“I hereby declare that I have read through this report entitle “Evaluation of Grid Connected Solar PV System Under Malaysia Environment” and found that it has complied the partial fulfillment for awarding the Bachelor in Electrical Engineering (Industrial Power)

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EVALUATION OF GRID CONNECTED SOLAR PV SYSTEM UNDER MALAYSIA ENVIRONMENT

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A report submitted in partial fulfillment of the requirements for the Bachelor in Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering
(UNIVERSITI TEKNIKAL MALAYSIA MELAKA)

2016

I declare that this report entitle "*Evaluation of Grid Connected Solar PV System Under Malaysia Environment*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature : ....

Name : NORAZWANI BINTI OMAR

Date : ....

To my beloved mother and father

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Thank You.

ABSTRACT

This project is conducted at the main campus of Universiti Teknikal Malaysia Melaka (UTeM), Melaka. The changes of weather and passing cloud may caused variation of solar irradiation that contributed to variation of PV output power . Unfortunately, the variation of PV output will cause energy losses and harmonic distortion. Thus, the aim of this project is to study the correlation between solar irradiance and Total Harmonic Distortion (THD) contributed from PV inverter and investigate the efficiency of PV inverter with variation of solar irradiance. Fluke 43B meter and Automatic Weather Monitoring System(AWS) were used to record the required data. The data was collected for 3 to 6 months in order to analyse the data. In addition, the value of THDi, current, solar irradiance, output and input voltage have been recorded for 8 hours a day for 30 days. From the collected data, its shown that the variation of solar irradiance effects the THDi and current profiles. When the solar irradiance is high the value of current also increase. However, THDi increases when the solar irradiance is low. This implies that, in order to get high power quality of output, the value of solar irradiance should be high. Based on the result, it shows that the average value of THDi fulfil the requirement from TNB Technical Guidebook. Furthermore, the inverter efficiency is high when the DC power output is high. Low and fluctuating DC power output cause the value of inverter efficiency to decrease. In addition, the value of solar irradiance give impact to inverter efficiency. The finding shows that the of solar irradiance, DC power output and efficiency have the same behavior.

ABSTRAK

Projek ini dijalankan di kampus utama Universiti Teknikal Malaysia Melaka (UTeM), Melaka. Perubahan cuaca dan pergerakan awan mungkin menyebabkan perubahan sinaran suria yang menyumbang kepada perubahan keluaran kuasa PV. Malangnya, perubahan keluaran PV akan menyebabkan kehilangan tenaga dan herotan harmonik. Oleh itu, tujuan kajian ini adalah untuk mengkaji hubungan antara sinaran suria dan Jumlah Herotan Harmonic (THD) dihasilkan dari PV penyongsang dan menyiasat kecekapan PV penyongsang dengan variasi dari sinaran suria. Meter Fluke 43B dan Sistem Pemantauan Cuaca Automatik (AWS) digunakan untuk merekodkan data yang diperlukan. Data dikumpul selama 3 hingga 6 bulan untuk dianalisa. Oleh yang demikian, nilai THDi, arus, keamatan cahaya, keluaran dan kemasukan voltan telah dicatatkan selama 8 jam sehari. Data yang dikumpulkan menunjukkan bahawa perubahan sinaran suria memberi kesan kepada THDi dan profil arus. Apabila bacaan sinaran suria tinggi, nilai arus juga meningkat. Walau bagaimanapun, THDi meningkat apabila sinaran suria rendah. Dalam usaha untuk mendapatkan kualiti keluaran kuasa yang tinggi, nilai sinaran solar juga perlu tinggi. Bedasarkan keputusan, ia menunjukkan nilai purata THDi memenuhi syarat dari Buku Panduan Teknikal TNB. Kemudian, kecekapan penyongsang adalah tinggi apabila keluaran kuasa DC adalah tinggi. Pengeluaran kuasa DC yang rendah dan turun naik menyebabkan nilai kecekapan inverter rendah. Dapatan kajian menunjukkan bahawa sinaran suria, keluaran kuasa DC dan kecekapan mempunyai tingkah laku yang sama.

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LIST OF SYMBOLS

AC	-	Alternating Current
AWS	-	Automatic Weather Monitoring System
CSI	-	Current Sourse Inverter
DC	-	Direct Current
GCPV	-	Grid Connected Photovoltaic
P	-	Power
PCC	-	Point of Common Coupling
PQ	-	Power Quality
PV	-	Photovoltaic
STC	-	Standart Test Condition
THDi	-	Total Harmonic Distortion of current
THDv	-	Total Harmonic Distortion of voltage
V	-	Voltage
I	-	Current

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Recently, because of the increase in energy demand, the needs of alternative energy sources are also increasing. Rapidly in 1950s, the negative effect from fossil fuel inspire scientist and engineers to growth other alternative energy that benefits the people and environment. Thus, the renewable energy have been promoted because of it free pollution . The solar energy is the one of clean renewable energy resources. The Photovoltaic (PV) system directly convert light energy to electricity. However, the PV system produce Direct current (DC) output which is not suitable for the most electrical appliances. Hence, the PV inverter used to convert DC to AC output. Unfortunately, the major power quality problem is Total Harmonic Distortion (THD) that contributed by the PV inverter. Hence, this project is conducted to study the THD levels contributed by PV inverters under various irradiance levels.

1.2 Problem Statement

Electrical energy is very important in our daily life. Most of the electrical energy is produced by fossil fuels and the nuclear energy. Since the these kinds of energy source are exhaustible, many countries start to promote the renewable energy. Grid Connected Photovoltaic (GCPV) is a very clean system that generates electric energy from solar energy . To operate this system solar PV panels and PV inverter are needed . The generated electric energy is in direct current output. However, to fed into the grid, the output need to convert to alternating current (AC) by using an PV inverter . The changes of weather and passing cloud may caused variation of solar irradiation that contributed to variation of PV output power . Unfortunately, the variation of PV output will cause energy losses and harmonic distortion. This project is conducted to investigate the PQ behavior of GCPV and and also PV inverter efficiency. Under different weather conditions, analyses produced from this study may provide information on how weather condition may effect the output quality of PV inverter

1.3 Objective

The objective of this project are:

1) To evaluate the correlation between solar irradiance and total harmonic distortion contributed from the GCPV inverter.
2) To investigate the efficiency of GCPV inverter under different solar irradiance levels.

1.4 Scope of Work

The scope of this project focuses on GCPV system located at the Faculty of Electrical Engineering (FKE), Universiti Teknikal Malaysia Melaka (UTeM), Melaka. The PV systems include mono crystalline silicon (Mono), thin film (TF), heterojunction with intrinsic thin layer (HIT) and poly crystalline silicon (Poly) . The main aim of this project is to investigate the PQ behavior of GCPV under Malaysia climate condition in addition of PV inverter efficiency. This project focuses on total harmonic distortion for current and efficiency of GCPV inverter. Data are collected for the duration of between 3 to 6 month by using suitable appliances such as Fluke meter and instrument Automatic Weather Monitoring System (AWS).

CHAPTER 2

LITERATURE REVIEW

This section will discuss about the book and other reading materials that are used as reference in order to understand and develop the project. The articles review, book and other research material were review in order to get main idea about the project conception and any information that related to conduct the project. Besides that, this chapter also reviews the project that have been done by other researchers with different concepts and design. By doing the review will provide a better understanding of the system. Furthermore, this chapter will discuss the overall theories and concept of the project. Finally this chapter also explains the theories used in order to implement the project.

2.1 Theory and basic principles

2.1.1 Photovoltaic system

Edmund Bequerel is the first person reported the effect photovoltaic in 1839. He was discover that the action of light on silver coated platinum electrode immersed in electolyte produce electric current.[1] And then, in 1887 German physicist Heinrich Hertz has refined the finding.

The PV system can supply electric for small or large application. This sytem already apply around world in individual homes, offices and small or large building. Most of electrical appliances used alternating current . However, the PV system produce direct current which is not suitable for most equipment and appliances design for alternating current. Due to this problem,inverter is used to convert the direct current to alternating current. The solar panel and inverter are the main component of PV system. Basicly the

PV system design in storage and direct system.[2]The system called as on-grid (Grid Connected) and off-grid (stand alone) system. Grid connected PV system are linked to grid, while stand alone system operated without grid.

2.1.2 Solar panel

The basic of solar cell is an electrical device that converts the light energy into electric energy by the reaction of photovoltaic. The solar cell has been design as two terminal device which operate like diode when there is no light and produces a photovoltaic in present of light. However, the generated DC voltage is too small for the most application which is o.5 to 1Vdc. [3]

To generated acceptable DC voltage, the solar cell is linked together in series to form PV module as shown in Figure 2.1. The PV module usually connected into 28 to 36 cell in series to produces 12Vdc in standard illumination condition. [4] To produce larger voltage and current output, the PV module separately or linked in series and parallel to form an array.

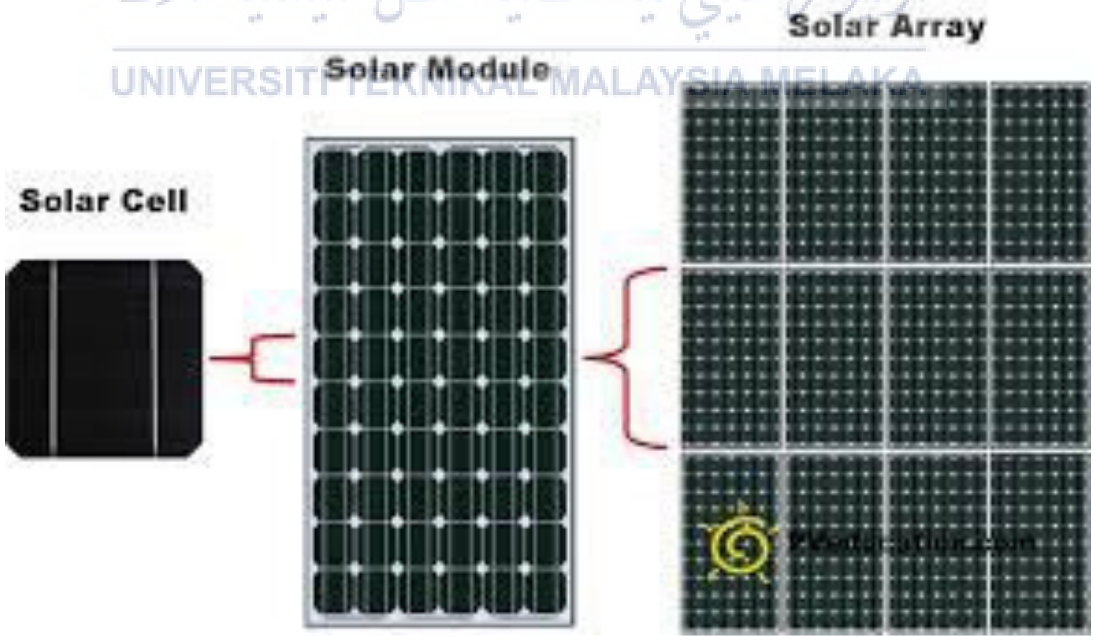

Figure 2.1: The cell, module and array [5]

2.1.3 PV inverter

Converter is power electronic device, its can divided into 3 types which is rectifier, chopper and inverter [6]. The inverter are device that convert direct current (DC) to Alternating Current (AC). The DC current that provide by PV system is not suitable for the most of electrical appliances. Inverter have two main type which is single phase inverter and three phase inverter. For low to medium voltage the single phase inverter is applied. Then, for high voltage load the three phase inverter is used.

