DEVELOPMENT OF MICROGRID WITH ENERGY STORAGE SYSTEM

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requirements for the award of the degree of
Bachelor (Honours) of Electrical & Electronic Engineering

Lee Kong Chian Faculty of Engineering and Science
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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

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DEVELOPMENT OF MICROGRID WITH ENERGY STORAGE SYSTEM

ABSTRACT

Microgrid is a system that consists of a bidirectional inverter, energy storage system, load, controller, grid and communication. It helps to improve electric reliability, enhances the resilience of the energy, lower energy cost, improves the environment, and promotes clean energy. This project aims to develop a microgrid system by using a bidirectional inverter with the monitoring and control system, LabVIEW, through YAOPC server via SMA communication protocol. The communication technique used in the system is the USB/RS485 converter called i-7563U converter. The load banks with a capacity of 3 kW and 9 kW are developed to emulate the load profiles of users. They are controlled using NI-9403 through IDC cables. A 24-hour grid voltage fluctuations for the energy storage system and the utility supply are recorded for imbalanced voltage investigation. The results showed that for a balanced load study, the grid voltage decreases with the increment of load. For the unbalanced load condition, the phase voltages with lower loads will increase while the phase voltage with higher loads will decrease.

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CHAPTER 1

INTRODUCTION

1.1   Background Studies

The existing grid that we have today has improved and maintained regularly for many years to achieve the increasing demand. However, it has reached its limits in a few of the requirements such as the reliability in providing continuous supply to the overgrowing consumers and sustainability due to the emission of greenhouse gases (GHG) from the usage of fossil fuels in most of the major cities (Ang KH., 2016).

One of the primary sources of energy, natural gas, is being consumed enormously with a consumption rising rate of 3% or 96 billion cubic meters (bcm) in 2017 as stated in (BP Statistical Review of World Energy 2018, 2018). The increase in energy consumption has increased the emission of GHG which ultimately contributes to climate change. Thus, the usage of renewable energy (RE) has to be implemented to substitute current resources.

Technologies have to be established to capture REs efficiently such as solar energy, gravity energy, nuclear energy, and wind energy. REs are resources that do not deplete when used or can be refilled continuously. Therefore, solar photovoltaic (PV) systems and wind energy systems have been developed to counter the current situations. Moreover, with the extension of microgrids, energy collection, and energy management can be improved. The implementation of microgrids is considered as a possible answer to solving unexpected power interruption due to islanding and possibility to withstand the penetration of renewable energies (Hussain A., 2018). With the islanding properties, consumers will have a higher resilience solution and a more stable grid system.

Electricity consumers such as railways, airports, and hospitals are essential to have continuous electricity supply including situations of low-probability high-impact events such as seismic shocks, disturbing the main grid (Hussain A., 2018). Consequently, having a microgrid system will be reassuring to have continuity of electricity supply even during emergencies. It also reduces congestions of the main grid, resulting in an increase of line efficiency.

1.2   **Problem Statement**

Microgrid with energy storage system (ESS) requires a load bank to simulate the profile for testing. Other than that, it requires a monitoring and control program for data collection and current output controlling. The setup for load bank also needs communications for signalling.

1.3   **Aim and Objectives**

1. To develop a microgrid with energy storage system.
2. To develop a monitoring and control system for the microgrid.
3. To assess the performance of the microgrid developed.

1.4   **Scope and Project**

The scope of the project is to develop a monitoring system and also a control system for the microgrid existing on UTAR KB Block 11th floor. National Instrument (NI) LabVIEW^{TM} is be used to program the Sunny Island 5048, which is a bi-directional inverter. Programs such as sunny island program, power monitoring, data logging system, load bank controller, microgrid controller, and energy storage system have been developed.

1.5 Gantt Chart

The progress of the overall Final Year Project is shown in Figure 1.1.
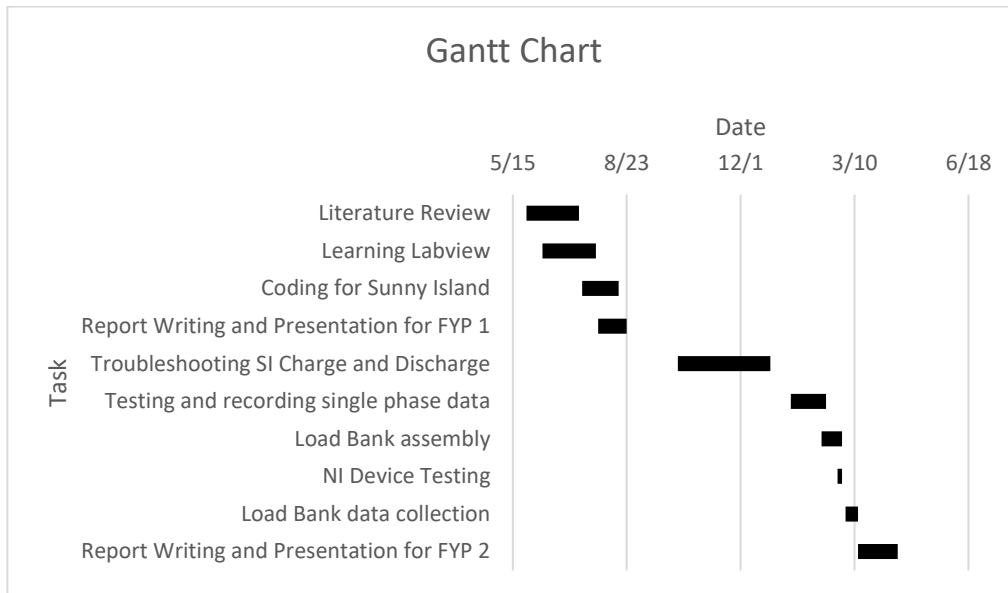
Figure 1.1: Gantt Chart

CHAPTER 2

LITERATURE REVIEW

2.1   Introduction

The concepts of microgrid and the importance of applying microgrid in the current transmission system is introduced here in this chapter. Other than that, the benefits and the usage of the energy storage system (ESS) are explained. It also discusses the difficulties faced when applying renewable energy to the system. Some of the methods on microgrid system control and the factors that affect the microgrid are explained.

2.2   Concept of Microgrid

A microgrid is a system that can provide itself with adequate energy which is collected from renewable energies such as wind turbines, microturbine, solar energy, etc. with the electric energy stored in ESS. It is a local, independent and intelligent system that can operate while being connected to the main grid or disconnect from the grid under a few circumstances. A microgrid connected to the grid is called on-grid while a microgrid with no connection to the main grid is called off-grid. Other than that, if the on-grid system disconnects from the main grid and provides energy to the load from the energy storage system, it is called islanding.

On-grid has its benefits such as higher efficiency, and lower cost in installation. With the backup energy from ESS, it can operate independently during a power outage from the main grid. Islanding can be operated intentionally or unintentionally when it detects fault to prevent the microgrid from any disturbances such as voltage and frequency to maintain the power quality of the system (Wood, 2017).

Unintentional islanding is one of the most crucial properties of the microgrid as it guards the microgrid against fault which originates from the main grid. It also improves the stability of the system and protects the people who are working in the system. Not only the safety of the people, but it also protects the equipment from breakdown or damage. This can be done in a local method or remote method. Local method is where the measurement of the distributed

generation such as voltage and frequency are monitored continuously and remote method is where the monitoring is done in between the utilities and load. (Bhatia, Kirar and Tailor, 2016)

The whole system of microgrid considers of generation, transmission, storage, control, metering and more. They are connected to maintain the energy balance and to counter situations including critical load or any sudden energy loss. It can also be interconnected with other microgrids to function economically like energy purchasing and ancillary services from the main grid and sell back during excess energy (The Microgrid Concept | Building Microgrid, 2019).

2.3   Importance of Microgrid

Microgrid is implemented for its reason in the present time as the demand increases as the time goes. There are also some facilities which are crucial to have constant electricity supply such as hospitals, airports, railways, etc. Thus, the implementation of microgrid is important as it:

    A. Provides continuity of power supply

In times where the main grid meets unstable voltage and frequency due to unforeseen circumstances such as short-circuit or spike in voltage due to lightning, the main grid will affect the load side and causes damages or even power outage. In order to maintain the quality of power supply and continuity of power source during high impact events, the system should be connected to the microgrid for those crucial facilities to maintain the services (Hussain, Bui and Kim, 2019).

    B. Increases the reliability of the grid

With the islanding properties of microgrid, it is possible to provide stable voltage and frequency during unstable periods of the main grid to protect the equipment from overheating or any breakdowns. Microgrids can also reduce the congestion on the transmission line which increases the efficiency and also the lifetime of the transmission line. Consequently, increasing the reliability of the system (Bhatia, Kirar and Tailor, 2016).

C. Improves the flexibility of the grid

With properties of on-grid, off-grid and islanding, the microgrid delivers a more flexible solution to the rural areas where it is difficult to connect to the main grid. Off-grid systems are those that do not attach the energy generation to the main grid (Khodayar, 2017). Therefore, the energy generation rests on renewable energy supplies, for instance, solar panels and wind turbines. Allowing a lower cost of installation to obtain electricity supply for daily usage. However, an off-grid system can still be expensive due to the installation of batteries with large capacity and its energy storage management in order to maintain the system's reliability and stability.

D. Encourages the penetration of Renewable Energy (RE)

In the microgrid system, power generation is a must on the load side, thus renewable energy systems such as solar panels, wind turbine, microturbine and more are preferred comparing to diesel generators. It reduces the cost which is related to electricity purchasing, demand peaks reduction and provides a platform for energy negotiation (Rosales-Asensio et al., 2019). With proper designs on the renewable energy system, the microgrid can sustain itself without relying on the main grid during blackouts. On the other hand, the system can sell energy back to the utility side as well.

2.4   Energy Storage System

The energy storage system, which refers to the batteries, is an important section of the microgrid system. It acts as emergency power for the microgrid during a blackout or inconsistent voltage and frequency. There are a few advantages of having an energy storage system. One of the advantages is providing electricity during blackouts. In situations where the main grid breaks down and loses energy due to unforeseen cases or high impact events such as an earthquake or any natural disaster, the backup batteries will discharge to supply electricity to the whole system by using the microgrid. Subsequently, it will have a stable frequency and voltage when discharging through an inverter because of the fixed frequency. With the batteries, it can also reduce the peak value of electricity intake to reduce the cost implemented by the utility service.

However, without an appropriate setting for microgrid, the energy storage system will experience different voltage and frequency charging from time to time. This will cause shortening in the lifespan of the batteries, increasing the additional cost of replacing the batteries which are avoidable. In order to maintain the lifespan of the batteries, the battery power profile should be smoothened and the fluctuations supplied by battery should be reduced (Hajiaghasi, Salemnia, and Hamzeh, 2019).

2.5   Challenges in Microgrid

In the application of microgrid, it encourages the penetration of renewable energy to reduce the GHG and also to promote clean energy. With the abundant solar irradiance in Malaysia, the installation of solar panel photovoltaic (PV) system is promising to lessen the usage of fossil fuels. However, the installation of solar panels, wind turbine and more have caused certain issues to the whole system (Lim et al., 2015).

The high amount of Renewable Energy Sources (RES) translates to a high amount of power electronics installation in the system. Power electronics interfaces-based RESs will create stability problems for the main grid such as a reduction in inertia power. With the reduction of inertia, it will greatly affect the frequency of the system, causing power blackouts. (Kerdphol et al., 2019).

Other than that, there are some factors stated by (Olivares et al., 2014) that need to be considered when applying microgrid and they are:

A. Bidirectional power flow

The energy storage system connecting to the inverter will need to have a bidirectional flow of power to charge and discharge the energy. There are times where it needs to be charged and discharged at the same time. However, the distribution network is a unidirectional system. The microgrid may cause a reverse power flow which will disturb the distribution network, creating unwanted voltage disturbances and fault current distribution.

B. Transient Stability issues

When the local oscillation of the distribution grid occurs in the system, it may affect the main grid to be unstable and causes blackout as well. With

different properties such as on-grid or off-grid, they will cause unwanted transient stability issues to the main grid as well differently.

C. Modeling

The conditions of a typical conventional grid are not applied in microgrids. Each of the microgrid systems has to be designed individually according to the load and the condition of the area such as the rural areas and area with extreme weather.

D. Uncertainty

With different specifications made for each microgrid, there will be difficulties in coordinating with each other. Affecting the economical and the reliability of the operation. It is also difficult to solve the critical demand and supply issues of an isolated microgrid which has higher component failure rates due to the uncertainty of load profile and weather forecast.

2.6   Control of Microgrid

With the penetration of renewable energy and the problem brought by it, a new solution has to be made to solve the voltage fluctuations. That's when the fuzzy controller is introduced to control the real and reactive power of the distribution network along with the energy storage system. Then, the network's efficiency can also be improved by maintaining the voltage unbalance, network voltage, power factor of the network using fuzzy controller (Lim et al., 2015).

Next is the output control of the microgrid which needs to be controlled to be constant to ensure the oscillations are damped correctly. When outputting, it should have a power balance to maintain the frequency and voltage within tolerable ranges and capable of handling sudden power imbalances. The design of the frequency and voltage needs to be designed following the standards to have a normalized design so that each system can coordinate together without issues regarding the frequency difference or voltage difference which will cause disturbances to each of the microgrid systems or the main grid.

