table 7: Quotation Solar System with Battery Inverter and Battery Bank Aquion [Installer]

Quotation List	Parts	Cost
Material Bay WA	Backup Inverter Fronius 2KW Battery BOS	$7,760
Material AC Power	RCBO for backup power circuit Cables Isolators Fuses Cond	$580
Electrical Equipment	String Fuse Box Isolator Enclosure IP65 under array	$412
Transport	Batteries Warehouse to Campus	$340
Labour	PV Array re configure disconnect old Inverters, install new Inverters, install Batteries with all the BOS	$2,520
Total incl GST		$12,773

The installation for this project has been delayed as the funding approve from Murdoch University is still in progress.

Chapter 4: Performance Analysis

4.1 Methodology

The approach used in this chapter involved using Australian Technical Guidelines APVI (Australian PV Institute) standard for Monitoring and Analysing Photovoltaic System which is developed and adaptations from IEC Standard IEC61724 (Photovoltaics system performance monitoring – Guidelines for measurement, data exchange and analysis) have been used as a reference to evaluation the performance on this project [19].

4.1.1 Recording and Monitoring Intervals

The Table below shows the list of recording interval per use to measured PV data which have been adopted from the Australian PV Institute Standard. Further, the parameters should be continuously sampled and processed into time-weighted averages at the sample interval (τs) rate through the specified recording interval (τr). However, the monitoring period should continue until the PV system is decommissioned as recommended from the Table below [19].

Table 8: Recording Interval list per use of Measured PV Data [19]

Use	Use of Measured PV Data	τ_r	Period of Monitoring
1	Performance assessment of PV technologies under outdoor conditions	Max 15 min	Min 1 Year
2	Performance diagnostics	Hourly	System lifetime
5	Forecasting PV performance	5min, 30min or hourly	Min 1 Year

The data which have been used for this analysis is not accurate enough to comply with the table above and with IEC 61724 Standard. As the recording data period started from September 2018 and end in March 2019. Therefore, the data used as a guide to achieving system performance.

4.1.2 Analysis Parameters

To analysis PV system performance and the data obtained from the array using IEC 61724 Standard as a reference. Furthermore, that can be calculated from the listed derived parameters, which in Table 8 below.

Table 9: Derived Parameters List [19]

Parameter	Unit	Symbol
Specific Array Yield (d.c)	KWh/KW	Y_A
Final PV System Yield (a.c)	KWh/KW	Y_f
Reference Solar Yield	KWh/KW	Y_r
Array Capture Losses	h/d	L_c
Performance Ratio	PR	R_p
Array Efficiency (d.c)	η_A	
PV System Efficiency (a.c)	η_{PV}	

However, these parameters can be calculated for any period that is greater than the recording interval (τr), which is the period from the data was recorded.

4.1.2.1 Specific Array Yield (d.c)

The array yield (YA) is the daily energy output of the PV array (E_A) per installed KWP of capacity [19].

$$YA = E_A/P_0 = \text{KWh/KWp}\ YA = \text{h} \quad (9)$$

Where P_0 is the ratted output power of the array and E_A is the energy produced by the array

4.1.2.2 Final PV System Yield (a.c)

From IEC 61724 Standard, the final PV system yield (Yf) is the daily net energy output produced by the PV system (Eout) per the rated power output of installed capacity [19].

$$Yf = E_{AC}/P_0\ (\text{KWh/KWp}) \quad (10)$$

Where E_{AC} represents the Energy output to the Utility grid or load

4.1.2.3 Reference Solar Yield

Reference solar yield (Y_r) is the total daily in-plane solar irradiation divided by the module's reference in-plane irradiance G_{ref} (KW/m^2) within standard test condition (STC), where G_{ref} = $1KW/m^2$, and Y_r is the number of peak sun-hours (PSH) per day (h/d) [19].

$$Yr = H_{I,\ tilted}/Gref \quad (11)$$

Where, H represents in-plane radiation and G_{ref} is the reference irradiance at STC.

4.1.2.4 Performance Ratio

The performance ratio (PR) of the array is, the ratio of the final PV system yield to the reference solar yield and this quantity indicates for the overall losses associated with array's rated output as well as inverter efficiencies [19].

$$PR = Yf/Yr \quad (12)$$

4.1.2.5 Array Efficiency

The array d.c efficiency is the total efficiency of the system ratio to the product of daily solar radiation, which is received by the total area of PV array (A_a) [19].

$$\eta_A = E_A /(Aa \times H) \quad (13)$$

E_A represent the total d.c efficiency of the system and A_a is the array area (m^2)

4.1.2.6 Overall PV System Efficiency

The Overall PV system efficiency (η_{tot}) is the total output AC energy of PV system over the daily solar radiation, which is received by the total area of PV array (A_a) [19].

$$\eta_{tot} = E_{out} /(Aa \times H) \quad (14)$$

Where E_{out} represent the a.c energy output from the inverter.

4.2 Data Sources

The Structured Query Language (SQL) server and Murdoch MET Station were accessed to obtain data. The AC power output from SMA inverter system 1 data can obtain from SQL. Furthermore, there are different parameters can find from that server, for example, AC and DC for current, voltage, power and frequency. However, the temperature and solar irradiance have obtained from Murdoch MET Station.

4.2 Result and Discussion

The discussion and investigation have been done with Will Stirling the technical officer at MU about PV Training Facility system data acquisition issues and some of the development history. The founding was both the dbo.SMA and dbo.SMAI1 tables (from SQL Server) are data from the SMA No.4 inverter. The previous projects have only been able to implement data recording from the SMA No.4 inverter and the Samil No.3 inverter. Taking a look at the actual time stamps for the records it fits that the dbo.SMA table holds the earlier data with the dbo.SMAI1 table created later.

Further, the most recent LabVIEW program form the project however, it is not writing data to the data base for the SMA No.4 inverter. An earlier version of the program does log the data but does not have the programming for the Samil inverter. The version of the data acquisition program that has been found is labelled :(25_05_2017__EEPV_Phase3\ENG447_EEPV_Main_Code_rev 5), when this program was running and inserting the records into the SMA_old table it was inserting incorrect values for the TimeStamp. Watching the values in the running LabView program did not show the incorrect values. It showed correct TimeStamp values. This observation led to investigate the compatibility of the TimeStamp column data type for the data that was being inserted. The data type was defined as “text”. There is no specific issue as to why the corruption of the TimeStamp data was occurring. Will Stirling disused to establish a new table which replicated the same column structure but defined the TimeStamp column with “char (22)” data type. This table is the new SMA_I4 table. It has been also aware that the EEPV data base had been moved to an upgraded MS SQL Server, from Version 9.0.4035 to version 10.50.4000. However, the other inverters do not have data available due to the LabVIEW program not being written and implemented for them. The section of the LabVIEW program covering the Samil inverter does not have the code to do the various statistical calculations for the one minute period of data. It is, therefore, just inserting the raw measured values every 1 second. After one week from the address the new table SMA_I4 at SQL server, the LabVIEW program that is running to acquire data from the SMA No4 and Samil inverters were crashed and the error message has been obtained from LabVIEW.

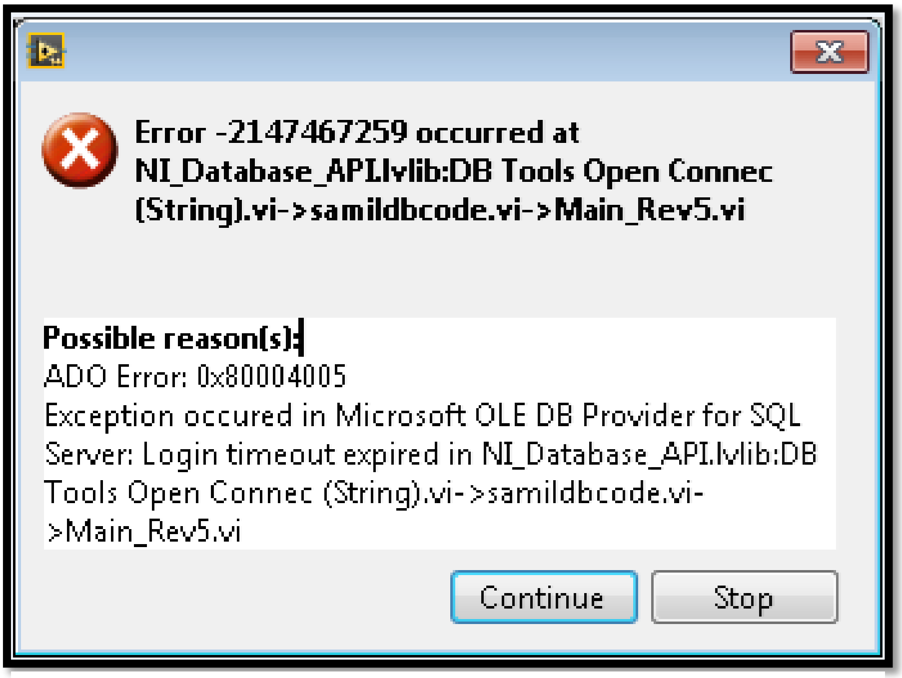

Figure 8: Error-2147467259 Message.