2.1.3.1 Single phase inverter

Basicly, single phase inverter divided into 2 categories which is Voltage Source Inverter (VSI) and Current Source Inverter (CSI). The type of VSI include the Square Wave Inverter, Quassi Square Wave Inverter and Sinusoidal PWM Inverter (bipolar switching scheme). The Figure 2.2, Figure 2.3 and Figure 2.4 show Voltage Source Inverter (VSI).

A. The Square - Wave Inverter

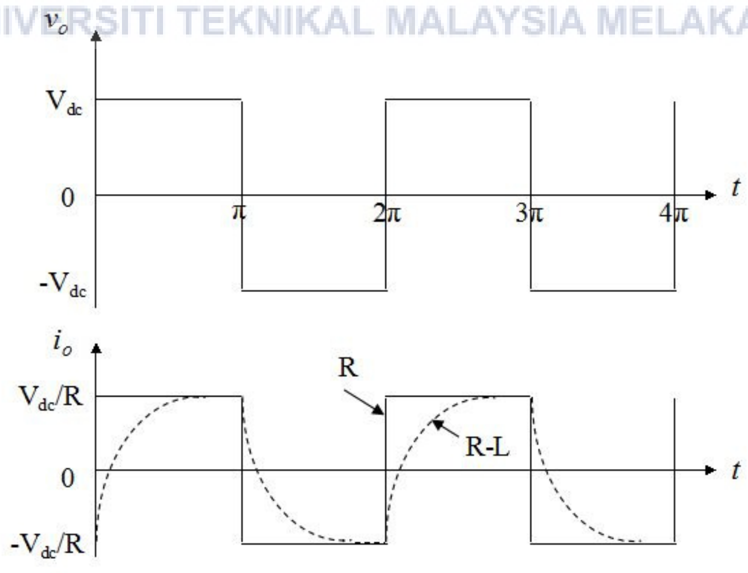

Figure 2.2: The Square - Wave Inverter [7]

B. Quassi Square Wave inverter

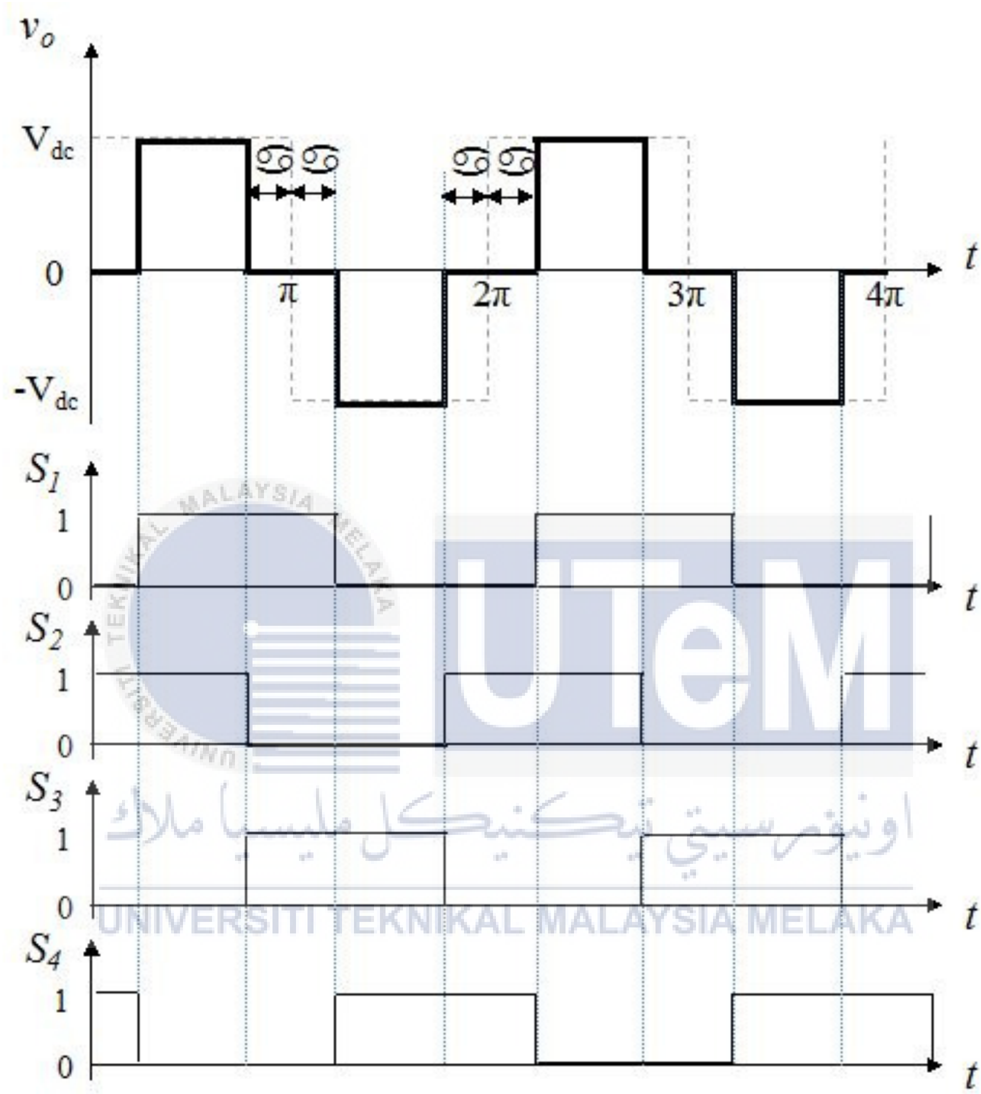

Figure 2.3: Quassi Square Wave inverter [7]

C. Sinusoidal PWM Inverter (bipolar switching scheme)

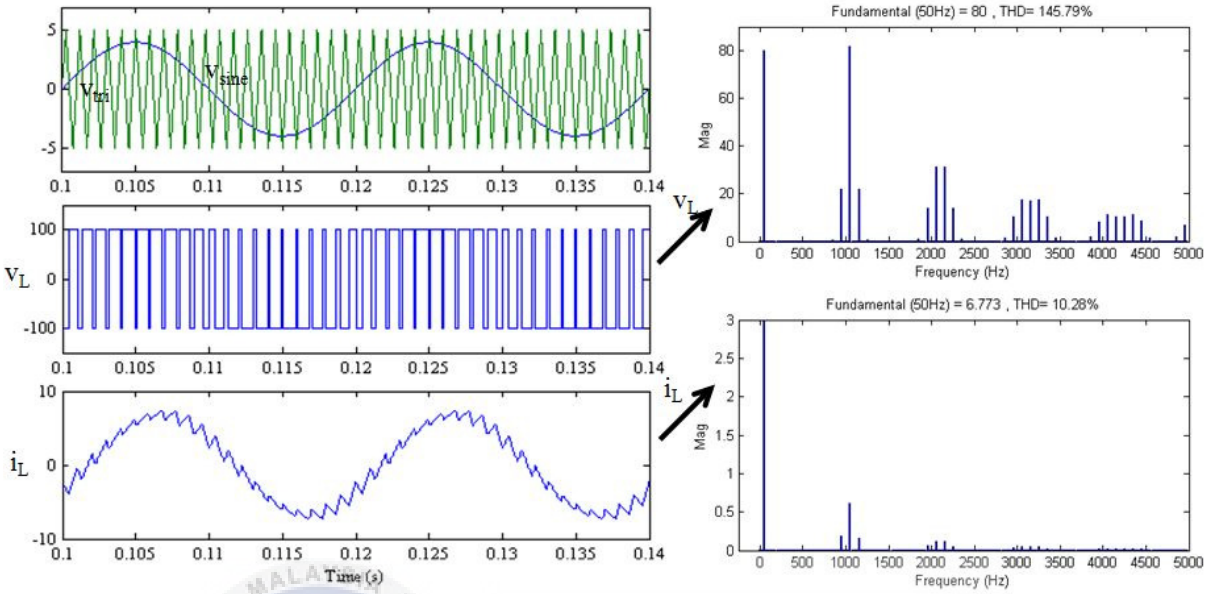

Figure 2.4: Frequency spectrums of output voltage and load current [7]

The type of CSI include Hysteresis-based current control and Carrier based current Control. The Figure 2.5 and Figure 2.6 show the CSI type.

