Feasibility Study on Grid Connected Solar PV AC Output during Grid Low/High Voltage

by

Hazim Bin Suhaimi
17132

Dissertation submitted in partial fulfilment of the requirements for the

Bachelor of Engineering (Hons)

(Electrical & Electronic)

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
32610 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

____

(Ir. Dr. Mohd Faris Bin Abdullah)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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HAZIM BIN SUHAIMI

ABSTRACT

Voltage stability is a very serious concern in power systems because many equipment are connected to it; ranging from inexpensive one to a very expensive equipment. At distribution level trend nowadays, other kind of generation like Photovoltaic (PV) system, micro Combined Heat and Power (CHP) plants and wind turbines are connected to it. The purpose of this research is to study the behaviour of AC output of the grid connected solar photovoltaic (PV) during grid low and high voltage. The grid's low/high voltage tests are conducted at three different period of time namely, morning, noon, and afternoon. This is because the irradiance and ambient temperature magnitude are distinctively different among these time zones. In the experiment it can be concluded that the output of solar is maintained at maximum level during the low and high voltage periods because the inverter's Maximum Power Point Tracking (MPPT) algorithm reacted to ensure the maximum power is delivered to the grid. This is achieved through the current variation with respect to voltage change in maintaining maximum power.

ACKNOWLEDGMENT

Every work we do is linked directly or indirectly to many different aspects, circumstances and people. Aspects which we try to understand, work on and come to a conclusion, circumstances which motivate us and people who help us and guide us to achieve what we are intend to. Recollecting the near past events, I am deeply indebted to the people who were responsible for the successful completion of my Final Year Project.

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LIST OF ABRREVIATIONS

MPP: Maximum Power Point

MPPT: Maximum Power Point Tracking

PMMD: Property Management and Maintenance Department

PV: Photovoltaic

CHAPTER 1: PROJECT BACKGROUND

1.1 Background Study

Under voltage and high voltage event are normal phenomenon occur in power system. Under voltage usually caused by a high resistance connection at wiring junctions or outlet terminals. Severe high voltage is most often cause by excessive correction for voltage drop on the utility transmission and distribution system. At distribution level trend nowadays, other kind of generation like Photovoltaic (PV) system, micro Combined Heat and Power (CHP) plants and wind turbines are connected to it. Power flows of the system will be changes due to this issue. In near future where smart grid expected to become next kind of generation grid, more of these alternative generation will be added to the system and will cause a significant effect to the power system stability.

1.2 Problem Statement

Solar PV DC power output is given by the manufacturer depending on the solar irradiation and ambient temperature. However during grid low and high voltage no data is provided on solar PV DC and AC output. Hence it is very important to study the solar PV AC output during grid high and low voltage because it will affect the quantum of power feed into the grid system.

1.3 Objective

The main objectives of this study are:

1) To establish solar PV AC output with rated grid voltage

2) To study the effect of grid low/high voltage on the solar PV AC output

1.4 Scope of Study

The scope of the research is distributed into 3 stages. The first stage is named phase 1, where the author conducted the experiment in power system laboratory using three 10W PV solar panel, voltage dip/swell simulator and 240 W inverter to get the relationship between the grid voltage dip/swell and the output of the solar PV panel. This phase could not be continued because the inverter is not capable to export the power to the grid using the existing solar PV panel at the lab.

The second stage is named phase 2, was also to get the relationship between the grid voltage dip/swell and the output of the solar PV panel but using Universiti Teknologi PETRONAS Property Management and Maintenance Department (PMMD) solar electric system facilities. This phase was also discontinued because the data analyzer could not record the output data during the voltage dip/swell simulation due to the analyzer sampling capability limitation.

Then third stage is named phase 3, was conducted to get the relationship between the grid low/high voltage and the AC output of the solar PV panel. The experiment still using the PMMD solar electric system facilities. Series of experiments conducted by varying grid voltage level from 85 % to 110 % for duration of 10 minutes for each level. The range was selected in-line with the inverter voltage levels continuous operation.

CHAPTER 2: LITERATURE REVIEW

2.1 Under Voltage and Overvoltage Definition

According to IEEE 1159-1995 standard, under voltage definition is a voltage between 10 % - 90 % of the nominal and last more than 1 minute. Overvoltage definition is a voltage that exceed 100 % of the nominal and last more than 1 minute. Figure 1 illustrates the definition of under voltage and overvoltage.

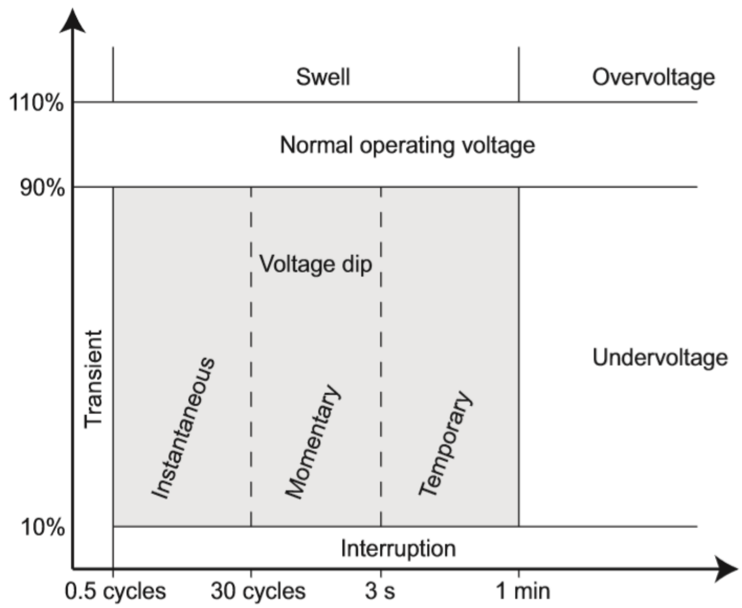


Figure 1: Under voltage and overvoltage definition according to IEEE 1159 - 1995 standard. [1]

2.2 Under Voltage Causes

Under voltage usually caused by a high resistance connection at wiring junctions or outlet terminals, usually due to:

- loose or intermittent connections anywhere in the circuit
- corroded connections anywhere in the circuit

It also occur due to a huge current flowing in some other part of the system. The high current can be due to [1]:

- short circuit
- starting machine
- energizing of a transformer

2.3 Overvoltage Causes

Severe high voltage is most often cause by excessive correction for voltage drop on the utility transmission and distribution system. Voltage drop on electrical conductors is a common situation anywhere. To correct a voltage drops, the utility employs on-load tap changing voltage regulators (OLTCs) and line drop compensating voltage regulators (LDCs) to boost (raise) or buck (lower) the voltage. Impedance causes the voltage to decrease along the length of a conductor as the current flow increases to meet the demand. Customers nearest to an OLTC or LDC can experience overvoltage as the utility tries to overcome conductor voltage drop for those customers at the far end of the line [2].

2.4 Voltage Dip/Swell

Voltage dip is one of the main serious issue in power quality because some of the sensitive load in industrial sector will be affected. This sudden change in voltage could bring damage to the consumer equipment [3]. Sensitive equipment could trip if the voltage drop below 90 % of the equipment nominal voltage [4]. Voltage dip can be defined as reduction of voltage below 90 % of the rated voltage, occur in duration ranges from 10 ms until 1 minutes [3]. One of the main contribution factor to the event of voltage dip is short circuit in electrical distribution [5] . According to IEE definition, voltage swell is as sudden increase of voltage at 120 % - 180 % of nominal voltage. The duration of voltage swell is from 10 ms to 1 minute. Figure 2 and Figure 3 show the voltage dip and swell illustration.

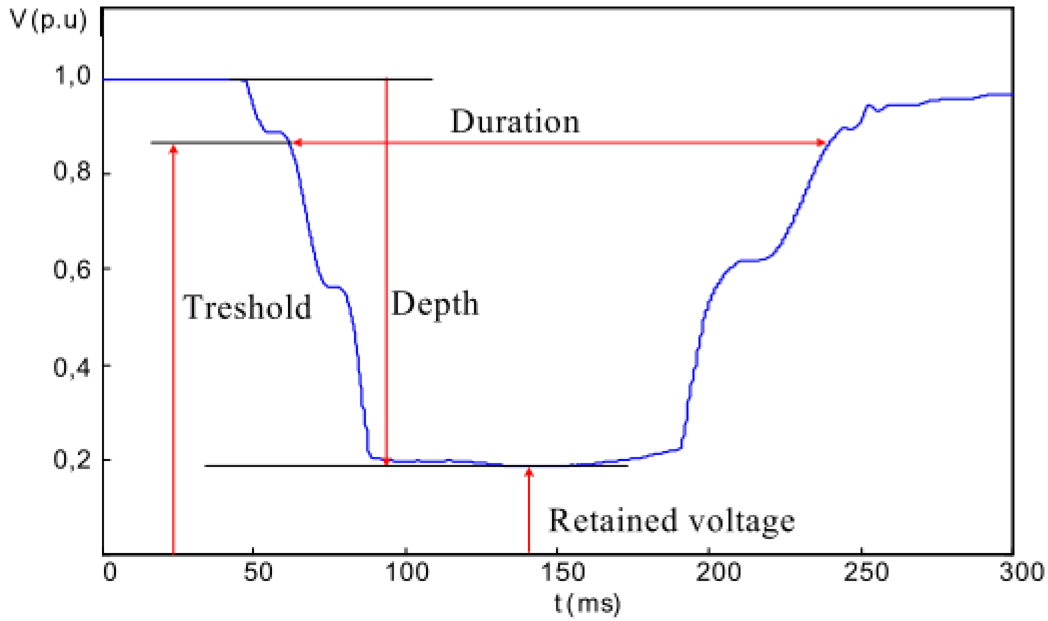


Figure 2: Voltage dip illustration [5].

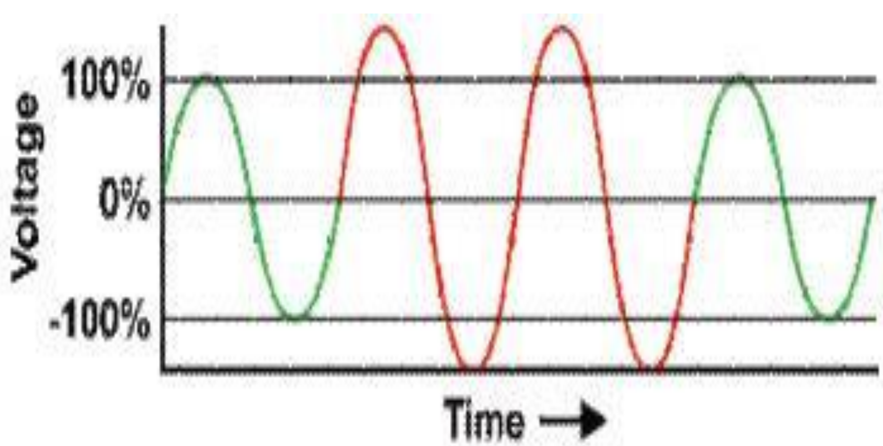


Figure 3: Voltage swell illustration [6].

2.5 Renewable Energy

Today renewable energy is not still fully utilized and commercialized to the greater extent due to their inconsistent sources availability. Integration of renewable energy to the power supply system will help to cut cost on fossil fuel for power generation.

Wind, solar, geothermal, hydropower and ocean energy are example of the renewable energy that being utilized in the world. Introducing renewable energy to power system is still something new to some part of the world. In India, a lot of effort and works must be done in term of improvement and better understanding of renewable energy characteristic, investment, and research and development [7]. Renewable energy does not contribute much harmful effect to environment which is why continuous and excessive research and development must be done to fully utilize this so called green energy. In Malaysia solar energy utilization has been growing rapidly and extensive research are done by universities and research and development institution [8].

2.5.1 Solar Electric System

Solar energy is use by solar electric system known as photovoltaic (PV) system to produce electricity. The origin of photovoltaic term is comes from the Latin words photo (light) and Voltaic (energy). PV device receive the energy in sunlight and convert it into electricity. Another system that utilize solar energy is solar thermal system which use the sun's energy to heat a substance (typically water). Electric and thermal systems should not be confused between each other. These two system are very different in appearance and operation. Figure 4 shows the solar electric system implemented at a house. There are two common type of solar electric systems application namely, off-grid systems and grid connected systems. This research will be using grid connected system installed at Universiti Teknologi PETRONAS Property Management and Maintenance Department (PMMD).

Figure 4 : Solar PV panel installed at home [9].

2.5.1.1 Off Grid System

An off grid also known as stand-alone solar electric system is use to replace or act as a backup power to conventional mains supply. This application of solar electric system mostly found in rural area where mains power is not available due to high cost of grid extension. Off grid solar system use batteries to store the power that harnessed from solar energy. The battery power is then power up the appliances either directly from the batteries for low voltage equipment (e.g. 12V DC light) or from a power inverter which is connected to the batteries and converts the battery voltage to mains equivalent for use in regular AC equipment. Figure 5 summarize the operation and the components of a standalone solar system.

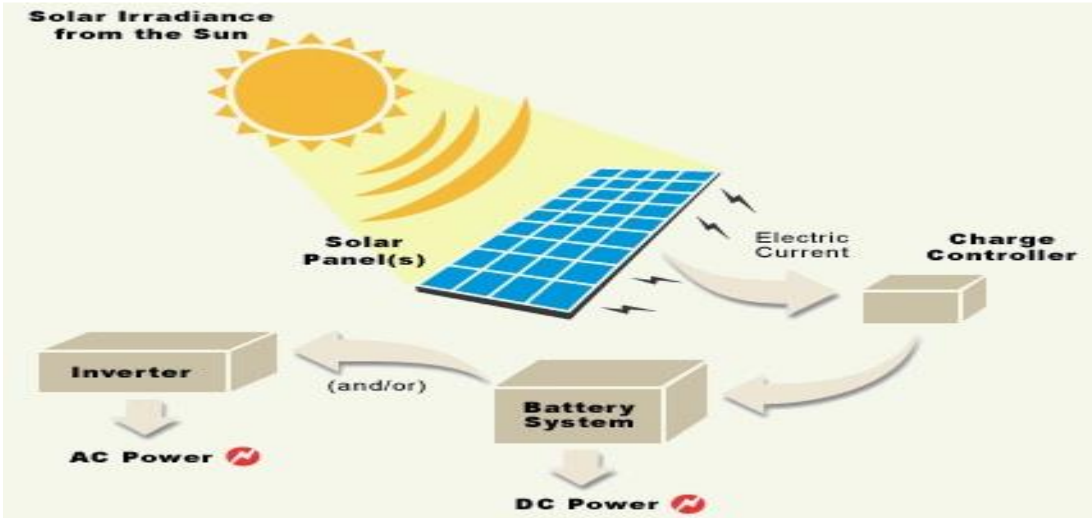


Figure 5 : Off grid solar system [10].

2.5.1.2 Grid Connected Systems

Different from off grid system, grid connected system is designed not as a replacement to grid power. This system is normally found in urban area that readily have access to mains supply and instead of storing the generated electricity by the PV system in batteries, the power is exported to grid. In this configuration, grid act as a kind of storage medium and the load can import the power from the grid when needed. One of the main benefit of a solar system configured in this way is the system does not have to be designed to supply enough demand power to the load as in off grid system. Figure 6 shows a grid connected system that exported the power produce by the PV array to grid. The load can be powered up by the PV system, the grid supply or combination of the two, meaning the system can be designed as small or large as the owner wants. In many area the owner is paid for the excess exported power to the grid. The main component of a grid connected system are PV arrays, inverter and the metering system. Other components are the cables, combiner box, protection devices, switches and lightning protection.

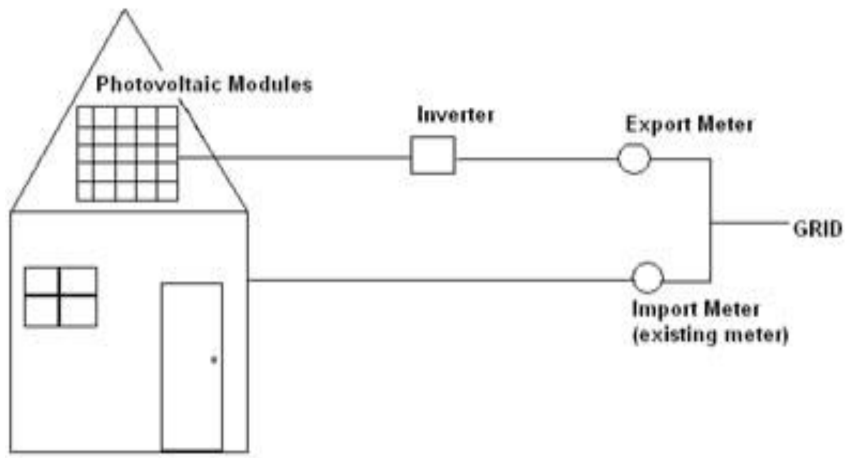


Figure 6 : Grid connected solar system [11].

2.5.1.3 Solar Radiation

The energy produce by the sun is emitted in the form of electromagnetic radiation which consist many form of wave like microwave, radio waves and visible light. Solar cell task is to capture energy from visible light. There are actually very significant variation in term of radiation receives at the Earth's surface due to earth rotation and resistance of certain places that the radiation face before it reach Earth's surface. PV system designer should be able to estimate how much solar radiation a given site will receive throughout the year. Solar radiation is interpreted in term of Irradiance; the solar radiation incident on a surface at any particular point in time measured in W/m^2

2.5.1.4 PV Array Installation Geometry

Because of Earth orbit and rotation, the position of the sun relative to a solar array is constantly changing. Position of sun is located based on two angle; altitude and azimuth as shown in Figure 7. Designer use several geometrical method to locate an array so that it will capture the most solar energy possible. The position of solar module is referred as its orientation. The solar array orientation will determine the amount of solar radiation received by the array panel and hence affected the power produced. The orientation generally includes the solar module direction its face and the tilt angle which is the angle between the base of the solar module and the horizontal. Figure 8 shows how the tilt angle is measured. Commonly, the PV array is located at rooftop so the orientation is likely to follow rooftop angle and direction. Usually this type of installation will be using a mounting system so that the module can be elevated to be at optimum tilt angle to improve the modules power's output.

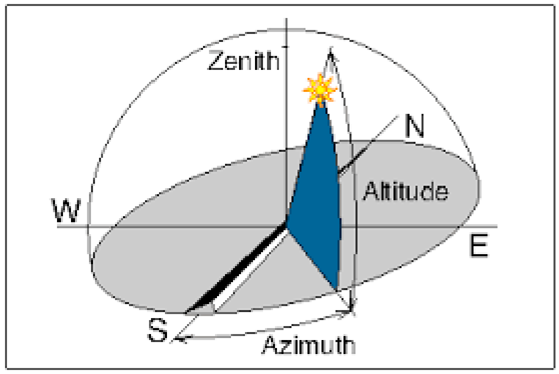


Figure 7 : Positon of the sun is specified by two angles; 1). Altitude 2). Azimuth [12].

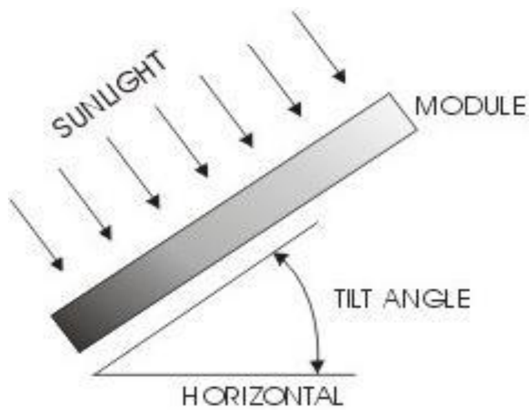


Figure 8 : Tilt angle of a solar module [13].

2.5.1.5 PV Modules Characteristics

Solar cell are made from semiconductor material. One of the semiconductor material property is it will conduct electricity under certain condition. Most solar cell are made of silicon. PV cell commonly represented as a current-voltage (I-V) curves. Performance of a PV cell can be analyzed and key features such as open circuit voltage,V_{oc}, short circuit current,I_{sc} and maximum power,P_{max} will be highlighted in this curve. PV cell will be operated along this curve, i.e. at a given voltage; the current produced will always have the same value and vice versa. Power curves is plotted by multiplying the voltage and the current of every point on the I-V curves. When both graph is superimposed, the maximum power point can be located on the graph. Figure 9 shows how an I-V curves and power curve looks like.