Proper demand-side management (DSM) should be made as well to have better control over some of the load. With the information collected over time, it can create new strategies in load-frequency control to improve the cost of the system. Thus, improving the economics of the system, reducing the production

cost while improving the profit margin. There are also issues such as the transition between modes of operation that need to be solved. A working microgrid will have to overcome the transients created by islanding and that's why it has to have the ability to create a smooth transition during switching.

CHAPTER 3

METHODOLOGY

3.1   System setup

At the beginning of the project, the microgrid simulation hardware has been partially built on the 11th floor of UTAR KB block. This microgrid is used to collect data and control to obtain the anticipated result. The bidirectional inverters are connected to the university power grid to act as an on-grid system. Lastly is that the microgrid is connected with sets of energy storage system. Nearby the system, there are PV systems that can be connected for future development and testing. Figure 3.1 shows the Sunny Islands setup on the 11th floor of UTAR KB block with the energy storage system. Figure 3.2 shows the connection between the PC-unit and i-7563U USB-RS485 converter.
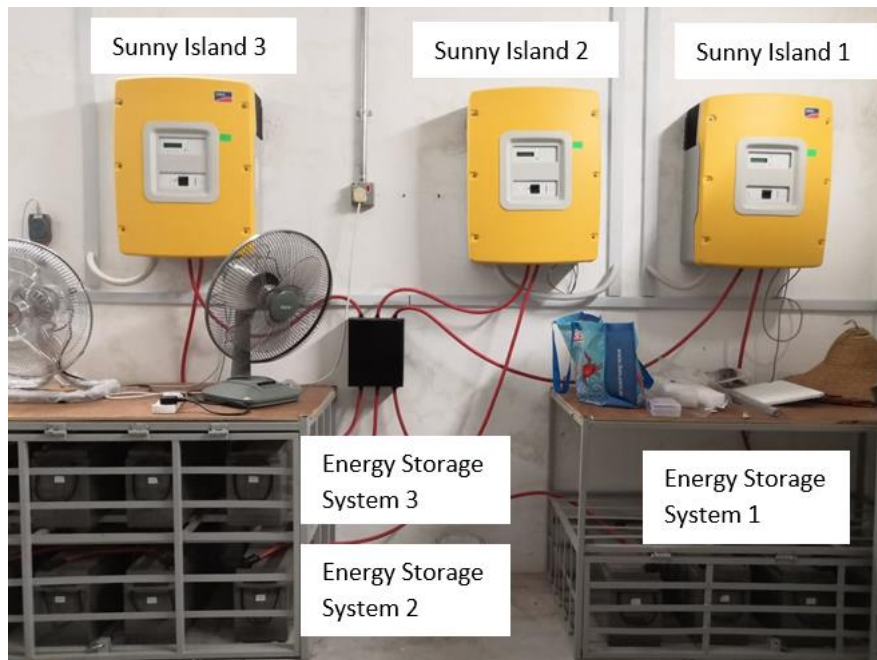
Figure 3.1: Sunny Island and battery setup

Figure 3.2: Connection between PC unit and i-7563U

3.2 Sunny Island 5048

The bidirectional inverter that has been used in the system is the Sunny Island 5048, by SMA Solar Technology AG from Germany. It can operate in both conditions of on-grid and islanding with the connection of RES, PV system. Thus, it can be used to charge the energy storage system and also providing electricity to the load. The microgrid is connected with 3 sets of sunny islands for 3 different phases, red, yellow and blue. Red is appointed as the master unit while yellow and blue are the slave units. For communication, the microgrid is connected with a RJ45 cable to the PC unit with a i-7563, USB to RS485 converter.

In the installation of the sunny island with the energy storage system and PV system, the technical data of the sunny island is studied before connecting the hardware to avoid inconsistent frequency and voltage. Leading to failure of the installation. The technical information about the sunny island is shown in Table 3.1.

Table 3.1: Sunny Island Specification(Source)

Output values		SI 5048
Nominal AC voltage (adjustable)	$U_{AC, nom}$	230 V (202 V ... 253 V)
Nominal frequency	f_{nom}	45 ... 65 Hz
Continuous AC output at 25 °C	P_{nom}	5000 W
Continuous AC output at 45 °C	P_{nom}	4000 W
AC output power for 30 min at 25 °C	$P_{30\ min}$	6500 W
AC output power for 1 min at 25 °C	$P_{1\ min}$	8400 W
AC output power for 3 seconds at 25 °C	$P_{3\ sec}$	12000 W
nominal AC current	$I_{AC, nom}$	21 A
Maximum current (peak value) for 60 ms	$I_{AC, max}$	120 A
Harmonic distortion of output voltage	K_{VAC}	< 3 %
Power factor cosφ		– 1 ... +1
Input data		
Input voltage (adjustable)	$U_{AC, ext}$	230 V (172.5 V ... 264.5 V)
Input frequency (adjustable)	f_{ext}	50 Hz (40 Hz ... 70 Hz)
Maximum AC input current (adjustable)	$I_{AC, ext}$	56 A (0 A ... 56 A)
Maximum input voltage	$P_{AC, ext}$	12.8 kW
Battery Data		
Battery voltage (range)	$U_{Bat, nom}$	48 V (41 V ... 63 V)
Maximum battery charging current	$I_{Bat, max}$	120 A
Continuous charging current	$I_{Bat, nom}$	100 A
Battery capacity	C_{Bat}	100 Ah ... 10000 Ah
Charge control		IUoU procedure with automatic full and equalization charge
Battery type		VRLA / FLA / NiCd
Efficiency / Power consumption		SI 5048
Maximum efficiency		95 % (at 1000 W)
Efficiency > 90 %		5 ... 120 % Pnom

Sunny Island 5048 has some control elements and electrical connection layout which is necessary for the communication and sensing inputs. The internal ports of the Sunny Island 5048 are shown in Figure 3.3 with the connection layout in Figure 3.4. The description of the labels is shown in Figure 3.4.
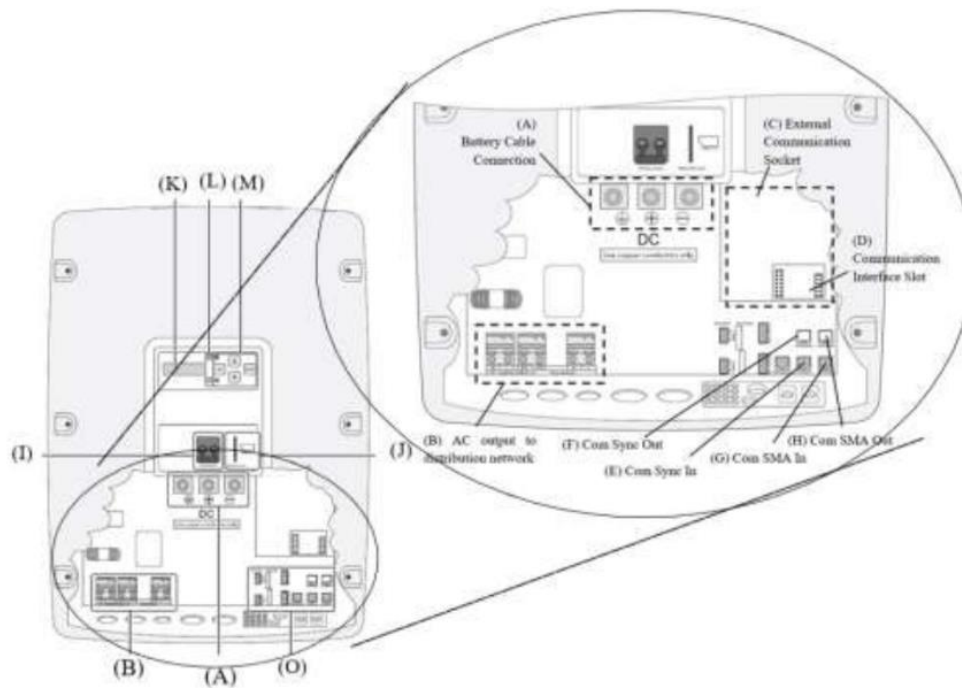
Figure 3.3: Sunny Island Internal Ports

	Description
A	Battery Cable Connection
B	AC Output to Distribution Network
C	External Communication Socket
D	Communication Interface Slot
E	Com Sync In Port
F	Com Sync Out Port
G	Com SMA In Port
H	Com SMA Out Port
I	DC Circuit Breaker
J	Slot for the SD Card
K	Display
L	LEDs showing device operation
M	Control buttons
O	Connection Area for additional connection

Figure 3.4: Description of the Internal Ports

3.3 Sunny Island 5048 Monitoring System

For the monitoring system, the data are sent to the PC unit with the help of the i-7563 converter. 3 communication stages have been done for the communication to be successful and they are hardware communication, communication protocol, and the user interface. The stages are stated in Figure 3.5.
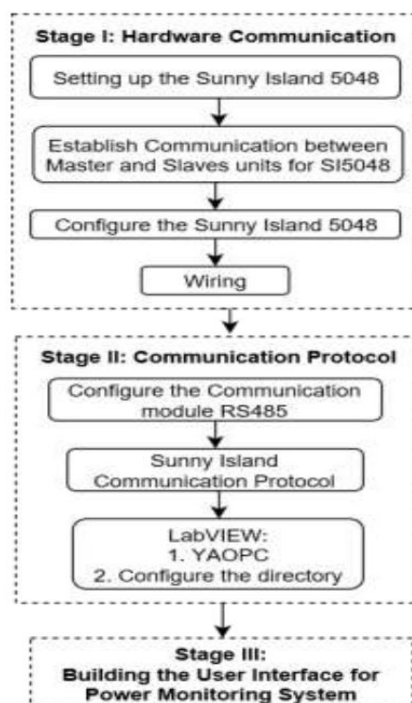
Figure 3.5: Stages of Communication

3.3.1 Hardware Communication

The hardware communication connection in stage I includes Sunny Island setup, connecting the master and slave unit, configuring the Sunny Island and wiring. Firstly, the Sunny Island is connected to UTAR power system to input 3 phase AC as a setup to acquire the input power. The mounting of the Sunny Island is done as stated in the technical manual for proper setup to avoid faults and damages to Sunny Island. Next is the configuration of the Sunny Island. It has been set to 50 Hz, 230 V single-phase power and 400 V 3-phase power. Lastly, the wiring of the Sunny Island from the master unit to the slave unit, energy storage system, load bank, and PC unit has been completed.

In the process of installing the Sunny Island, the batteries are installed as well. Following Table 3.2.2, the batteries are connected to the port, (A) which

is the battery cable connection while AC output cables to distribution network are connected to port (B). The batteries are connected to each of the Sunny Islands, Red, Yellow, and Blue to provide 3-phase energy storage system. Other than that, a cable is connected to (O), BatTmp for the input of battery temperature to Sunny Island in order for it to track. The cable is a special type of sensor which is a KTY type battery temperature sensor. The connection area for extra connection is shown in Figure 3.6.
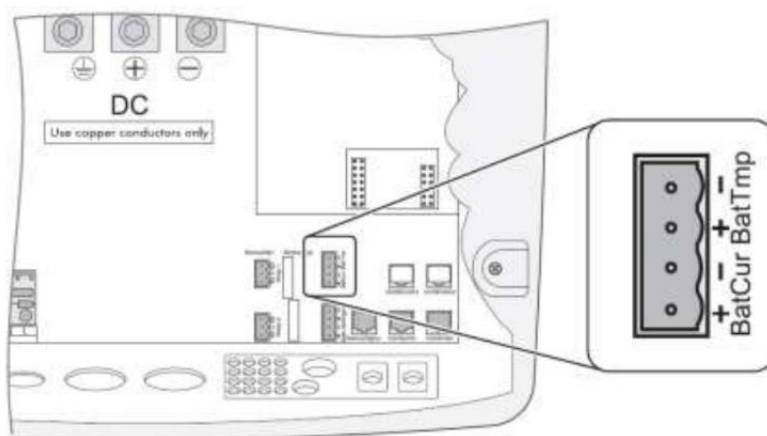
Figure 3.6: Connection area for Additional Connection

In the Sunny Island, a piggyback PB-485-G2 is installed. It is a chipset connected to the port (C) for external communication socket. The main purpose of this is to help Sunny Island to establish external communication and to activate the communication sockets of (E to H).