The type of CSI is:

A. Hysteresis-based current control

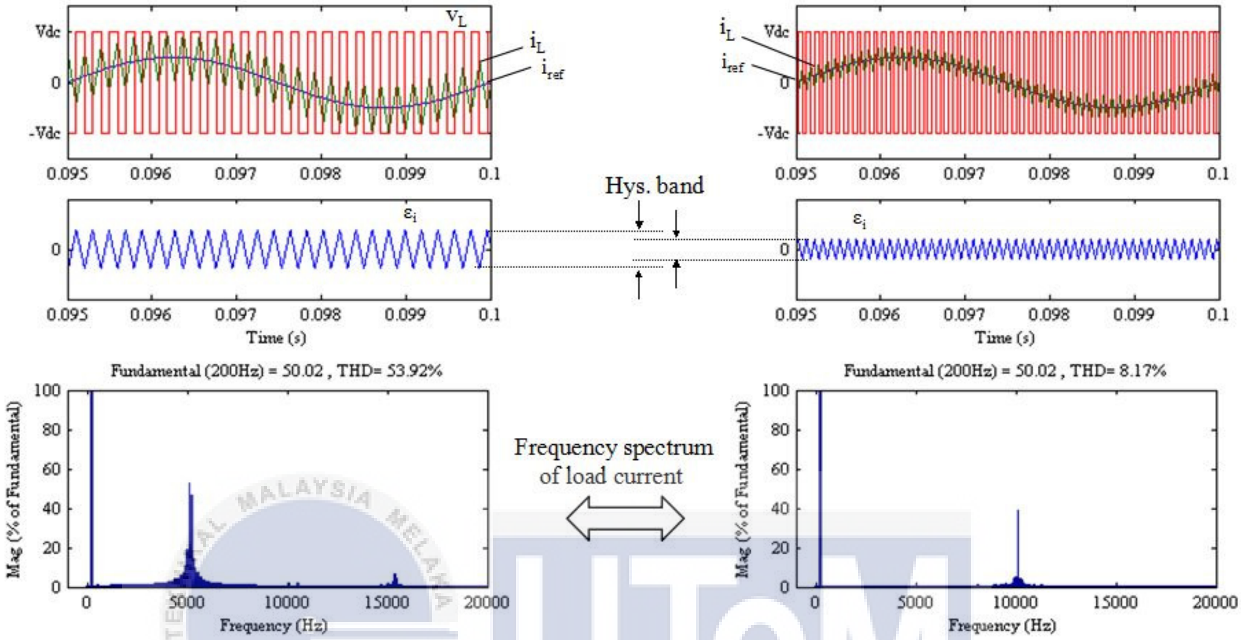

Figure 2.5: Hysteresis bandwidth [7]

B. Carrier based current Control

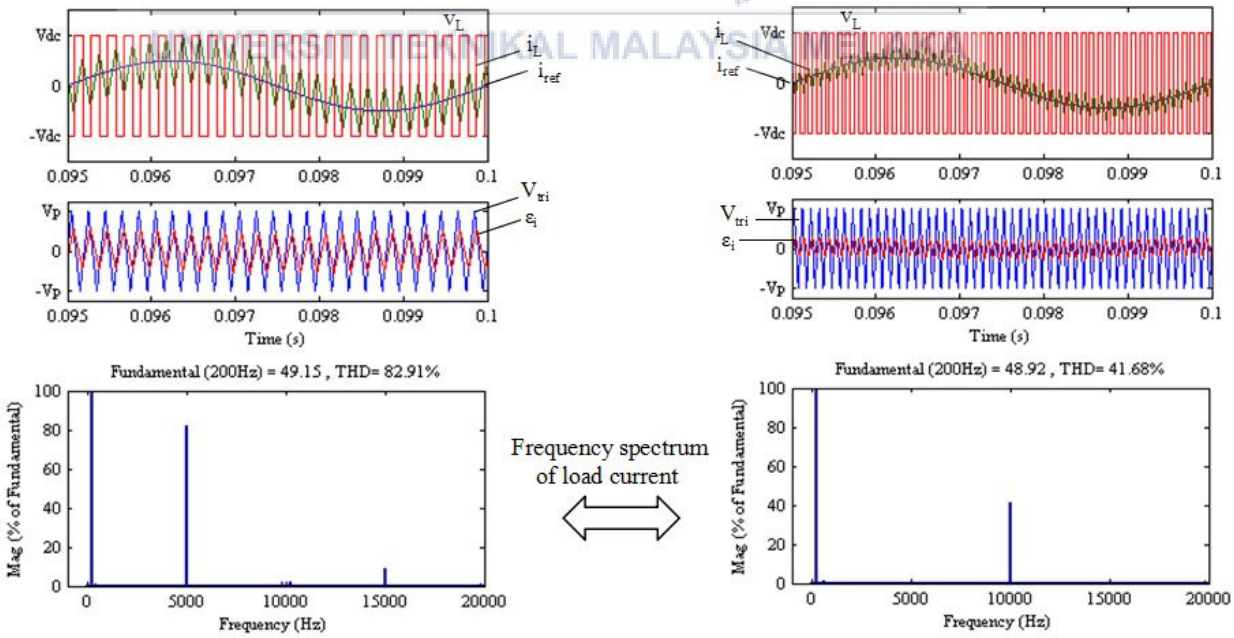

Figure 2.6: Constant frequency triangular waveform [7]

2.1.3.2 Three phase inverter

The three phase inverter divided into two categories which is Six step inverter and Sinusoidal Pulse-Width Modulation (SPWM) Inverter. The Figure 2.7, Figure 2.8 and Figure 2.9 show the three phase inverter type.

A. Six step inverter

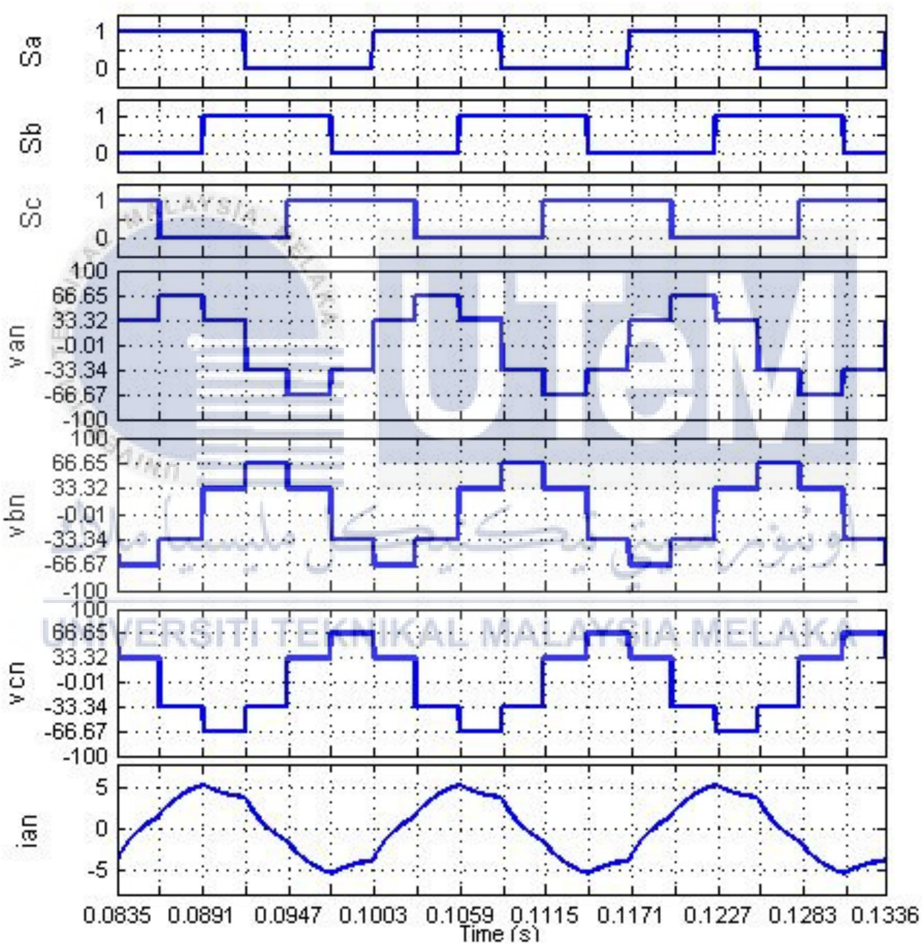

Figure 2.7: Six step inverter waveform [8]

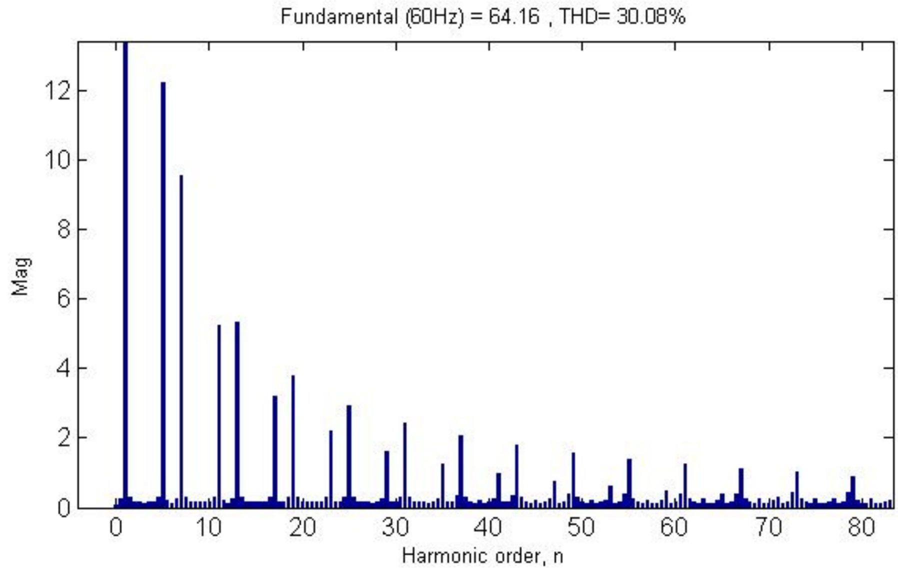

Figure 2.8: Frequency spectrum for Van [8]