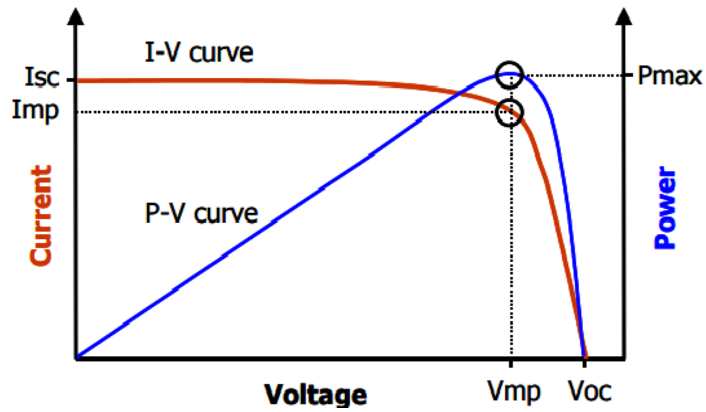


Figure 9: Solar PV module I-V curves and Power curve [14].

The PV array performance is affected by several factors; the most significant is the irradiance and the temperature. Different irradiance level and temperature will produce different I-V curve so the P_{max} known as maximum power point (MPP) will varies because of this changes. The higher the irradiance the higher the value of P_{max} and the higher the temperature of the PV array the lower the P_{max} value. This relationship is illustrate in Figure 10 for irradiance effect to the output power and Figure 11 for temperature effect to the output power.

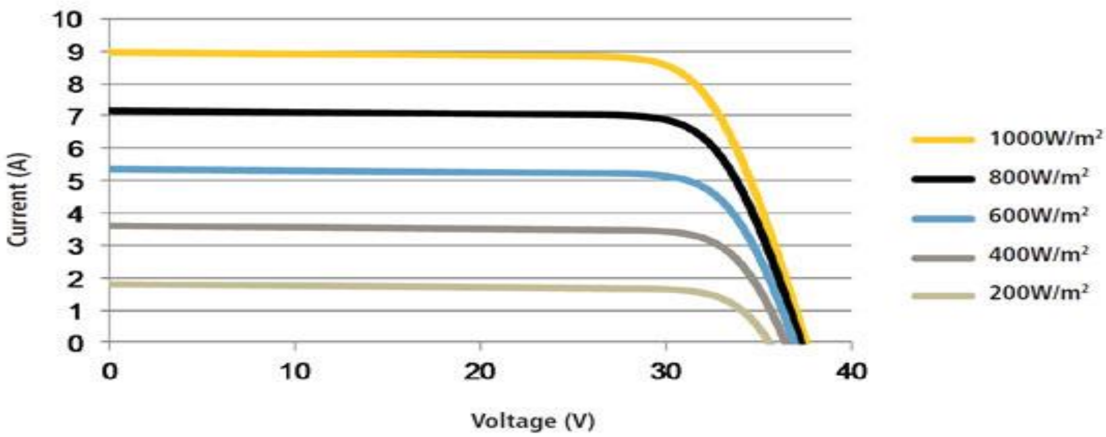


Figure 10 : PV module I-V curves at difference irradiance levels [15]

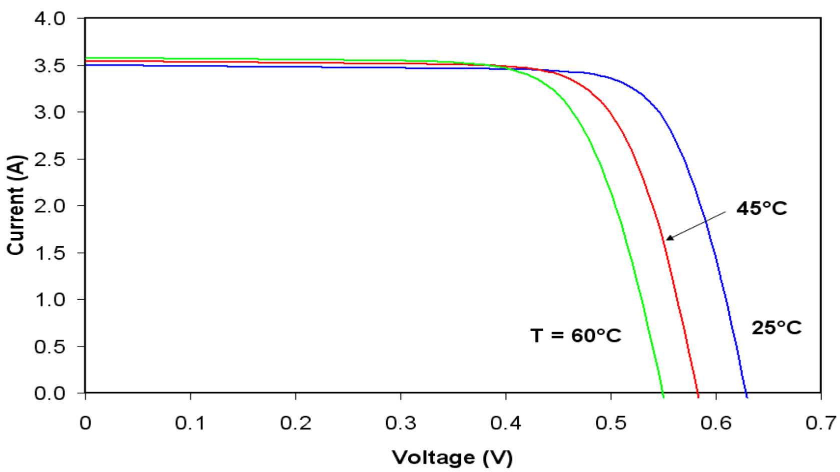
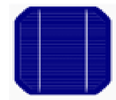


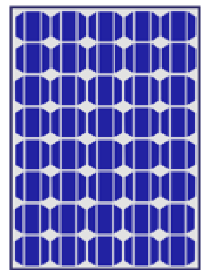
Figure 11: PV module I-V curves at different temperature levels [16].

2.5.1.6 PV Cell, Module, String and Arrays

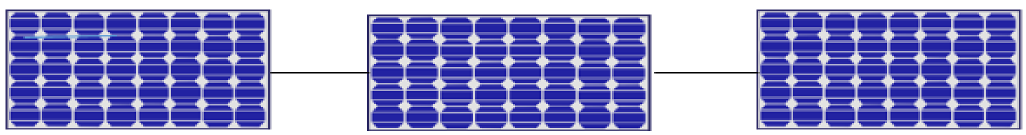
Several terms need to be familiar with when dealing with solar system configuration. Among these term are PV cell, module, string and arrays. Figure 12 illustrate how this term differ between each other



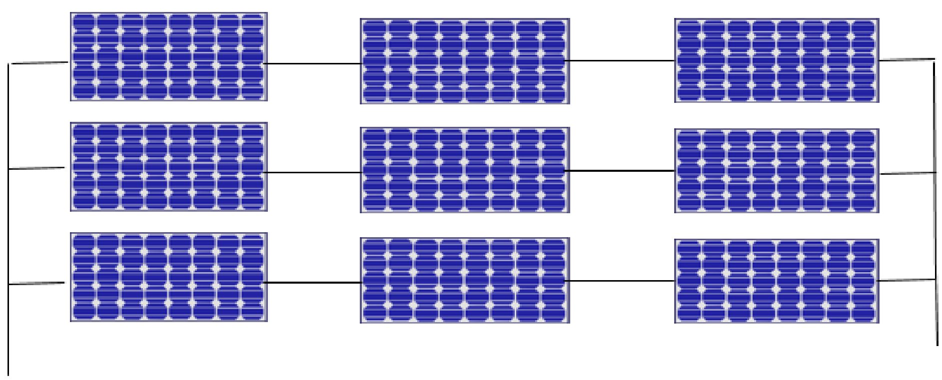
PV cell :A cell that produce electricity when receive solar radiation.



Module : PV cells of identical characteristics are wired together in series to create a module.



String ::A string comprises of a number of PV modules connected in series.



Array: Strings are connected in parallel to form an array.

Figure 12: PV cell, modules, strings and array definition

2.5.1.7 Systems Components of a Grid Connected Solar System

Besides PV module, there are several components in the PV array system in order the system can interact safely and effectively with the grid. This components are inverter, cables, disconnect devices, protection devices, combiner box and metering devices. Figure 13 shows the equipment that exist in a PV system installation.

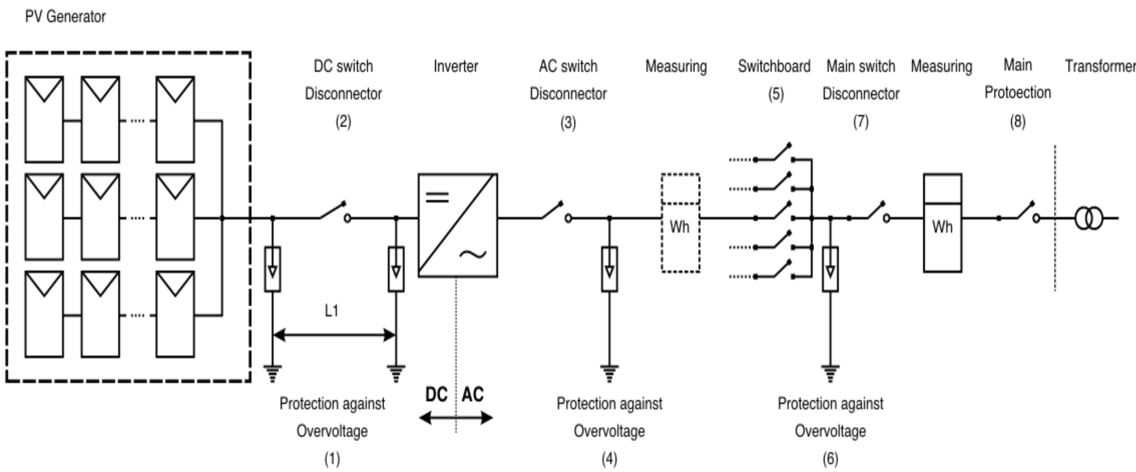


Figure 13: Grid connected solar system equipment

2.5.1.8 Inverter

To ensure the power produced by the PV system can be exported to the grid, it must be converted to AC power since the grid is AC system. This task is perform by an inverter. The inverter used in grid connected system is different type from inverter stand-alone solar system and it also known as grid-tied inverter. Several functions that perform by this type of inverter are:

- Convert DC power from the arrays to AC power so that can be exported to the grid or can be used by AC appliance at the site.
- Ensure the power being fed to the grid is at grid operating frequency and voltage tolerance. If inverter unable to do so, the power will not be exported to the grid.
- Has maximum power point tracking to ensure the maximum power possible will be converted to AC power at any condition.
- Has built in protection system to ensure the inverter shut down itself when the grid is not within the operating voltage and frequency tolerance.

The designed PV array should meet the inverter input specification.

2.5.1.9 Inverter protection systems

Grid connected inverter will only operates if the AC grid is functioning and within the grid operating condition. If there is any abnormality in grid condition, the inverter will disconnect and no output will be produced by the inverter. Grid-tie inverter incorporates both active and passive protection. Both form have the inverter switch off under/over frequency and over/under voltage. This protection designed for the inverter protection if extreme condition occur like reverse polarity array connection or over temperature and protection for the grid itself.

This type of inverter will disconnect itself if the grid operate outside the predetermined range. There has been concern that, if there were a sufficient number of inverter connected to the grids in an area and the grid supply to the area failed, the inverter would interact to each other, meaning that the voltage and frequency will become reference to each other. When this happen the passive protection that supposed to switch off the inverter when the grid operate outside it operating frequency or voltage may not works and would still 'think' the grid was 'on' and continue to output power to the grid that is failed. This situation is called 'islanding'. This issue will be overcome by both passive and active protection. Islanding is a serious safety concern for electricity's utilities because if technician are working on the failed grid, the grid connected solar system must also all disconnected from the grid to avoid electrocution to workers. Passive protection is provided by the inverter ability to detect the grid voltage and frequency for it able to shutdown itself when any abnormality occur in grid's voltage and frequency operating point. Active protection is provided by the inverter detecting any frequency instability, frequency shift or power variation that would vary the voltage that is detected by the inverter. The inverter will shut down when any of these condition happen. When the condition that cause inverter protection system to activate is cleared, the inverter will restart again after a period of time. This time delay can be programmed in the inverter.

2.5.1.10 Inverter Maximum Power Point Tracking (MPPT)

Maximum power point (MPP) is a point on the I-V curve when the array operates at optimum operating voltage and current to produces maximum output power. But this point is not always fix in the curve. Because the variation in irradiance and temperature the I-V curve will constantly changes and so does the MPP. Calculation model or a search algorithm is applied to track this point. This is known as maximum power point tracking technique (MPPT). There are several MPPT technique that commonly used nowadays among them are Perturb and Observe (P&O), Incremental Conductance, Constant voltage, Short Current Pulse and Open Circuit Voltage methods.

2.5.1.10.1 Perturb and Observe (P&O) Method

This algorithm will periodically introduce perturbation (incrementing or decrementing) to the array terminal voltage and comparing the value of output power at that point to the previous cycle of perturbation. If the value of power is greater at that point, then the control system will moves the array operating voltage to that direction, otherwise if the value of output power is less then it move the array operating voltage to opposite direction. The issue face by this method is the voltage is perturbs in every MPPT cycle and when it reaches the MPP value, the output power will oscillates around the maximum value and causes power losses. This usually happen in constant or slowly varying atmosphere condition and also rapidly atmosphere condition changes [17].

2.5.1.10.2 Incremental Conductance Method

This method is based on the equation that hold at MPP

$(dI_{pv}/dV_{pv}) + (I_{pv}/V_{pv}) = 0$

I_{pv} and V_{pv} are PV array operating voltage. When the PV operating voltage at the right of the MPP the equation will be $(dI_{pv}/dV_{pv}) + (I_{pv}/V_{pv}) < 0$ and when the array operating voltage at the left the equation is $(dI_{pv}/dV_{pv}) + (I_{pv}/V_{pv}) > 0$.

By comparing instantaneous conductance value I_{PV}/V_{PV} to the incremental conductance dI_{pv}/dV_{pv} the MPP can be tracked. The sign of the value $(dI_{pv}/dV_{pv}) + (I_{pv}/V_{pv})$ will indicate the correct direction of the perturbation that leads to MPP. Once it reach the MPP then the perturbation is stopped unless there is changes in dI_{pv} is noted. If this happen then the algorithm will increasing or decreasing the array voltage to track new MPP. The size of increment and decrement determines how fast it can track the MPP. This method offer good performance under rapidly changing atmosphere condition [17].

2.5.1.10.3 Constant Voltage Method

This method is considered the simplest algorithm to track the MPP. The PV array operating voltage is kept near the MPP by regulating the voltage to reach the fixed reference value of V_{mpp} on I-V curves or a preset calculated value. This method assumes that there is no significant variation in solar irradiance and array temperatures. The constant reference voltage is approximation of true MPP value. Therefore the array operating voltage will never at MPP and different irradiance and temperature data must be acquired for different geographical regions [17].

2.5.1.10.4 Short Current Pulse Method

The short current pulse method track MPP by giving an input current $I = I_{op}$ to the current controlled power converter. This taking account that the optimum operating current, I_{op} is proportional to the short circuit current under various irradiance levels.

$I_{op} = K \times I_{sc}$ [17]

Where k is proportional constant. This equation show that I_{op} can be determine if I_{sc} is measured. So to control this algorithm it is necessary to measure the I_{sc}. This is done by introducing static switch in parallel with the PV array, to be able to create a short circuit condition [17].

2.5.1.10.5 Open Voltage method

Open voltage method based on observation that optimum operating voltage that produce maximum output power is at a fixed percentage of the array open circuit voltage V_{op}.

Temperature and irradiance variation changes the MPP within 2 % tolerance band from the fixed percentage. This technique use 76 % of V_{op} as the array operating voltage and this value is close to V_{mpp}. This control algorithm required the measurement of V_{oc}. This is done by introducing static switch in series with the PV array. So when the switch is open the PV array circuit is open [17].

2.5.1.11 Cabling

DC cabling for array interconnection, from array to PV combiner box and from combiner box to the inverter input. AC cabling to connect the inverter to meter and from the meter to the grid and also the cabling for equipment grounding.

2.5.1.12 PV combiner box

Needed when PV array consist of multiple string. The cable from the array may be interconnected in the PV combiner box. Positives and negative cable of the strings will be combined in here allowing only one positive and negative array cable connect with the inverter.

2.5.1.13 Disconnector and Protection Devices

A disconnector/isolator is required to isolate the power from the system. Disconnector/ isolator should be installed on both DC and AC side of the inverter. Fuse and circuit breaker are used for overcurrent protection both at the DC side and AC side of the inverter.

2.5.1.14 Metering

Energy meter is installed to record the energy KWh consumed from or exported to the grid.

2.6 PROBLEM RELATED TO GRID CONNECTED RENEWABLE ENERGY

Introducing renewable energy to grid meaning it will be affected by common grid power system quality problem such as voltage dip or swell. While in wind farm the voltage dip event of 80 % - 90 % terminal voltage will disconnect the wind turbine from the grid [18].

Today homes that powered by solar energy are interconnected in an independent network community called microgrid. Despite of renewable energy being less carbon footprint, unfortunately the source is subjected to intermittent that lead to mismatch between home demand and the energy produced [19]. But it also can be the other way around where the energy produced might be greater compare to home demand. So, one of the solution is to sell the surplus energy to utility company and get energy from utility if there is any interruption in the renewable energy system. But this will cause the utility grid power system become unstable if large amount of energy is being transmitted [19].

Another problem of grid connected renewable energy is harmonic produced that will cause the equipment to be overheating or damage [20]. This is caused by harmonic of non-linear load that occur in electrical supply network which comes from renewable energy inverter. The renewable energy system fully utilize power electronic converter during increasing load demand in distribution level [20].

CHAPTER 3: METHODOLOGY AND PROJECT WORKS

3.1 Research Methodology

Figure 14 shows the flow of FYP1 methodology.

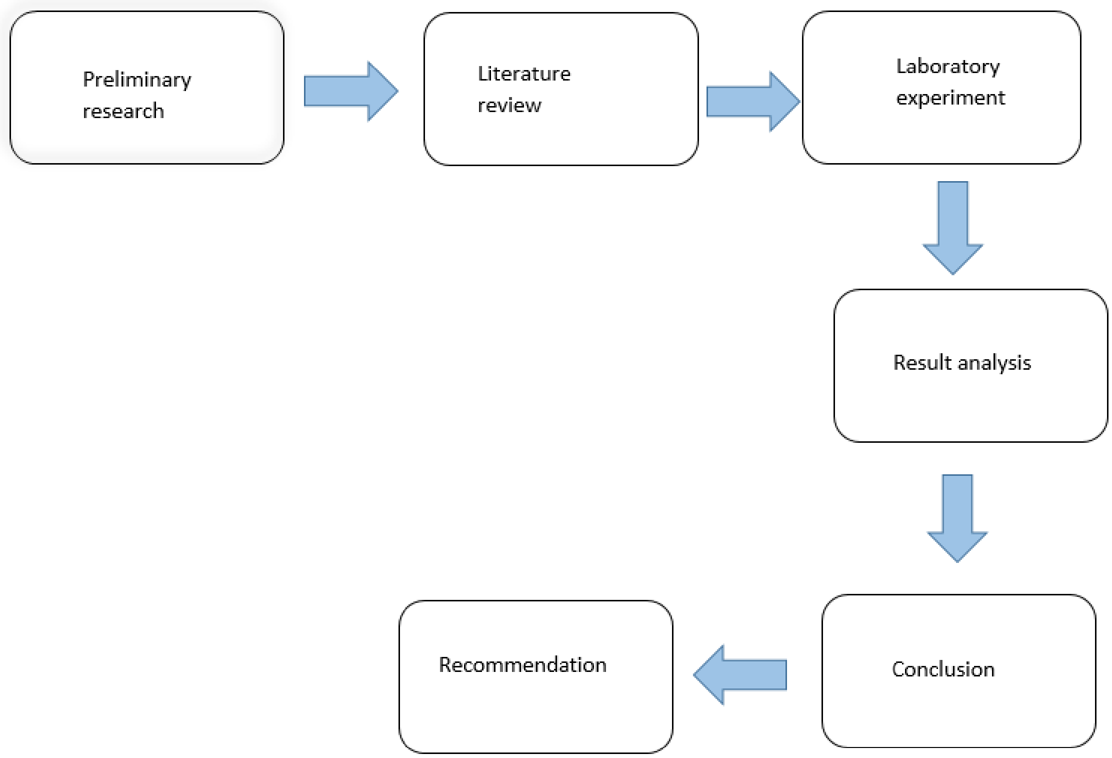


Figure 14: FYP1 research methodology

Figure 15 shows the flow of FYP2 methodology.