The error is associated with a “Running low on memory” warning from the operating system. It took a little time to investigate this issue and could not see a specific problem apart from the memory use was high at about 6GB but there was still memory available. Closing LabVIEW did not release a significant amount of memory. The LabVIEW program is running with only 3.29 GB memory in use.

4.2.1 Data Ordering

One minute interval data for the period of 17-Sep-2018 to 13-March-2019 was used to analyse the inverter performance at a different time of the day. The issues with data downloaded were not in proper time sequence. Even though the system was logging all one –minute interval data, some of the data was missing its place and shifted to different time and date randomly. Then, all data was sorted and filtered based on timestamp.

4.2.2 Inverter Efficiency Curve

The figures show the efficiency of the inverter at a different performance. The rated capacity of the inverter (Pr) is 2500 Watt. The efficiency of the inverter was calculated as the ratio of AC Power out of the inverter and DC power into the inverter. The efficiency curve was then plotted against the performance ratios (AC Power from Inverter to Rated Capacity of the inverter). The efficiency curve shows in Figure 10 that the efficiency of the inverter increases sharply at low standardised output power ratio. The efficiency increased sharply from 0% to 73% for 0 to 0.05 ratio of power output and then remains in steady position at 94%.

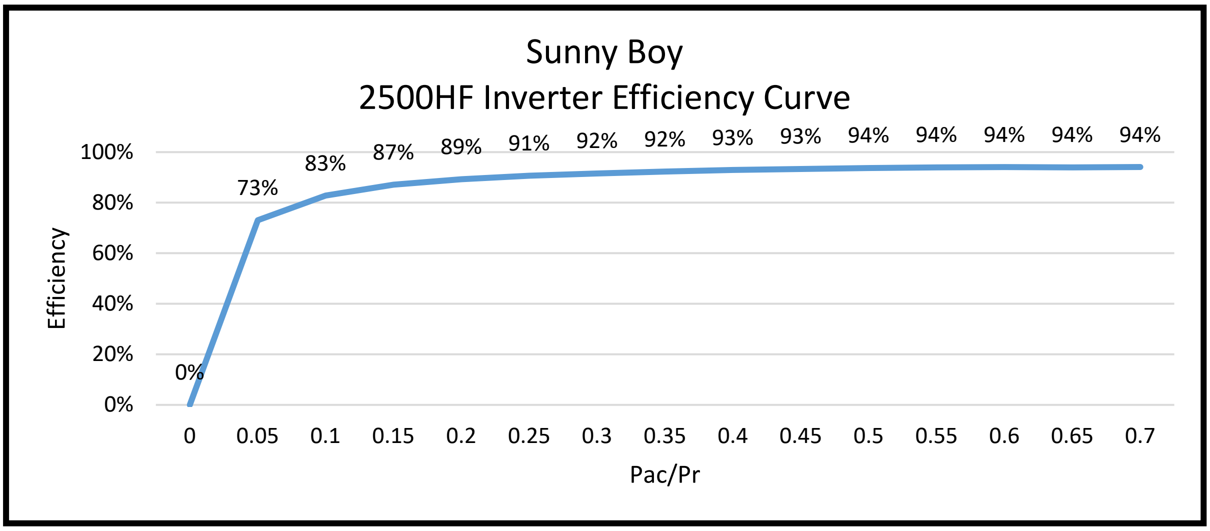

Figure 9: Inverter Efficiency Curve from of 17-Sep-2018 to 13-March-2019.

The low values of data where days containing (missing, night time and shading period) data have been omitted data when the inverter is not producing power against the full reflect the performance of the inverter as illustrated in Figure 11.

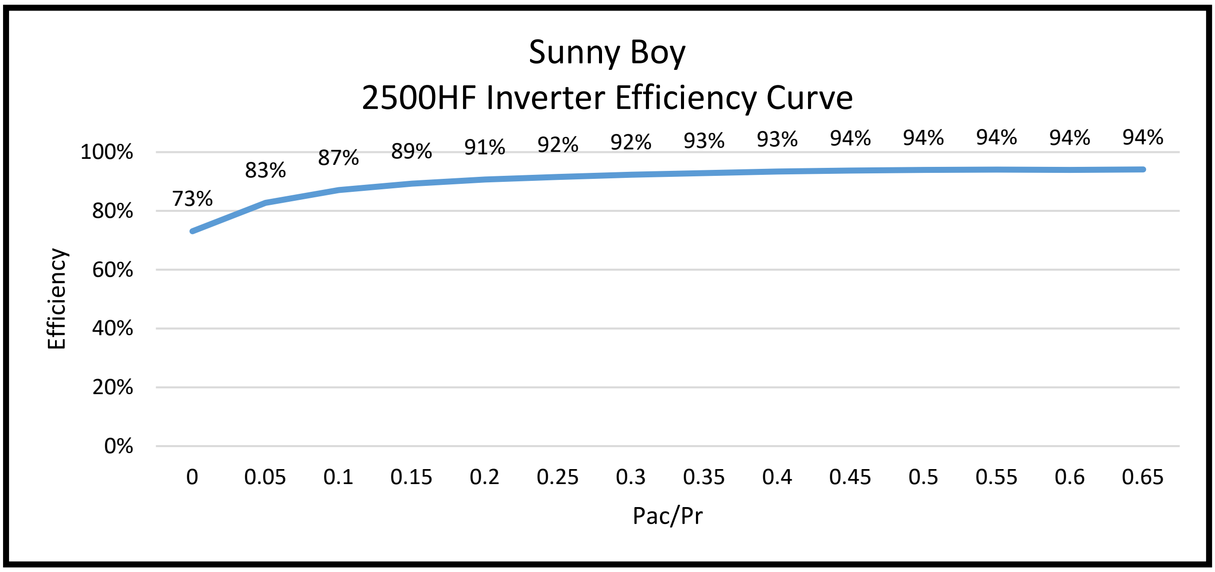

Figure 10: Inverter Efficiency Curve from of 17-Sep-2018 to 13-March-2019 After Omitted.

Figure 12 shows a scatter plot with the trend line from 17-Sep-2018 to 13-March-2019. The gradient of the graph was almost 0.1, as indicated by the goodness of the fit. Further, the goodness of the fit $R^2 = 0.9065$.

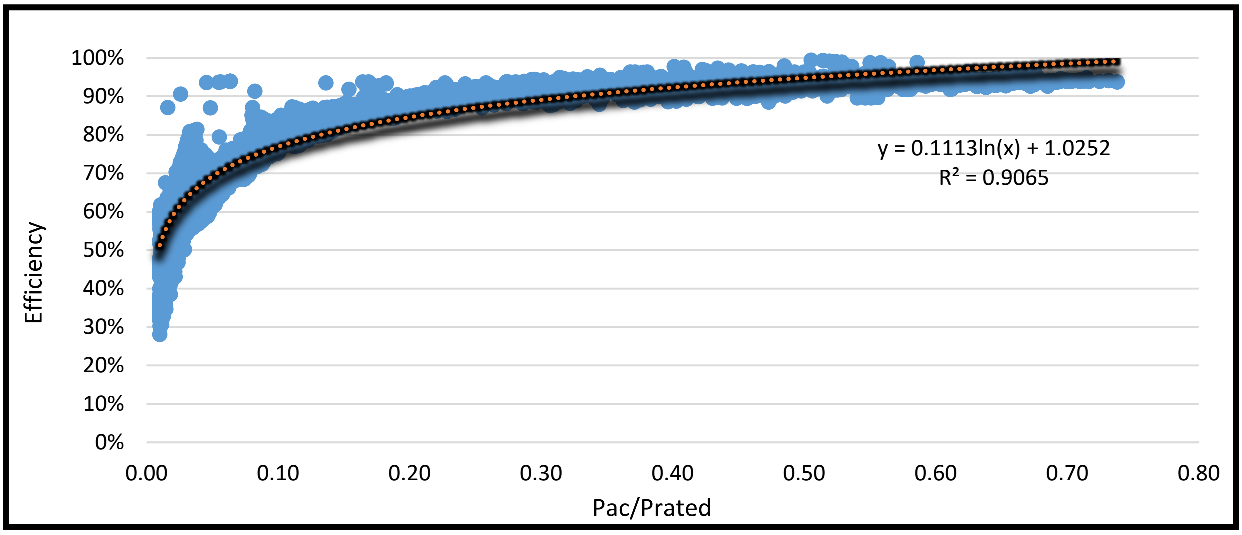

Figure 11: Inverter Efficiency Curve from of 17-Sep-2018 to 13-March-2019 Scatter

Figure 12 shows the hourly profile of performance for SMA 2500HF Inverter system 4 with calculated Pac/Pr. It is shown that at 12 PM is the peak for the period from of 17-Sep-2018 to 13-March-2019 with around 50%. It can also be noticed that the performance start increased from 6 AM till reach the peak. Then the trend dropped gradually after 12 PM to reach almost zero after sun set.