B. Sinusoidal Pulse-Width Modulation (SPWM) Inverter

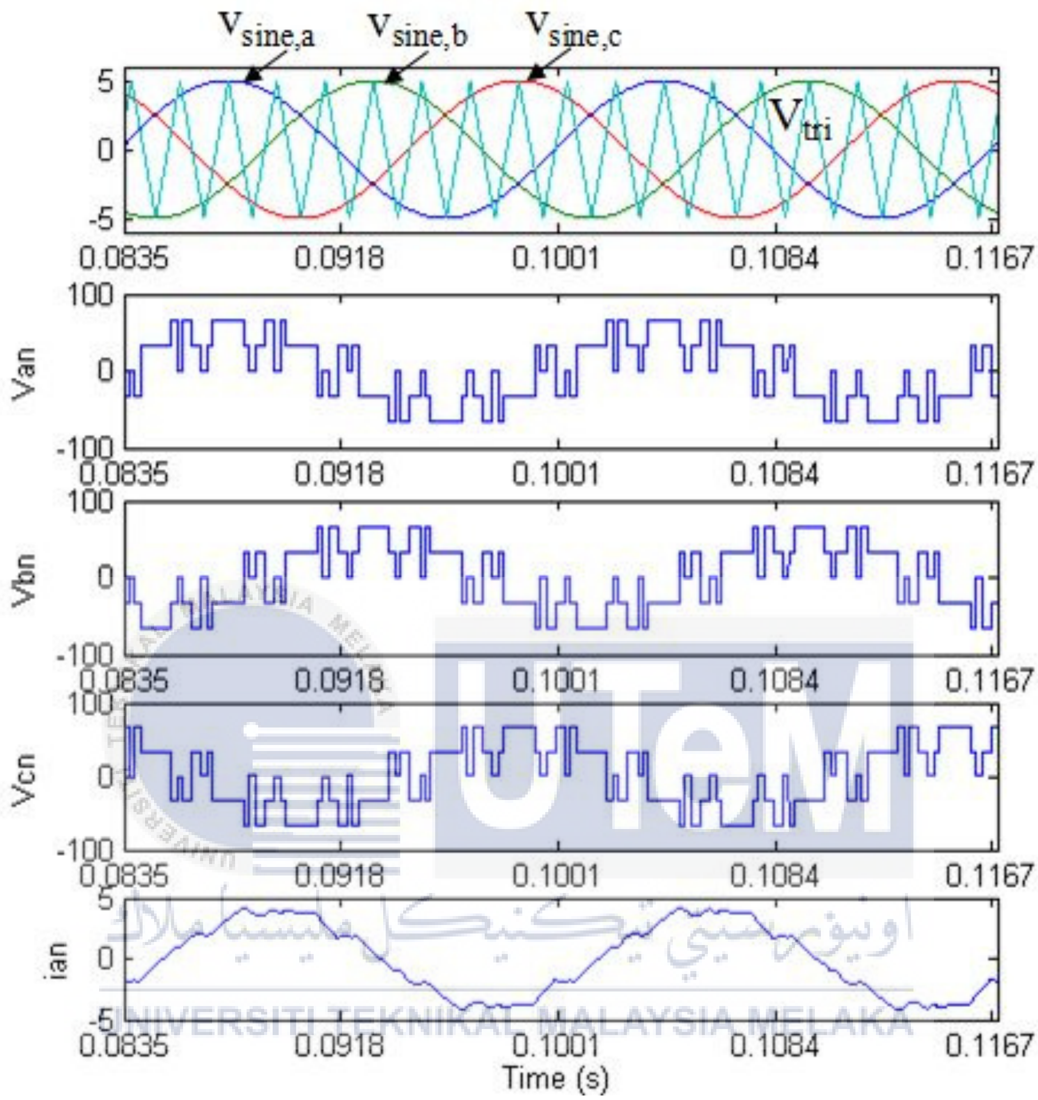

Figure 2.9: Waveforms of 3-phase SPWM inverter [8]

2.1.4 Power Quality

Power Quality (PQ) can be describe as the measurement of electrical power performance. It is set of electrical properties that may disturb the operation of electrical system. The electrical appliances may not operates properly without appropriate power quality. Low power quality can be define in other way such as continuity of power, variation frequency, harmonic distortion, poor power factor, and unbalance of phase.

Nowdays, the development of renewable energy and distribution generation growth faster. It always design microgrid via power inverter which may linked or not to the electrical grid. Unfortunately, harmonic in the voltage is the main power quality problem that contibute by the inverters. Usually, harmonic distortion come by two sources which is from the inverters and from the loads. Most of load are non-linear and purely sinusoidal and harmonic distortion of current is generated when a purely sinusoidal voltage supply presented. Thus, harmonic distortion of voltage can cause harmonic distortion of current.

On three phase system current is in zero sequence harmonics. The negative sequences harmonics such as 6n-1 harmonic can cause complication to electrical machines because its generate negative torque and try to run the machine in reverse. The harmonic can cause increase losses, overheating, neutral line overloading, decrease power capacity, distorted voltage and current output. The Table 2.1 show the maximum THD allowed for currents that fed to the grid. The total harmonic distortion of current and voltages needs to maintain below than 5%. [9]

Table 2.1: Max THD allowed for currents that fed to the grid [9]

Odd harmonics	$< 11^{th}$	11^{th} - 15^{th}	17^{th} - 21^{st}	23^{rd} - 33^{rd}	$> 33^{rd}$
Maximum THDi	< 4%	< 2%	< 1.5%	<0.6%	<0.3%

2.2 Review of previous related work

2.2.1 A Study of 6.12kW Mono- Crystalline GCPV System at FKE, UTeM

This paper study on the performance of PV system on THD due to different level of solar irradiance. The system located at admin rooftop of FKE at UTeM focus on 6.12kW mono -crystalline GCPV system. The Fluke 435 and weather instrument used to collecting data. From the result, the high solar irradiance cause increase in current and deacrease in THDi. However, the difference level of solar irradiance not much effected THDv and voltage output. [10]

2.2.2 Power Quality Analysis of GCPV Systems in Distribution Networks

This paper focus on PQ analysis on the effect of high penetration GCPV system with variation of weather condition. This system include 1.8 MW GCPV system in a radial 16 bus test system. This system modeled and simulated using matlab/simulink software under different solar irradiance level. The results show that the high penetrated of GCPV system cause power quality problem in term of voltage flicker, voltage raise and power factor reduction. [11]

2.2.3 Effects of low radiation on the power quality of a distributed PV-grid connected system

This paper focus on the effect of low solar irradiance below 400 W/m2 on PQ problem. The system has an array 42kWp representative of rooftop unit located at northern Thailand. From the result obtain the actual power is available when solar irradiance is high. At low solar irradiance level the system does not does not produce enough output power The reactive power is drawn from distribution transformer and feed into an PV inverter and loads. In order to make sure the power output is suitable to the most of electrical appliances the reactive power need to converted to real power. [12]

2.2.4 Study of a PV – Grid Connected System on its Output Harmonics and Voltage Variation

This paper is focus on the effect of solar irradiance on the voltage level and PQ at the point of common coupling (PCC). The system has 4.5 kWp array (60 panels of 75 Wp Siemens X-Si PV modules connected into 15 panels in series and 4 strings in parallel) and a 3.5 kW GCPV inverter. From the results, its show that at high level of solar irradiance, the harmonic current is increase. [13]

2.2.5 The Effect of Solar Irradiance on the Power Quality Behaviour of Grid Connected Photovoltaic Systems

This paper is study to determine how the changes in solar irradiance effected PQ. For this study 14 PV systems have been tested which include 12 fixed mounted flat-plat, one two-axis tracked flat plate and one two-axis tracked concentrated of PV system. The system is connected to grid produce a 14kWp output power. From the result obtain from this paper, the active power output strongly depent on solar irradiance. The PQ is correlated to solar irradiance. It can be conclude that the low solar irradiance give impact to power quality problem. [14]

2.2.6 The Performances of UTeM Solar PV Systems: An Evaluation

This paper present on the performances of the systems including Mono, TF, and HIT grid connected PV system at Universiti Teknikal Malaysia Melaka.. The study is base on climate condition in Malaysia which consider several factor, such as inverter losses, cable losses, mismatch, and cloudy weather. For the finding, The TF PV systems performed better compare to Mono PV systems and HIT PV systems base on energy yield, energy generation and system performance. [26]

From the literature review, solar irradiance give impact to power quality problem and cause energy losses. Low solar irradiance and fluctuating input are among the few important factors affecting the power quality and energy output of system. Therefore this project is to evaluate the each type of solar PV systems with different technologies, such as Mono, HIT, TF and Poly solar PV systems based on Malaysia tropical climate condition in terms of power quality and efficiency of PV inverter.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter consist of explanation about method used for fulfill the objective of project. Besides that, this chapter also explain about project flow from beginning until the project completely finish. The duration, selection and action will done also will discuss in this section. This explanation important for the project. This is for make sure the project that consist of the data collection and evaluation will developed smoothly, systematically and successfully.

3.1 Introduction

This project is consist of data collection and evaluate the data collection by using Fluke meter and instrument such as Automatic Weather Monitoring System (AWS) which is installed to recorded weather and solar irradiance . The weather station consist of the following parameters:

a) Titled Solar Irradiance
b) Global Solar Irradiance
c) Relative Humidity
d) Ambient Temperature
e) Back Panel Temperature Module
f) Rain
g) Wind Speed
h) Wind Direction

This project are include the mono-crystalline PV module, PV inverter and other system PV component to generate output power to fed in TNB grid.

3.2 Method or Technique used

The method used for this project is collecting data by using Fluke meter and other instrument such as Automatic Monitoring System (AWS) which is installed to recorded weather and solar irradiance. The value of THDi and output AC current recorded by Fluke meter to phase A the grid side at for 8 hour per day starting from 9.00am to 5.00pm. The data recorded with interval of 2 minutes. On other hand, the solar irradiance measurement was sense by sensing element called CMP 11 Pyranometer. The sensor are linked to data acquisition electronics, the covert the signal from sensor and relay them to computer server for data processing. The software in the server recorded in real time 1 second data in W/m^2.

For the next step, the collected data will be analyze after the recording data by fluke meter and AWS is finish. The evaluation of impact PV system on Power Quality Problem focus on the parameter such as THDi, output AC current, solar irradiance, input and output power. The recorded data will plot as line and scattered.

3.2.1 System Description of Solar PV System

The system include in this project is mono crystalline silicon (Mono), thin film (TF), heterojunction with intrinsic thin layer (HIT) and poly crystalline silicon . Figure 3.1 shows the block diagram of three phase grid connected for GCPV system. This consist solar PV array, GCPV inverter, DC link capacitor. The 2kW inverter connected to each phase of the system. For this system the data recorded to Phase A the grid side. The Figure 3.2 shows block diagram of Phase A grid connected PV system.