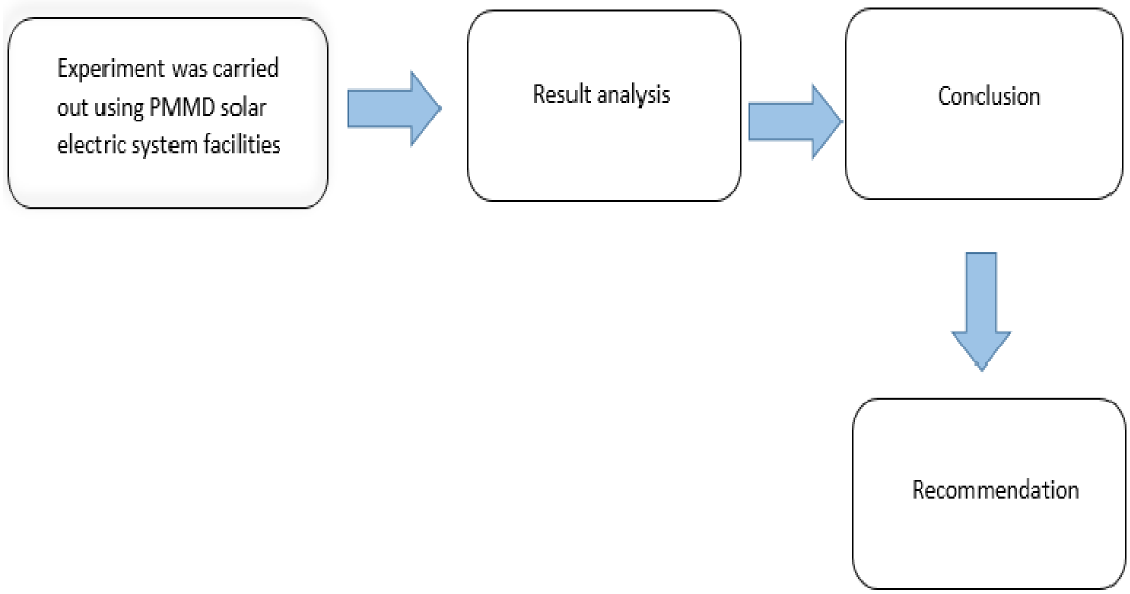


Figure 15: FYP2 research methodology

3.2 Project Activities

Figure 16 shows the FYP1 project activities based on the methodology on Figure 14.

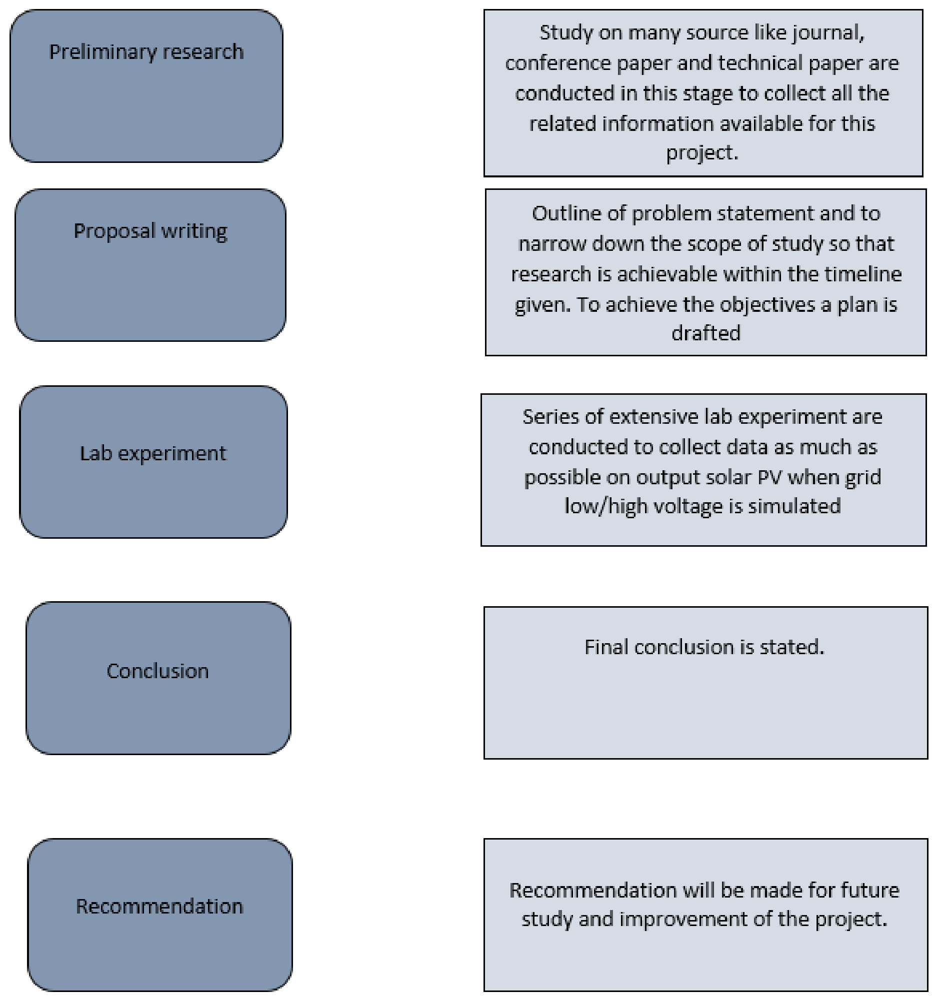


Figure 16: FYP1 project activities

Figure 17 shows the FYP2 project activities based on the methodology on Figure 15.

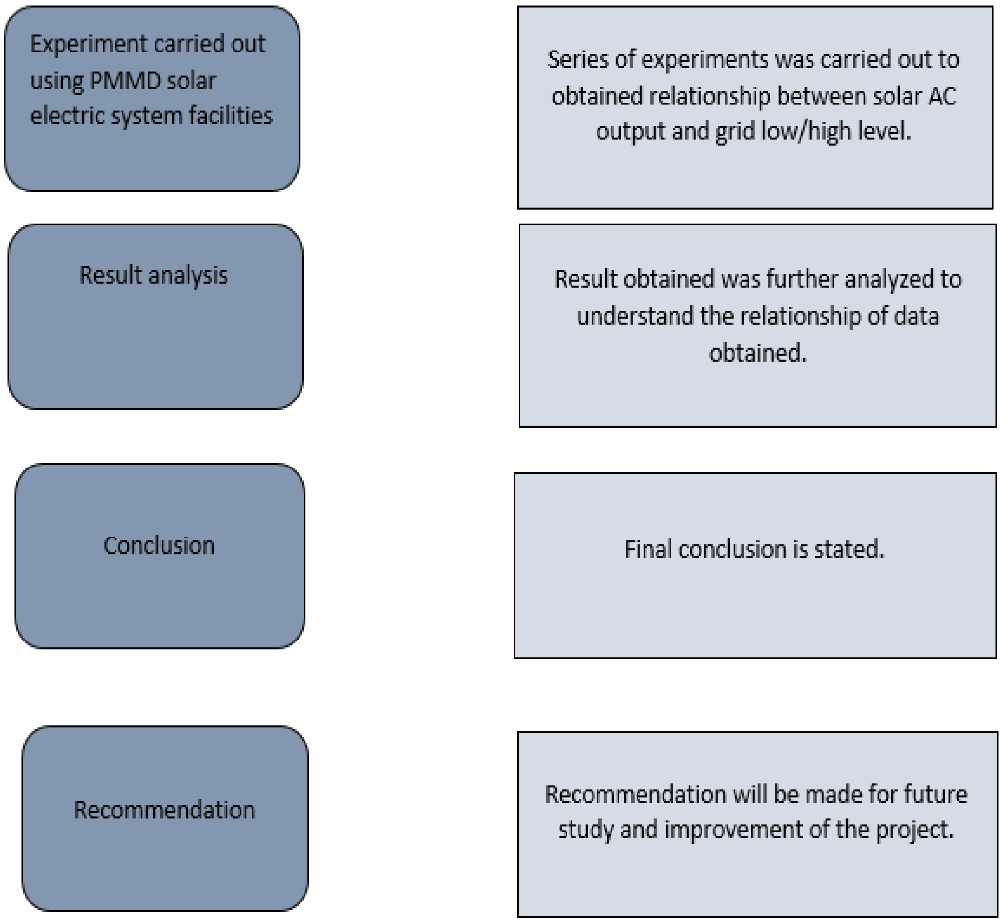


Figure 17: FYP2 project activities

3.3 Key Milestone

Table 1 shows the FYP 1 milestone that based on the requirement of FYP 1.

Table 1:FYP1 key milestone

No.	Action/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Allocation of FYP1 Project title														
2	Extended proposal submission														
3	Proposal Defense														
4	Submission Of interim draft report														
5	Submission of interim final report														

Table 2 shows the FYP 2 key milestone that based on the requirement of FYP 2.

Table 2: FYP2 key milestone

No.	Action/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Progress Report														
2	Pre-SEDEX/ELECTREX														
3	Draft Report														
4	Final Draft Report														
5	Technical Paper														
6	Viva														

3.4 Gantt Chart

Table 3 shows the Gantt chart of FYP1 based on deadlines date set by FYP 1 coordinator.

Table 3: Gantt chart for FYP1 progress

No.	Action/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	FYP1 project confirmation	■	■												
2	Preliminary research on the topic			■	■	■	■	■							
3	Lab experiment and simulation								■	■	■	■	■	■	■
4	Proposal Defense									■					
5	Writing of interim report Draft											■	■	■	
6	Writing of final interim report														■

Table 4 shows the Gantt chart of FYP2 based on deadlines date set by FYP 2 coordinator.

Table 4: Gantt chart for FYP2 progress

No.	Action/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Experiments Works.														
2	Data analysis														
	Writing of progress reports														
3	Writing of report draft														
4	Writing of final draft report														
5	Writing of technical paper														
6	Creating poster for Viva														

3.5 Property Management and Maintenance Department (PMMD) Grid Connected Solar System Design

Based on the datasheet in Table 5, there are several PV module rating at PMMD that will be used for this analysis. These are the basic rating that one should know in designing solar system. Of course, there are plenty of other module important ratings that must be considered when designing solar system. These rating value is located on the I - V curve of the module obtained when module are tested in Standard Test Condition (STC).

Module Model : PANASONIC HIT Photovolataic Module VBHN240SJ25

Voltage at maximum power, V_{pm} : 43.6 V

Current at maximum power, I_{pm} : 5.51 A

Maximum Power, P_{max} : 240 W

Open circuit voltage, V_{oc} : 52.4 A

Short circuit current, I_{sc} : 5.85 A

Maximum system voltage : 1000 V – The designed system array voltage should not exceed this value.

Table 5: PMMD PV module specification

Specification	
Model	PANASONIC VBHN240SJ25
Cell number in series	72
Rated Power, Watts (Pmax)	240
Maximum Power Volage (Vpm)	43.6
Maximum Power Current (Ipm)	5.51
Open circuit voltage	52.4
Short circuit current	5.85
Cell type	HIT
Maximum System voltage (Voc)	1000

3.5.1 PMMD solar system configuration

Table 6 provide the information of solar system configuration at PMMD that available in vendor report.

Table 6: PMMD solar system configuration information

PV array characteristic	
Model	PANASONIC VBHN240SJ25
Number of PV modules in series	8 modules
Number of PV modules in parallel	2 strings
Total Number of PV modules	16 modules
Array global Power	3840Wp

Total number of PV module : 16

The number of module can be installed depend on the inverter input rating which will be discussed more in the next section.

Number of PV module in series : 8

This is known as string when number of module connected in series. So one string is equal to 8 modules. The total modules is 16. So the configuration will be an array with two string. The calculation below is to calculate string output power and will be using module V_{mp} and I_{mp} values.

Total voltage in a string equal to voltage of each module available in the string.

Total voltage in a string: 8 module x 43.6 V = 348.8 V

Total current in a string equal to current value in a module because it connected in series.

Total current in a string : 5.51 A

Total a string output power : 348.8 V X 5.51 = 1921.88 W

Number of strings in parallel: 2

PMMD inverter have 2 input for MPPT. So each string will be connected to one MPPT input. Figure 18 illustrates how this configuration connection. More discussion on inverter specification effect on designing solar system will be cover on next section.

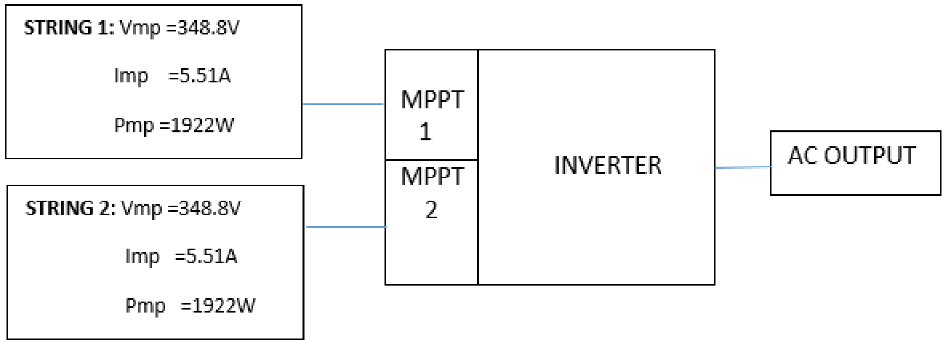


Figure 18: PMMD multistring inverter illustrated

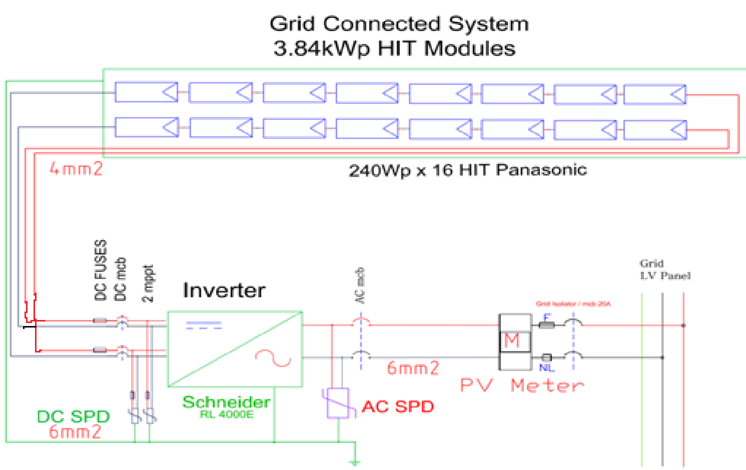


Figure 19: PMMD Grid connected solar system wiring drawing

In Figure 19 we can see that the two strings consist of eight modules each and connected to each inverter MPPT input. This form an array with two strings connected in parallel. Total array output power is equivalent to output power of these two strings combine. This type of inverter is called multi-string inverter because it has a number of MPPT inputs.

Advantages of multi-string inverter:

1) If the modules are facing different direction then the array could be divided into strings so that modules in the same string are all facing the same direction.
2) Energy yield from the system is greater than if the strings connected to an inverter with only one MPPT.
3) Multistring inverter is generally cheaper than using numbers of individual inverter.
4) Can offer the advantage of higher energy output for arrays where parts of the arrays face different direction or experience different level of shading.

Array global power: 3840Wp (p subscript refer to peak or maximum power)

Because modules connected in series to form a string, one string voltage equal to voltage of the individual module available in the string. In this case, eight module per string. So, voltage of one module need to times by eight to get a string voltage. Current in a string is equal to value of current in one module because the module connected in series.

Using V_{mp} and I_{mp} (assuming voltage and current at maximum power for this calculation).

1 string total voltage: 43.6 V x 8 = 348.8 V

1 string total current: Current in a module = 5.51 A

2 string connected in parallel. So the voltage of the array is equal to voltage of 1 string and total current of the array is sum of current in both string.

Array voltage: 1 string voltage = 348.8 V

Array current: 2 x string current = 11.02 A

Array power : 348.8 V x 11.02 A = 3843.78 W_p

The calculated array power is almost same as stated in Table 6. Since we are using module voltage and current at maximum power (V_{mp} and I_{mp}) and the one provided in Figure 14 maybe already considering some losses so it might be slightly difference or maybe it is because of the figures calculated already rounded off along the calculation.

Array operating characteristics : V_{mp}: 331 V

I_{mp} : 11 A

3.5.2 PMMD PV array system sizing based on inverter specification

There are two voltage specification need to be met:

1) The module itself: PV array's voltage must not exceed the maximum system voltage for the module.
2) Maximum input voltage to the inverter must not be exceeded the maximum DC voltage that the inverter is designed to handle safely. This normally lower than maximum system voltage and hence of greater concern. If the array's open circuit voltage exceed maximum input voltage, it may damage the inverter electronic components. PMMD is using Schneider Conext-RL 4000E type inverter.

Table 7 shows the inverter specification. Calculation was carried out to check whether the solar system design meet the inverter specification. The calculation is as following.

Table 7: Inverter specification

Electrical specification	
Input DC	
MPPT voltage range, full power	180-500V
Operating range, full power	90 – 550V
Starting Voltage	100 V
Max. Input voltage, open circuit	500 V
Number of MPPT	2
Max. input current per MPPT	12 A
Max. short current per MPPT	16.7A
Nominal input power	4.2kW
Max. DC input power per MPPT	3.2kw

a) Module maximum system voltage

From PV module datasheet,

Module maximum system voltage : 1000 V

PMMD array voltage : 348.8 V

So, PMMD array voltage < Module maximum system voltage.

b) Maximum inverter input voltage

From the inverter datasheet,

Maximum inverter input voltage : 550 V

Module open circuit voltage : 52.4 V

String open circuit voltage : 8 modules x 52.4 =419.2 V

Array open circuit voltage = string open circuit voltage: 419.2 V

So, array open circuit voltage < maximum inverter input voltage

c) Inverter MPPT range

The grid tie inverter also has a maximum power point tracking (MPPT) range with specified minimum and maximum input voltage applied to it. Within this range, the inverter track the maximum power point to ensure the array perform as well as possible and outside this range the array is likely to under perform.

The range of input voltage for MPPT to operate for this inverter : 180 V-500 V.

Total voltage per string : 348.8 V

So the input voltage still in the MPPT operating range.

d) Maximum inverter input current per MPPT : 12 A

PMMD design is one string per MPPT.

Value of current in a string in the design : 5.51 A

So,value of current in a string in the design < maximum inverter input current per MPPT.

e) Maximum inverter short circuit current per MPPT : 16.7 A

Value of short circuit current in a string : 5.85 A MPPT.

f) Nominal Input power : 4.2 kW

So, value of short circuit current in a string < maximum inverter short circuit current per

Array power : 3483.78 W_p

So, array power< nominal input power.

g) Maximum DC input power per MPPT : 3.2kW

Total power in a string: 1921.88 W

So, total power in a string < maximum DC input power per MPPT

So it can be concluded that the PMMD PV array installation was configured well and its output suit to the inverter rating requirement.

Table 8 and Table 9 contain the information about inverter AC output rating and efficiency.

Table 8: Inverter AC output rating

Electrical specification	
Output AC	
Nominal output power	4kVA
Nominal output voltage	230 V
Isolation	Tranformerless
AC voltage range	184 V – 276 V
Frequency	50/60 Hz
Frequency range	50/60 Hz +/- 5Hz
Max. output current	18.2 A

Table 9: PMMD Inverter efficiency

Efficiency	
Peak	97.5 %
European	97.0 %

3.6 Tools and Software

3.6.1 Phase 1: Equipment and Software

Tools

1. Noiseken Voltage Dip and Up Simulator model VDS-2002. Refer to Appendix 1.
2. FLUKE power quality analyzer. Refer to Appendix 4.
3. Multimeter
4. Solar panel
5. Lighting source
6. Computer/laptop
7. Battery charger
8. Battery 12V DC
9. Grid tie inverter

Software

1. MATLAB
2. Microsoft Excel

3.6.2 Phase 2 and 3: Equipment and Software

Tools
1. PMMD solar electric system
2. Noiseken Voltage Dip and Up Simulator model VDS-2002
3. HIOKI power quality analyzer model PW3198
4. PC to run the software

Software
1. Noiseken software VDS-2002 Remote Control Software. Refer to Appendix 2 and Appendix 3
2. HIOKI software PQA-HIVIEW PRO version 2.05. Refer to Appendix 5

3.7 Experimental setup for phase 2 and 3

Figure 20 shows the connection point of PMMD solar output from inverter to the grid. This is where the simulator will be placed and the location of the experiment will be conducted.

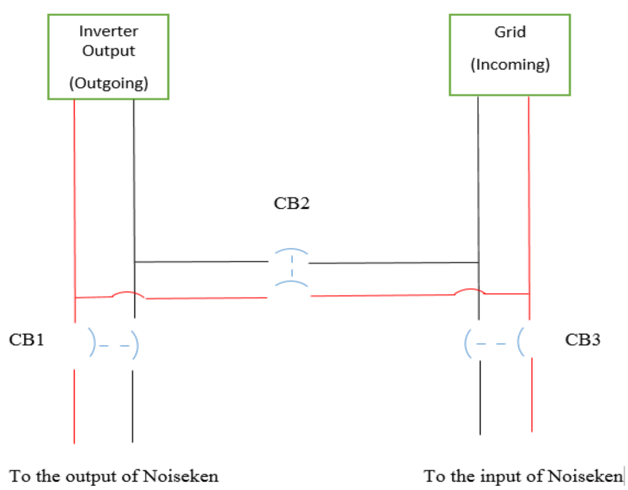


Figure 20: PMMD solar system point of grid connection

3.8 Circuit breaker operation

1. Grid connected solar inverter only functioning when it is connected to the grid.
2. CB2 breaker ensure that the output of the inverter is connected to the grid.
3. During the experiment, the breaker CB2 is in open state. The inverter will be connected to the grid through Noiseken voltage dip and up simulator when LINE button on the simulator is in ON state.
4. The inverter will operate only after 300 second when it was connected back to grid.