The setting for the 3 Sunny Islands is that the Red phase is the master unit while the other two phases act as slave units. To establish the internal communication between the master unit and the slave units, the ports (E), Com Sync In and (F) Com Sync Out are used. The communication cable used is RJ45. To connect the master unit to the slave units, the cable is connected from the master unit's (F) port to one of the first slave unit's (E) port. Next from the first slave unit's (F) port, it connects to the second slave unit's (E) port. As for the (E) port of the master unit, it is terminated with a termination resistor. It is done the same as the (F) port of the second slave unit (SMA Solar Technology AG, 2015). The connection between master and slave setup is shown in Figure 3.7.
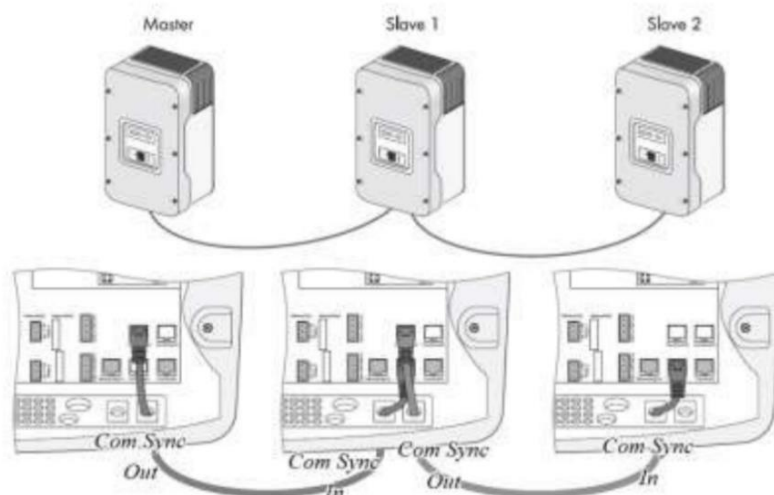
Figure 3.7: Connection for Master and Slave setup

3.3.2   Communication Protocol

In stage II, the communication between the sunny island and the PC unit is made. In between them is the USB/RS485 converter called i-7563u to construct a two-way communication. It is used to transfer the serial data to and from the sunny island with the PC unit. The main setting that needs to be made is the baud rate which is the speed of data transfer. The Figure in 3.3.2.1 shows that there are 3 sets of input that can be inserted, Data 1, Data 2 and Data3. RJ45 is connected from the master unit port (G) COM SMA IN to the i-7563u converter's port 9 and port 10 for Data 1. Taking the green cable to be data1- and green strip to be data1+. Figure 3.8 shows the communication port for the I-7563U USB-RS485 converter.
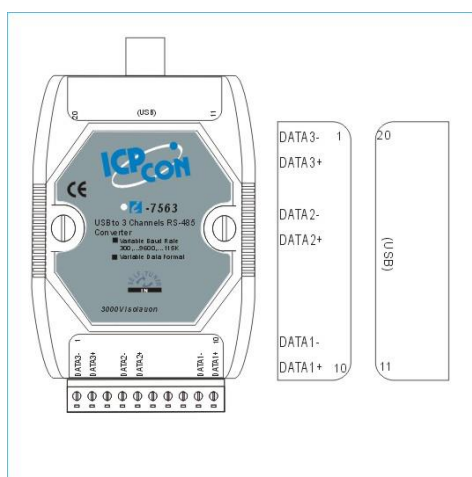
Figure 3.8: I-7563U Communication port

After the connection is done between the Sunny Island 5048 to the i-7563u together with the PC unit USB port, the PC unit required to run the virtual machine, Window XP, to operate SMA OPC Server. SMA OPC Server can only be operated using window XP due to version problem. In order to login to the virtual machine, it requires a password which is "123456".

Following up will be connecting the PC unit to acquire the result from Sunny Island 5048 using YAOPC. The SMA YAOPC Server translates the data that has sent by the sunny island through the RJ45 to i-7563u, converted to USB signals and finally to the PC unit. When the LabVIEW program runs, the communication between the PC unit and the Sunny island will be made automatically by the SMA OPC Server. The data is then being received by the monitoring system or the supervisory system, LabVIEW^{TM}. Figure 3.9 shows the process of YAOPC detecting the device for data transmission. While Figure 3.10 shows that the connection between the PC unit and the Sunny Island is complete and ready for data transmission.
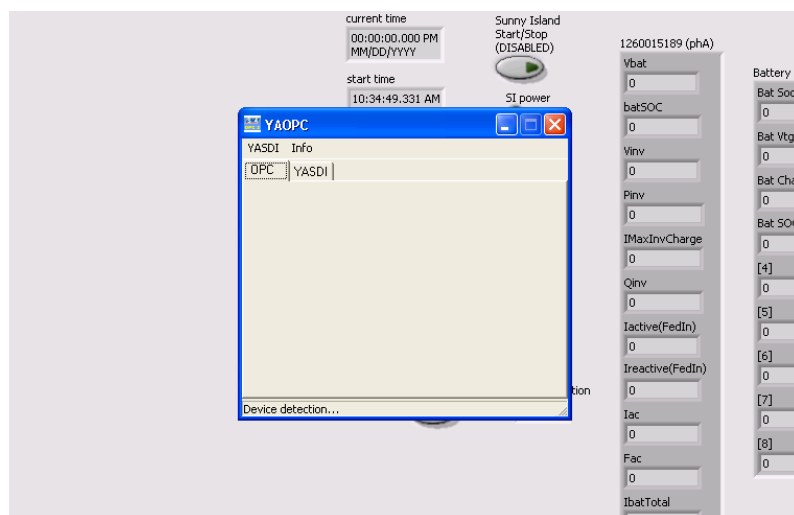
Figure 3.9: YAOPC Device Detection
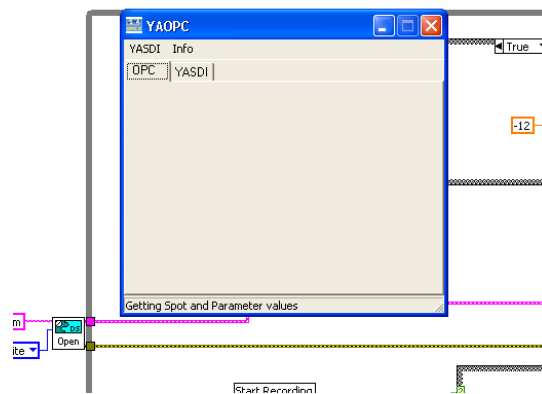
Figure 3.10: YAOPC Getting Spot and Parameter values

LabVIEW^{TM} can also send signals to the sunny island to control the energy storage system as well as to supply energy to the load. In order for the YAOPC to connect to the sunny island, the baud rate has to be the same in order for the information to be received correctly. Other than that, certain settings on the sunny island need to be configured before the sunny island can receive signals (Wong, 2014).

Step 1: Enter installer password (Sum of digits of the operating hours)

Step 2: Direct Access

Step 3: Parameter number: 23801 FedInMod: Com

3.4   Sunny Island Settings

Before the SI5048 runs, some main settings need to be set so that it adapts to the application. For example, the rating of the batteries, charging speed, nominal voltage, operating frequency, etc. The important settings are stated in Table 3.2:

Table 3.2: Sunny Island Specification

Settings	Parameters	Description
InvVtgNom	240 V	Nominal Inverter Voltage
InvFrqNom	50 Hz	Nominal Inverter Frequency
InvChrgCurMax	21.7 A	Max Inverter Charging Current
BatTyp	VRLA	Battery Type
BatCpyNom	150 Ah	Nominal Battery Capacity
BatVtgNom	48 V	Nominal Battery Voltage
ExtSrc	Grid	External Source
GdVtgMin	184.00 V	Minimum Grid Voltage
GdVtgMax	264.50 V	Maximum Grid Voltage
GdCurNom	20 A	Nominal Grid Current
GdFrqNom	50 Hz	Nominal Grid Frequency
GdMod	GridFeed	Grid Mode
ClstCfg	3Phase	Cluster Configuration
ComBaud	9600	Baudrate
ComAdr	1	Address for communication

3.5   Energy Storage System

The energy storage system is built with 3 sets of batteries with each unit having 4 units of 12 V 150 Ah batteries connecting in series to obtain a total of 48 V 150 Ah per phase. The energy storage system is communicated and controlled by the sunny island through the cable and also the temperature sensor. They are charged full at all time when the system is in idle mode so that the batteries' state of health is maintained for longer period of lifespan. The setup of the energy storage system with the Sunny Island is shown in Figure 3.11.
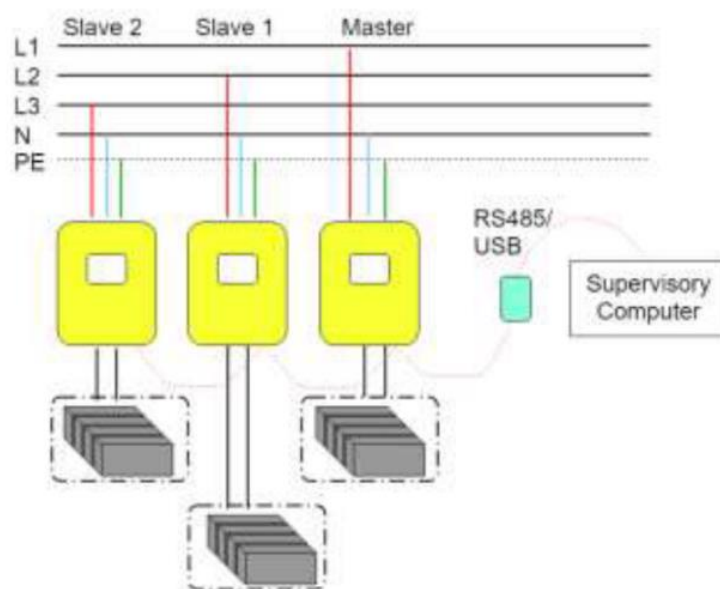
Figure 3.11: Energy storage system and Sunny Island setup

3.6   LabVIEW^{TM}

The main software that is used in this project is LabVIEW^{TM}. It is a powerful graphical programming software that can input data from National Instrument machines and control them as well. It helps in visualizing the aspects of the application, including hardware configurations, measurements and debugging.

The input data for the program is acquired from the hardware connection that is done from the sunny island to the PC unit. With the data acquired, it can be used for a lot of processing and also analysis. In order for the system to work properly, programming, logic circuits, and algorithms have to be designed in order to control appropriately of the system to obtain the anticipated result. Some of the important features of the program that are done to have the system working are as follows:

1. Sunny Island Reading Program
2. Power Monitoring Program
3. Data Logging Program
4. Load Bank Control Program

3.6.1   Sunny Island Reading Program

The main objective of this program is to read and obtain data from the sunny island. Each of the data is read and stored in a cluster type variable. Figure 3.12 shows the OPC address of the specified data to read from the sunny island.
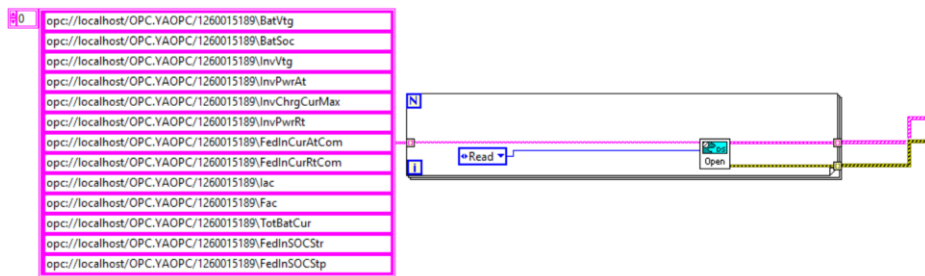
Figure 3.12: Data address from Sunny Island

Figure 3.13 shows the sub-vi for data updating of the sunny island to the cluster type variable.
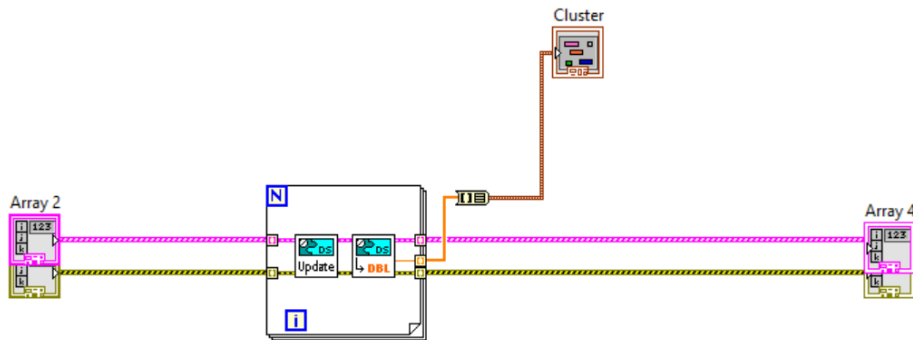
Figure 3.13: Sub-vi for data updating to cluster variable

3.6.2   Front Panel

The very first step for data collection is reading the information from the Sunny Island 5048. Through the YAOPC protocol that has been set up previously, the communication between the PC unit and the sunny island is done. Following is the front panel in the LabVIEW. It has the functions of starting up the Sunny Island, turning it off, sending current to the grid, control load bank and so on. Figure 3.14 shows the program for 3-phase Sunny Island reading.
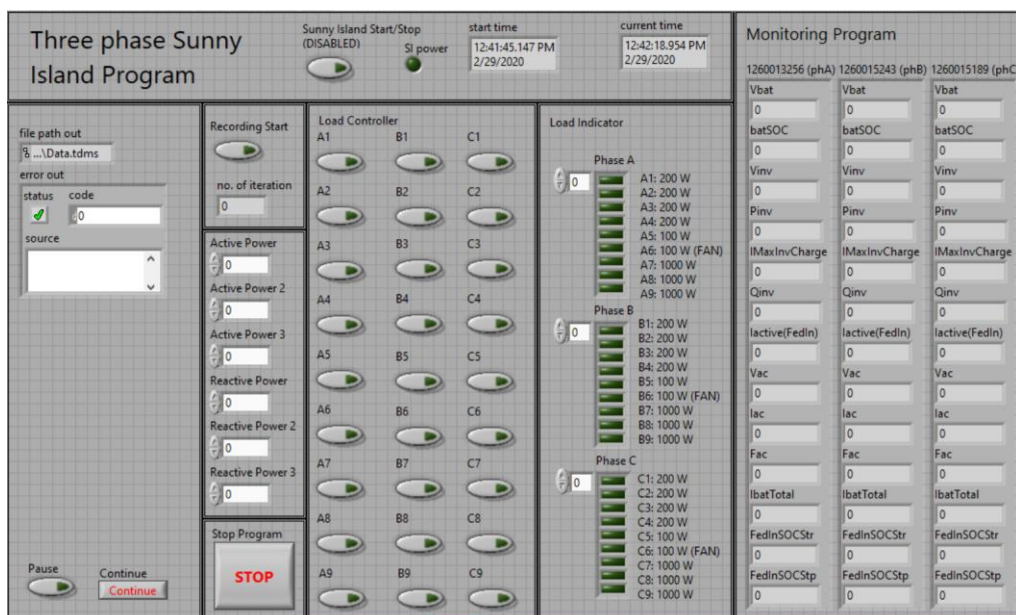
Figure 3.14: Front panel of SI Program.vi

3.6.3   Data Logging Program

In the data logging program, the data is read in a 5-minutes interval during charging and discharging modes. It is then saved in TDMS format. The extension file, Excel Importer, is used to convert the TDMS file to Excel. The extension can only be used by Microsoft Office 2016 or below. After the data is saved in the excel file, graphs are produced to see the fluctuations of the sunny island and the changes of data.