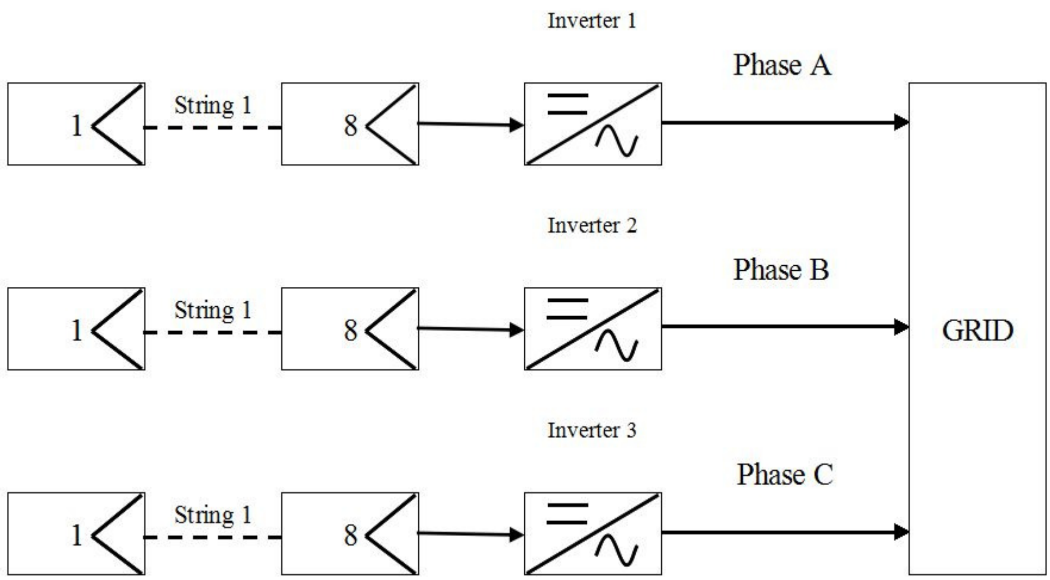

Figure 3.1: The block diagram of 3 phase grid connected PV system

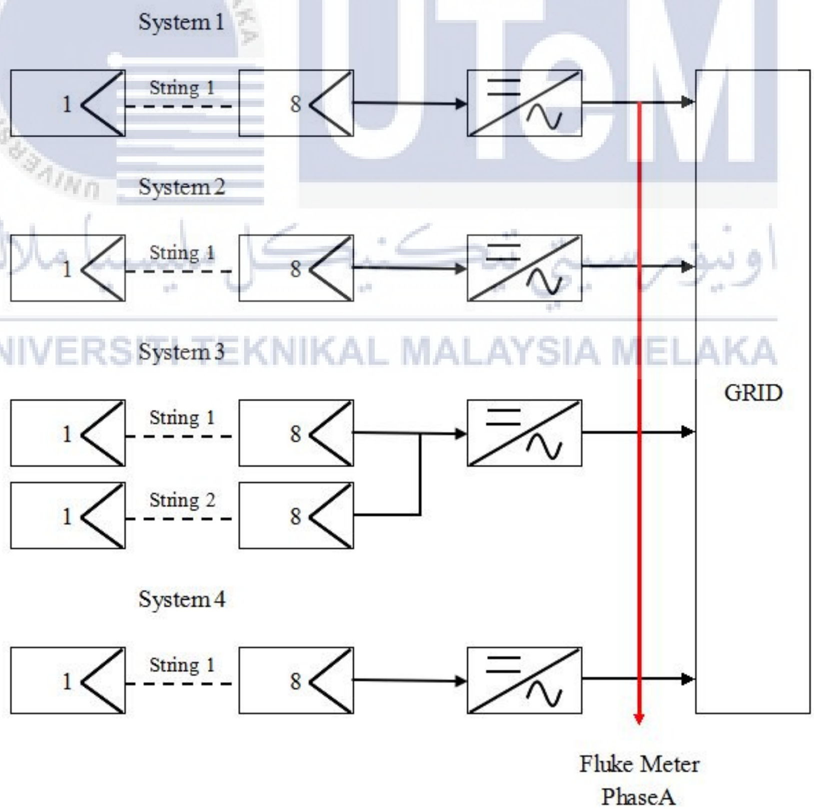

Figure 3.2: The block diagram of Phase A grid connected PV system

3.2.2 Description of PV Module

The PV model for this project has four different type which is Mono, HIT, TF and Poly. Table 3.1 shows the various type of solar GCPV system which are contributed in this study. The capacities of three type of GCPV system is 6.12kW, 5.64kW, 6.24kW and 5.88kW respectively. The various of capacity for each system contributed by different type of PV module performance. The Table 3.2 shows the Standard Test Condition for each PV module.

Table 3.1: Type of solar PV system.

	System 1	System 2	System 3	System 4
Panel type	Mono	HIT	TF	Poly
Max Power	6.12 kW	5.64 kW	6.24kW	5.88kW
Series Connection	8 units	8 units	8 units	8 units
String Connection	3 units	3 units	6 units	3 units
Location	Admin Rooftop	Admin Rooftop	Laboratory Rooftop	Ground Mounted

Table 3.2: Module performance under STC [15], [16], [17], [18]

Characteristic	Mono	HIT	TF	Poly
Maximum Power (Pmax)	255 W	235 W	130 W	245 W
Open-circuit Voltage (Voc)	37.8 V	51.8 V	60.4 V	37.5 V
Short-circuit Current (Isc)	8.66 A	5.84 A	3.41 A	8.49 A
Maximum power Voltage (Vmp)	31.4 V	43.0 V	46.1 V	30.8 V
Maximum power current (Imp)	8.15 A	5.84 A	2.88 A	7.96 A

*STC:1000W/m ^{2} , 25 ^{0}C, AM1.5

3.2.3 Description of PV Inverter

The inverter converts the DC power output to AC power output which similar to utility grid. For each phase of system connected to PV inverter with rating of 2kW. Figure 3.3 shows the PV inverter model used in this project. The maximum efficiency of PV inverter is 96.3%. Table 3.3, 3.4 and 3.5 shows the technical data of PV inverter model for SMA Sunny Boy 2000HF.

Figure 3.3: PV inverter model of SMA Sunny Boy 2000HF

Table 3.3 : DC Input [19]

Maximum DC power at pf = 1	2100 W
Maximum input voltage	700 V
MPP voltage range	175-560 V
Rated input Voltage	530 V
Start input voltage	220 V
Maximum input current	12 A

Table 3.4 : AC output [19]

Rated power at 230 V, 50 Hz	2000 W
Maximum apparent AC power	2000 VA
Nominal AC voltage	220 V/ 230 V/ 240 V
Nominal AC current at 240 V	8.3 A
Rated power frequency	50 Hz

Table 3.5: Efficiency [19]

Maximum efficiency	96.3 %
European weighted efficiency	95.0 %

3.2.4 Measurement Device

The Fluke 43B meter and Automatic Weather Monitoring (AWS) system used as measurement device in this study. The Figure 3.4 shows the Fluke 43B meter used to measurethe value of THDi and current at grid side. On other hand, the solar irradiance measurement was sense by sensing element called CMP 11 Pyranometer. The sensor are linked to data acquisition electronics, the covert the signal from sensor and relay them to computer server for data processing. The Figure 3.5 shows the Weather Station System that install at Admin Rooftop.

Figure 3.4 : Fluke 43B meter

Figure 3.5 : Weather Station System that install at Admin Rooftop.

3.3 Description of the Work to be Undertaken

Figure 3.6 shows the flowchart of the project research methodology. Firstly study of GCPV system is carried out to prepare the literature review. After discuss the project review with supervisor, the measurement device is setting up. Then, data collection process is start. When the output is not as wanted, the setting device is rechecked. However if the output is good, data obtained from the recording is analysed. Finally, after the completion of the recording, the impact of PV system on Power Quality Problem focus on the parameter such as THDi, output AC current, solar irradiance, input and output power is evaluated. The recorded data will plot as line and scattered.

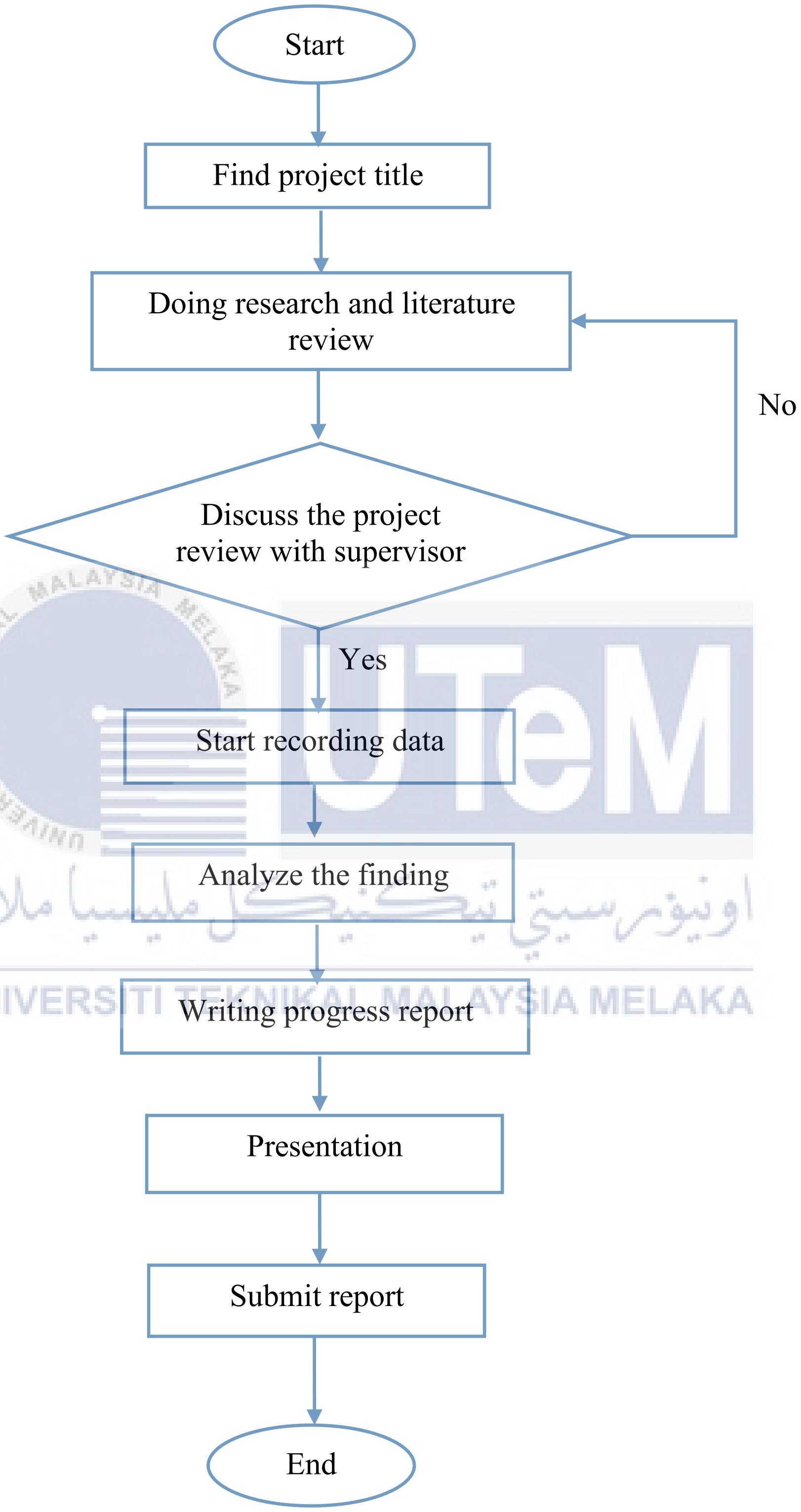

Figure 3.6: Flow Chart of Overall Methodology

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

The first objective of this research is to evaluate the correlation between solar irradiance and total harmonic distortion contributed from the GCPV inverter. The measurement for THDi, output AC current and solar irradiance have been recorded for 30 days starting from 29th October 2015. Then, the last objective is to investigate the effect of PV inverter efficiency with different value of irradiance. To complete this objective, the value of DC power and AC power is recorded for 30 days starting from 29th October 2015 to 24th March 2016.