3.9 Procedure for using the PMMD solar system facilities to conduct the experiment

<u>Starting the experiment</u>

1. During normal operation, CB2 is closed and CB1, CB3 is opened.
2. When all the measuring instrument is connected and ready to start the experiment, open the CB2 first and then close the CB3 followed by CB1.
3. Turn ON the simulator and press the LINE button so the grid and the output of the solar inverter now is connected.
4. Wait for 300 seconds or 5 minutes before start recording any data using analyzer equipment because the inverter only operates after 300 seconds when it was connected back to the grid (when the LINE button on simulator is press).

<u>Ending the experiment</u>

1. Turn OFF the recording instrument (charger, current clamp power).
2. Turn OFF the simulator.
3. Open the CB1 followed by CB3.
4. Then close the CB2.

CHAPTER 4: RESULT AND DISCUSSION

4.1 Phase 1: Lab Inverter Functionality Testing

The first phase of this research is to ensure the laboratory grid tie inverter is functioning. There are three setup in this experiment where first experiment was to use two 10 watt solar PV array. The solar panel was subjected to constant lamp source. The output of the solar was measured by multimeter. The reading was 34 V DC. The minimum voltage required by the inverter was 22 V DC and the maximum voltage is 45 V DC. When the solar PV was connected to the inverter, the voltage of the PV solar dropped to 8 V DC. The inverter could not be turned on at this voltage level. The green led light that indicate the inverter was in operation also did not light up.

The second setup was using battery to replace solar PV panel. Two 12 V DC battery were used in series to get 24 V DC to be supplied to the inverter. This setup successfully operated the inverter. The green led lighted up. The FLUKE power quality analyzer was used to measure power at both DC side and AC side of the inverter to determine the power flow direction. This setup showed that the power flow of the output inverter is from the grid to the inverter since the value of the power was negative. The power should flow in the other way around which was from the inverter to the grid. This maybe because of the value of the input current from battery was not adequate.

The third setup was using DC charger where the DC voltage and DC current can be varied. The voltage and current were varied during this setup and the output power of the inverter was observed on the FLUKE power quality analyzer. The minimum input 0.2 A DC was required for the inverter output power to flow to the grid.

4.1.1 Using 24 V DC Battery

The experiment was conducted using 24 VDC battery. At first setup the direction of FLUKE meter clamp was towards the grid. Figure 21 shows the value of power, P_{out} was negative. This indicated the power flow direction was reversed of the clamp direction. To confirm this observation the direction of the clamp was reverse, now it was pointing towards the inverter. The value of the power is now positive as indicated on Figure 22.

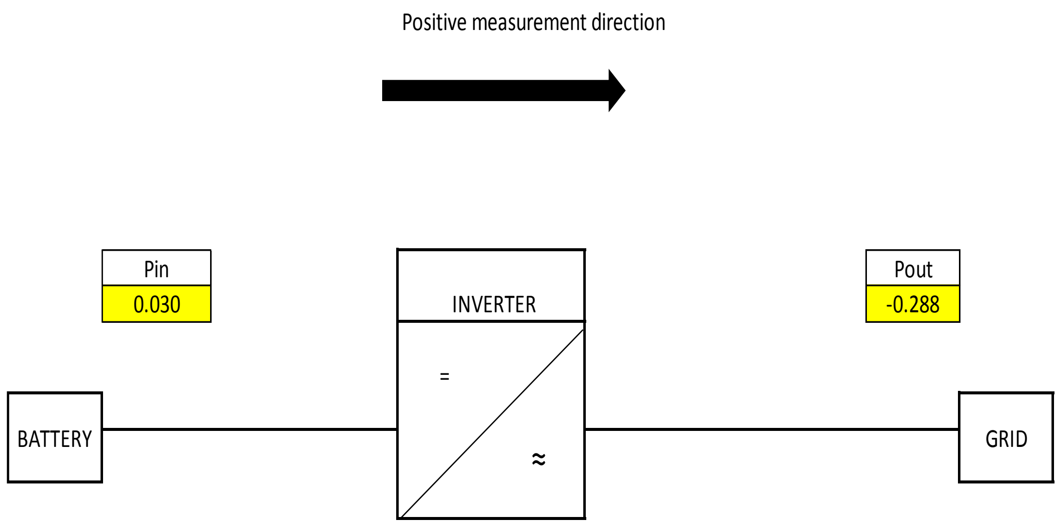


Figure 21: Inverter power flow when using 24VDC battery as an input

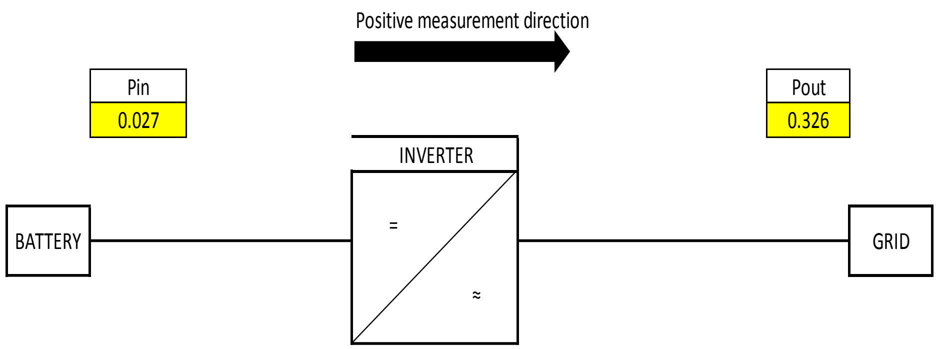


Figure 22: Inverter power flow when using 24VDC. Reverse clamp direction

4.1.2 Using DC supply charger

When using DC charger the value of current can be varied at several values. The value of voltage was set at 22 V DC and the current was varied at 0.1 A, 0.2 A, and 2.13 A. The results are shown in Figure 23, Figure 24 and Figure 25. The minimum current required was 0.2 A DC in order for the power to flow from the inverter to the grid.

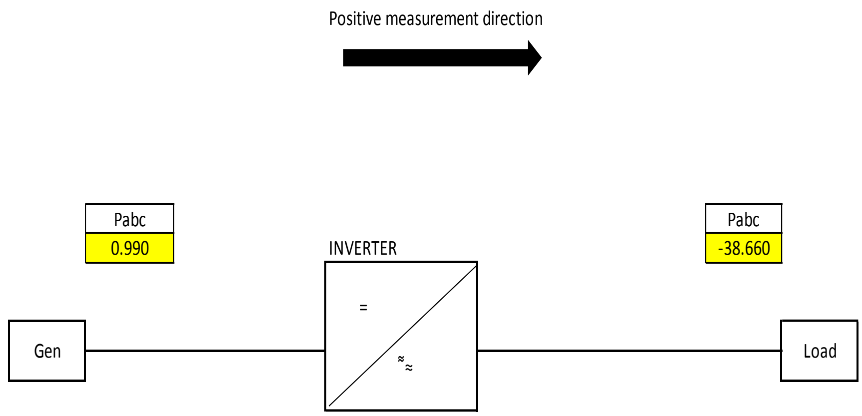


Figure 23: Power flow when current is 0.1

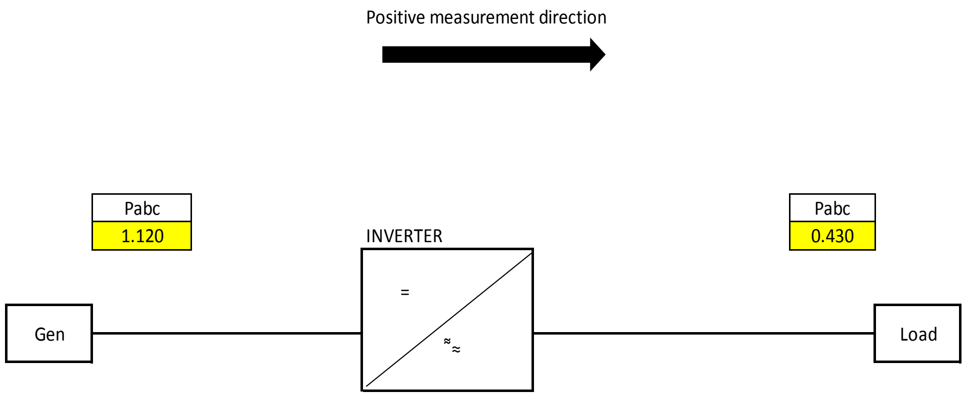


Figure 24 Power flow when current is 0.2

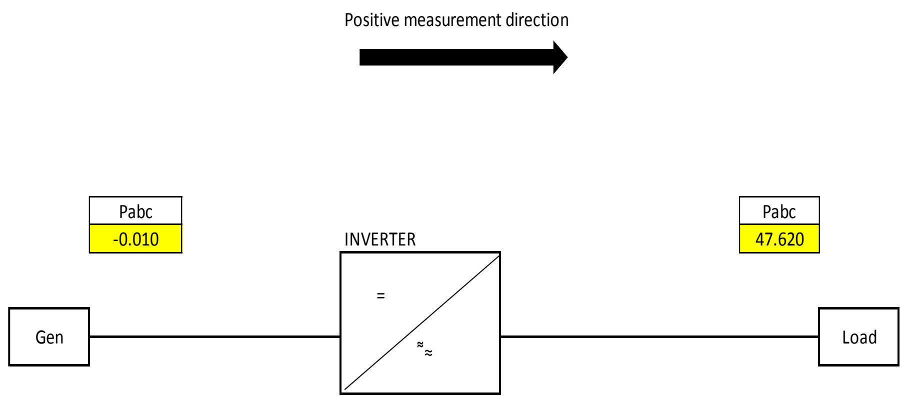


Figure 25: Power flow when current is 2.13A

4.2 Phase 2: Voltage Dip and Swell Experiment at PMMD

Inverter is equipped with protection to shutdown itself if grid voltage is outside its predetermined range. So before the experiment can proceed, the allowable voltage operating range and time before it will shutdown if the inverter detect any abnormality in the grid must be determined. This is to avoid the inverter shutdown during experiment. Figure 26 shows the PMMD inverter operating range specified by the manufacturer.

Voltage (at point of utility connection)	Maximum trip time*
V < 0,5 × Vnominal	0,1 s
50 % ≤ V < 85 %	2,0 s
85 % ≤ V ≤ 110 %	Continuous operation
110 % < V < 135 %	2,0 s
135 % ≤ V	0,05 s
* Trip time refers to the time between the abnormal condition occurring and the inverter ceasing to energize the utility line. The PV system control circuits shall actually remain connected to the utility to allow sensing of utility electrical conditions for use by the "reconnect" feature.	

Figure 26: PMMD inverter operating range

Voltage Dip and Swell range

The range of the voltage dip and swell that will be simulated in this experiment is restricted by its definition.

1) Dip - Voltage magnitude between 10 % and 90 % of nominal voltage occur in duration of 0.5 cycles to 1 minute.

2) Swell - Voltage magnitude between 110 % and 180 % percent of nominal voltage occur in duration 0.5 cycles to 1 minute.

In this experiment, the voltage dip/swell duration simulation was determined based on fault clearing time because considering the dip last only until the protection relay clear the fault. Thus durations between 0.5 cycles to 1 second is considered.

Based on all of these information the range of the voltage magnitude level and duration of the simulation was calculated as in Table 10.

Table 10: Calculated voltage dip and swell allowable range

Voltage(at a point of grid connection)	**Maximum trip time**	**The dip magnitude (10% ≤v<90 %)**	**The swell magnitude**	**Maximum duration of the dip can be simulated (cycles) before the inverter trip.**
V < 0.5 (50 %)	0.1s	10 % ≤ V < 50 %	-	0.5 < cycle < 5(0.1s)
50 % ≤V < 85 %	2.0s	50 % ≤ V < 85 %	-	0.5 < cycle < 50 (1s)
85 % ≤V ≤ 110 %	Continuous operation	85 % ≤ V ≤ 90 %	100 % <V≤ 110 %	0.5<cycle<50(1s)
110 % <V <135 %	2.0s	-	110 % <V < 135 %	0.5 < cycle < 50 (1s)
135 % ≤V	0.05s	-	135 % ≤ V ≤ 180 %	0.5 < cycle < 2.5 (0.05s)

If the maximum trip time of the inverter at the point of voltage dip simulated longer than the maximum fault clearing time (1 second), then the maximum duration of the dip can be simulated equal the maximum fault clearing time (1 second). If the maximum trip time of the inverter at the point of voltage dip simulated faster than the maximum fault clearing time (1 second), then the maximum duration of the dip can be simulated equal the maximum inverter trip time. But when the voltage dip range experiment conducted, the real maximum inverter trip time estimated is as shown in Table 11. For the voltage swell range the real inverter trip time is yet to be determined. Table 11 shows the finding of the real inverter trip time according to voltage level.

Table 11: Real maximum cycle allowable for respective grid voltage operating range.

Test level	**No. of cycle**
10 % - 48 %	4.69
50 % - 59 %	5.6
60 % - 70 %	6.7
70 % - 85 %	7
85% - 90%	Continuous operation

4.2.1 Experiment Procedure

There are two methods used:

Method 1

Each level of voltage dip and swell in the specified ranges will be simulated from the minimum time to maximum time it is allowed.

Method 2

Each level of voltage dip and swell is simulated at maximum time it is allowed for its specified range respectively. This mean only the worst case scenario considered when the voltage dip or swell last longer.

4.2.2 Method 1

The first range of voltage dip is 10 % - 48 % and the allowable duration time is 0.05 to 4.69 cycle. Voltage magnitude of 10 % and duration of 0.5 cycle was simulated first and then the cycle was increased by 0.01. Then the ratio of output solar power when voltage dip occur to the normal power before the voltage dip was calculated. Figure 27 shows the simulation of 10 % of voltage dip level simulated from 0.5 cycle up to 1.5 cycles.

In the first method, the value of the ratio is almost one for every value of cycle. This means that there was no change in the solar output power when voltage dip level of 10% is simulated at 0.5 up to 1.5 cycles. At several point the value is not 100%, either greater than 100% which means the value of power during voltage dip simulation is higher than the power before voltage dip simulation or less than 1 for output solar power during voltage dip simulation is lower than the power before voltage dip simulation

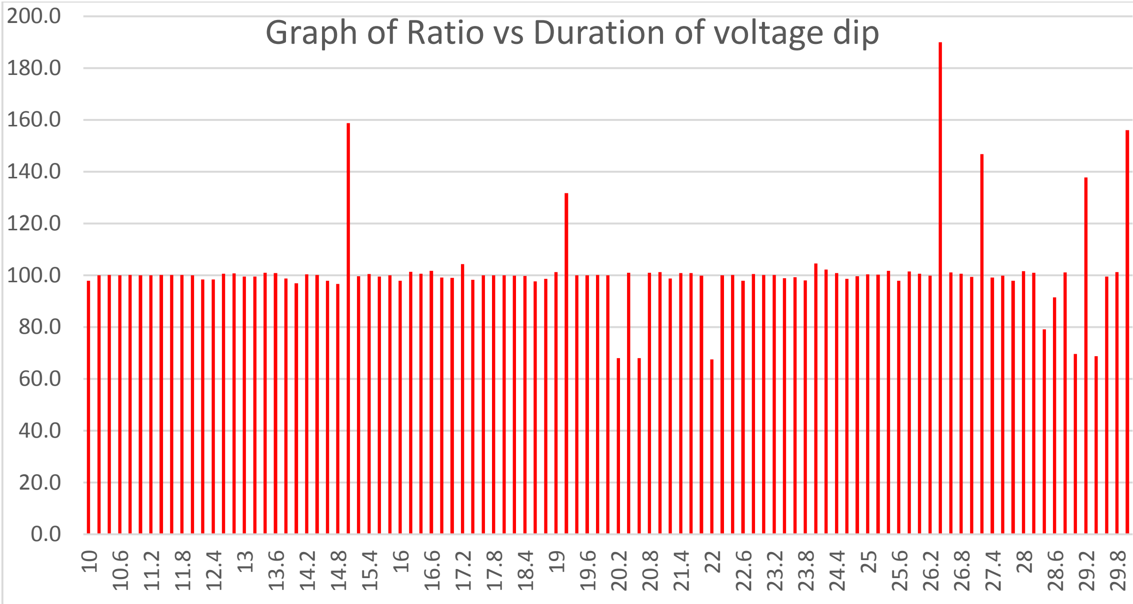


Figure 27: Graph of power ratio

4.2.3 Method 2

All the voltage dip range were simulated with their allowable maximum duration time of their respective range. Then the ratio of power when voltage dip happen to the normal power before the voltage dip was calculated. Figure 28 shows for voltage dip level from 10 % to 50 % increment by 1%.

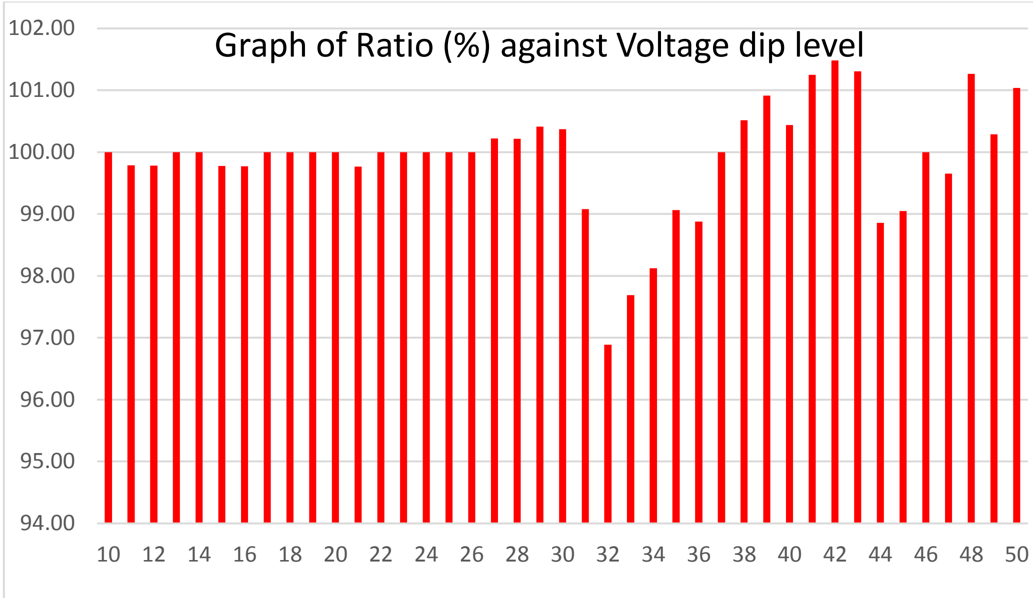


Figure 28: Graph of power ratio

In the second method, the ratio value almost one at low voltage level and varies when at higher voltage level. But there has been concern that power solar output was not constant throughout the whole experiment because the solar output power was dependent on the solar irradiance level that time. The irradiance was not constants every time and constantly change. Maybe at the time the simulation was done the irradiance value was different from the irradiance value before it was simulated. This might be the factor that contributed to the ratio value that was less or greater than 1 or 100 %.

Another problem was the data sampled by the HIOKI analyzer is at every 3 seconds. So the data obtained might not be correct because all the voltage dip was simulated at the duration of less than 1 second. So, the solar output power value captured by HIOKI is the average of power every 3 second. The value might not represent the value at moment of voltage dip. The fastest time interval HIOKI is capable to sample the data is at 1 second which is still not suitable for this purpose since voltage dip level up to 85 % only can be simulated at maximum time of 0.14 ms. Only 85 % to 90 % of voltage dip level can be simulated at 1 second.

4.3 Solar Irradiance and Ambient Temperature Data between 7 am to 6 pm

Figure 29 and Figure 30 show the value of solar irradiance and ambient temperature value from 7 am to 6 pm at Universiti Teknologi PETRONAS Solar Research Centre for on 25th October 2015. The solar irradiance and temperature is low at morning and slowly increasing as the time passes. The highest value for both data is during noon 12 -2 pm. Then after 2 pm both of the values started to decrease. This trend was almost the same for the whole week but there were slightly different if the weather was cloudy or raining. When these conditions happened, the irradiance value and temperature would drop abruptly.