During the data logging phase, the first part is to check whether there is an existing file on the current day. If there is no new file on that day, the system will initiate the creation of a file to store the data collected. With specified data of date and time in order to follow up on the changes for each day and time of collection. When the initialization is done, the data will be taken from the local variable to write into the file created. The file will be closed after the data writing is done. A single line of the program for data logging for one set of data is shown in Figure 3.15 for single phases, and Figure 3.16 for 3-phase.
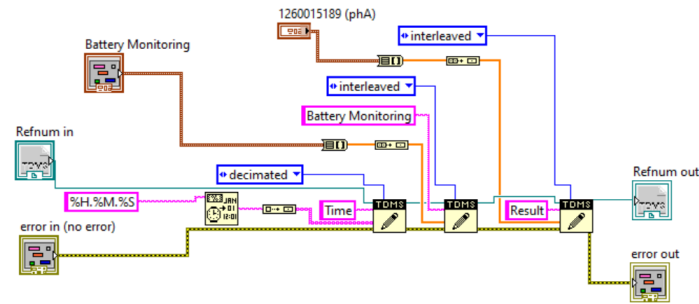
Figure 3.15: Data logging block diagram for single phase sub-vi
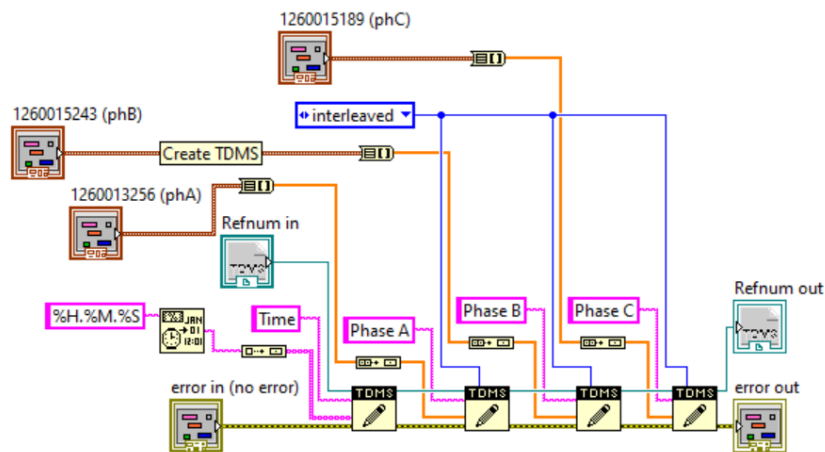
Figure 3.16: Data logging block diagram for 3-phase sub-vi

3.6.4 Load Bank Control Program

The load bank control device uses 32 digital input-output pins to transfer and receive signals to and from the load bank. Thus, the program written for the load bank consisted of 8 "True or False" signals for a single phase of load bank. The signals are then sent to the NI9403 DIO program to pass the signals to the load bank. The sample of a single-phase load bank control is shown in Figure 3.17.
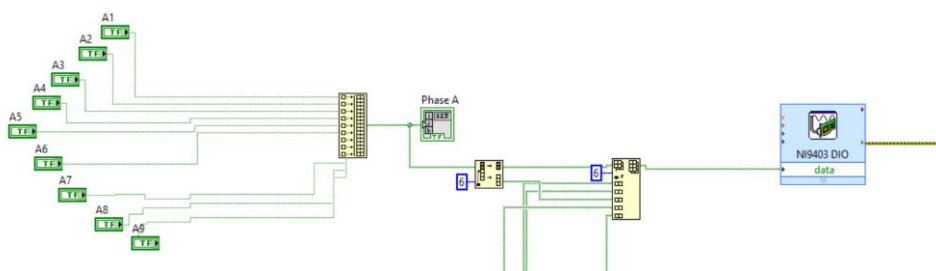
Figure 3.17: Data logging block diagram for 3-phase sub-vi

3.7   Data Collection

In the data collection part, one single Sunny Island is used instead of three because the system setting of 3 single phases connecting together, the result is the same as one single Sunny Island. This set of data is collected without the connection of the load bank. The data logging program has been set to have a 5 minutes interval between each data reading. There are two types of condition in the testing part which are charging and discharging. In the charging phase, the power is taken from the grid through the Sunny Island and charged the batteries. As for the discharging phase, the power is released from the batteries to the grid. A sample of three-phase Sunny Island charging and discharging is also collected.

Through the LabVIEW program, the charging and discharging current can be controlled. The data is collected using charging and discharging current with the values of 2A, 3A, 4A, and 5A. A sample of the data collected is shown in Figure 3.18.

	A	B	C	D	E	F	G	I	J	K
1	BatVtg	BatSoc	InvVtg	InvPwrAt	InvChrgCurMax	InvPwrRt	FedInCurAtCom	Iac	Fac	TotBatCur
2	51.00000076	97.2000991	242.4000036	0.400097661	21.70000076	-0.199902348	2	2.100097686	50.00000075	9.700097799
3	51.00000076	96.7000991	242.2000036	0.400097661	21.70000076	-0.199902348	2	2.200097688	49.90000074	10.0000978
4	51.00000076	96.10009909	242.3000036	0.400097661	21.70000076	-0.199902348	2	2.100097686	49.90000074	9.600097798
5	51.00000076	95.60009908	243.3000036	0.400097661	21.70000076	-0.199902348	2	2.100097686	50.00000075	9.200097792
6	51.00000076	95.00009907	243.5000036	0.400097661	21.70000076	-0.199902348	2	2.100097686	50.00000075	9.700097799
7	51.00000076	94.50009906	244.4000036	0.500097662	21.70000076	-0.199902348	2	2.200097688	50.00000075	10.20009781
8	51.00000076	93.90009905	244.8000036	0.400097661	21.70000076	-0.199902348	2	2.200097688	50.00000075	10.0000978
9	51.00000076	93.40009905	244.0000036	0.400097661	21.70000076	-0.199902348	2	2.100097686	49.90000074	9.700097799
10	51.00000076	92.80009904	244.5000036	0.400097661	21.70000076	-0.199902348	2	2.100097686	50.00000075	9.900097802
11	50.90000076	92.20009903	243.3000036	0.400097661	21.70000076	-0.199902348	2	2.200097688	49.90000074	10.0000978
12	50.90000076	91.70009902	243.2000036	0.400097661	21.70000076	-0.199902348	2	2.100097686	49.90000074	9.700097799
13	50.80000076	91.10009901	243.2000036	0.400097661	21.70000076	-0.199902348	2	2.200097688	50.00000075	9.800097801
14	50.80000076	90.600099	243.3000036	0.400097661	21.70000076	-0.199902348	2	2.200097688	49.90000074	9.800097801
15	50.80000076	90.000099	243.3000036	0.400097661	21.70000076	-0.199902348	2	2.000097685	50.00000075	9.300097793
16	50.80000076	89.50009899	243.5000036	0.400097661	21.70000076	-0.199902348	2	2.200097688	49.90000074	9.800097801
17	50.80000076	88.90009898	243.5000036	0.400097661	21.70000076	-0.199902348	2	2.200097688	50.00000075	9.700097799
18	50.70000076	88.40009897	243.7000036	0.400097661	21.70000076	-0.199902348	2	2.200097688	50.00000075	9.900097802
19	50.70000076	87.80009896	244.4000036	0.400097661	21.70000076	-0.199902348	2	2.200097688	50.00000075	9.900097802
20	50.70000076	87.30009896	245.2000037	0.400097661	21.70000076	-0.199902348	2	2.100097686	50.00000075	9.800097801
21	50.60000075	86.70009895	245.2000037	0.400097661	21.70000076	-0.199902348	2	2.100097686	50.00000075	9.800097801
22	50.60000075	86.10009894	245.5000037	0.400097661	21.70000076	-0.199902348	2	2.000097685	50.00000075	9.200097792
23	50.60000075	85.60009893	245.6000037	0.400097661	21.70000076	-0.199902348	2	2.200097688	49.90000074	10.0000978

Figure 3.18: A Sample of the raw data collected

3.8   Load Bank

After the basic setup for monitoring and control of the sunny island is set, load bank is then connected for testing. The load bank was made with resistors connected in frames in a series connection, controlled by relays in order to change the load value. As for the signals to the relays, it is sent from the PC unit through the NI-device to the load bank.

The NI-device consists of a chassis and a digital module. The chassis used is called NI cDAQ-9184 and the digital module is called NI-9403. They are shown in Figure 3.19 and Figure 3.20.

Figure 3.19: NI cDAQ-9184 Chassis

NI cDAQ-9184 is a 4 slotted chassis that is designed to connect with NI C Series modules. It can be linked to the PC unit through an Ethernet cable. The PC unit will need to have NI-DAQmx driver software in order to detect and communicate with the device. With the usage of the virtual machine in this project, some settings have been done for the virtual machine to detect the connection of the NI device. The connection of the network setting for a virtual machine needs to match to the host PC network connection for the virtual machine to detect the device since the NI Max software is in the virtual machine.

Figure 3.20: NI-9403 Module

NI-9403 is a C series Module that is used in this project for digital input/output to the load bank. It is placed on the chassis in order to complete the connection between the PC unit and the load bank relays or SSR. It contains 32 digital input-output channels which are also bidirectional. From DIO1 to DIO18

are connected to the 3kW Load Module while DIO19 to DIO27 are connected to the 9kW Load Module. The stated signals output corresponding to the load module is shown in Figure 3.21. Figure 3.22 shows the front panel on the LabVIEW Program for the load modules and the labeled load value (TAN, 2018).
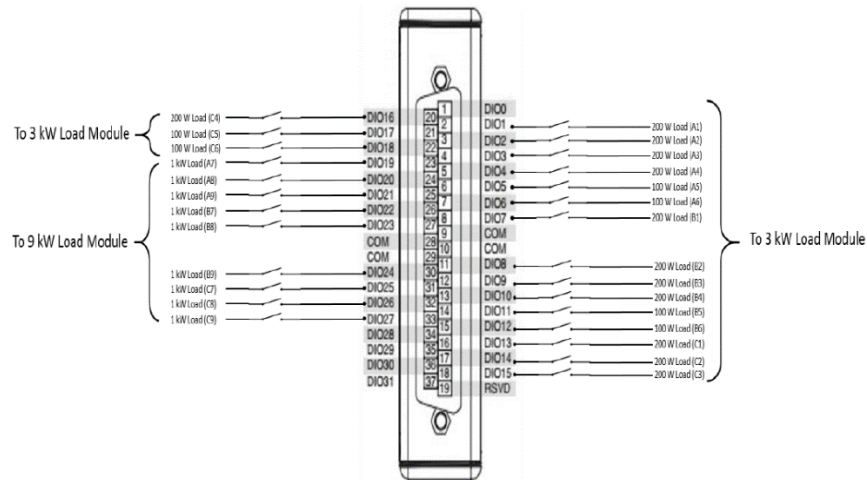

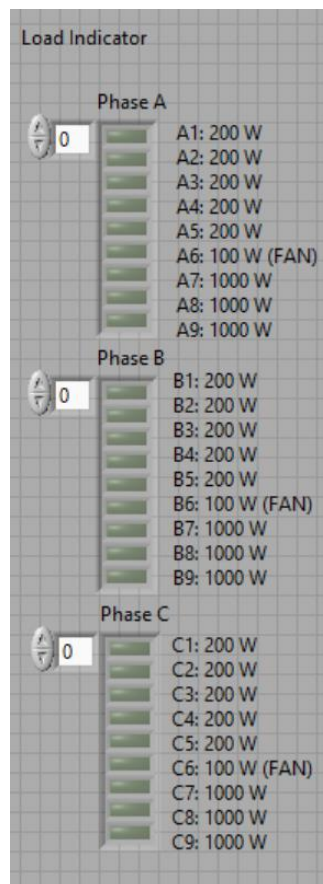Figure 3.21: Signal output from NI-9403 to load modules

Figure 3.22: Load Module labeling on Front Panel

In Figure 3.23, the relay panel, resistors and IDC cable connectors are fixed together with wheels for flexibility. The resistors were set to be 200W per step for convenient control.