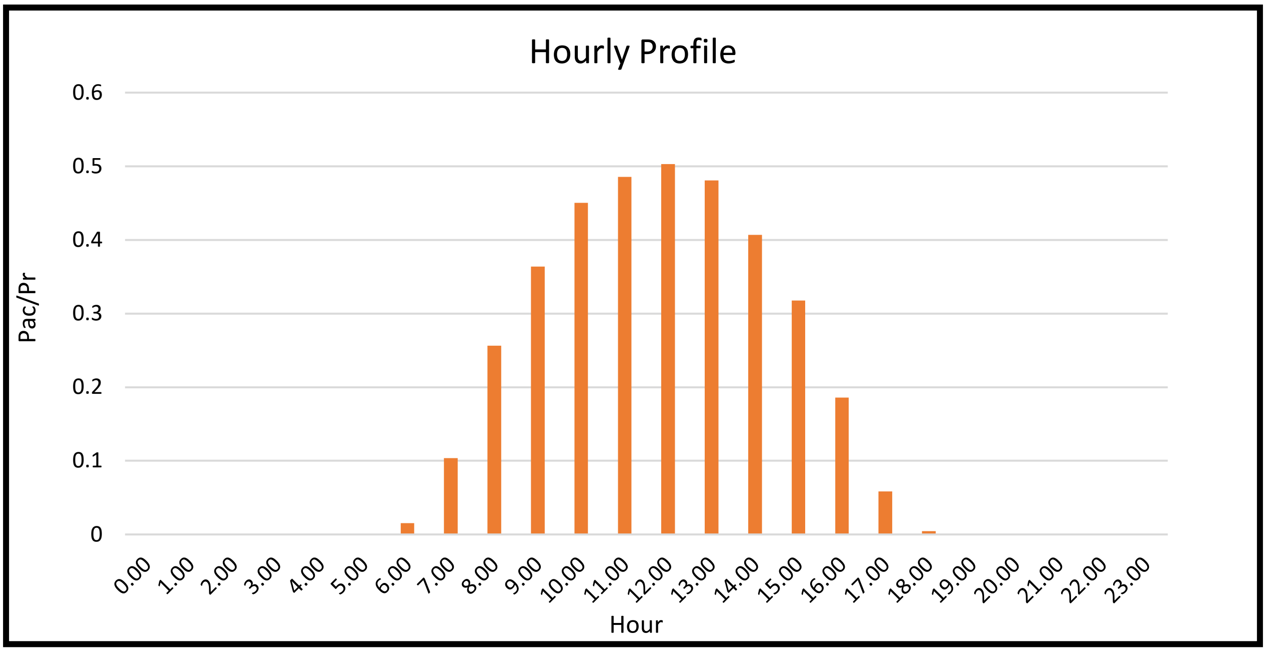

Figure 12: Performance of SMA 2500HF against Hour.

4.2.3 Cleaning Array before 10th May and after

The other task has been done in this project was cleaning for all arrays at the PV Training Facility at Murdoch University on 10th of May 2019. Module performance reduced by the accumulation of dirt on the top surface. Self-cleaning of glass surfaced modules by wind and rain keep these losses under 10%. However, they can be much more significant for other surface materials. There are some issues faced during the data collection to do the performance analysis before and after the cleaning. Firstly, the PV array for system 4 which need to be evaluated is located on the top roof of Engineering and Energy Building (220) and the irradiance and temperature data were from Murdoch MET Station which is far away from the E&E Building around 1 Km as is illustrated in Figure 13.

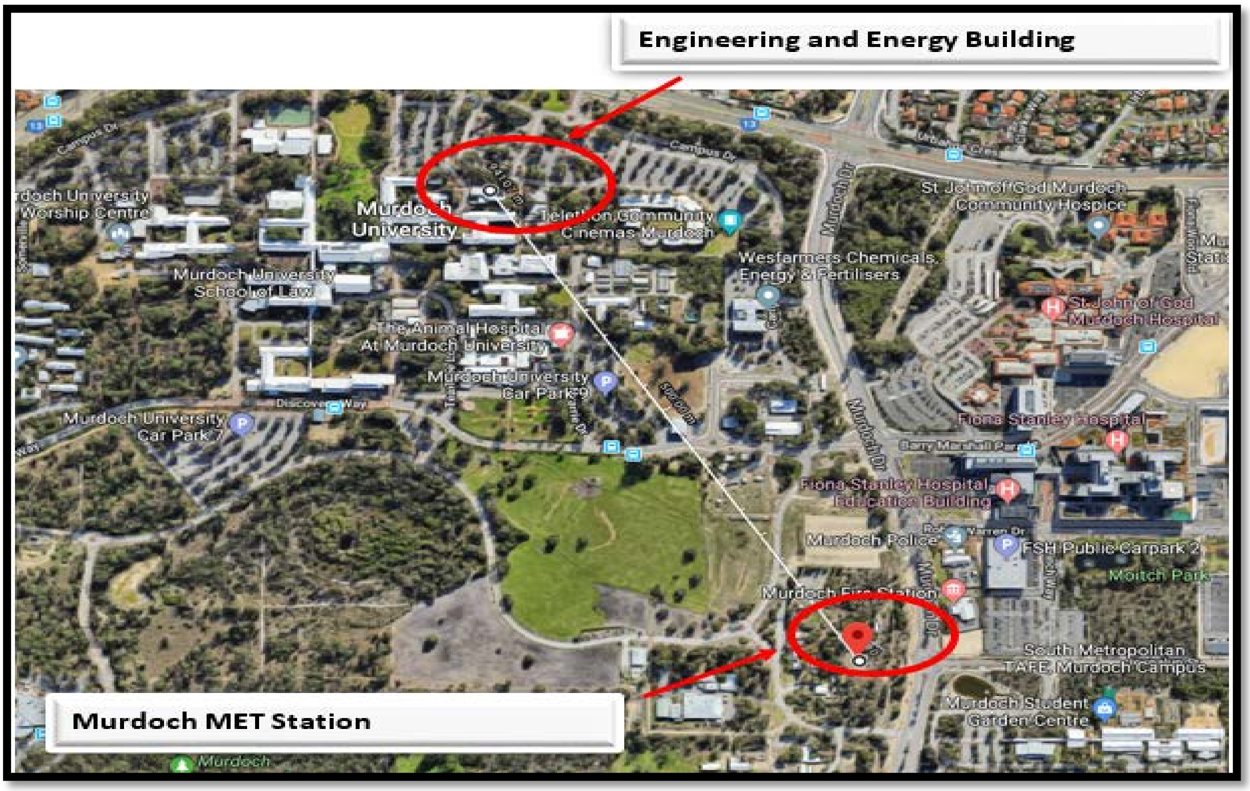

Figure 13: Distance difference between E&E Building and Murdoch MET Station [Google Maps]

Furthermore, there is no irradiance data in the plane of array at E&E Building as they still working to provide a monitoring system on the building and the nearest best location to get the data the MMS only. The second issues were the shading, due to the arrays positioning within trees, shading of direct beam radiation effect module performance on May. Dr Martina and Trevor Pryor prepared the solar path finder readings and position on the roof of E&E Building with a stand lifting it approximately 40 cm above the roof plane as is shown in Figure 14 [27].

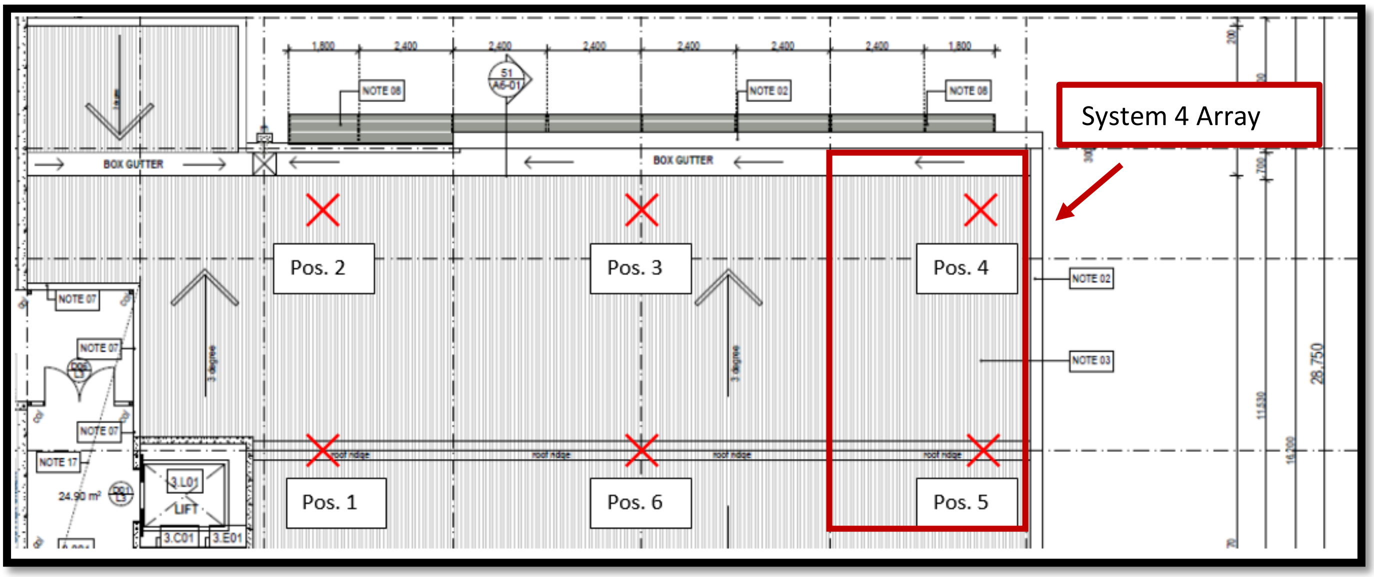

Figure 14: Solar Path Finder Position at E&E Building Roof [27].