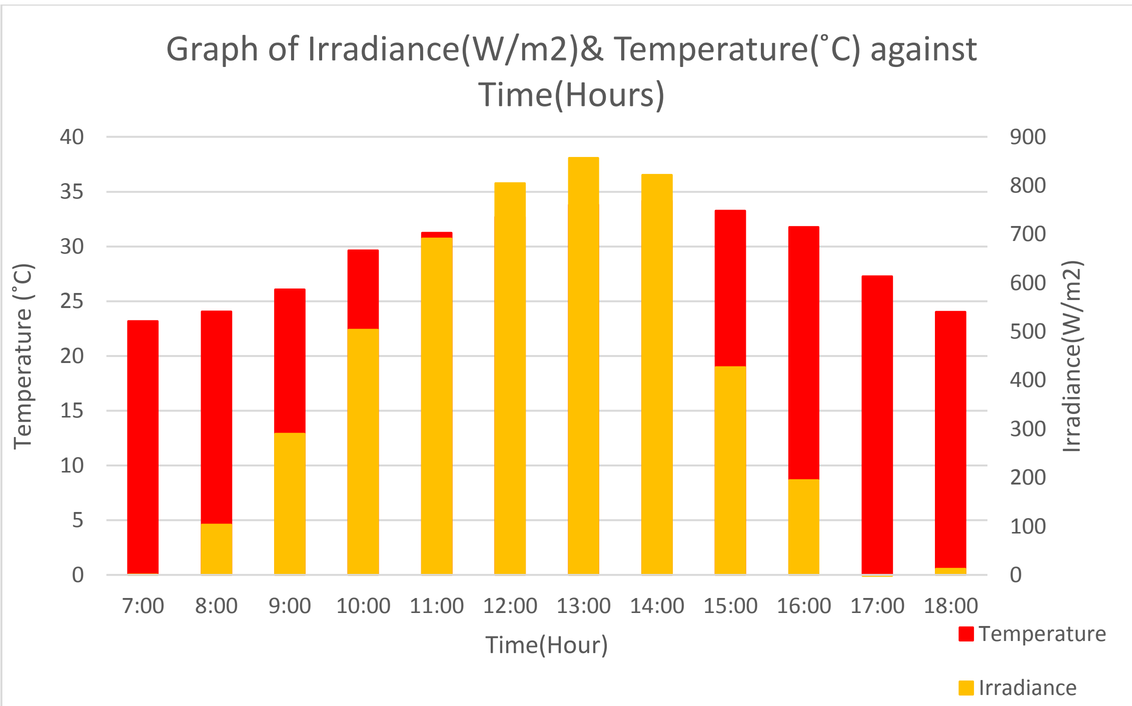


Figure 29: Graph of irradiance and ambient temperature plotted at hourly interval from 7 am to 6 pm

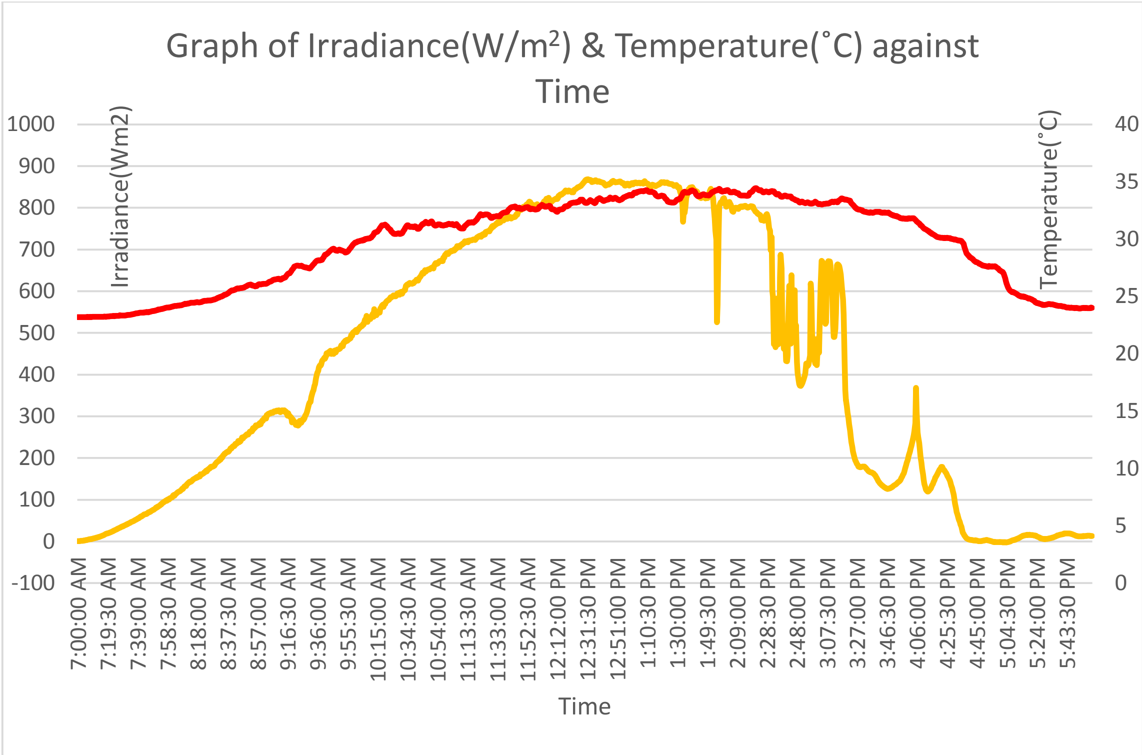


Figure 30: Graph of irradiance (yellow) and ambient temperature (red) plotted continuously from 7 am to 6 pm

4.4 Day Time PMMD Output Solar Data

PMMD solar output voltage, current and power were taken from 9:38 am to 4:48 pm. In Figure 31, the voltage value shows a constant reading and started to decrease during afternoon period. Similar trend for the solar output current as in Figure 32. The value started to slowly increase from the morning and reach it peak at noon and then start to decrease during afternoon. Both of these data will affect the output power. Figure 33 shows the output power is higher during the noon and lowest during afternoon. All of these value were related to solar irradiance and ambient temperature at that time. Solar irradiance is highest at noon that was why the voltage, current and power is the highest during this period. All of these value started to decrease when reach afternoon period. This can be reflected to the low value of solar irradiance level at that time.

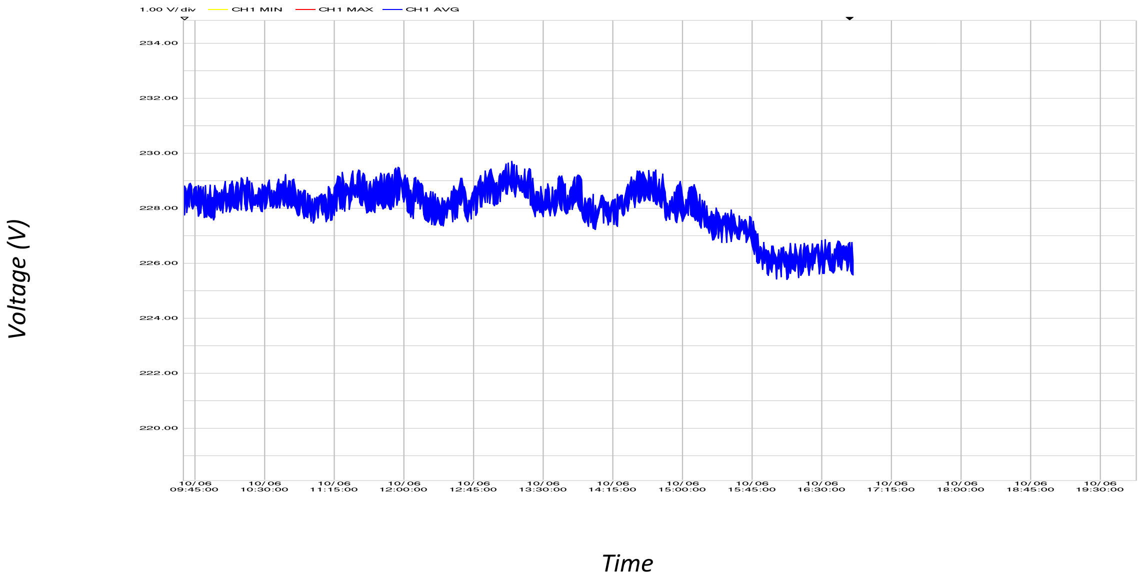


Figure 31: Voltage

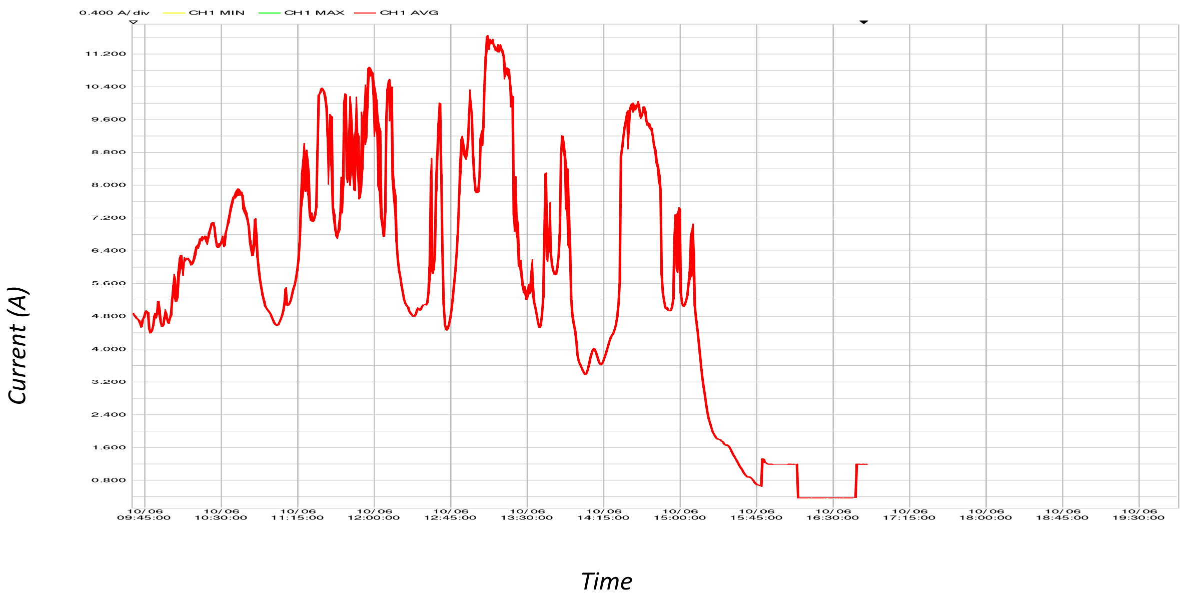


Figure 32: Current

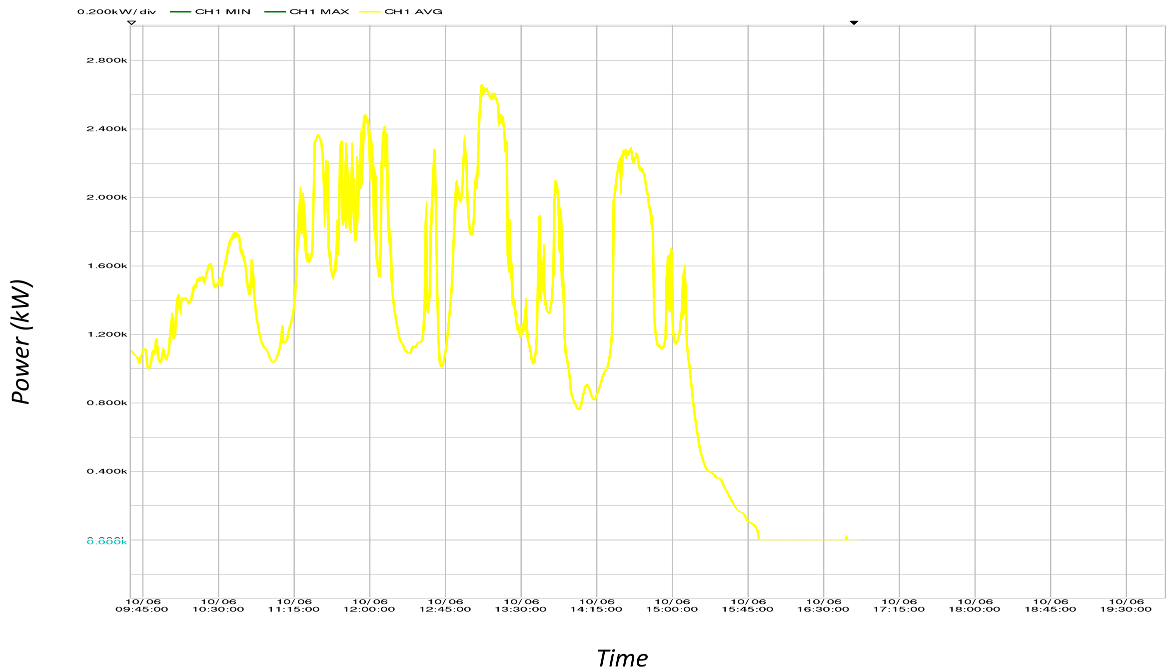


Figure 33: Power

4.5 Solar Output Behavior during Low and High Grid Voltage

4.5.1 Low Voltage

A grid low voltage test was simulated using the simulator to see the solar output data characteristics when subjected to low grid voltage. Grid voltage is set at 90 % for almost 50 minutes. Normal data reading is taken around 11 minutes before low voltage test start. In Figure 34, when the grid voltage is lowered to 90 % the current value and power increased as shown in Figure 35 and Figure 36 correspondingly. This was because the action of MPPT. MPPT ensured the maximum power was delivered during that low grid operating voltage by increasing the solar AC output current.

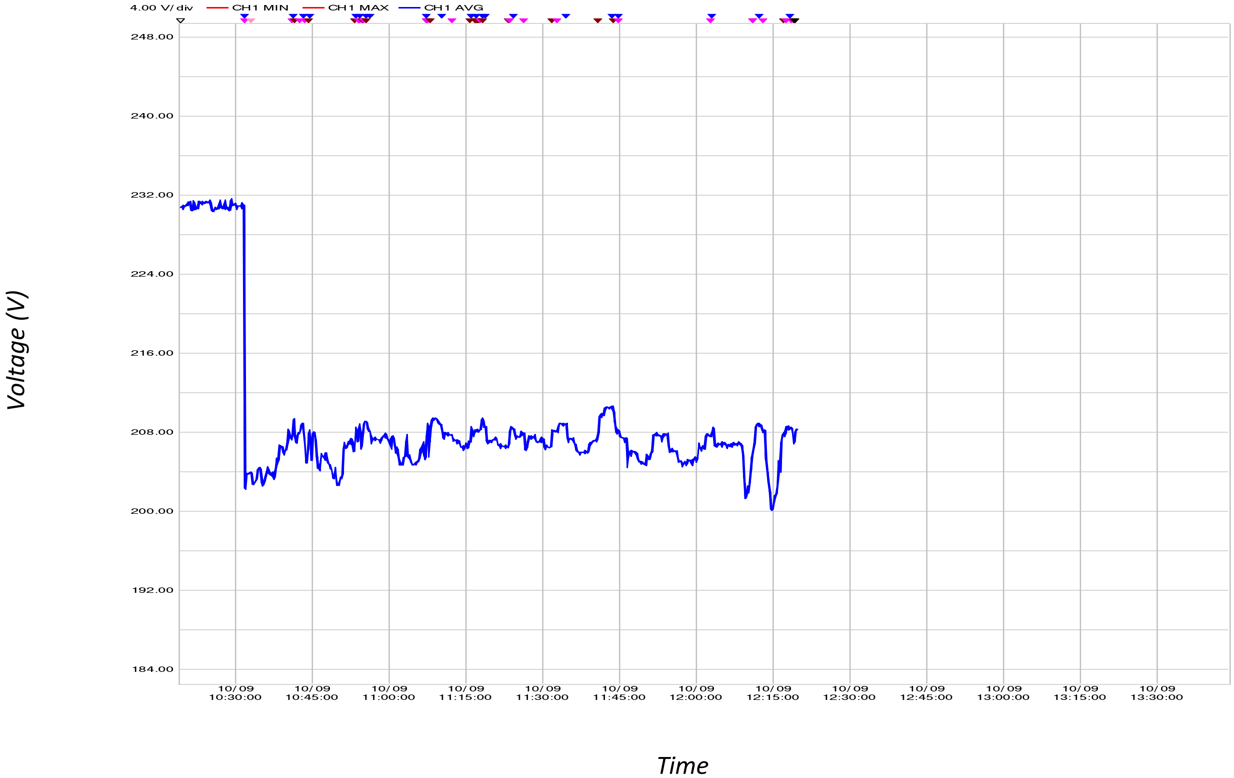


Figure 34: Voltage

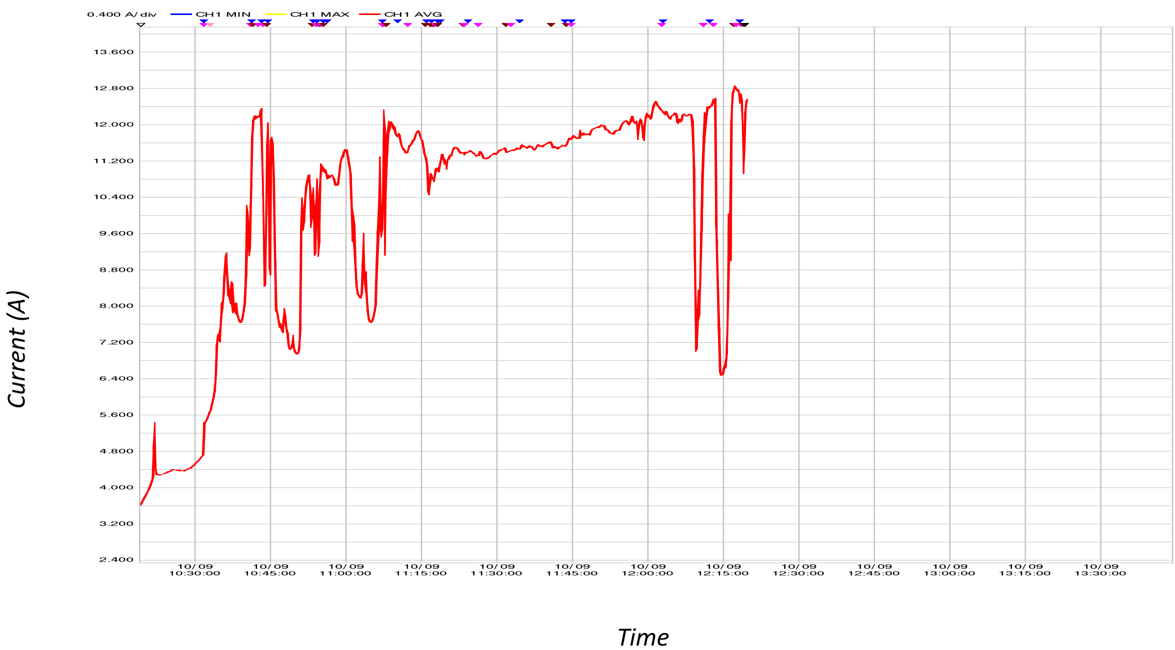


Figure 35: Current

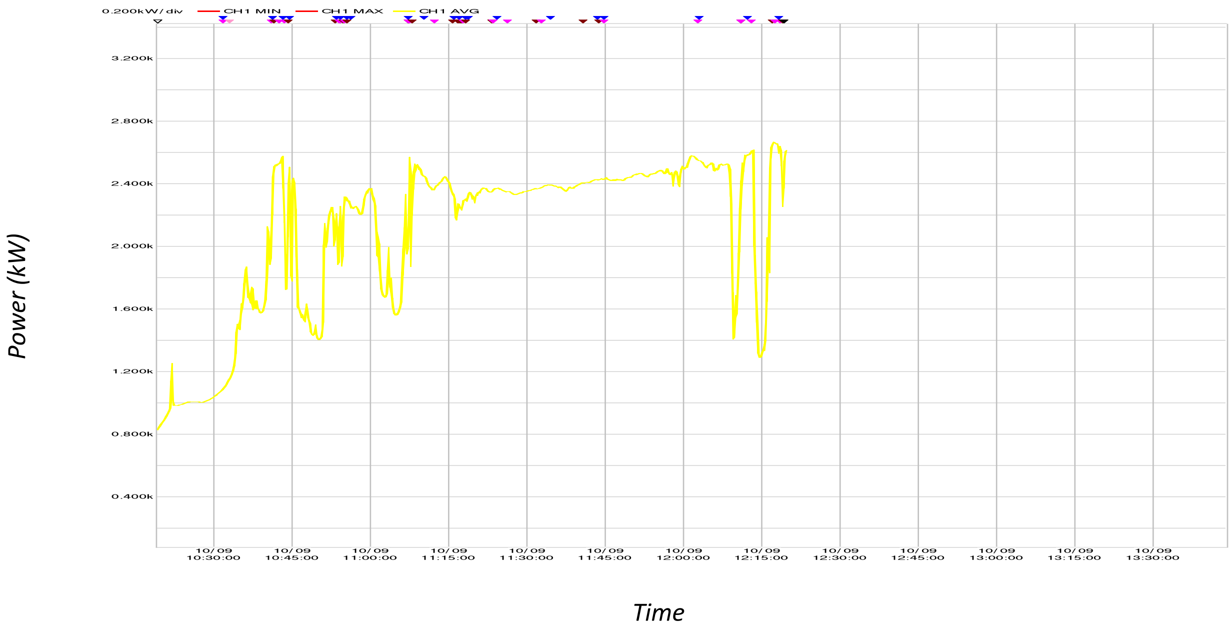


Figure 36: Power

4.5.2 High voltage

A grid high voltage test was simulated using the simulator to see the solar output data characteristics when subjected to high grid voltage. Grid voltage is set at 110 % from nominal 230 V for almost 50 minutes. Normal data reading was taken around 20 minutes before high voltage test start. When the grid voltage was increased to 110 % as in Figure 37, the current value also increased as shown in Figure 38. This was because of the MPPT action. MPPT ensured that maximum power was achieved by lowering that solar output current. Figure 39 shows the output power during the simulation.