The correlation between solar irradiance and total harmonic distortion will be evaluated into three conditions which are on sunny, rainy and cloudy days. Then, THDi is based on the TNB Technical Guidebook. The requirement of THDi shall be less than 5 % at rated PV inverter power output[20]. Then, for second objective the power conversion efficiency is 95% during normal operating condition, as published by the inverter manufacturer.

4.2 Solar irradiance and total harmonic distortion

4.2.1 Sunny day

For the first condition the data recorded on 3rd November 2015 as sunny day. The data with 2 minute interval of irradiance was recorded. Figure 4.1 shows the fluctuating solar irradiance starting from 9.00am to 5.00pm. The average of data is 684.49 W/ m^2 . The maximum value of solar irradiance is 1339 W/ m^2 at 12.19 pm while the minimum value is 156 W/ m^2 at 16.36pm.

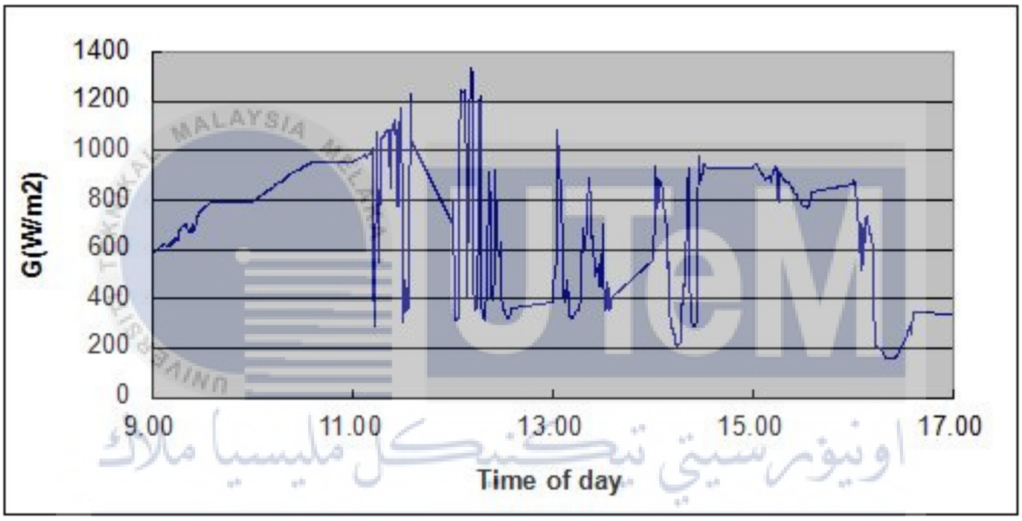

Figure 4.1: The solar irradiance data on sunny day.

Figure 4.2 shows the THDi and Current on sunny day. The data is recorded by Fluke meter with 2 minutes interval on 3rd November. From the graph its shown that the solar irradiation and current have same profile. However, for THDi the profile is opposite with solar irradiation. The solar irradiation give significant impact on current profile on sunny day. For this condition, the average of current is 17.78A while THDi is 6.93%. At 12.01pm it shows that maximum value of current is 31.23 A while minimum value of THDi is 4 % at high solar irradiance. For minimum value of current is 4.43 A while maximum value of THDi is 13.80 % recorded at 16.28 pm at low solar irradiance.

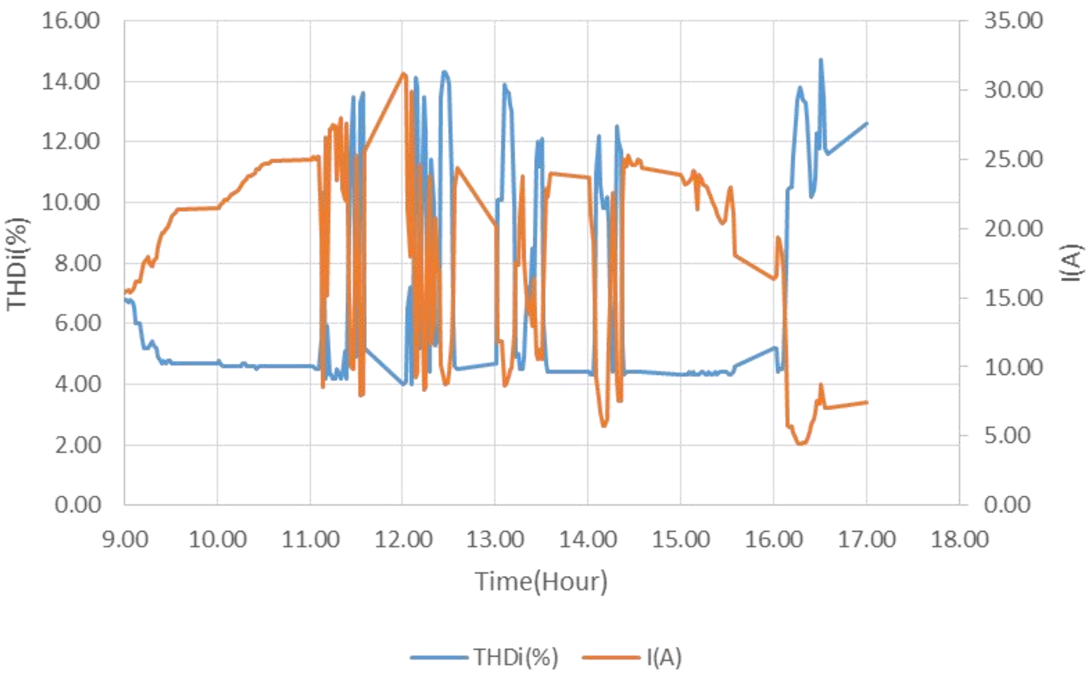

Figure 4.2: Current and Total Harmonic Distortion of Current on sunny day.

4.2.2 Cloudy day

For the second condition the data recorded on 27th November 2015 as cloudy day. The data with 2 minute interval of irradiance was recorded. Figure 4.3 shows the fluctuating solar irradiance starting from 9.00am to 5.00pm. The average of data is 569.23 W/ m^2 . The maximum value of solar irradiance is 1062 W/ m^2 at 12.33 pm while the minimum value is 188 W/ m^2 at 17.00 pm.

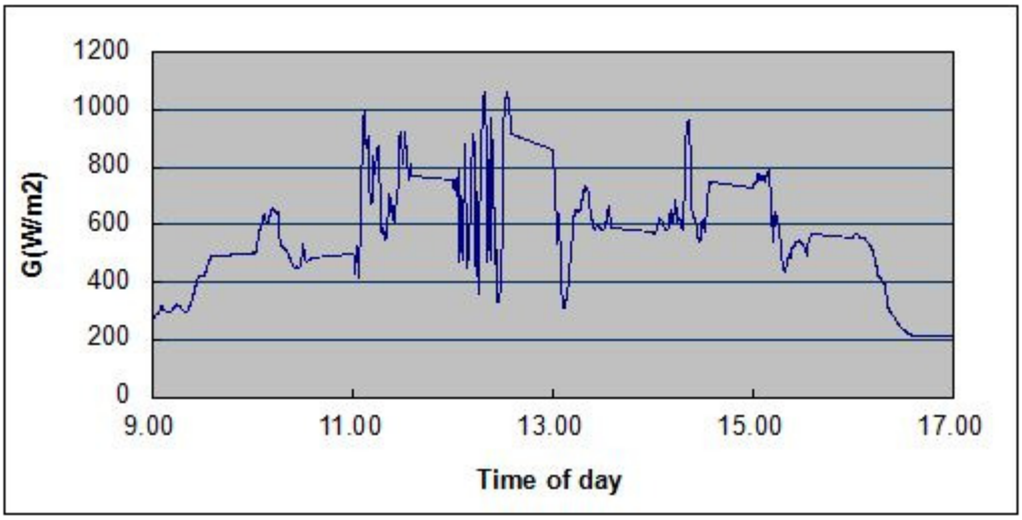

Figure 4.3: The solar irradiance data on cloudy day.

Figure 4.4 show the THDi and Current on cloudy day. The data is recorded by Fluke meter with 2 minutes interval on 27th November. From the graph its shown that the solar irradiation and current have same profile. However, for THDi the profile is opposite with solar irradiation. The variation of solar irradiation effect the current profile on cloudy day. For this condition, the average of current is 15.18 A while THDi is 7.68 %. At 12.29 pm it shows that maximum value of current is 27.68 A while minimum value of THDi is 4.2 % at high solar irradiance. For minimum value of current is 5.12 A while maximum value of THDi is 10.8 % recorded at 17.00 pm at low solar irradiance.