Figure 3.23: 3kW Load Bank Module

In the load bank, one resistor is controlled by one relay. From the design, one phase consisted of 6 resistors and three-phase consisted of 18 resistors. From that, the connection for the relays and resistors following the color "R", "Y" and "B" is shown in Figure 3.24.
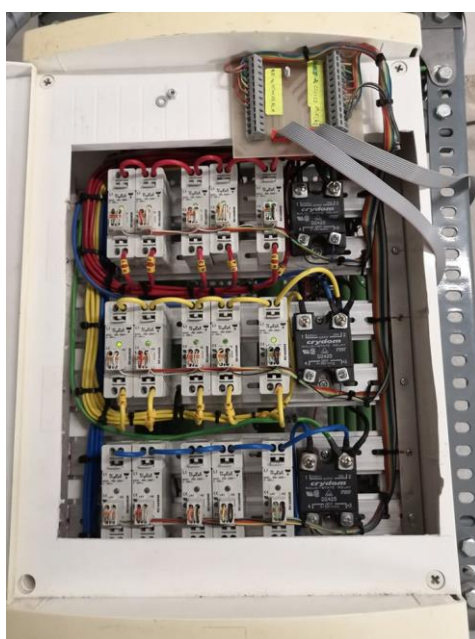
Figure 3.24: Relays on the 3kW load module

When the signals are sent from the NI-device to the relays, signal lights can be seen from the relays. This is used to test the connection between the relays and the chassis. The testing result is shown in Figure 3.25.

Figure 3.25: Testing load module relays

Lightbulbs were connected parallel with the resistors as indicators that the resistors have been turned on. Other than that, fans are used to blow on the load bank to increase heat dissipation so that it won't overheat. The features are shown in Figure 3.26.

Figure 3.26: Testing resistors connection

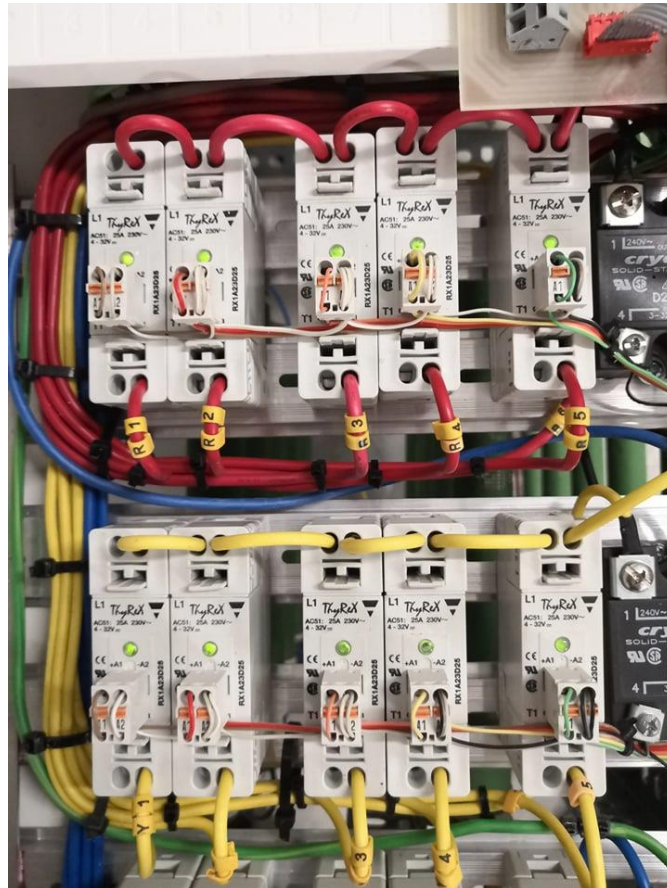When the resistors are done testing, follow up is the simulation of balanced load and unbalanced load. For balanced load, the load is increased from 200W to 2600W with an interval of 200W each for all three phases. For 200 W to 800W, the number of relays used are from 3 to 12 units. When reaching to 1000W, 15 units of SSRs are used. That is when the triggering voltage drops below 4.5V.

This is the limitation of the load bank. When more SSRs are needed to trigger, the higher the voltage drop from the NI-device. Thus, when the triggering voltage or signal voltage drops below 4.5V, the load bank will be turned off instead. The triggering voltage outcoming from the NI-device is ideally 5V, but the voltage tested is 4.9V instead. Slight voltage drop is caused by the long-distance IDC cable but mostly is from the SSRs.

After the balanced load is tested, next is the unbalanced load. The unbalanced load is tested in three cases which represents all of the cases. The cases are single-phase unbalanced load, two phases unbalanced load, and single-phase unbalanced load with single power output from another phase. Each of the cases, the loads are increased 200W each from 200W to around 3000W. The data are then logged into the excel file for processing.

3.9 Single Line Diagram and Overall Setup

The overall setup for the project is as shown in Figure 3.27. The left side of the figure shows the hardware connection of the system while the right side shows the program of the LabVIEW. The left side of the figure shows the incoming of the three phases, Red, Yellow, and Blue as the input into the Sunny Island. Each of the Sunny Island is connected to one set of battery. Following with the RJ45 cables connecting from each of the Sunny Island to the i-7563U converter for signals to be sent to and from of the PC unit.

The load bank is split into three different phases as well and connected to each of the Sunny Island for simulation. The load bank is connected to the PC unit with the NI-devices called NI-9403 and NI-9184 through IDC cables from inputs of 1 to 27. On the pc unit, the hardware is connected through YAOPC to the LabVIEW program for data collecting, signal controlling and processing.
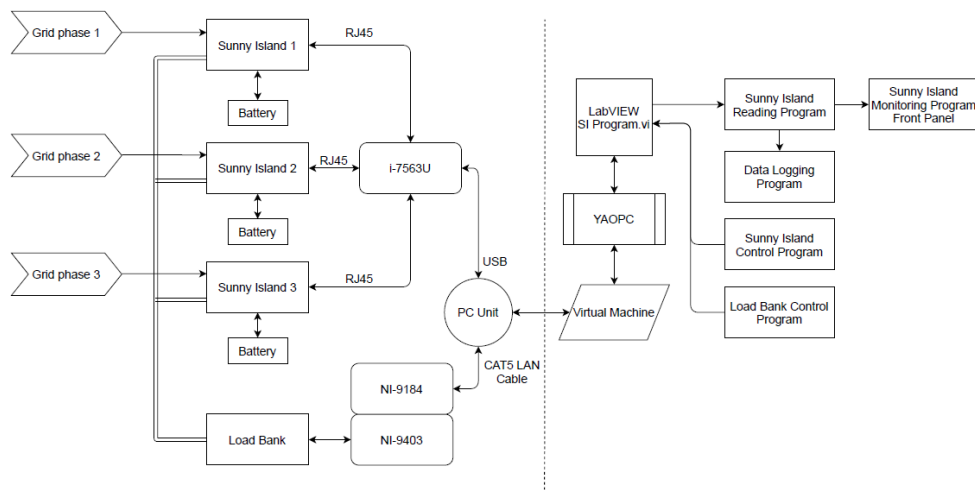
Figure 3.27: Overall setup of the hardware and program

The single line diagram in Figure 3.28 shows the whole connection of the system in 11th floor at UTAR KB Block.

Figure 3.28: Connection of DB-11F

Figure 3.29 shows the connection of the Sunny Island input and output. The grid with 240V is connected to the Sunny Island with the load bank to simulate the load. The 48V battery is connected below the Sunny Island as well for the energy storage system. The setup is similar to Sunny Island 2 and 3.
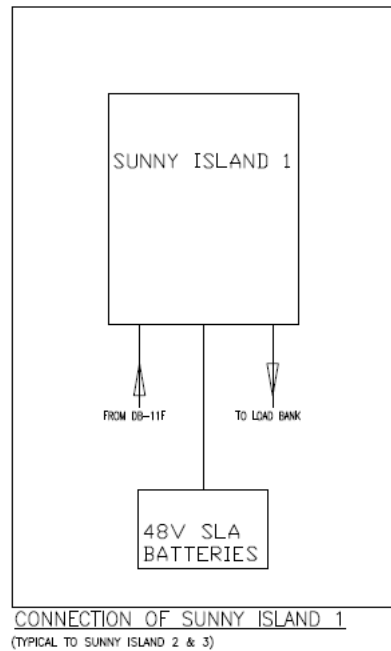
Figure 3.29: Connection of Sunny Island

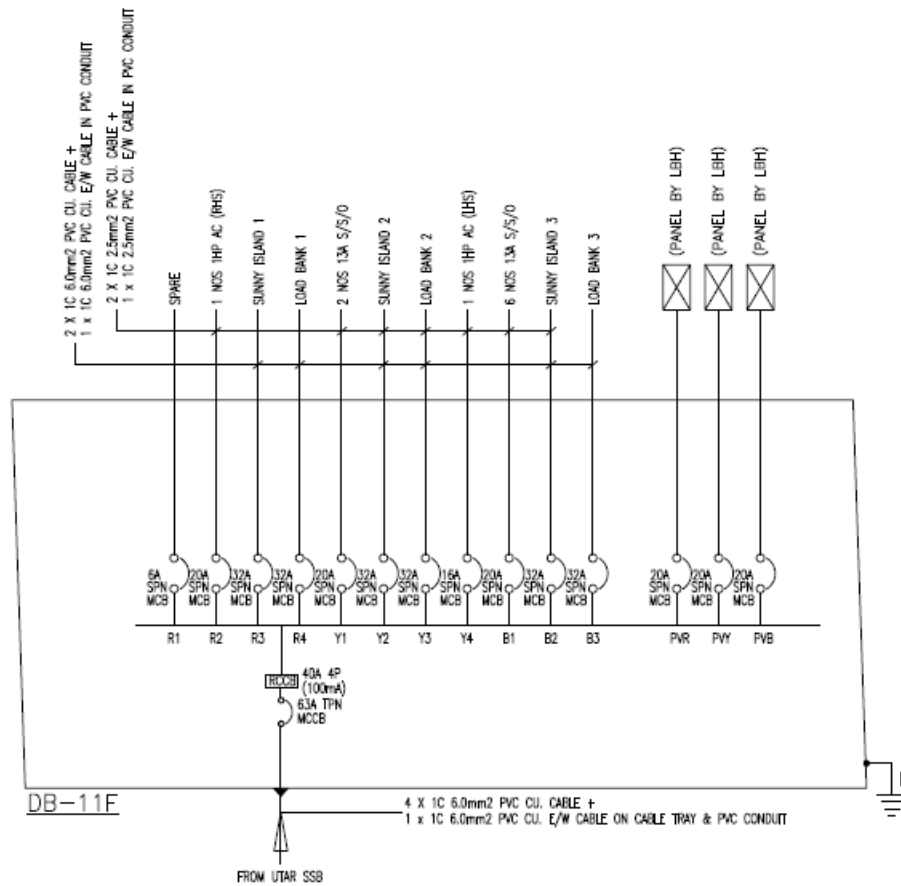Figure 3.30 shows the connection of the load bank. In the load bank, it consisted of the coils, solid-state relays control panel, 32A TPN isolator, and 63A 4P changeover switch. The changeover switch is to change the power input either from Sunny Islands or the grid. When the changeover switch is turned to the grid, the load will be part of the grid for simulation on how load can affect the grid voltage.