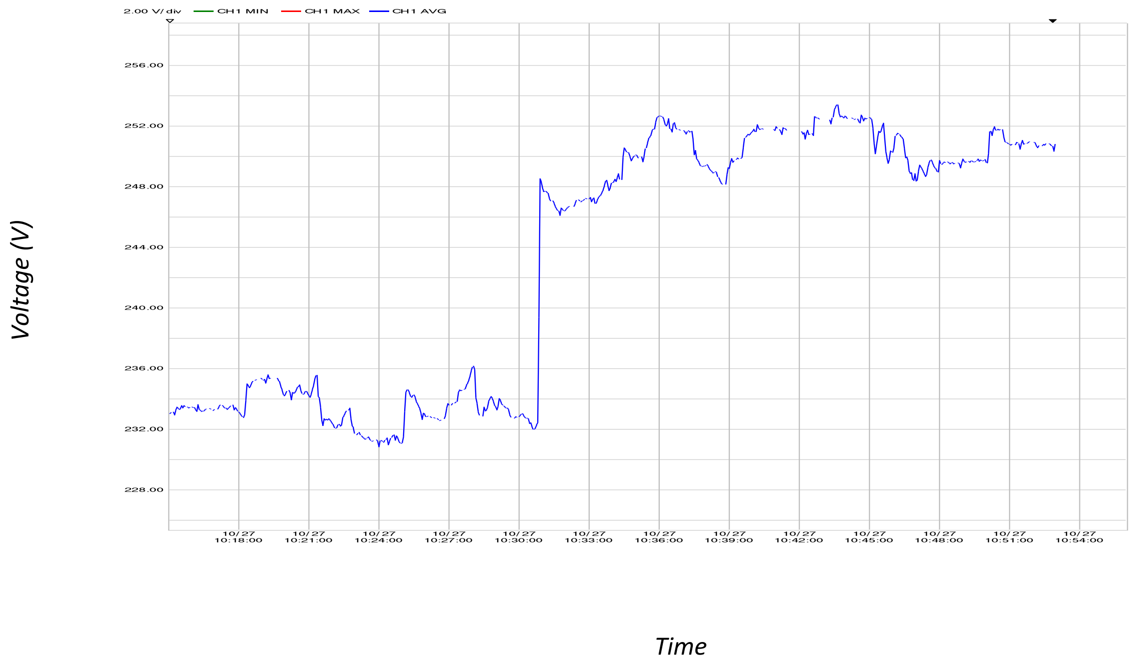


Figure 37: Voltage

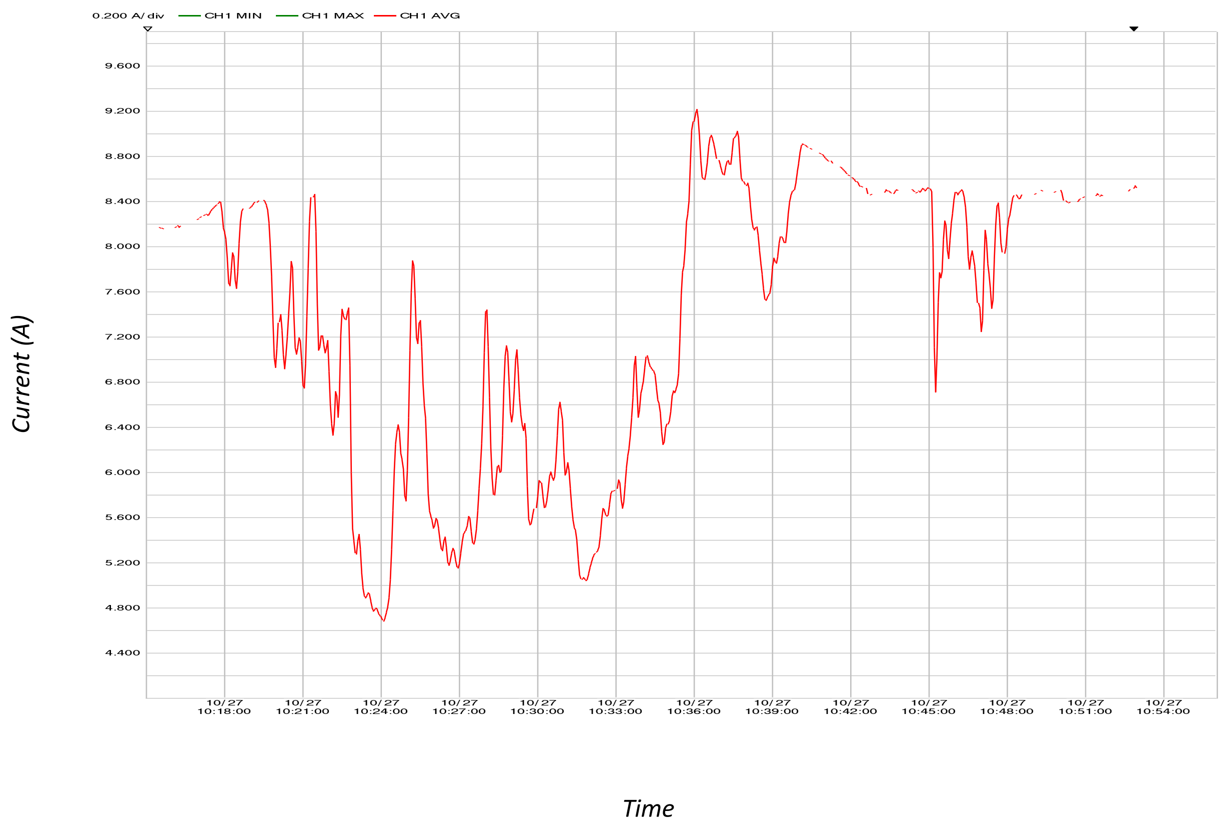


Figure 38: Current

Figure 39: Power

4.6 Phase 3: Grid Low and High Voltage Experiment

This experiment is to investigate the solar AC output when the grid operate at lower or higher operating point than its nominal voltage.

Procedure:

1. The grid low and high voltage test were simulated using the Noiseken software. Each test level was tested in duration of 10 minutes and before each simulation, normal reading was taken for 2 minutes. The tests were conducted at 3 different period of time namely morning (8.30 am to 11.30 am), noon (10.30am-1.10pm) and afternoon (2.20pm to 5.30pm). This different irradiance level and temperature are group into 3 different time zones. The experiment test level is shown in Table 12 and Table 13.

Table 12: Grid voltage range for low voltage test

Low Voltage		
Test Level (%)	**Voltage under test(V)**	**Duration(minutes)**
85	195.5	10
87	200.1	10
89	204.7	10
91	209.3	10
93	213.9	10
95	218.5	10
97	223.1	10
99	227.7	10

Table 13: Grid voltage range for high voltage test

High Voltage		
Test Level (%)	**Voltage under test(V)**	**Duration(minutes)**
102	234.6	10
104	239.2	10
106	243.8	10
108	248.4	10
110	253	10

The result of solar AC output data for low/high voltage simulation obtained during the three different time zone were analyzed. For each time zone, the low and high voltage simulation of only one level of grid voltage was shown in this report because other level of low and high voltage showed almost the same pattern. Other levels test result can be viewed in Appendix 6. Graph in the following figures show the voltage at point of grid connection, solar PV output current, and solar PV power output against time for all the tests conducted. Voltage is indicated using blue line while current is indicated using brown line. Light brown shows the normal current and dark brown indicated current during low or high voltage. Power is indicated using yellow line.

4.6.1 Morning Result

Low voltage test

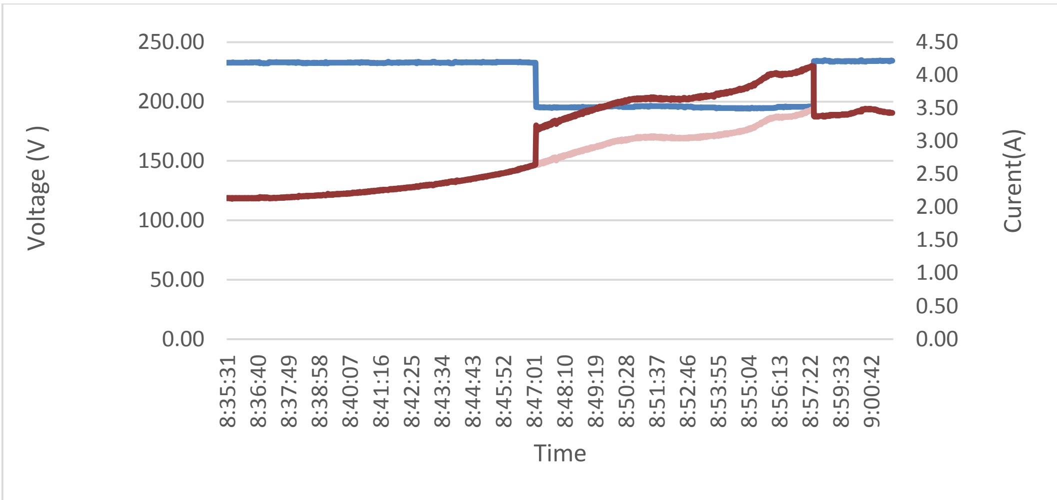


Figure 40: Graph of voltage and current

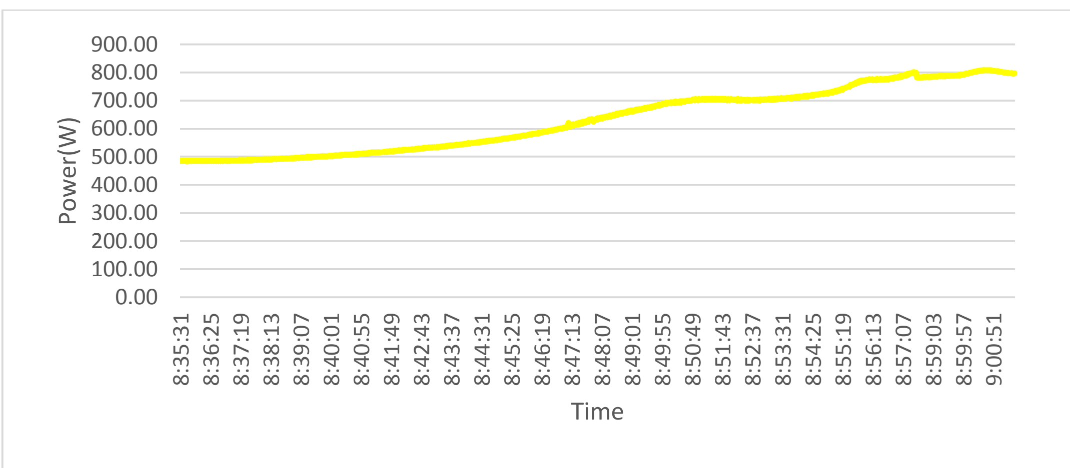


Figure 41: Graph of output solar power

High voltage test

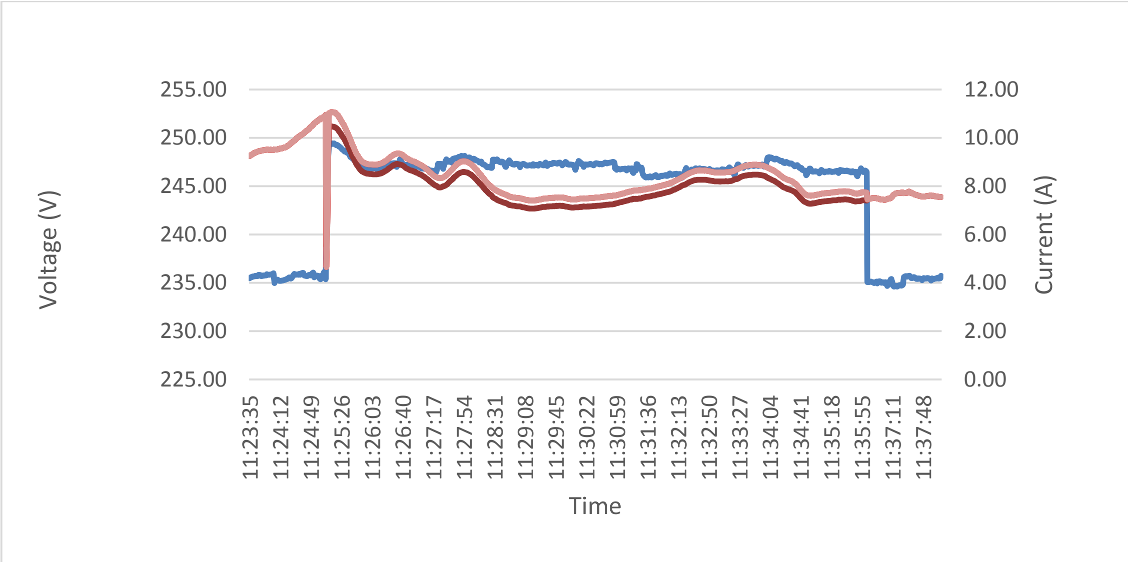


Figure 42: Graph of solar output voltage and current

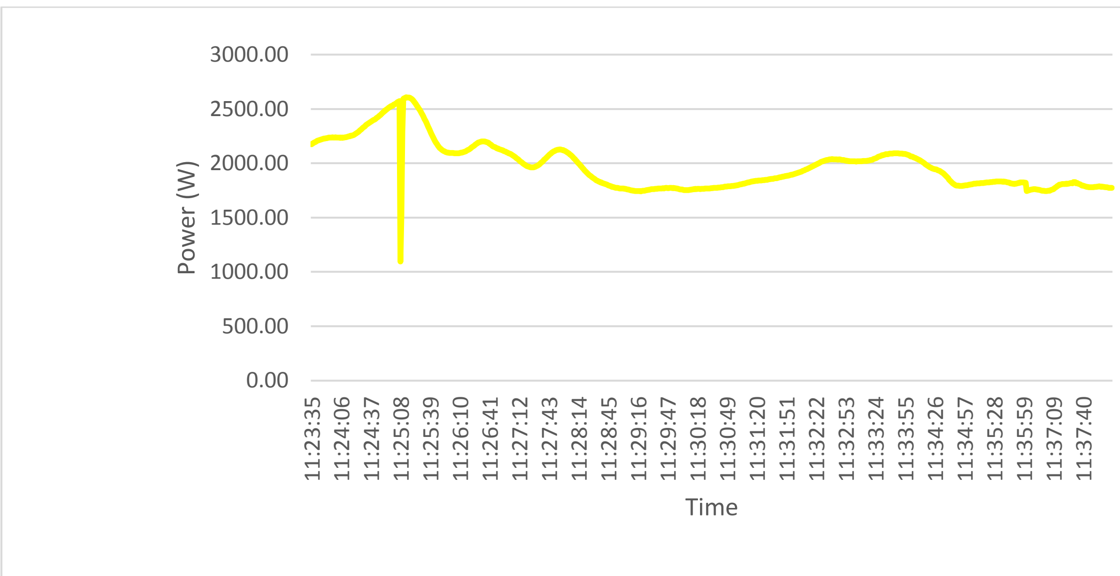


Figure 43: Graph of solar output power

4.6.1.1 Low voltage test

In Figure 40 and Figure 41, it can be seen that, when the grid low voltage is simulated for 10 minutes, the values of current increase from the normal value and the power value during that time did not show any sign of abnormality or fluctuation. The power was increasing during that period because of increasing irradiance in the morning period. The MPPT try to deliver or maintain the maximum power possible from output of the solar PV at that grid operating range, irradiance level and temperature by increasing the inverter output current due to decrease in grid voltage. The current and power profiles are identical with profile that MPPT operation to maintain maximum power at constant low voltage.

4.6.1.2 High voltage test

From Figure 42 and Figure 43 show that, when the grid high voltage is simulated for 10 minutes, the values of current decrease from the normal value and the power value during that time did not show any sign of abnormality or fluctuation. The power correspond to the irradiance at that time. The MPPT try to deliver or maintain the maximum power possible from output of the solar PV at that grid operating range, irradiance level and temperature by decreasing the inverter output current due to increase in grid voltage. Both the current and power profile are similar which dictates that during constant high voltage MPPT reduce the current to achieve maximum power.