Figure 15 below shows the solar path finder which used to determine shading located at position 4. The calculated percentage result for shaded caused by the trees on May was 4+5+6+7+7+7+8+8+7= 59%, and unshaded was 2+3+4+7+7+6+5+4+3 = 41%.

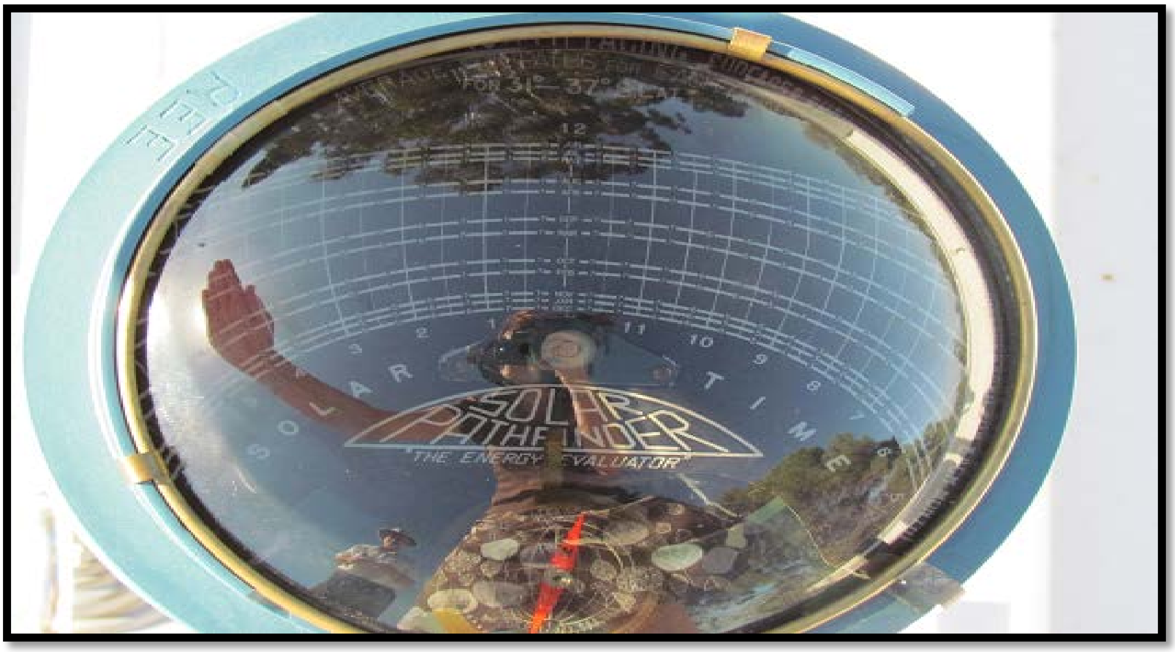

Figure 15: Solar Phat Finder at Position 4 [27].

However, there is no shading for the solar path finder at position 5 as is shows in Figure 16 with unshaded percentage 100% from the trees.

Figure 16: Solar Phat Finder at Position 5 [27]

The figures below shows the performance analysis result before and after cleaning for two selected days in May. The first Figure 17 illustrated the temperature and average AC power before cleaning (3rd MAY) and after cleaning (18th MAY) with time interval of 10 minutes. Analysis of Ac power data for 3rd and 18th May shows there is shading 9 AM to 2 PM with the temperature increased for both days respectively.

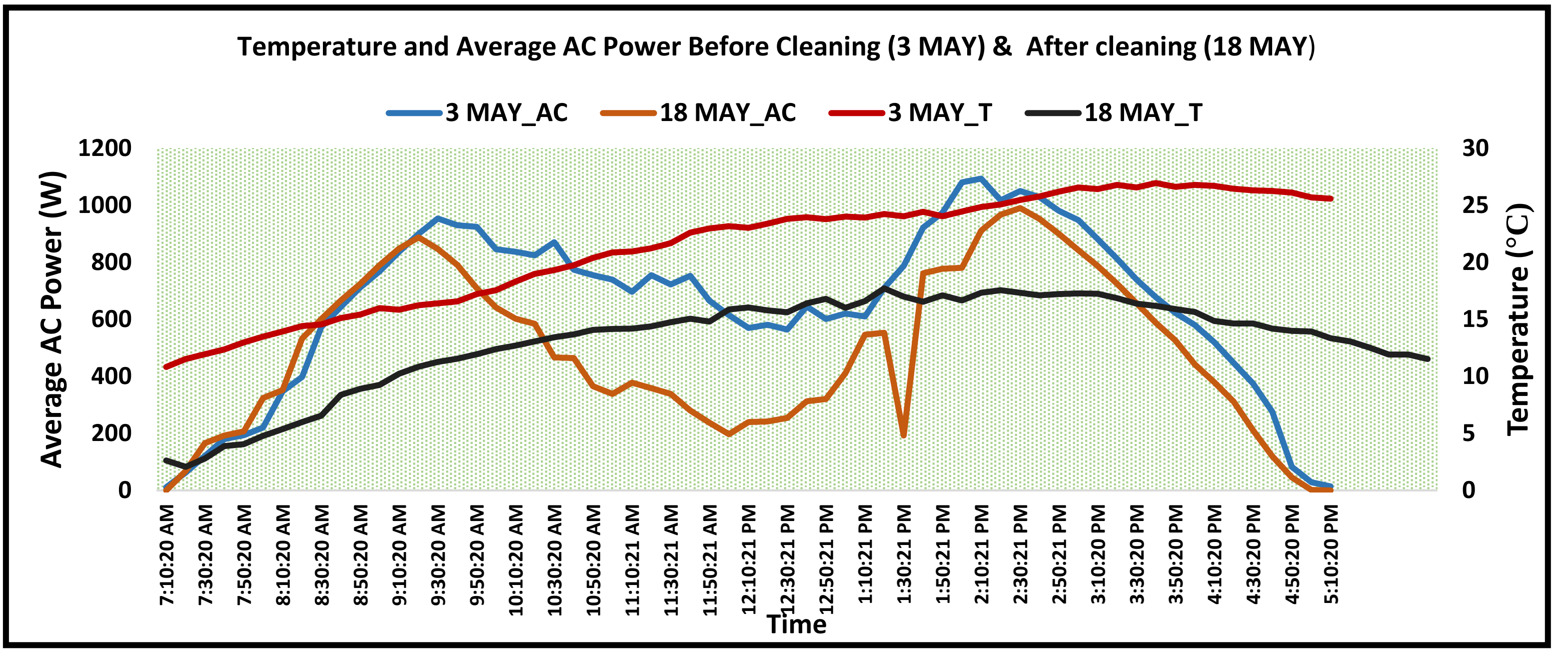

Figure 17: Temperature and Average AC Power before Cleaning (3 MAY) & after cleaning (18 MAY).

Figure 18 shows solar irradiance and average AC power before cleaning (3rd MAY) and after cleaning (18th MAY). The 18th May line shows clear day comparing with 3rd May with some shading come from the cloud. As have been disused and mentioned above about the accuracy and different data location, the result from both graphs are no possible as it can be from Figure 18 the yellow line 18th May shows clear day and it should be more Ac power on the same day, but the orange line shows the opposite with some shading for the same day and same time.