The other part which is the changeover switch to Sunny Island can be used to test islanding property of the system. When the load bank and the sunny islands are disconnected from the grid, they can form their microgrid system and simulated an "islanding" mode.
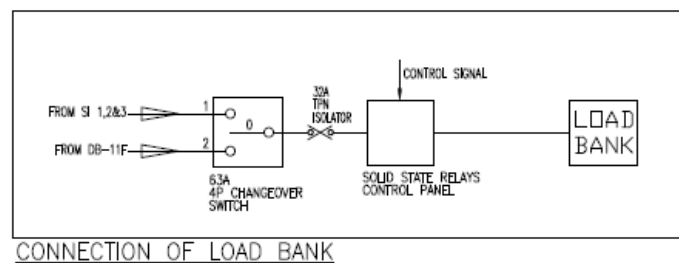
Figure 3.30: Connection of Load Bank

Figure 3.31 shows the connection of the resistors with the SSR on how the signals are controlling. Each of the SSRs handled a load of 1000W for a single-phase, thus one step of the signal increases the load by 1000W.
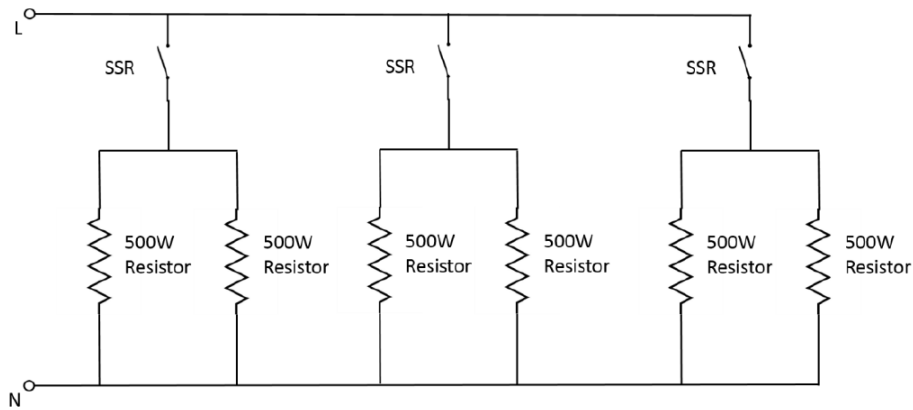
Figure 3.31: Single Line Diagram of single-phase of 9kW Load Bank

Figure 3.32 shows the whole single line diagram for the 9kW load bank. Each of the phases consists of 3kW, connecting to the same NI-device to the PC unit for signal control.
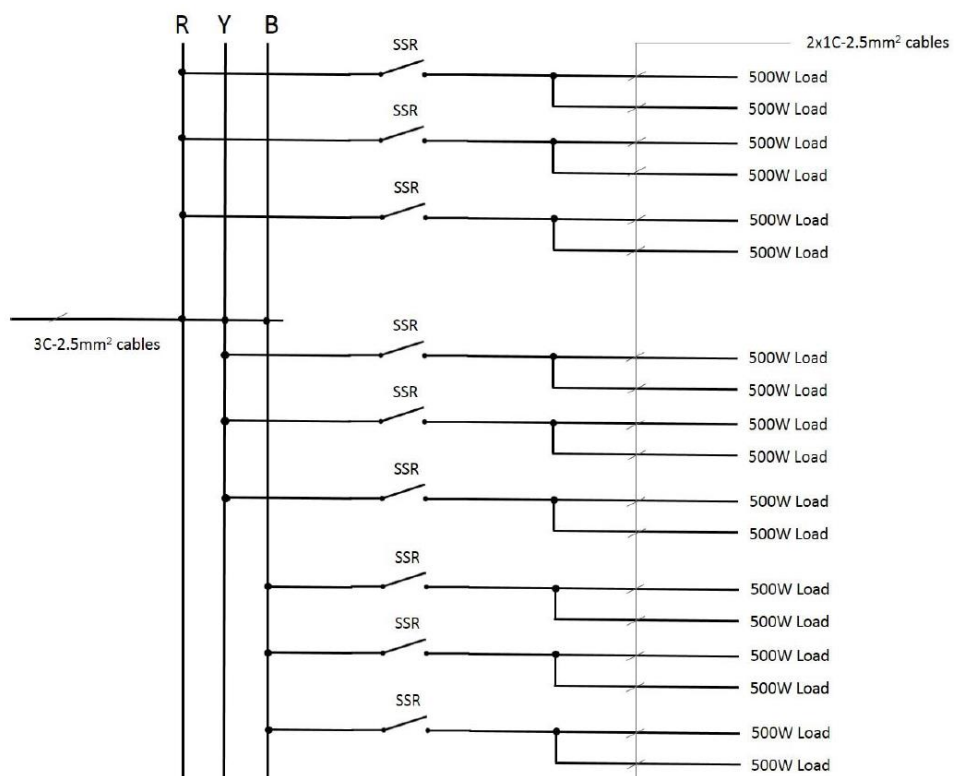
Figure 3.32: Single line diagram of 9kW Load Bank

In Figure 3.33, the panel of the SSRs for the 9kW load bank is shown. Each relay handles two 500W resistors. Labels are placed near the relays to indicate which resistors the relays are connected to and also to indicate the signals that are controlling the relays for easy setup on the PC unit.
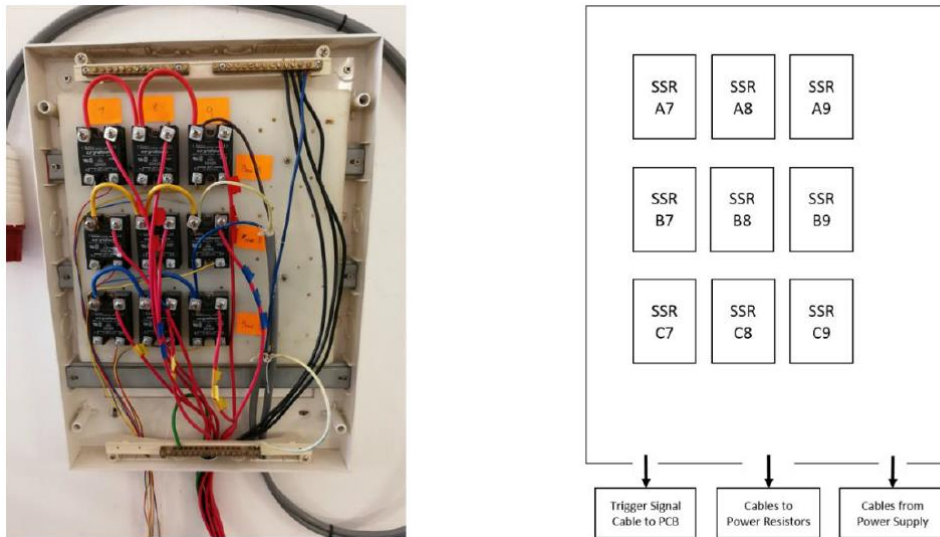
Figure 3.33: 9kW Load Bank SSR Panel

Next, the single line diagram for a single-phase load for the 3kW load bank is shown in Figure 3.34.
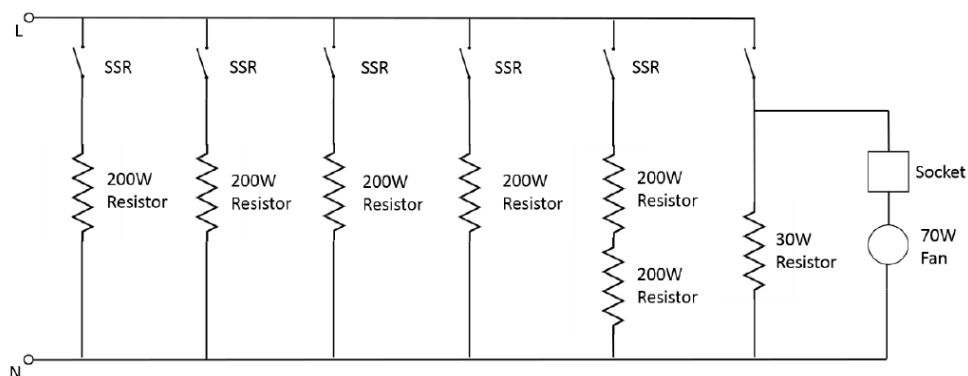
Figure 3.34: Single Line Diagram for single-phase 3kW Load Bank

The single line diagram for the 3kW load bank is shown in Figure 3.35.
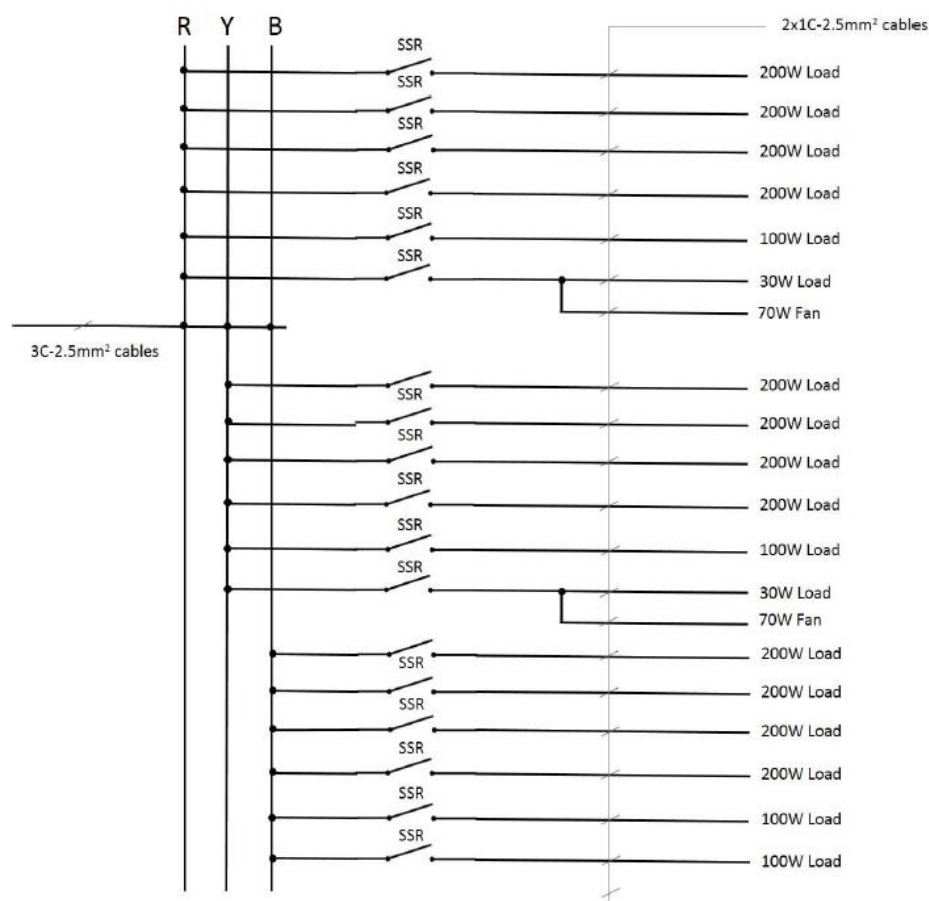
Figure 3.35: Single line diagram of 3kW Load Bank

3.10   Summary

In the progress of this project, the overall hardware and software control has been completed from Sunny Island communication to load bank control. To conclude, the Sunny Island's data can be monitored and the settings to allow it to discharge power has been fixed. Its current input and output can also be controlled manually or even automatically through the LabVIEW program.

The data logging program is done so that the data can be recorded for processing. The NI-device has been connected to the PC unit for load bank control. Other than that, the 3kW and 9kW load banks have been fixed for load simulation. In the data collecting phase, the voltage and current graphs have been plotted. As for the load bank, the balanced load and unbalanced load graph for voltage have been plotted as well.

CHAPTER 4

RESULTS AND DISCUSSION

4.1   Introduction

In the data collection phase, different cases have been tested and the results are shown in the figures below. It started with the testing of the battery charging and discharging curve. Voltage and current are collected into excel file and plotted in graphs. Phase Blue is taken to collect the data as it is similar to the other Sunny Islands' results. After that, the result of voltage over 24 hours for all three phases have been recorded to indicate the fluctuation of the voltage over one whole day. Lastly is the voltage drop caused by a balanced load and an unbalanced load.

4.2   Charging and Discharging of Battery Bank

The battery state of charge is collected for input and output current from 2A to 5A. The battery state of charge was set at 60% for each of the currents for easy comparison. Figure 4.1 and Figure 4.2 show the graph of the discharging and charging phase of the battery.
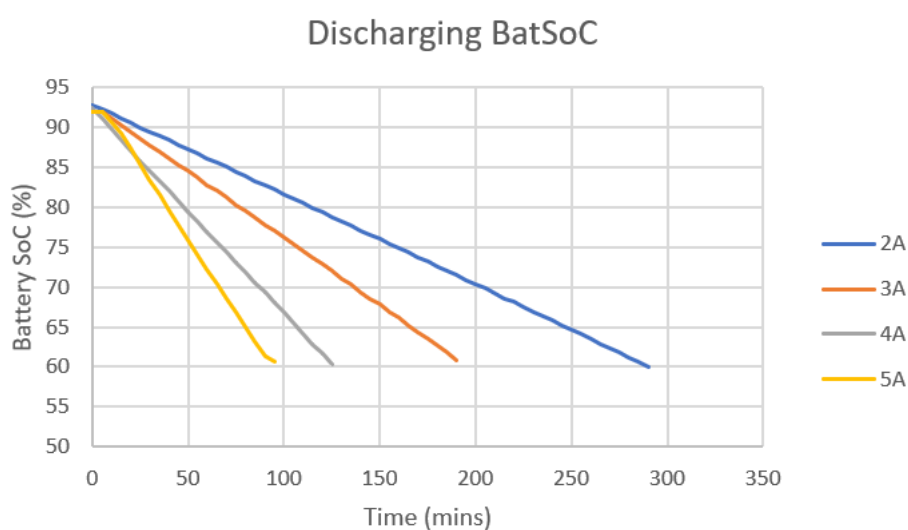
Figure 4.1: Battery SOC of Discharging phase
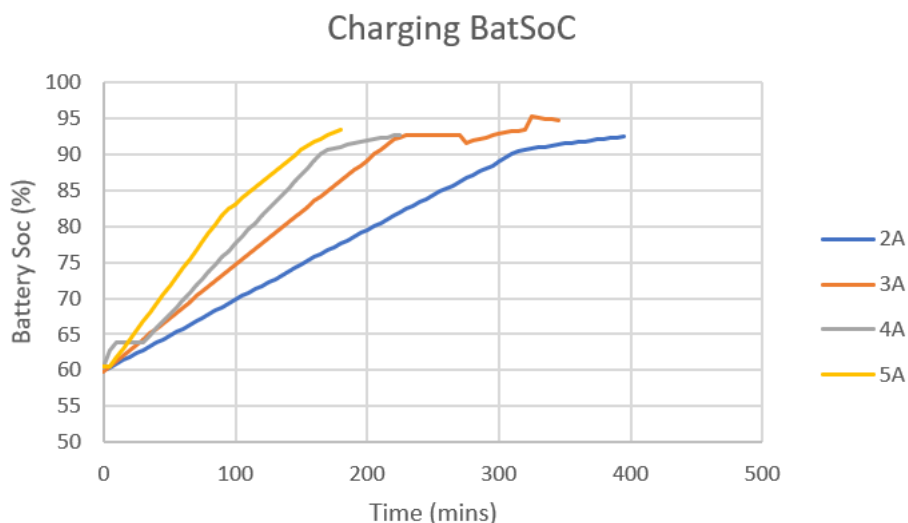
Figure 4.2: Battery SOC of Charging phase

It can be seen in Figure 4.1 that as the output current set by for the Sunny Island increases, the faster the battery state of charge drops. As in Figure 4.2, the battery state of charge can be seen that 5A charges the battery faster than the others. When the battery state of charge almost reaches the maximum, the charging current starts to reduce. This is to avoid overcharging of the battery as set by the Sunny Island.