4.6.2 Noon Result

Low voltage test result

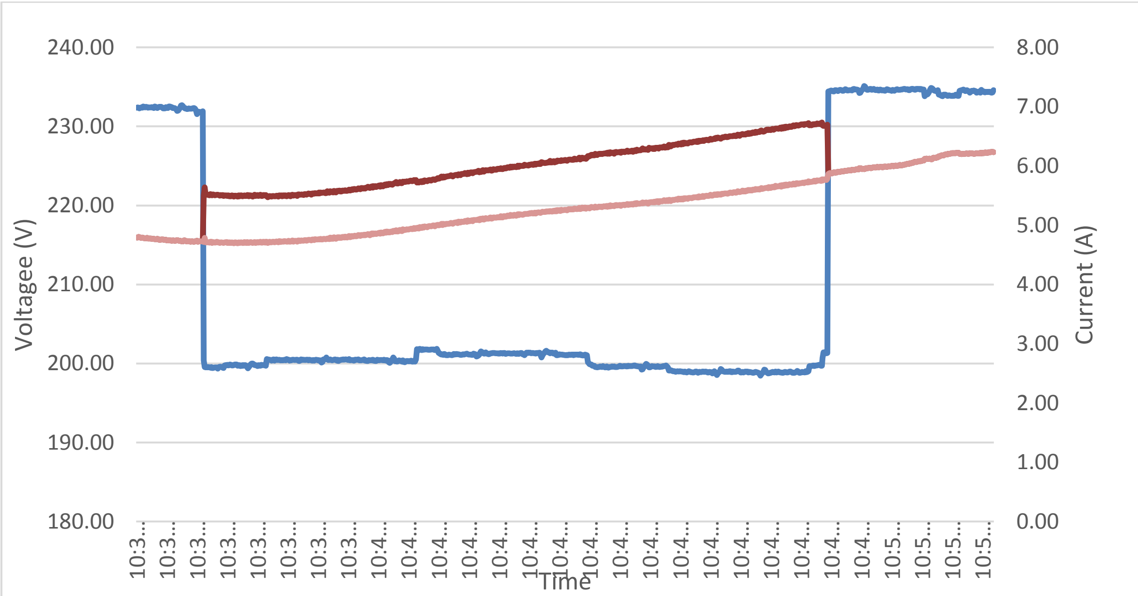


Figure 44: Graph of solar output current and voltage

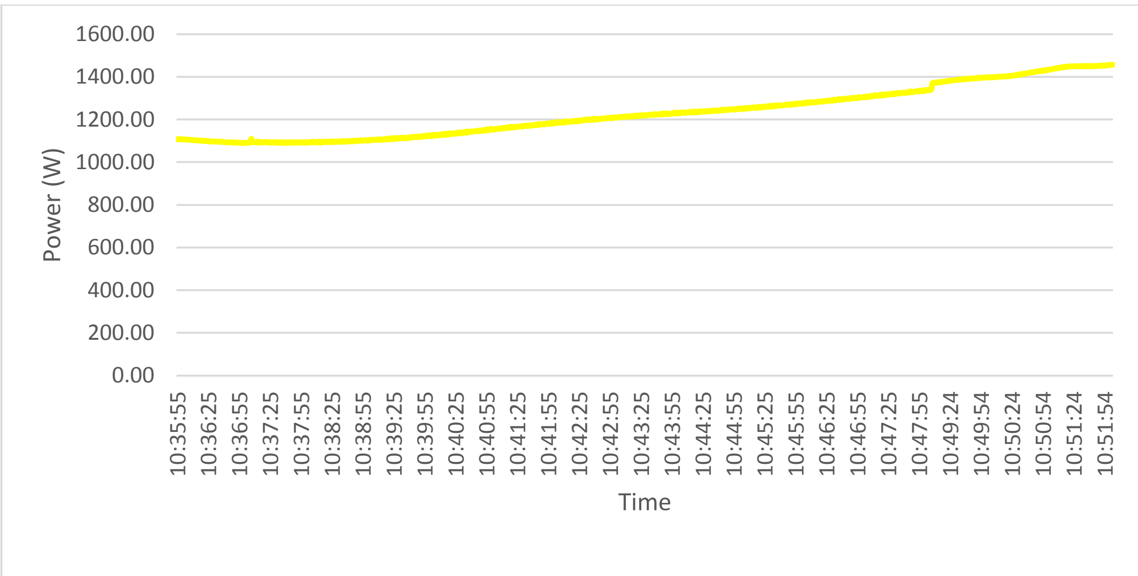


Figure 45: Graph of solar output power

High voltage test result

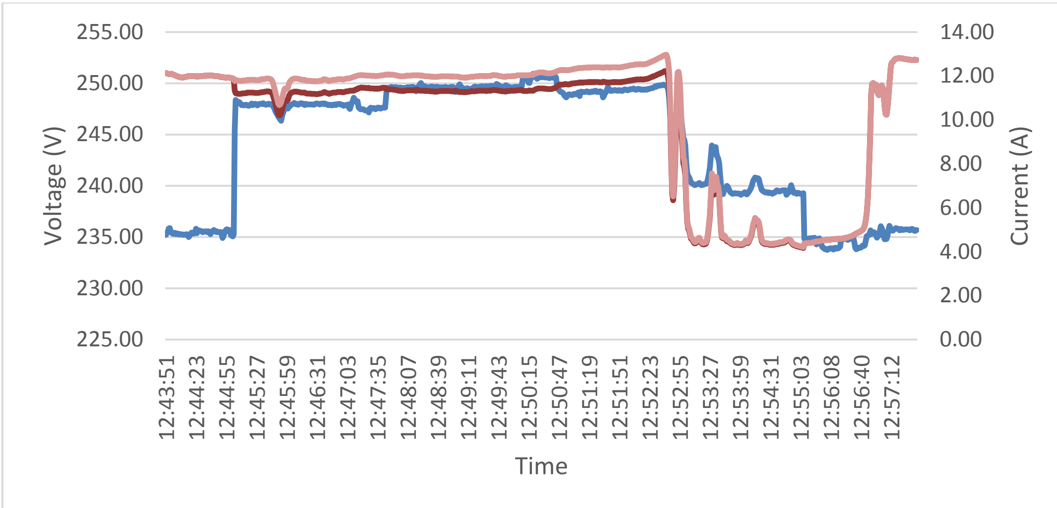


Figure 46: Graph of solar output current and voltage

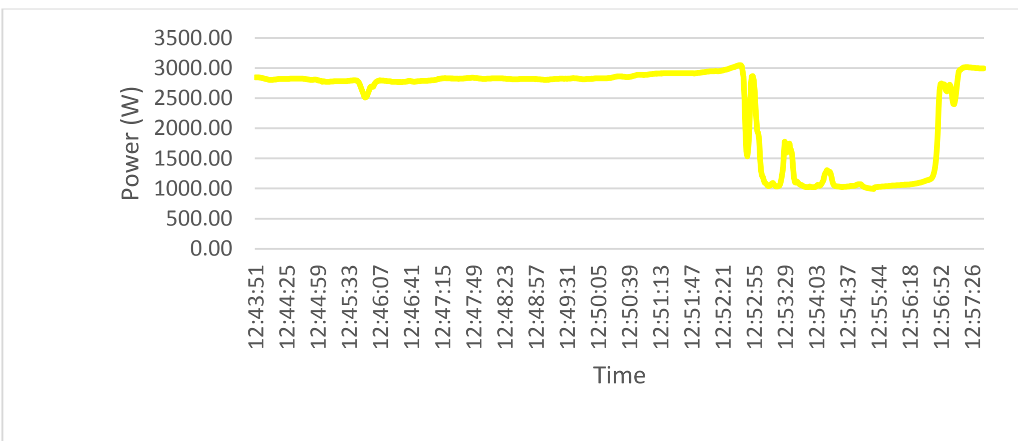


Figure 47: Graph of solar output power

4.6.2.1 Low voltage test

From Figure 44 and Figure 45 show that, when the grid low voltage is simulated for 10 minutes, the values of current increase and the power value during that time did not show any sign of abnormality or fluctuation. The power was increasing during that period because of increasing irradiance in noon period. The MPPT try to deliver or maintain the maximum power possible from output of the solar at that grid operating range, irradiance level and temperature by increasing the inverter output current due to decrease in grid voltage. Abrupt change in power was due to changes in irradiances due to cloudy weather.

4.6.2.2 High voltage test

In Figure 46 and Figure 47, it can be seen that, when the grid high voltage is simulated for 10 minutes, the values of current decrease from normal value and the power value during that time did not show any sign of abnormality or fluctuation. The power correspond to the irradiance at that time. The MPPT try to deliver or maintain the maximum power possible from output of the solar at that grid operating range, irradiance level and temperature by decreasing the inverter output current due to increase in grid voltage.

4.6.3 Afternoon Result

<u>Low voltage test result</u>

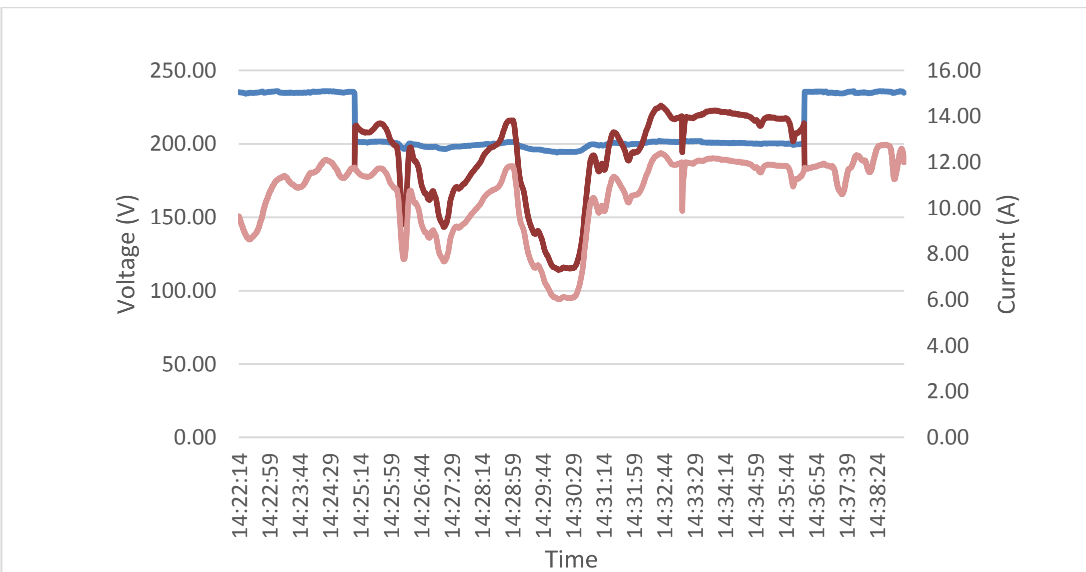


Figure 48: Graph of solar output current and voltage

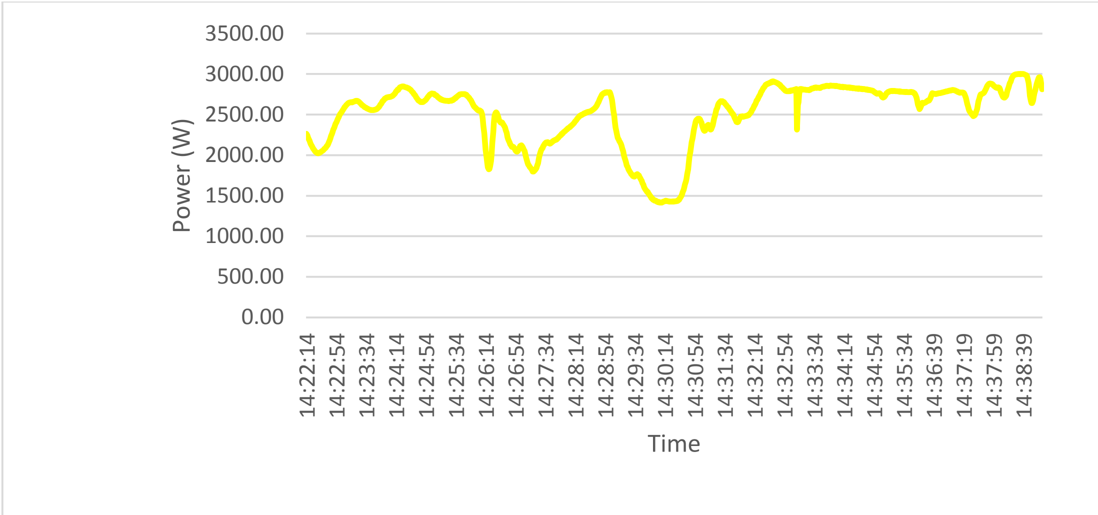


Figure 49: Graph of solar output power

<u>High voltage test result.</u>

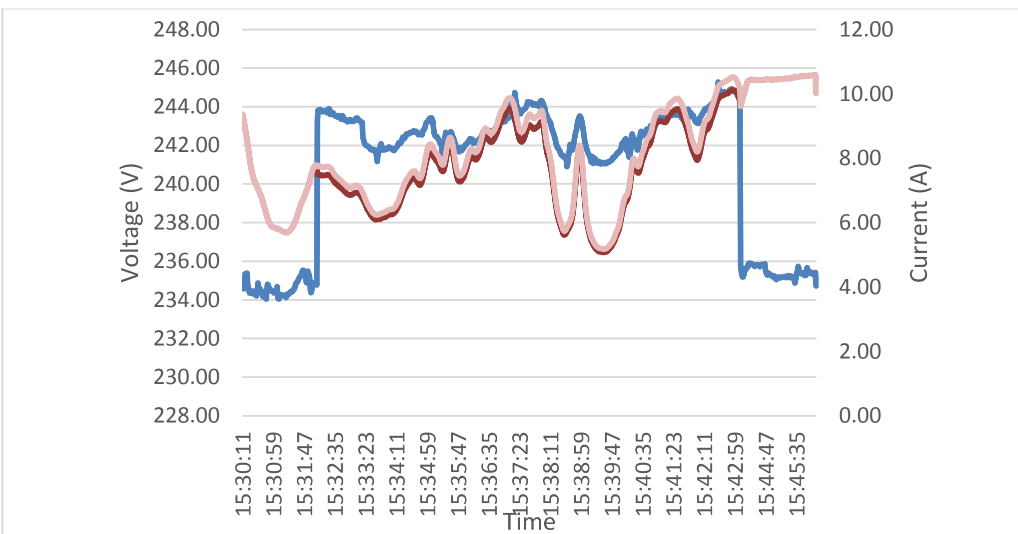


Figure 50: Graph of solar output voltage and current

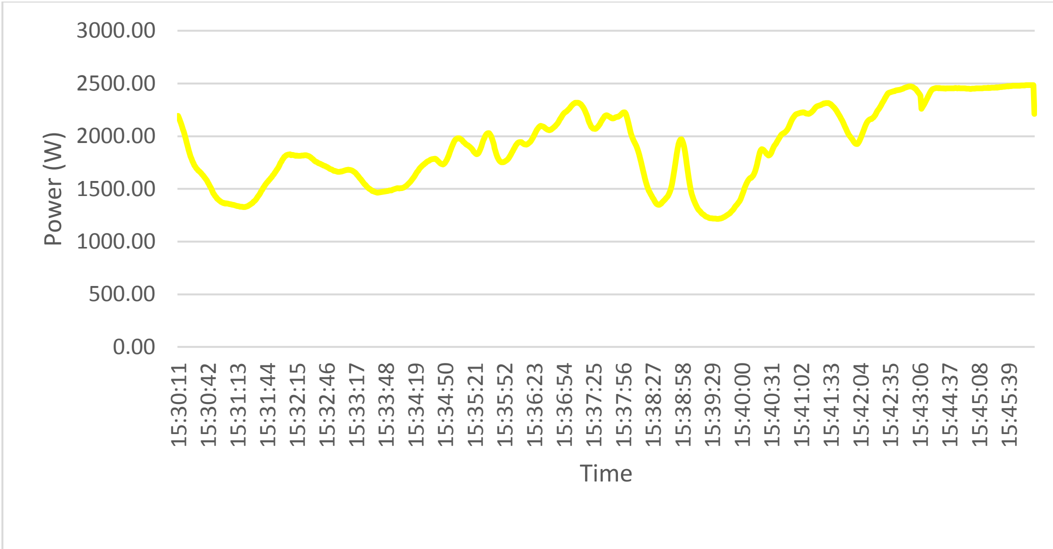


Figure 51: Graph of solar output power

4.6.3.1 Low voltage test

In Figure 48 and Figure 49 it can be seen that, when the grid low voltage is simulated for 10 minutes, the values of current increase and the power value during that time did not show any sign of abnormality or fluctuation. The power correspond to the irradiance at that time. The MPPT try to deliver or maintain the maximum power possible from output of the solar at that grid operating range, irradiance level and temperature by increasing the inverter output current due to decrease in grid voltage.

4.6.3.2 High voltage test

Figure 50 and Figure 51 show that, when the grid high voltage is simulated for 10 minutes, the values of current decrease from normal value and the power value during that time did not show any sign of abnormality or fluctuation. The power correspond to the irradiance at that time. The MPPT try to deliver or maintain the maximum power possible from output of the solar at that grid operating range, irradiance level and temperature by decreasing the inverter output current due to increase in grid voltage.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Phase 1

The minimum current required by the lab inverter so that the power flow from the inverter to the grid is 0.2 A DC. Using light lamp source for PV panel is not enough to generate output 0.2 A current to the inverter. This experiment can be repeated by using real radiation from the sun to see the output current value.

5.2 Phase 2

The result obtained is not valid because the data analyzer is not capable to sample at the rate of voltage dip event speed. This type of experiment need an analyzer that is capable of sampling data at the speed of milliseconds.

5.3 Phase 3

Grid connected solar PV system inverter has MPPT function. It ensure the maximum power available at that time is transferred to the grid. The MPPT electronic is capable to maintain the solar PV output power available during grid low voltage by increasing the inverter output current and during grid high voltage by decreasing the inverter output current. This research can be extend to investigate the power harmonic during grid low voltage and high voltage.

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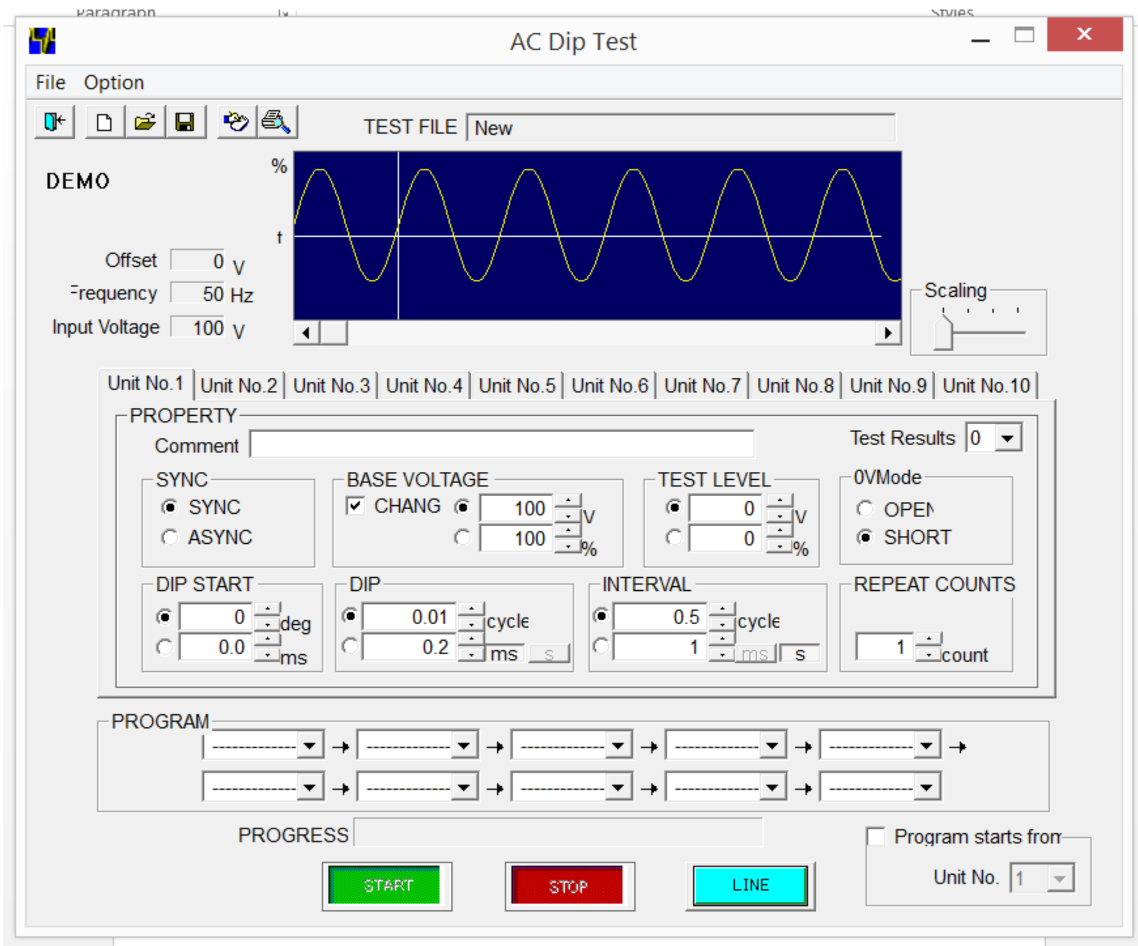
APPENDIX 1

APPENDIX 2

Parameters	VDS-2002	Remote control by PC
EUT voltage	100% fix	1V to 120% of input
Test level	0, 40, 70, 80, 120% of input	0v to 120% of input
OV status	Fixed to low impedance	Low or high impedance selectable
DIP start phase angle	0° to 315° at a step of 45° plus 360°	0° to 360° at a step of 1°
DIP start setting by time	Not selectable	0.1ms to time equivalent to 360°
DIP cycle	0.5, 1, 5, 10, 12, 25, 30, 50, 250, 300 cycles	0.01 to 5000 cycles at a step of 0.01 cycle
DIP duration Setting by time	Not selectable	0.1ms to duration equipment to 5000 cycles
Interval	1,3,5,10,30,50,100,300,500 cycles, 10s	0.5 to 5000.5 cycles or 1s to 100 s
Repetition of events	1,3,5,10,30,50,100 events or continuous	1 to 1000 events or continuous
Test sequencing	Not available	Up to 10 tests

APPENDIX 3


AC Dip Test
File Option
TEST FILE New
DEMO
Offset 0 V
Frequency 50 Hz
Input Voltage 100 V
Scaling
Unit No.1 Unit No.2 Unit No.3 Unit No.4 Unit No.5 Unit No.6 Unit No.7 Unit No.8 Unit No.9 Unit No.10
PROPERTY
Comment
Test Results 0
SYNC
SYNC
ASYNC
BASE VOLTAGE
CHANG 100 V
100 %
TEST LEVEL
0 V
0 %
0VMode
OPEN
SHORT
DIP START
0 deg
0.0 ms
DIP
0.01 cycle
0.2 ms s
INTERVAL
0.5 cycle
1 ms s
REPEAT COUNTS
1 count
PROGRAM
PROGRESS
Program starts from
Unit No. 1
START
STOP
LINE