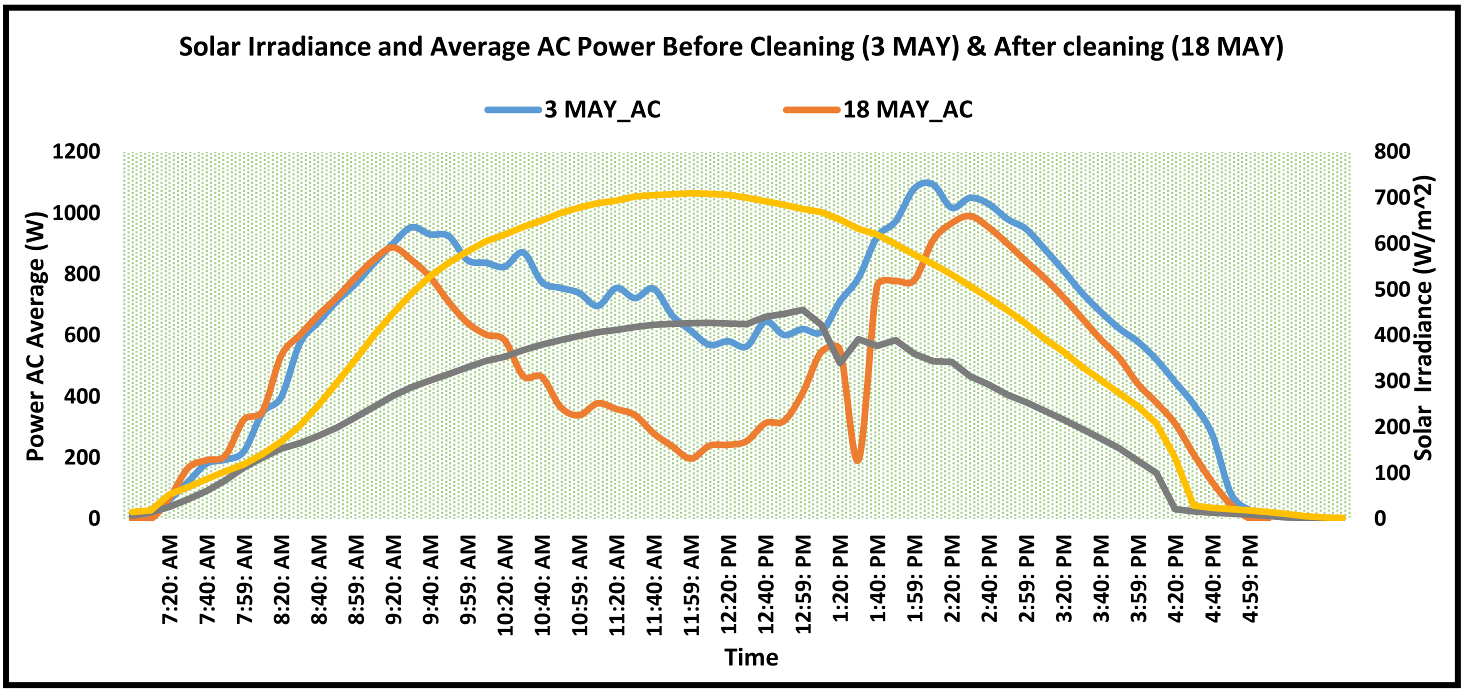

Figure 18: Solar Irradiance and Average AC Power before Cleaning (3 MAY) & after cleaning (18 MAY).

Chapter 5: Conclusion & Future Work

Installation of the PV (Photovoltaic facility) at the School of Engineering and Energy building in Murdoch University was done in the year 2012 on the building's north-east rooftop. Background information on the facility illustrates that the main goal of the facility was to enable students as well as researchers to analyse the performance of PV technologies (and inverter typologies) in addition to their behaviour. Through the PV Training Facility, the University will also experience some specialisations such as Renewable Energy Engineering. Upon conducting this project, detailed information has been develope, aiming to create an upgrade system. The upgrade system is made up of the PV Training Facility's multimode inverter system. The information discussed in this project has also shown an appropriate framework through which to monitor the upgrade system of the facility and engage in related duties such as evaluation and documentation. It is essential that there be a monitoring system that records, stores, and communicates data regarding the performance of the PV system and also environmental data. The individual upgrades that have been made on the PV facility since 2012 have been discussed in this project including the 2016 installation of a program – 'Sunny Data Control' – in the place of 2 SMA inverters that were possible solutions to the problem of communication of data.

A comprehensive evaluation of the PV Training Facility in its current state has shown that the inverter system presently has five varying types of inverters. One inverter is the one that requires an upgrade given that it is not operational and fails to meet the AS4777 requirements. The system that requires an upgrade also has other problems about monitoring as well as documentation capabilities because the inverter is not compatible with the available software.

The value of compatibility between the inverter and the available software is observed to be significant, particularly regarding enhancing documentation and monitoring. Regarding the multimodal inverter possesses battery charging capabilities although it may be considered less preferable since it has no solar controller. When grid conditions are normal, the multimodal inverter ensures that battery charge is managed by utilizing the interconnection device. Consequently, the multimodal inverter has capability of using the grid's power to charge the battery.

The results from this project show that upon evaluation of the current PV facility, it was determined that corruption of the TimeStamp data was occurring. A 'running low on memory' error was also experienced after the one week in which the LabView programs was run to acquire data from two inverters (Samil and SMA No 4). Since there was still memory available, the inference was that there was another problem causing the error. Among the tasks done were cleaning up of the individual arrays at the PV Training Facility and in the process, issues associated with data collection for analysis of performance were done. For instance, it was determined that system 4's PV array had to be evaluated, but its location makes it difficult to collect temperature data from the MET Station at Murdoch. The positioning of the arrays within trees also raised concern because shading occurred hence impacting performance analysis.

5.1 Future Work Opportunities for the PV PV Training Facilities

- The design is been revised due to availability of the equipment and need to be installed.
- In term of performance analysis the limitation in data monitoring of the inverters for system 2, 3 and new one need to be implemented.
- The irradiance data in the plane of array or near the building for all system need to be implemented.

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Appendix A: A Constructed Drawings

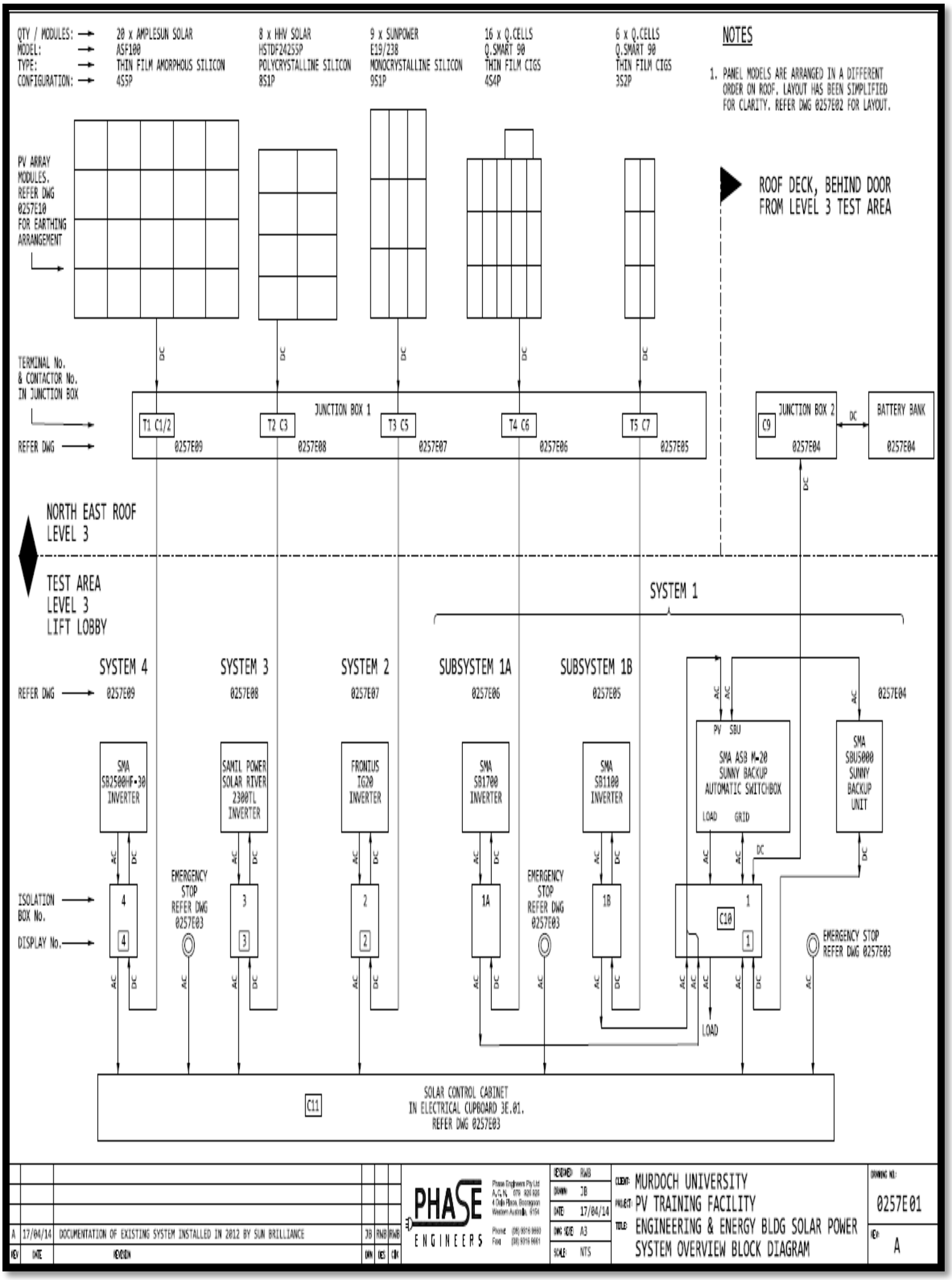


Figure 19: PV Training Facility Constructed Drawings [2]

Appendix B: Grid Connected Inverter

/ Perfect Welding / Solar Energy / Perfect Charging

Fronius

FRONIUS GALVO

The future-proof inverter for small self-consumption systems

SnapINverter Technology | HF transformer switchover | Integrated data communication | Smart Grid Ready | Zero feed-in

With power categories ranging from 1.5 to 3.1 kW, the Fronius Galvo is perfect for households – and is especially suitable for self-consumption systems. The integrated energy management relay allows the self-consumption component to be maximised.