4.3   Grid Voltage

Across 24 hours, the grid voltage fluctuates due to uncertain conditions such as increasing load in the grid, input power from photovoltaic systems, short circuits, and so on. Other than the load from the same building, load from other places may affect the grid voltage as well depending on the connection and the severity of the situation. The amount of voltage fluctuated within one day is shown in Table 4.1.

Table 4.1: Grid Voltage Fluctuation

Phase	Minimum Voltage (V)	Maximum Voltage (V)	Voltage Fluctuation (V)
R	237.1	245.5	8.4
Y	239.1	245.5	6.4
B	240.3	247.2	6.9
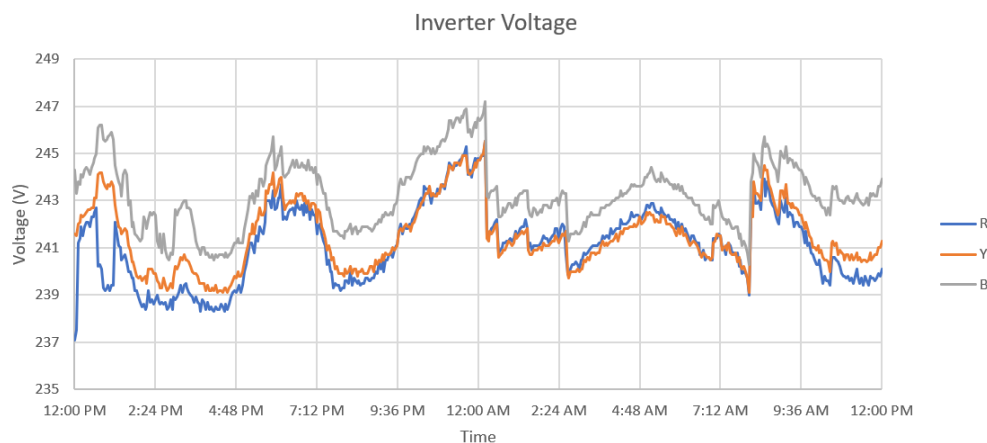
Figure 4.3: Grid Voltage across 24 hours

In ideal scenarios, the grid should be maintained in a balanced manner with all three phases near 240 V. However, in normal electrical design, the Red phase will be connected with more load compared to the other two phases due to common practices. The voltage level difference can be seen from Figure 4.3 above.

4.4 Balanced Load Voltage

Figure 4.3 shows the normal voltage level from the grid without any output from Sunny Island nor any disturbance from the load bank. The next part is the result of increasing the load in a balanced manner to the grid. The loads for each phase increase with an interval of 200W from 200W to 2600W. The graph of grid voltage against load is plotted in Figure 4.4 and the change in voltage against load is plotted in Figure 4.5.

$$V_{UF} = \frac{Max\ Deviation}{Average\ Voltage} \times 100\%$$

As stated in the Tenaga Nasional Berhad (TNB), Distribution Code for Peninsular Malaysia, Sabah & F.T Labuan, 5.4.6.6, that the voltage unbalance peak should only has a maximum peak of 2% only in a short duration occasionally (Malaysian Energy Commission, 2017). The tabulated data is shown in Table 4.2 below with the Voltage Unbalance Factor calculated.

Table 4.2: Grid Voltage of Three Phases as Load increases

Load (W)			Voltage (V)			Voltage Unbalance Factor
R	Y	B	V_R	V_Y	V_B	(V_{UF})
0			243.30	248.10	250.50	2.91
200			243.00	248.00	250.30	2.95
400			243.00	247.70	249.40	2.59
600			242.70	247.60	249.40	2.72
800			242.40	247.40	249.60	2.92
1000			242.00	246.60	249.10	2.89
1200			241.20	246.20	248.70	3.06
1400			240.90	245.80	248.10	2.94
1600			240.60	245.60	247.80	2.94
2000			239.00	244.00	245.00	2.47
2400			238.30	243.00	245.00	2.77
2600			238.00	242.50	244.00	2.48

From the result calculated in Table 4.2 for voltage unbalance voltage, the very start of voltage unbalance factor is 2.91% which is already over the standard from TNB. However, the result taken is not accurate as the result is taken from the endpoint of the distribution system while the 2% standard is set at the start point of the building.
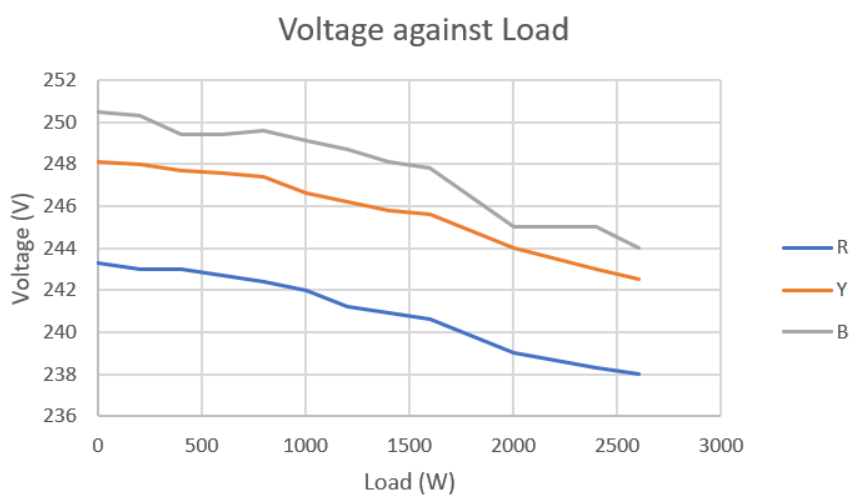
Figure 4.4: Grid Voltage against Load
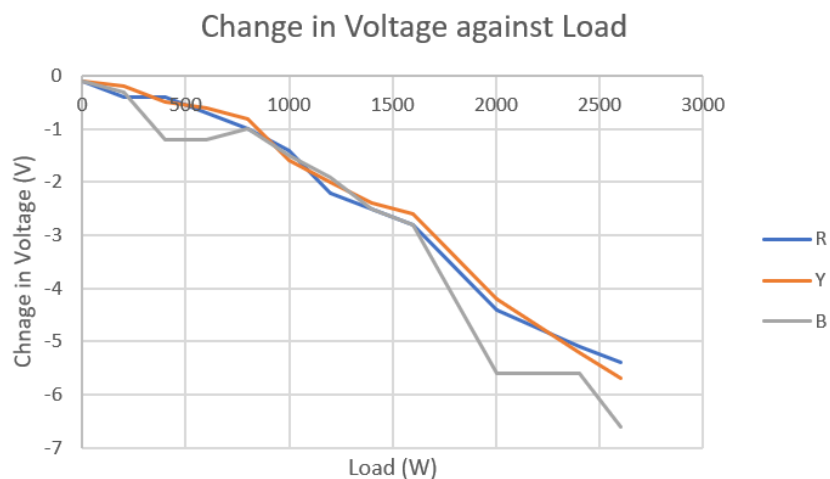
Figure 4.5: Change in Voltage against Load

From Figure 4.4, it can be seen that when the load increases, the voltage drop of the grid voltage increases as well. This means that the larger the load, the lower the grid voltage will be until a certain extend. This can be used to understand the amount of effect caused by the increased load to a grid system. Follow up with countermeasures on when and how to maintain the voltage level of the system. The voltages on the grid fluctuate due to uncertain loads from the system outside of the controlled environment such as the PV system and also capacitor bank installed in the building. The change in voltage can be seen from Figure 4.5 above.

4.5   Unbalanced Load Voltage

Balanced load in a grid system is an ideal situation where there are no short circuits, tripping of circuits, failure in machinery and so on. When there is some unbalanced load in the system, it can cause the voltage to drop on one and rise on the other. If the situation is severe, it will cause a certain phase to be overvoltage, resulting in damage or even black-out. Voltages too high or too low are not suitable for appliances operations.

The first part of unbalance load testing is single-phase unbalanced load. The load in phase R is increased from 0W to 4000W with an increase of 200W each step. The result is recorded in Table 4.3. The voltage and change in voltage against Load are plotted in Figure. 4.6 and Figure 4.7.

Table 4.3: Grid Voltage as Load R increases

Load (W)	Voltage (V)			Voltage Unbalance Factor,
R	V_R	V_Y	V_B	V_{UF} (%)
0	241.00	245.70	247.30	2.57
200	241.10	246.50	247.90	2.77
400	240.60	246.70	248.00	3.02
600	240.10	247.50	249.30	3.75
800	239.70	247.90	249.90	4.15
1000	239.50	247.80	250.20	4.35
1200	240.50	247.60	249.10	3.50
1400	240.50	247.90	249.20	3.54
1600	239.40	248.10	249.40	4.07
1800	239.10	248.40	249.80	4.35
2000	238.60	248.20	249.20	4.32
2200	238.70	248.90	249.80	4.52
2400	238.20	249.10	249.70	4.68
2600	237.80	249.40	250.40	5.12
2800	237.10	249.70	251.00	5.65
3000	237.30	249.90	250.70	5.45
4000	234.50	250.50	251.40	6.88
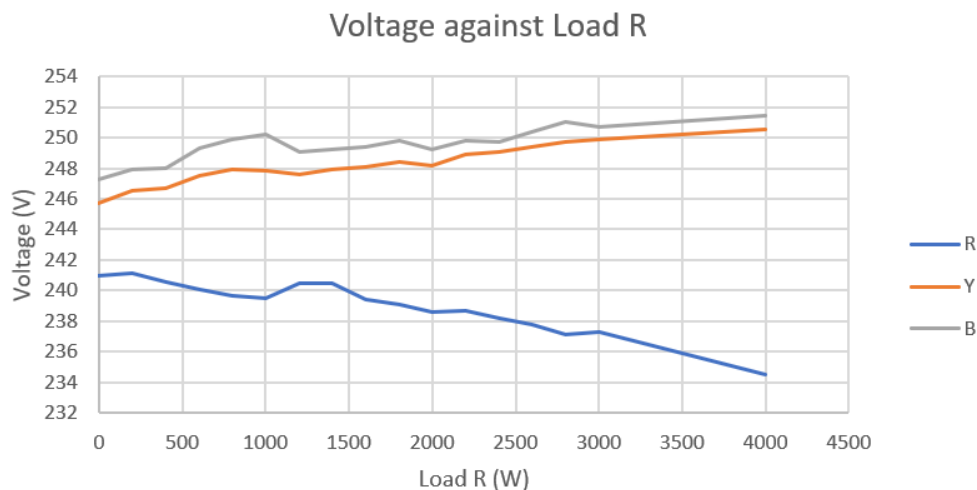
Figure 4.6: Voltage against Load R
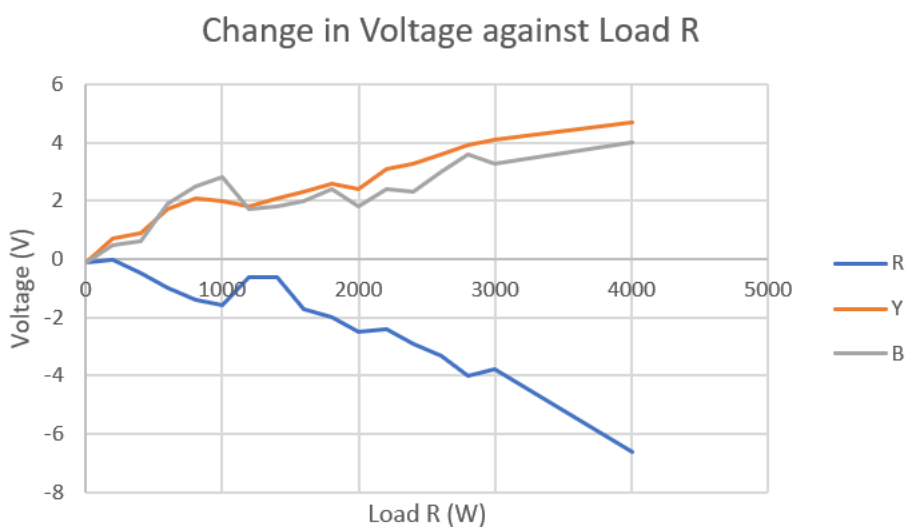
Figure 4.7: Change in Voltage against Load R

From Figure 4.6, the voltage level for phase R dropped as the load increases. At the same time, voltages of phase Y and phase B increased. The voltages are not dropping and rising at a constant rate due to voltage fluctuation from the grid system. The voltage unbalance factor increases as the load increases.