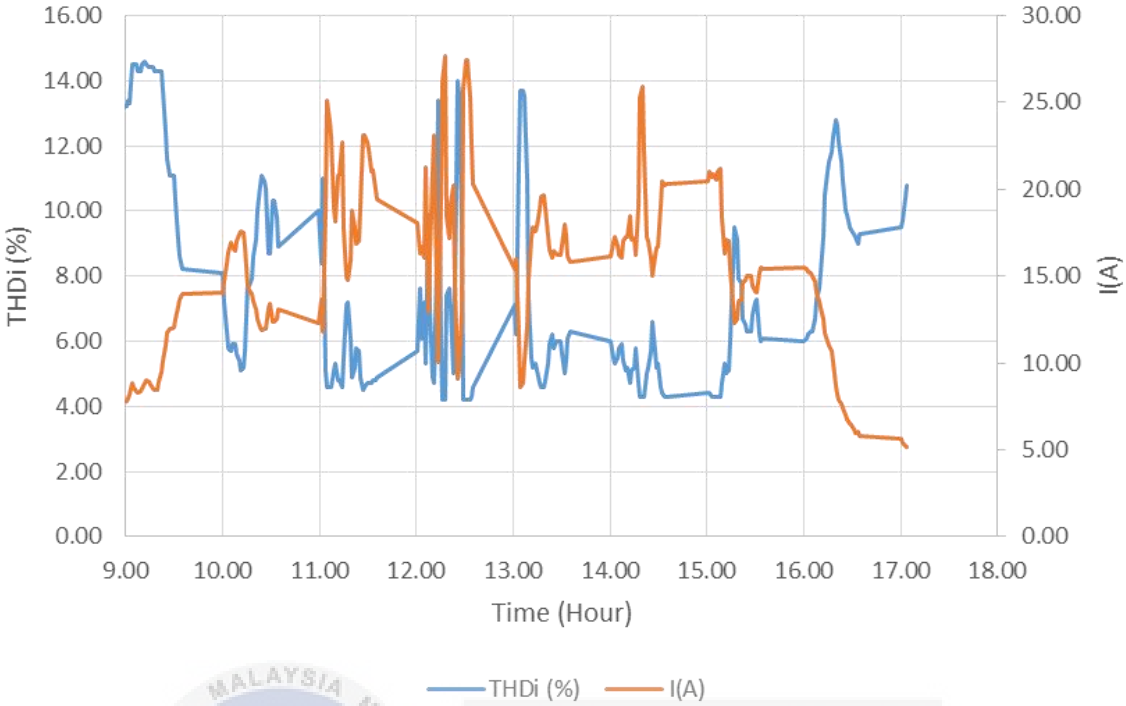

Figure 4.4: The relationship between Current and Total Harmonic Distortion of Current at cloudy day.

4.2.3 Rainy day

For the third condition the data recorded on 26th November 2015 as rainy day. The data with 2 minute interval of irradiance was recorded. Figure 4.5 shows the fluctuating solar irradiance starting from 9.00am to 5.00pm. The average of data is 373.92 W/ m^2 . The maximum value of solar irradiance is 1283 W/ m^2 at 12.02 pm while the minimum value is 19 W/ m^2 at 16.50 pm due to raining occur at 16.30 pm until 5.00 pm at UTeM.

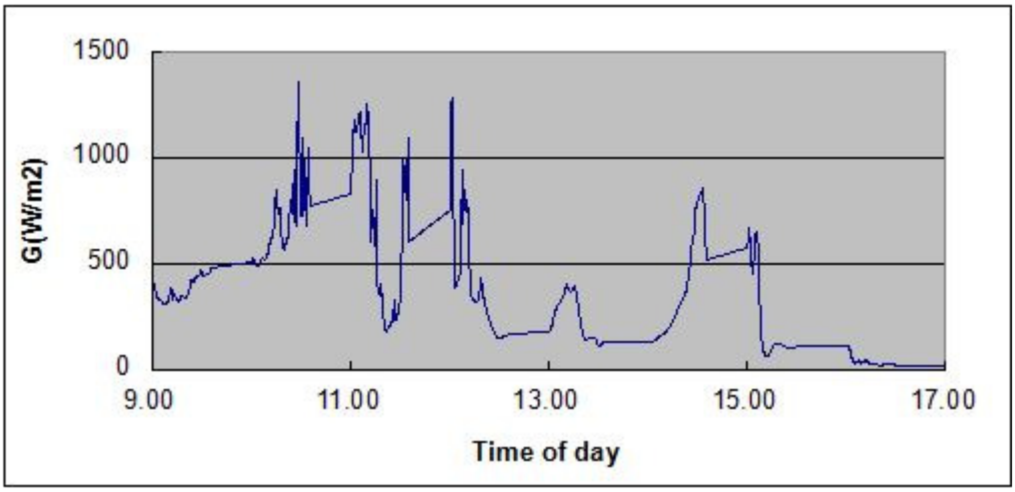

Figure 4.5: The solar irradiance data on rainy day.

Figure 4.6 shows the THDi and Current on rainy day. The data is recorded by Fluke meter with 2 minutes interval on 276^{h} November. From the graph its shown that the solar irradiation is tally with the current profile. However, for THDi the profile is opposite with solar irradiation. The variation of solar irradiation effect the current profile on rainy day. For this condition, the average of current is 10.16 A while THDi is 11.81 %. At 11.13 am it shows that maximum value of current is 29.93 A while minimum value of THDi is 4.1 % at high solar irradiance. For minimum value of current is 1.99 A while maximum value of THDi is 32 % recorded at 16.05 pm at low solar irradiance.

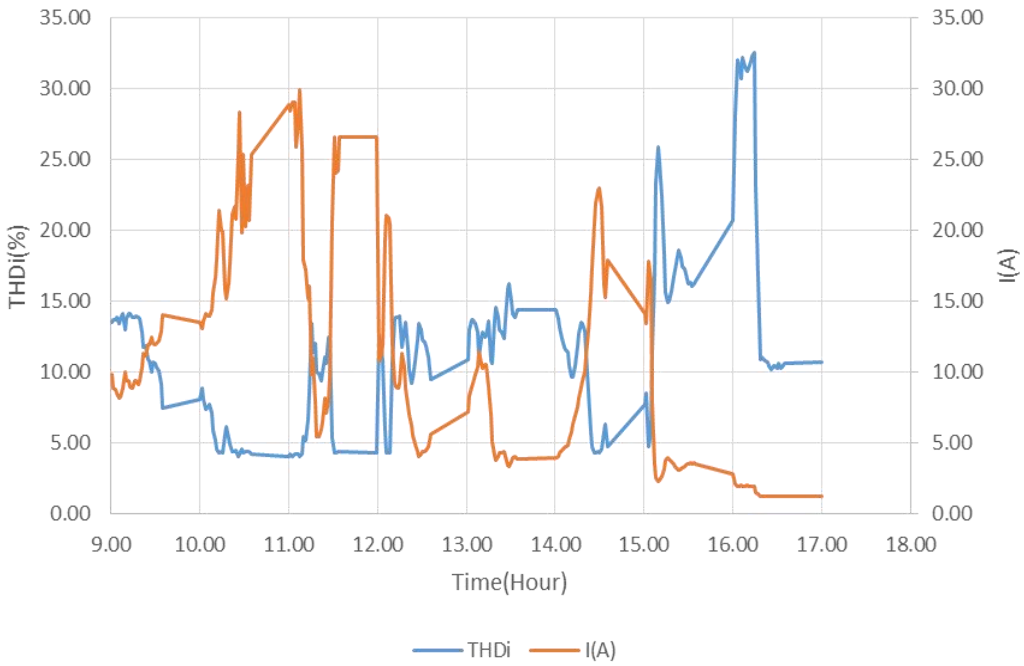

Figure 4.6: The relationship between Current and Total Harmonic Distortion of Current

For all weather condition it shows that solar irradiation influence current profile. When the solar irradiance high the value of of current also increase. However, THDi is increase when the solar irradiance is low. In order to get high power quality of output, the value of solar irradiance should be high.

Figure 4.7 shows the relationship between THDi and current for 30 days starting from 29th October 2015. From the graph its show the decreasing of current give result increasing of THDi. Then, Figure 4.8 shows the relationship between THDi and power output. From the graph its show the decreasing of power output give result increasing of THDi. The graph shows that the maximum value of power output is 7528.8 at minimum THDi which is 4%. Then, average value of THDi less than 5% at 50% rated power output which is 4-8kW. However, some value of THDi more than 5% at 50% rated power output. Base on the TNB Technical Guidebook THDi shall be less than 5 % at rated PV inverter power output. [20] From the collected data, average value of THDi is 4.64% at 50% rated power ouput.. Based on the result it show that the average value of THDi pass the requirement from TNB Technical Guidebook.