A host of other smart features make the Fronius Galvo one of the most future-proof inverters in its class: for example, the integrated datalogging, the simple connection to the internet by WLAN, or the plug-in card technology for retrofitting additional functions.

TECHNICAL DATA FRONIUS GALVO

INPUT DATA	GALVO 1.5-1	GALVO 2.0-1	GALVO 2.5-1	GALVO 3.0-1[1]	GALVO 3.1-1
Number of MPP trackers	1				
Max. input current ($I_{dc\,max}$)	13.3 A	17.8 A	16.6 A	19.8 A	20.7 A
Max. array short circuit current	20.0 A	26.8 A	24.8 A	29.6 A	31.0 A
DC input voltage range ($U_{dc\,min}$ - $U_{dc\,max}$)	120 - 420 V		165 - 550 V		
Feed-in start voltage ($U_{dc\,start}$)	140 V		185 V		
Usable MPP voltage range	120 - 335 V		165 - 440 V		
Number of DC connections	3				
Max. PV generator output ($P_{dc\,max}$)	3.0 kW_{peak}	4.0 kW_{peak}	5.0 kW_{peak}	6.0 kW_{peak}	6.2 kW_{peak}

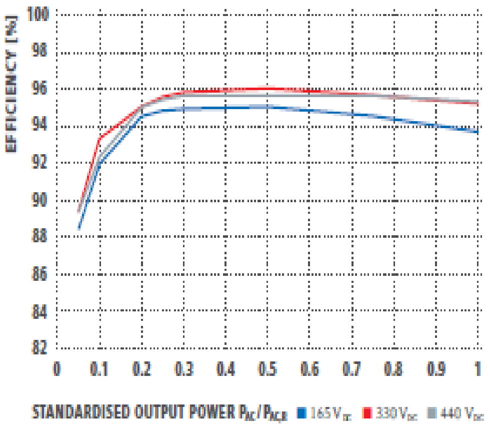
OUTPUT DATA	GALVO 1.5-1	GALVO 2.0-1	GALVO 2.5-1	GALVO 3.0-1[1]	GALVO 3.1-1
AC nominal output ($P_{ac,r}$)	1,500 W	2,000 W	2,500 W	3,000 W	3,100 W
Max. output power	1,500 VA	2,000 VA	2,500 VA	3,000 VA	3,100 VA
AC output current ($I_{ac\,nom}$)	6.5 A	8.7 A	10.9 A	13.0 A	13.5 A
Grid connection (voltage range)	1-NPE 230 V (+17% / -20%)				
Frequency (frequency range)	50 Hz / 60 Hz (45 - 65 Hz)				
Total harmonic distortion	< 4 %				
Power factor (cos $\varphi_{ac,r}$)	0.85 - 1 ind. / cap.				

GENERAL DATA	GALVO 1.5-1	GALVO 2.0-1	GALVO 2.5-1	GALVO 3.0-1[1]	GALVO 3.1-1
Dimensions (height x width x depth)	645 x 431 x 204 mm				
Weight	16.4 kg		16.8 kg		
Degree of protection	IP 65				
Protection class	1				
Overvoltage category (DC / AC)[2]	2 / 3				
Night-time consumption	< 1 W				
Inverter concept	HF transformer				
Cooling	Regulated air cooling				
Installation	Indoor and outdoor installation				
Ambient temperature range	-25 - +50 °C				
Permitted humidity	0 to 100 %				
Max. altitude	2,000 m / 3,500 m (unrestricted / restricted voltage range)				
DC connection technology	3x DC+ and 3x DC- screw terminals 2.5 - 16 mm²				
AC connection technology	3-pin AC screw terminals 2.5 - 16 mm²				
Certificates and compliance with standards	ÖVE / ÖNORM E 8001-4-712, AS 4777-2, AS 4777-3, AS3100, DIN V VDE 0126-1-1/A1, VDE AR N 4105, IEC 62109-1-2, IEC 62116, IEC 61727, CER 06-190, CEI 0-21, EN 50438, G83, G59, NRS 097				

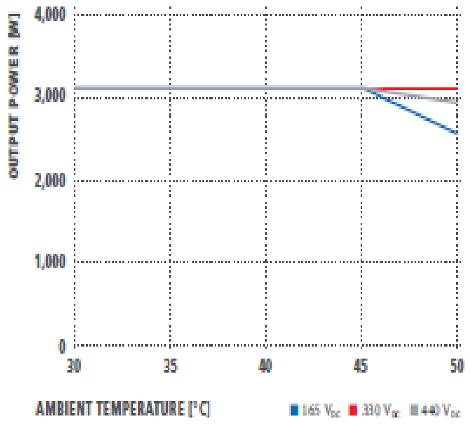
[1] Available for countries where 3 kW restrictions apply. [2] Testing to IEC 62109-1.
Further information regarding the availability of the inverters in your country can be found at www.fronius.com.

Figure 20: Fronius Galvo Data Sheet [22]

FRONIUS GALVO 3.1-1 EFFICIENCY CURVE



FRONIUS GALVO 3.1-1 TEMPERATURE DERATING



TECHNICAL DATA FRONIUS GALVO

EFFICIENCY	GALVO 1.5-1	GALVO 2.0-1	GALVO 2.5-1	GALVO 3.0-1[1]	GALVO 3.1-1
Max. efficiency	95.9 %	96.0 %		96.1 %	
European efficiency (ηEU)	94.5 %	94.9 %	95.2 %	95.4 %	95.4 %
MPP adaptation efficiency	> 99.9 %				

PROTECTION DEVICES	GALVO 1.5-1	GALVO 2.0-1	GALVO 2.5-1	GALVO 3.0-1[1]	GALVO 3.1-1
DC insulation measurement	Warning/shutdown (depending on country setup) at RISO < 600 kOhm				
Overload behavior	Operating point shift, power limitation				
DC disconnector	Included				
Reverse polarity protection	Yes				

INTERFACES	GALVO 1.5-1	GALVO 2.0-1	GALVO 2.5-1	GALVO 3.0-1[1]	GALVO 3.1-1
WLAN / Ethernet LAN	Fronius Solar.web, Modbus TCP SunSpec, Fronius Solar API (JSON)				
6 inputs and 4 digital inputs/outputs	Interface to ripple control receiver				
USB (A socket)[2]	Datalogging, inverter update via USB flash drive				
2x RS422 (RJ45 socket)[2]	Fronius Solar Net				
Signalling output[2]	Energy management (floating relay output)				
Datalogger and Webserver	Included				
External input[2]	S0-Meter Interface / Input for overvoltage protection				
RS485	Modbus RTU SunSpec or meter connection				

[1] Available for countries where 3 kW restrictions apply. [2] Also available in the light version.
Further information and technical data can be found at www.fronius.com.

/ Perfect Welding / Solar Energy / Perfect Charging

THREE BUSINESS UNITS, ONE GOAL: TO SET THE STANDARD THROUGH TECHNOLOGICAL ADVANCEMENT.

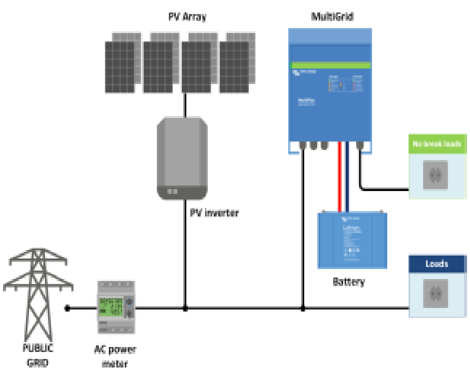
What began in 1945 as a one-man operation now sets technological standards in the fields of welding technology, photovoltaics and battery charging. Today, the company has around 3,800 employees worldwide and 1,242 patents for product development show the innovative spirit within the company. Sustainable development means for us to implement environmentally relevant and social aspects equally with economic factors. Our goal has remained constant throughout: to be the innovation leader.