Next is the result with two unbalanced loads increasing at the same rate or 200W from 0W to 3000W. The result is tabulated in Table 4.4. Phase R and phase Y are used for this testing and the case is similar to the situation using load on phase Y and phase B as well as with load on phase R and phase B.

Table 4.4: Grid Voltage as Load R&Y increases

| Load (W)		Voltage (V)			Voltage Unbalance Factor,
R	Y	V_R	V_Y	V_B	V_{UF} (%)
0		243.40	248.30	249.50	2.47
200		242.90	247.80	249.40	2.63
400		242.70	247.40	250.00	2.96
600		242.20	247.10	250.30	3.29
800		242.10	246.90	250.80	3.53
1000		243.10	246.10	250.50	3.00
1200		242.50	245.70	250.80	3.37
1400		242.40	245.40	251.10	3.53
1600		241.80	245.00	251.50	3.94
1800		241.30	244.50	251.70	4.23
2000		240.90	244.20	251.90	4.48
2200		240.90	244.10	251.70	4.40
2400		239.90	243.40	252.20	5.02
2600		240.00	242.80	252.30	5.02
2800		239.40	242.50	253.00	5.55
3000		239.20	242.50	253.00	5.63
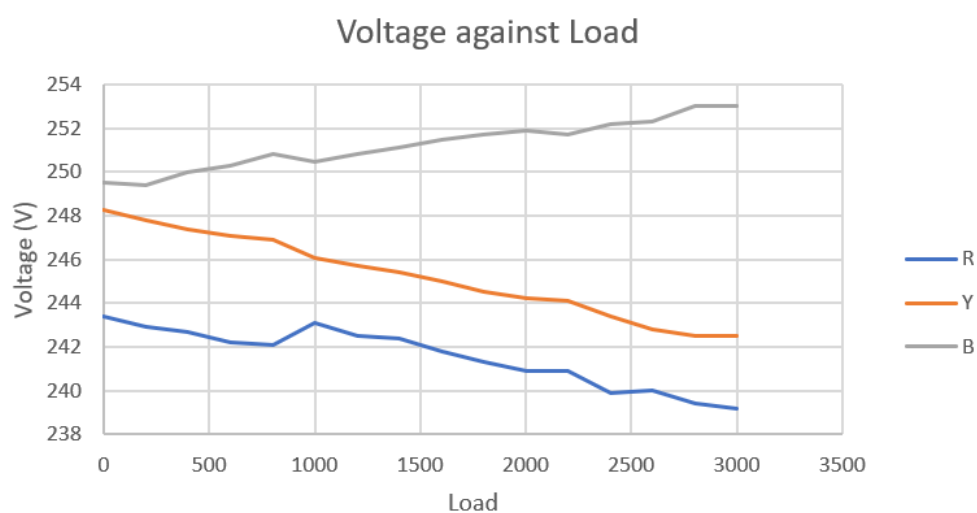
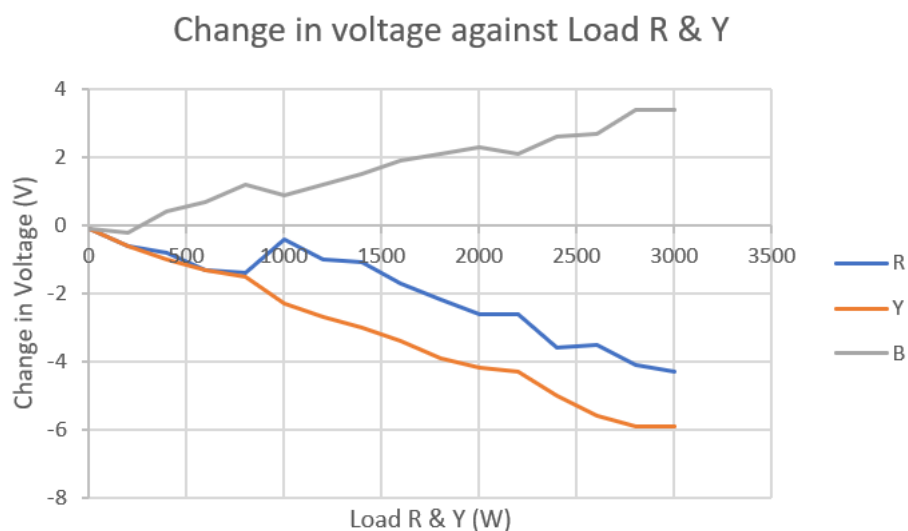Figure 4.8: Grid Voltage against Load R&Y

Figure 4.9: Change in Voltage against Load R & Y

As expected, when the loads increased, the voltage of phase R and phase Y decreased while the voltage of phase B increased.

4.6   Single-phase Unbalanced Load with Single-phase Output Power

In reality, there are situations where a PV system is connected to one of the phases and constantly inputting power into the grid system. When there is a sudden increase in load on another phase, it will cause the grid to be more unbalanced. In the end, it may result in some damage to the grid or the appliances. In the simulation, the load and the input power from another phase is increased in the same manner of 200W per step from 0W to 2000W. The result is tabulated in Table 4.5 below. The graphs for voltage and change in voltage against load R and Output Y are plotted in Figure 4.10 and Figure 4.11.

Table 4.5: Voltage with increase in load R and Ouput Y

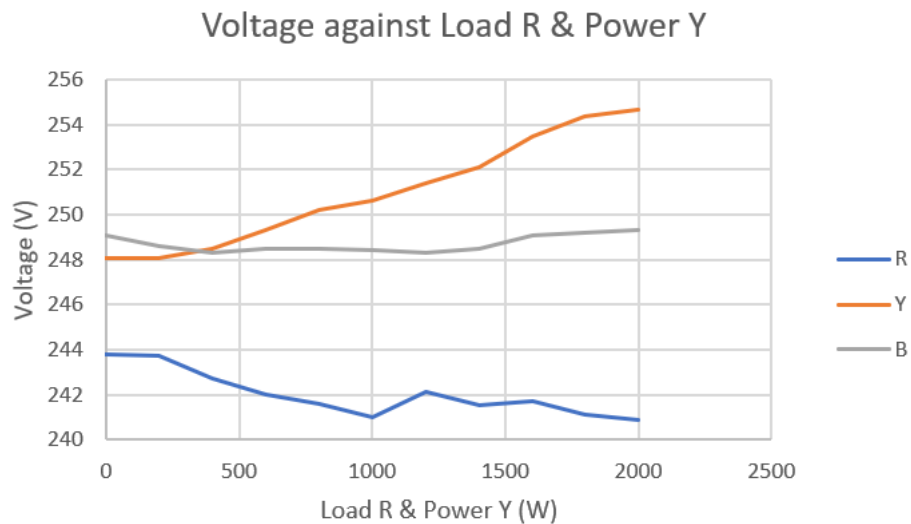| Load (W)	Output (W)	Voltage (V)			Voltage Unbalance Factor, V_{UF} (%)
R	Y	V_R	V_Y	V_B	
0		243.80	248.10	249.10	2.15
200		243.70	248.10	248.60	1.99
400		242.70	248.50	248.30	2.35
600		242.00	249.30	248.50	2.96
800		241.60	250.20	248.50	3.49
1000		241.00	250.60	248.40	3.89
1200		242.10	251.40	248.30	3.76
1400		241.50	252.10	248.50	4.29
1600		241.70	253.50	249.10	4.76
1800		241.10	254.40	249.20	5.36
2000		240.90	254.70	249.30	5.56

Figure 4.10: Voltage against Load R and Output Y
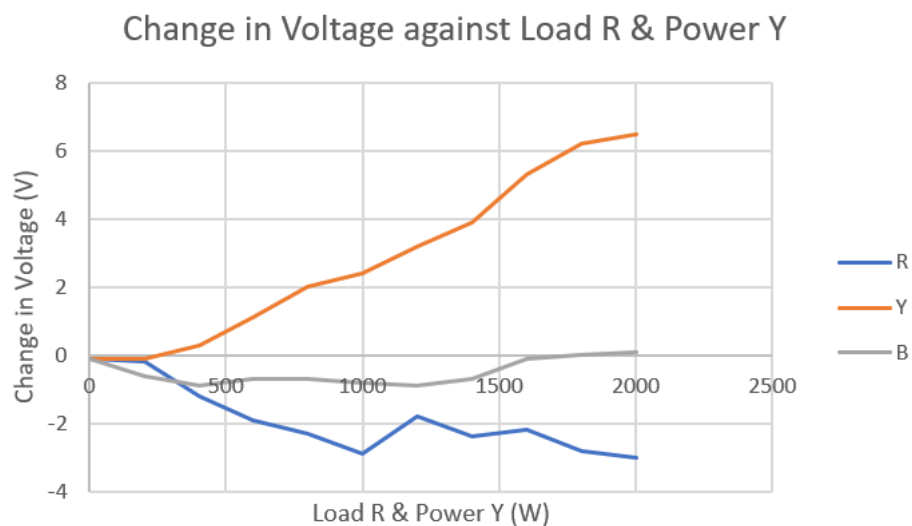
Figure 4.11: Change in Voltage against Load R and Output Y

From the result, it shows that when load R and output Y increases, the voltage for phase R dropped and the voltage for phase Y increased significantly. As for phase B, the voltage level maintained with very little fluctuation. With this, the voltage unbalance factor is much higher compared to the other cases. This means that when there is an increase in load and an input of power from output Y, the grid voltage will be affected severely and may cause damages or shutdown of systems.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

In the project, a microgrid system using Sunny Island connecting the energy storage system has been completed. The system can manage to monitor the current data of the Sunny Island through the software, LabVIEW. Not only that, with the settings made, but Sunny Island can also be controlled to output power from the energy storage system into the grid as well. This means that with the correct settings, the system can be adjusted to Islanding mode for further applications. It can also be set to provide power to a specified load in the system. When the setup of the system is completed, the performance of the system is tested.

5.2 Problems encountered

In the process of running the project, there are a few issues regarding the continuation of the project due to unarranged documentation and unlabelled parts. This leads to questions of how to use and why the certain setup was done so. Follow up with the previous students takes time and effort. Thus, efforts will be wasted on the processes that have already been done. There are some other problems that have been faced during the project.

5.2.1 Sunny Island Control Settings

After the monitoring program for Sunny Island was done, there was an issue regarding the current control in and out of the Sunny Island. Guesses were that the program is written had some bugs or there were some settings left unchecked in Sunny Island. Running through the manuals and previous reports, there was very less info about the settings for Sunny Island. In the end, the issue was solved through a Direct Access setting which was not documented in the manuals. The method has been written in 3.3.2 of Methodology in this report.

5.2.2   LabVIEW Programming

In the project, there is a limitation in speed processing due to the processing power of the PC unit. The PC unit is a window 7 running with a virtual machine to make a connection with the Sunny Island and also the load bank. Therefore, when designing the program for Sunny Island in this setup, the "wait" function is very important as it helps to stabilize the PC. Other than that, "Flat Sequence" can also be used to split the functions to run individually instead of running all functions together.

The other important point is that the LabVIEW can only make settings to the NI-device or NI-9403 in this project only when it is connected to the PC. The connection of the NI-device can be checked using NI Max in the PC.

5.2.3   IDC Cable for Load Bank

The IDC cable used for the load bank signal transmission is long which resulted in a high impedance path. It causes the signals to disconnect when a high amount of signals are being sent. It couldn't reach the required triggering voltage for more than 16 signals. Thus, the impedance of the IDC cables is checked using a multimeter to check the stability of the connection.

5.3   Recommended Solutions

Technical manuals, reports, data, procedures, and other related documents should be documented neatly with labels and latest updates so that the project can be followed up easily and quickly. Reducing the amount of time needed to understand and experiment with the parts that have been confirmed. There should also be a follow up for each project so that there won't be any buffer time for new students to follow up on the project.

5.4   Future Developments

For the following part, the system can be set to auto-discharge the power from the energy storage system to balance the grid voltage, reducing the voltage unbalance factor automatically. Other than that, the system can also be set to islanding mode for further simulation on how the Sunny Island reacts and also the setup for LabVIEW program for the islanding mode.

Next is the demand side management using techniques such as peak shaving, load shifting, and valley filling on the load profile. Following up is the hardware side, the PV system outside of the 12th floor can be connected directly to the Sunny Island to charge the battery instead of connecting to the grid, forming a renewable energy system with the energy storage system.

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