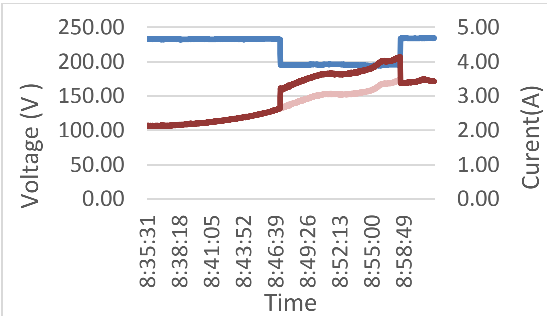
APPENDIX 4

APPENDIX 5

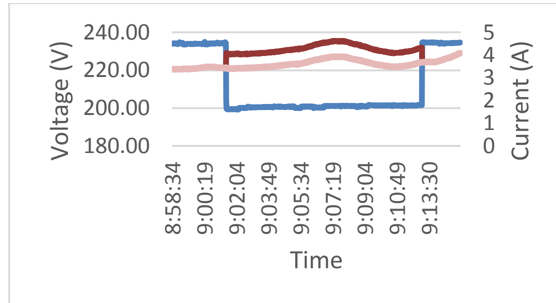

HIOKI 9624-50 PQA-HiVIEW PRO - [C:\Users\USER\UTP\4th year 8th semester\FYP2\FYP2 Data\Hioki File\High Voltage 110%\B5100900]
File Edit View TIME PLOT Report Window Help
EVENT LIST
TIME PLOT - RMS U, CH1
No. Date Time Eve... ch IN/...
1 10/09 15:40:00.004 Start
2 10/09 16:49:27.977 Stop
4.00 V/div — MIN — MAX — AVG
232.00
224.00
VOLTAGE/CURRENT WAVEFORM
CH1: 0.4000kV/div — CH1
CH1: 100.00 A/div — CH1
2015/10/09 15:40:03 - 10/09 16:49:28 Ready

APPENDIX 6

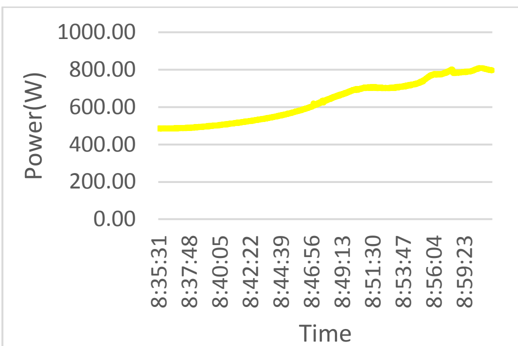
A. Low voltage



85% Test

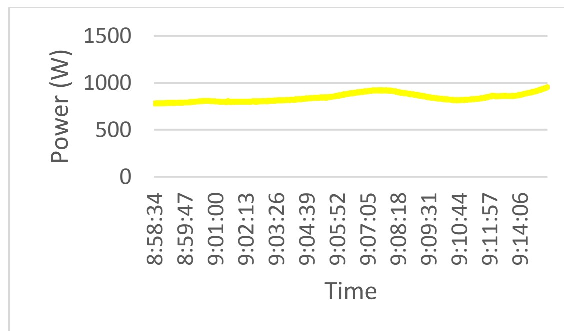


87% Test



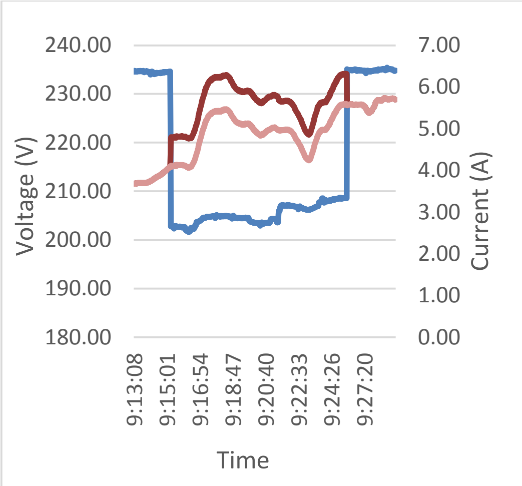
Inverter output power during

85% test

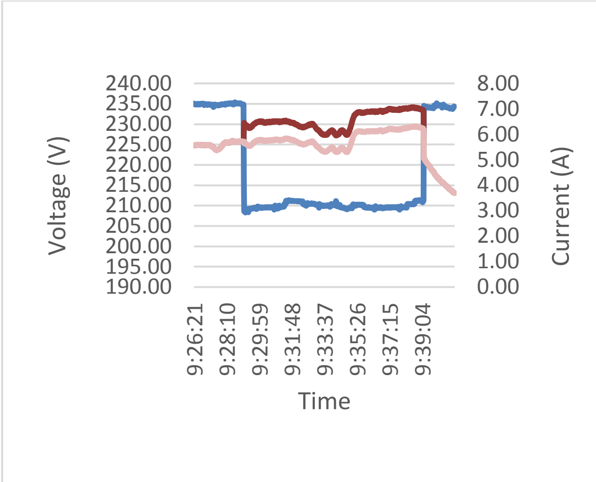


Inverter output power during

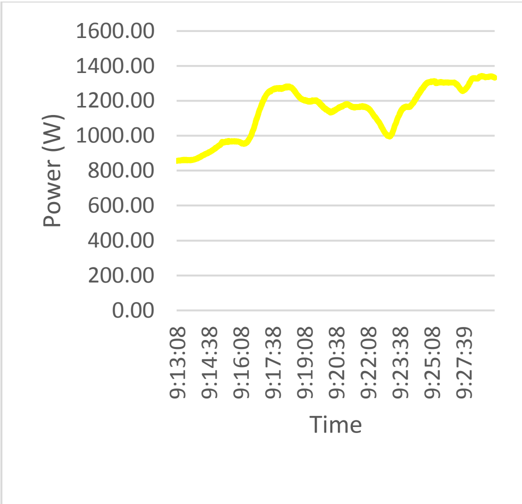
87% test



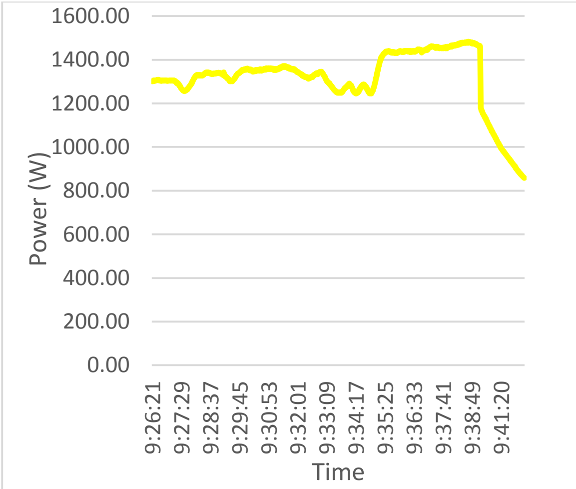
89% Test



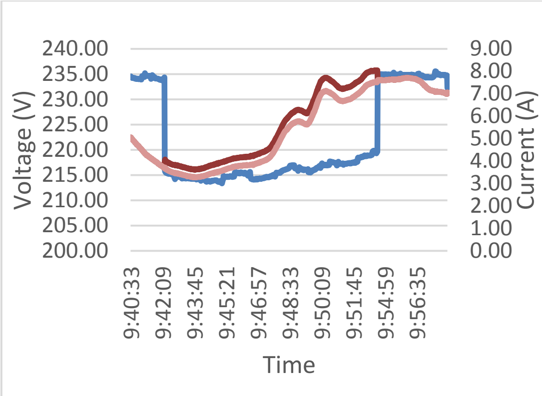
91% Test



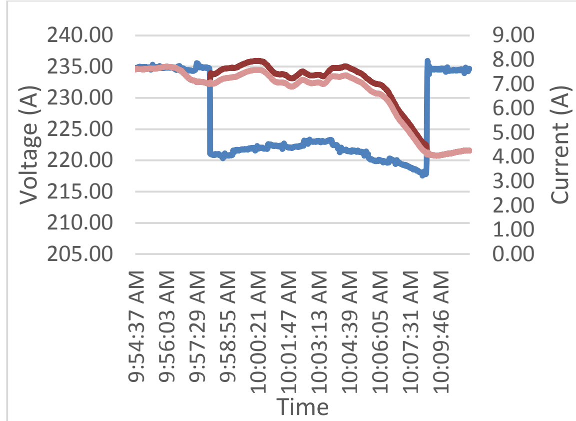
Inverter output power during 89% test



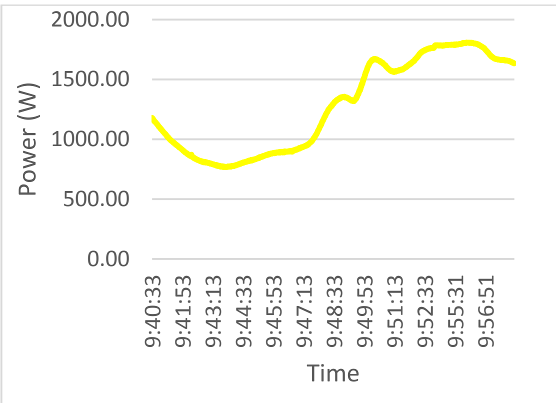
Inverter output power during 91% test



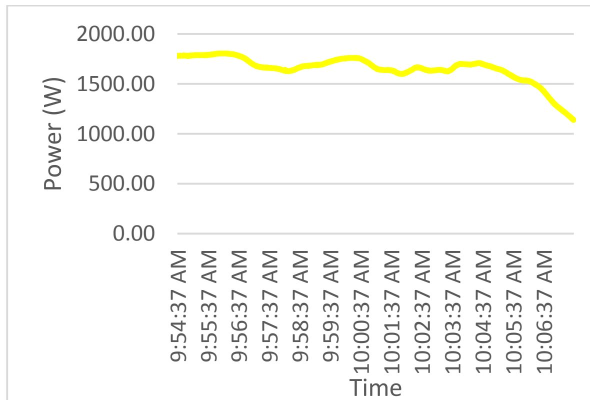
93% Test



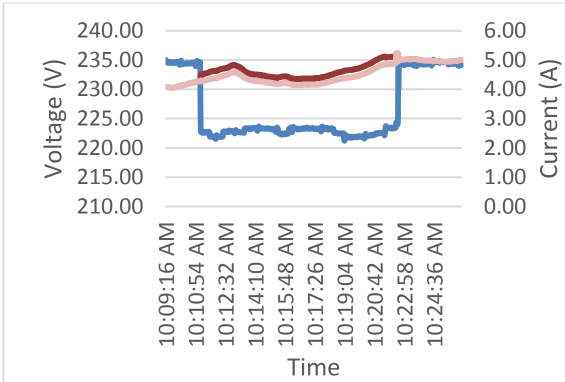
95% Test



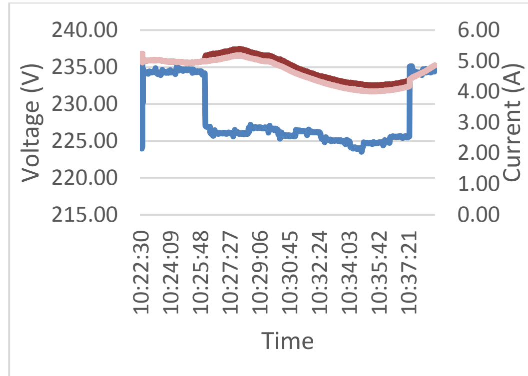
Inverter output power during 93% test



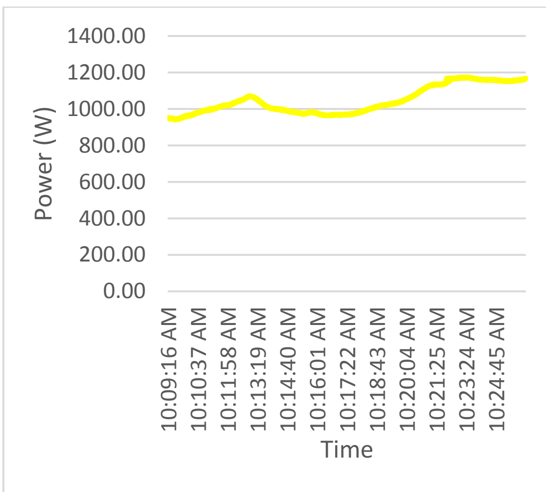
Inverter output power during 95% test



97% Test



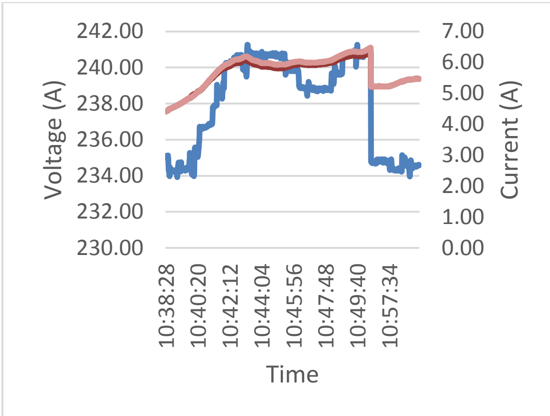
99% Test



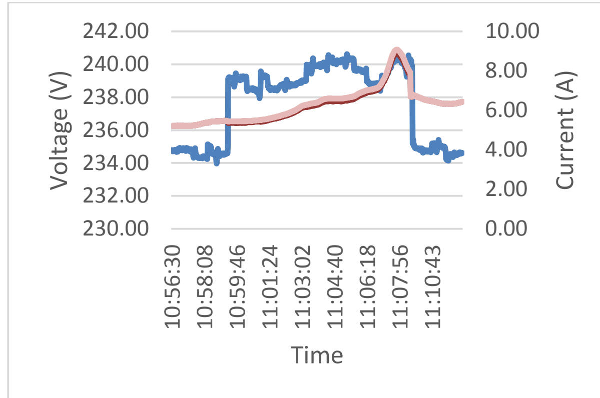
Inverter output power during 93% test

Inverter output power during 99% test

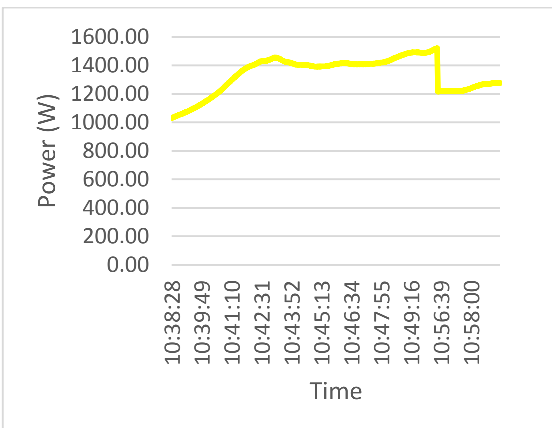
B. High Voltage



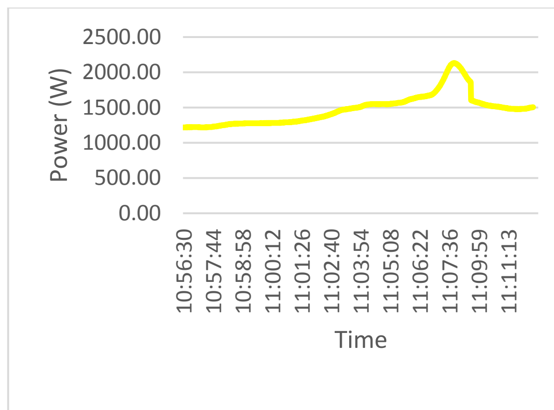
102% Test



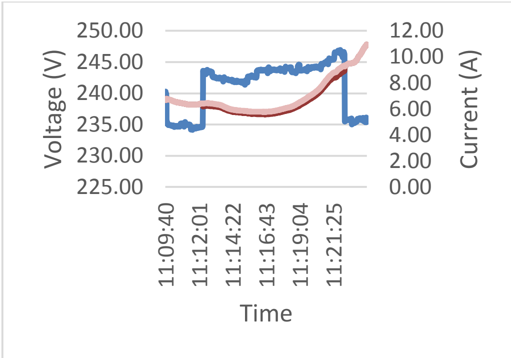
104% Test



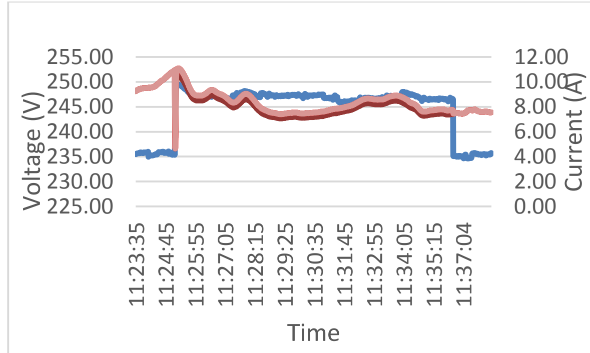
Inverter output power during 102% test



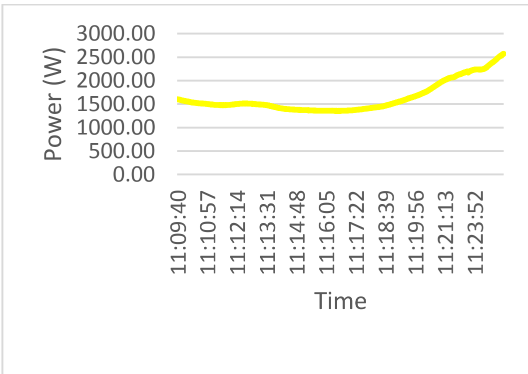
Inverter output power during 104% test



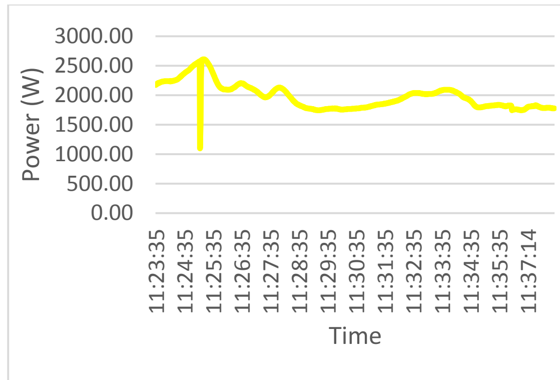
106% Test



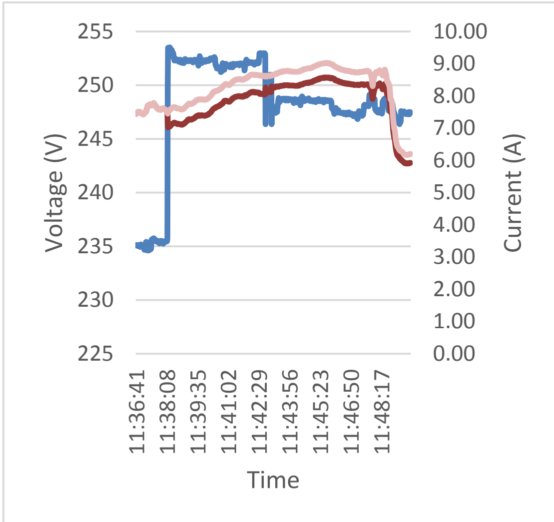
108% Test



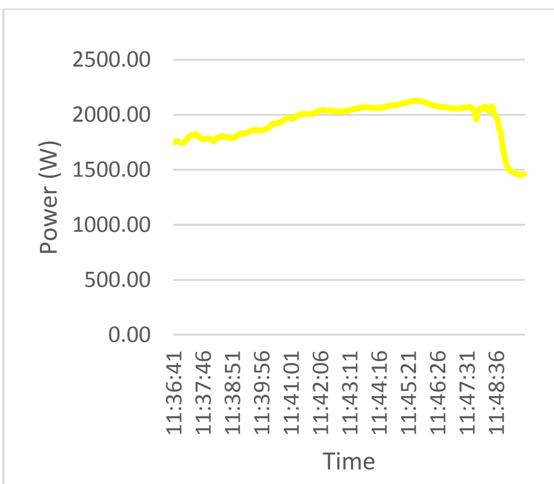
Inverter output power during 106% test



Inverter output power during 108% test



110% Test



Inverter output power during 110% test