Further information about all Fronius products and our global sales partners and representatives can be found at www.fronius.com

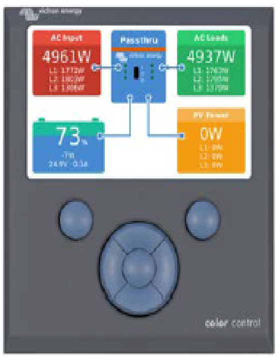
v08 Aug 2017 EN

Figure 21: Fronius Galvo Data Sheet Page 2 [22]

Appendix C: MultiGrid 3000VA Inverter (Backup System) and associated with Color-Control-GX-EN.



Grid parallel topology with PV inverter
Similar to Hub 4-2 but in this topology the PV inverter will shut down in case of a power outage.
Certain critical loads only are protected against a power outage.
The MultiGrid will use data from the power meter to optimise self-consumption and, if required, to prevent back feed of excess solar power into the grid.



Color Control Panel (CCGX)
Provides intuitive system control and monitoring
Besides system monitoring and control the CCGX enables access to our free remote monitoring website: the VRM Online Portal

MultiGrid 24 Volt / 48 Volt	24/3000/70 / 48/3000/35
PowerControl & PowerAssist	Yes
Transfer switch	50 A
INVERTER	
Input voltage range	19 – 33 V 38 – 66 V
Output	Output voltage: 230 VAC ± 2% Frequency: 50 Hz ± 0,1% (1)
Cont. output power at 25°C (3)	3000 VA
Cont. output power at 25°C	2400 W
Cont. output power at 40°C	2200 W
Cont. output power at 65°C	1700 W
Peak power (W)	6000 W
Maximum efficiency	94 / 95 %
Zero load power	20 / 25 W
Zero load power in AES mode	15 / 20 W
Zero load power in Search mode	10 / 12 W
CHARGER	
AC Input	Input voltage range: 187-265 VAC Input frequency: 45 – 65 Hz
Charge voltage 'absorption'	28,8 / 57,6 V
Charge voltage 'float'	27,6 / 55,2 V
Storage mode	26,4 / 52,8 V
Maximum battery charge current (4)	70 / 35 A
Battery temperature sensor	yes
GENERAL	
Auxiliary output	Yes (16 A) Switches off when no external AC source available
Programmable relay (5)	Yes
Protection (2)	a - g
VE.Bus communication port	For parallel and three phase operation, remote monitoring and system integration
General purpose com. port	Yes
Remote on-off	Yes
Operating temperature range	-40 to +65°C (fan assisted cooling)
Humidity (non-condensing)	max 95%
ENCLOSURE	
Material & Colour	Aluminium, blue RAL 5012
Protection category	IP 21
Battery-connection	Four M8 bolts (2 plus and 2 minus connections)
230 V AC-connection	Screw terminals 13 mm² (6 AWG)
Weight	18 kg
Dimensions (hxwxd)	362 x 258 x 218 mm
STANDARDS	
Safety	EN-IEC 60335-1, EN-IEC 60335-2-29, EN-IEC 62109-1, EN-IEC 62109-2
Emission, Immunity	EN 55014-1, EN 55014-2 EN-IEC 61000-3-2, EN-IEC 61000-3-3 IEC 61000-6-1, IEC 61000-6-2, IEC 61000-6-3
Uninterruptible power supply	IEC 62040-1, AS 62040.1.1
Anti-islanding	VDE-AR-N 4105, AS/NZS 4777.2, NRS 097-2-1, UTE C15-712-1, C10/11, RD 1699-RD 413, TOR D4

1) Can be adjusted to 60 HZ
2) Protection key:
  a) output short circuit
  b) overload
  c) battery voltage too high
  d) battery voltage too low
  e) temperature too high
  f) 230 VAC on inverter output
  g) input voltage ripple too high3) Non-linear load, crest factor 3:1
3) Non-linear load, crest factor 3:1
4) At 25°C ambient
5) Programmable relay which can be set for general alarm, DC under voltage or genset start/stop function
  AC rating: 230V / 4A, DC rating: 4A up to 35VDC and 1A up to 60VDC

Figure 22: MultiGrid 3000VA Inverter (Backup System) Data Sheet [23]

Appendix D: Aquion Energy Battery Bank

S30-0080 Battery Stack

AQUION ENERGY

PRODUCT SPECIFICATION SHEET

Aquion Energy's S-Line Battery Stack is a modular building block for clean energy storage systems. Based on Aquion's safe, clean, and sustainable Aqueous Hybrid Ion (AHI™) technology, the S30-0080 is the only Cradle to Cradle Certified™ energy storage product on the market. Designed for years of hassle-free operation in stationary, long-duration applications, AHI batteries are optimized for storing energy for residential, off-grid, and microgrid applications. The S30-0080 delivers an unmatched combination of performance, safety, and environmental sustainability in a cost-effective battery platform.

PRODUCT PERFORMANCE

Testing Performed at 30°C

Embodied Energy (Wh)		Charge Duration (h)				
		4	8	10	12	20
Discharge Duration (h)	4	1,264	1,520	1,600	1,647	1,803
	8	1,335	1,672	1,780	1,848	2,055
	12	1,389	1,775	1,900	1,982	2,217
	20	1,569	2,046	2,200	2,307	2,603

Embodied Capacity (Ah)		Charge Duration (h)				
		4	8	10	12	20
Discharge Duration (h)	4	28.7	35.0	37.2	38.7	42.5
	8	30.3	37.0	39.4	40.9	44.9
	12	31.3	38.2	40.6	42.3	46.3
	20	32.6	39.8	42.3	44.0	48.3

PHYSICAL CHARACTERISTICS

Height	935 mm (36.8")
Width	330 mm (13.0")
Depth	310 mm (12.2")
Weight	118 kg (260 lbs)

OPERATION & PERFORMANCE

Cycle Life	3,000 cycles (to 70% retained capacity)
Operating Temperature	-5°C to 40°C ambient
Voltage Range	40.0 to 57.6 V
Nominal Voltage	48 V
Continuous Power	680 W
Peak Power	800 W
Continuous Current	17 A
Usable Depth of Discharge	100%
Round Trip Efficiency	>90%

CERTIFICATIONS

Sustainability	Cradle to Cradle Certified™ Bronze product
UL Recognition	UL recognized
CE Recognition	CE marked
Shipping Testing	Modified ISTA 3H
IP Rating	IP22

WARRANTY

Limited Warranty	5-year full plus 3-year prorated

Performance characteristics based on testing conducted by Aquion Energy. Performance may vary depending on use, conditions, and application.
For the most up-to-date specification, visit http://aquionenergy.com.

Cradle to Cradle Certified™ is a certification mark licensed by the Cradle to Cradle Products Innovation Institute.

Figure 23: S30-0080 Battery Stack Data Sheet [25]

Appendix E: Wiring Set Up Generic

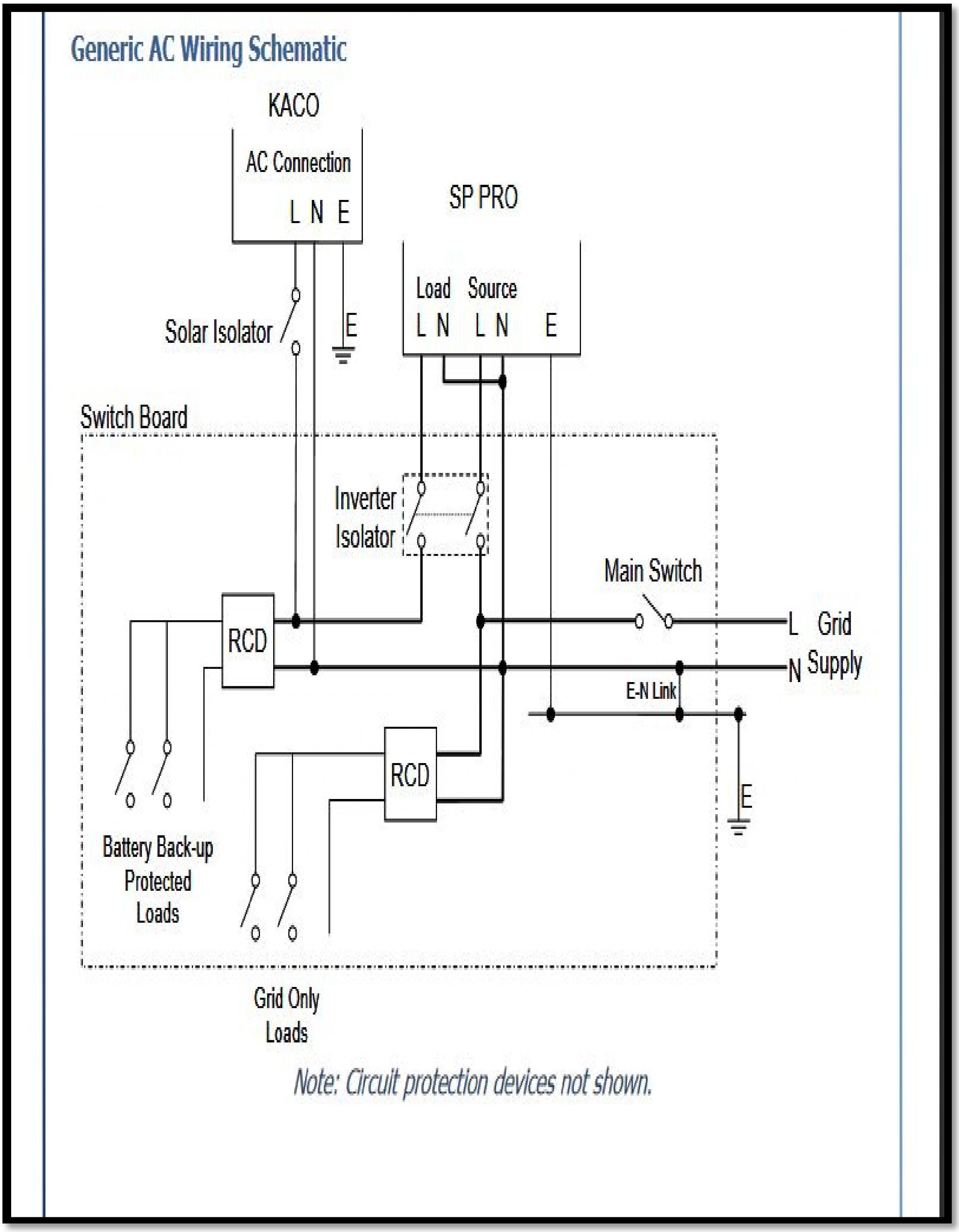


Figure 24: Selectronic and Aquion set up Battery Installation [Installer]

Appendix F: Selectronic and Aquion set up Battery Quote

Stefan's Electrical
10 Royal Melbourne Avenue
Connolly WA 6027
phone: 08 9301 5414
mobil: 0408 899 066
stefan_koefler@optusnet.com.au
ABN 92158955027

Stefan's Electrical & Solar
SUPPLY & INSTALL

Licence No. EC005280 CEC Accreditation 6450311

MURDOCH UNIVERSITY
PV TRAINING FACILITY
ENGINEERING & ENERGY BLDG SOLAR POWER

Martina Calais Mobile #: ++61 8 9360 7628 E mail : M.Calais@murdoch.edu.au

Connolly, 21/05/2019

Quotation Solar System with Battery Inverter and Battery Bank Aquion

Supply and Install Solar PV System to existing Q Cell Panels 90W thin film on existing roof frame plus rewire panels to new lay out , disconnect of old equipment as per scedule (Disconn old SMA Synny Boys x2 with old Sunny Boy Storage) adabt old installation to new Selectronic charge inverter with a new Fronius 2KW Galvo (negative earth) as a Ac Coupled Inverter with a 4 Stack Aquion Battery Bank plus Back up/Emergency Power set up as a Power Points as old was , installed and commissioned complete

Address of install: Murdoch University Campus Building 220

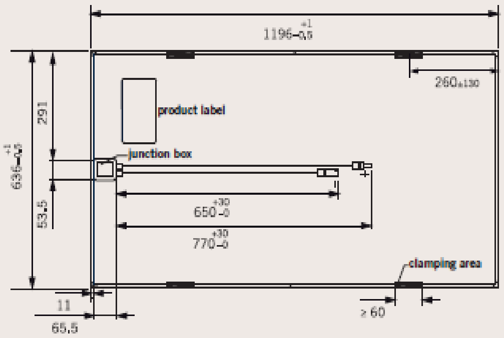
1	Material Bay Wa (Fronius Galvo 2KW , Battery BOS (Cables Fuses Conduits Cable Trunking ..)	$ 2130.–
1	Transport Batteries Warehouse to Campus final position	$ 340.-
1	Selectronic SP Pro SPMC481 complete with new Coms. card and Select Live	$ 5630.-
1	String Fuse Box + Isolator + Enclosure IP65 under array	$ 412.-
1	Material AC Power (RCBO for back up power circuit , Cables Isolators Fuses Cond)	$580.-
1	Labour PV Array re configure 6HR	$720.-
1	Labour disconn old Inverters , install new Inverters , install Batteries with all the BOS included 15HR	$1800.-
	Subtotal without GST	$ 11612.–
	GST	$1,161.20
	Sub Total incl GST	$ 12773.20.-

Figure 25: Quotation with Acceptance Selectronic with Fronius Galvo 2 [Installer]

Appendix G: Q.CELLS 90 Thin Film modules

MECHANICAL SPECIFICATION	
Format	1196 mm x 636 mm x 36 mm (including frame)
Weight	14.5 kg
Front Cover	4 mm tempered low iron glass
Back Cover	3 mm float glass
Frame	Black anodized aluminium
Cell Type	CIGS [Cu(In, Ga) Se_2]
Junction box	Protection class IP 65, with bypass diode
Cable length	(+) 770 mm; (–) 650 mm
Cable type	Solar cable 1.5 mm²
Connector	MC4

TECHNICAL DRAWING

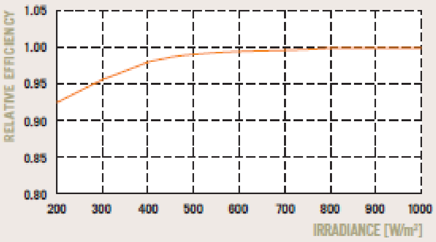


ELECTRICAL CHARACTERISTICS

PERFORMANCE AT STANDARD TEST CONDITIONS (STC: 1000 W/m², 25 °C, AM 1.5 SPECTRUM)[1]							
POWER CLASS			70	75	80	85	90
Nominal Efficiency	η	[%]	9.2	9.9	10.5	11.2	11.8
Nominal Power (+5/-0 Wp)	P_{MAX}	[W]	70.0	75.0	80.0	85.0	90.0
Short Circuit Current	I_{SC}	[A]	1.66	1.66	1.67	1.68	1.69
Open Circuit Voltage	V_{OC}	[V]	69.1	70.5	71.8	73.1	75.1
Current at Maximum Power	I_{MPP}	[A]	1.40	1.42	1.46	1.49	1.52
Voltage at Maximum Power	V_{MPP}	[V]	50.2	52.7	54.8	57.2	59.2

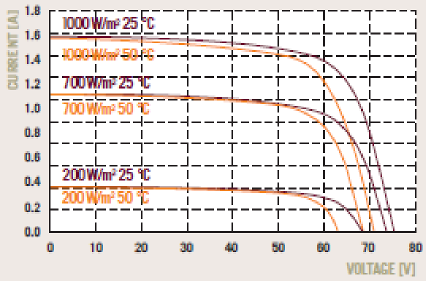
PERFORMANCE AT NORMAL OPERATING CELL TEMPERATURE (NOCT: 800 W/m², 51 ± 2 °C, AM 1.5 SPECTRUM)							
POWER CLASS			70	75	80	85	90
Nominal Power	P_{MAX}	[W]	50.7	54.3	57.9	61.5	65.1
Short Circuit Current	I_{SC}	[A]	1.32	1.33	1.33	1.34	1.35
Open Circuit Voltage	V_{OC}	[V]	62.8	64.1	65.2	66.5	68.3
Current at Maximum Power	I_{MPP}	[A]	1.11	1.13	1.16	1.18	1.21
Voltage at Maximum Power	V_{MPP}	[V]	45.5	47.8	49.7	51.8	53.7

PERFORMANCE AT LOW IRRADIANCE



The typical relative change in module efficiency at an irradiance of 200 W/m² in relation to 1000 W/m² (both at 25 °C and AM 1.5 spectrum) is -7 %.

CHARACTERISTICS AT DIFFERENT TEMPERATURES AND IRRADIANCES



TEMPERATURE COEFFICIENTS (AT 1000 W / M2, AM 1.5 SPECTRUM)							
Temperature Coefficient of I_{SC}	α	[%/K]	– 0.01 ± 0.04	Temperature Coefficient of V_{OC}	β	[%/K]	–0.30 ± 0.04
Temperature Coefficient of P_{MAX}	γ	[%/K]	–0.38 ± 0.04				

[1] The power classes are defined by positive sorting (+5 W/-0 W) according to measured P_{max} under STC. The accuracy of this measurement is ± 3 %. I_{sc}, V_{oc}, I_{mpp}, V_{mpp} are within ± 10 % of the indicated values under STC. Valid indoor measurement of STC performance is obtained by pretreating the modules before measurement with 1 hour light soak (at approx. 1000 W/m² in open circuit) followed by cool down to 25 °C.

Figure 26: Q.CELLS 90 Thin Film modules Data Sheet