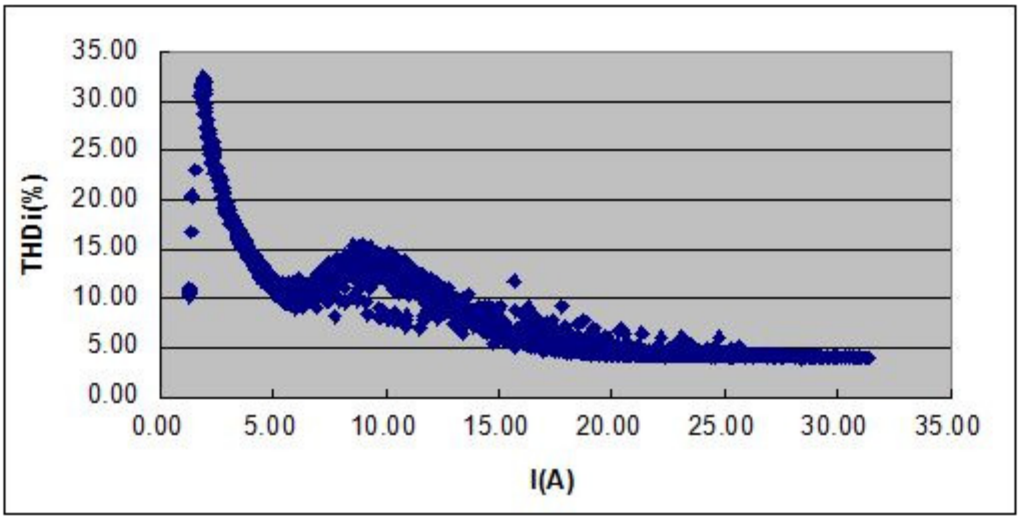

Figure 4.7: The THDi vs current

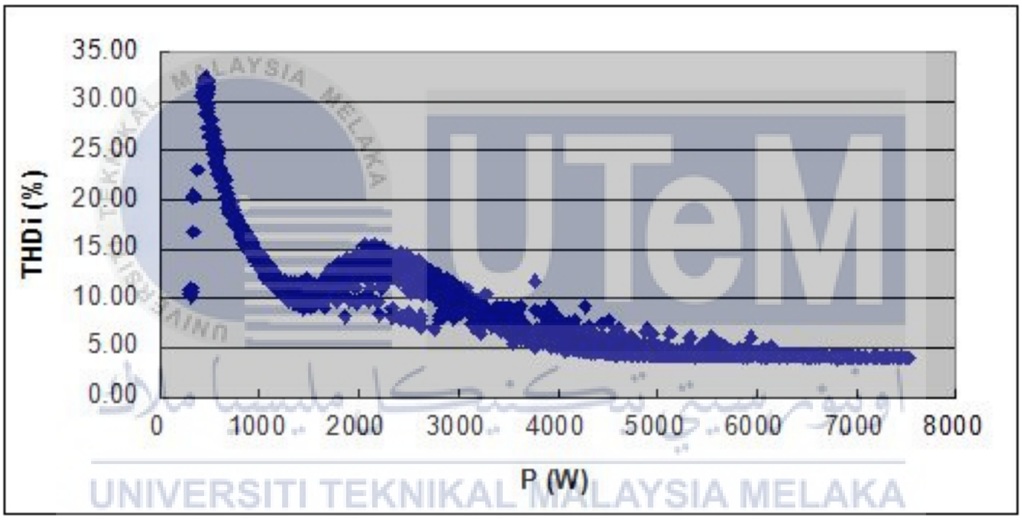

Figure 4.8: The THDi vs Power

4.3 Inverter Efficiency

GCPV inverter is used to convert the DC power output to AC power output. Figure 4.9 shows the DC power of Mono type solar panel for 30 days. The data from the is recorded from 9.00 am until 5.00 pm. Then, the graph shows that the increasing of DC power output give result of increasing of efficiency. The GCPV efficiency is 95%, as published by the inverter manufacturer. From the graph, the minimum value of efficiency is 56.45% when the DC power output is 58.71W. While, the maximun value of efficiency is 96.94% when the DC power output is 1368 W.

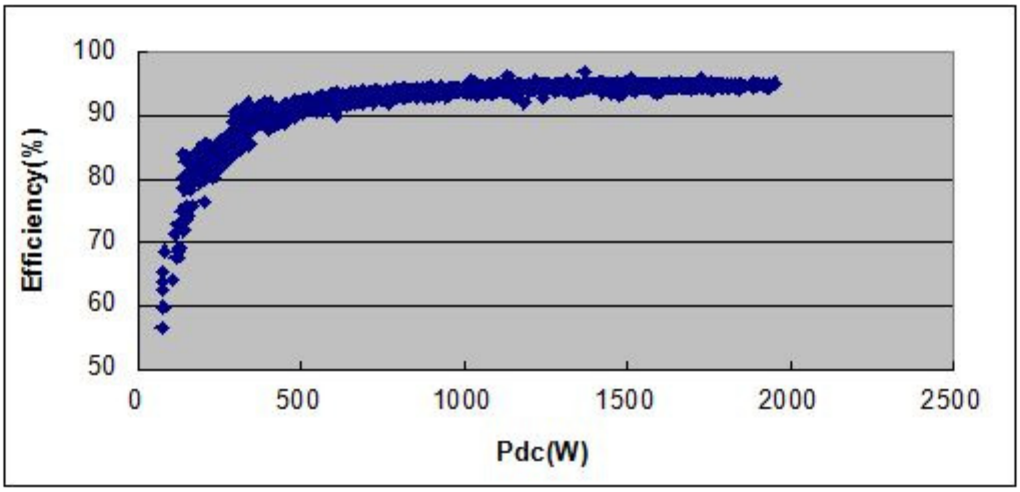

Figure 4.9: The inverter efficiency vs Pdc of monocrystalline

Figure 4.10 shows the graph of the efficiency against time of days start at 9.00am until 5.00 pm on 3rd November 2015. Its consist of 4 system which is mono, HIT, TF and poly. From the graph its show that the solar irradiance give effect to efficiency of inverter. Refer to figure 4.11, when solar irradiance is minimum at 4.40 pm, the efficiency for all system also minimum at the same time. Moreover, the solar irradiance graph is fluctuated at 11.15 am until 2.45 pm give result to fluctuating graph to efficiency also. Hence, the solar irradiance give impact to efficiency of GCPV inverter.

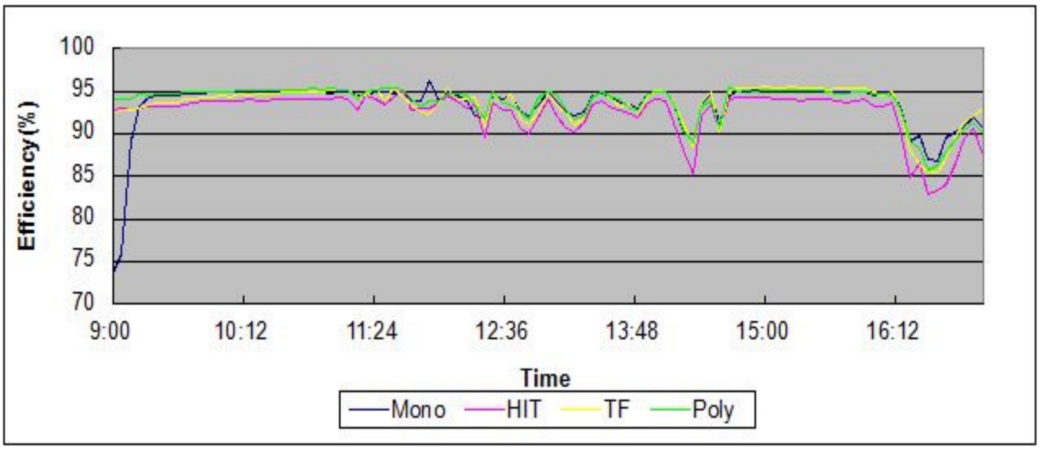

Figure 4.10: The inverter efficiency vs time

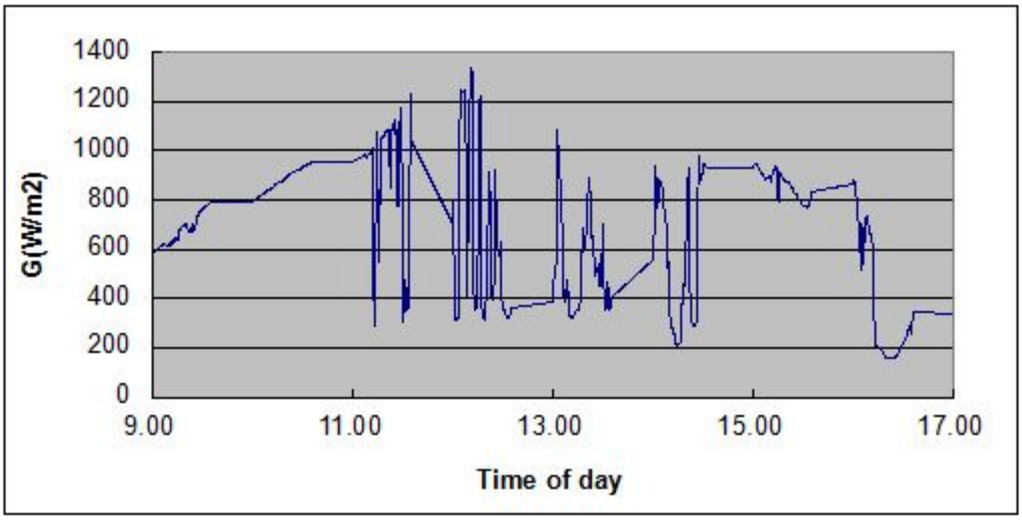

Figure 4.11: The solar irradiance 3rd November 2015

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This project presents an evaluation of the power quality problem resulted from the PV inverter. The evaluation is based on power quality such as THDi and efficiency of PV inverter. The data collected starts from 29th October 2015 for 30 days to analyze the PQ behavior of GCPV under Malaysia climate condition in addition of PV inverter efficiency. The value of THDi, current and irradiance have been recorded to analyze the correlation between solar irradiance and THDi. The value of THDi and current were recorded by using Fluke Meter 43B for difference weather conditions which are sunny, cloudy and rainy days. Then, the analyses of THDi, current and solar irradiance show that the fluctuating solar irradiance effects the current and THDi. When the solar irradiance is high the value of current is also increase. However, THDi increases when the solar irradiance is low. In order to produce high quality of power output, the value of solar irradiance should be high. Then, the graph of THDi against power output show the decreasing of power output give result increasing of THDi. Based on the result it show that the average value of THDi pass the requirement from TNB Technical Guidebook. For the last objective, the value of DC power output and AC power output is recorded for 8 hour. Then, the graph efficiency against DC power output shows the inverter efficiency is high when the DC power output is high. However, low and fluctuating DC power output cause the value of inverter efficiency to decrease. In addition, the graph efficiency against time and solar irradiance against time show the value of solar irradiance give impact to inverter efficiency. The finding shows that the the of solar irradiance, DC power output and efficiency have same behavior. Hence, to get the high value of efficiency, the value of solar irradiance should be maintain high. The PV generating system only produce electricity during daylight. Hence, to maximize the power output, high intensity of solar irradiance is needed. However, there are several advantages of PV generating systems which include reduce gas emissions into atmosphere, lower maintenance cost, easy to install and no noice pollution. Therefore, from this information, solar PV systems have many advantages for the environment. By proceeding the development of solar PV systems, people may have a great chance to live in a natural and healthful environment in the future.

5.2 Recommendation

Among various sources of renewable energy systems, PV systems are expected to play an importance role as a promising clean power source in generating electricity. This project shows that the solar PV system is depend on solar irradiance. However, there are several factor that influence the efficiency and power quality of power output such as temperature, type solar panel and solar panel tilted angle. There is a need to study further on effect of other factor as stated above.

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APPENDIX A

Module Data Sheet Mono Crystalline Silicon (Mono)

Sunmodule® Plus SW 255 mono

PERFORMANCE UNDER STANDARD TEST CONDITIONS (STC)*

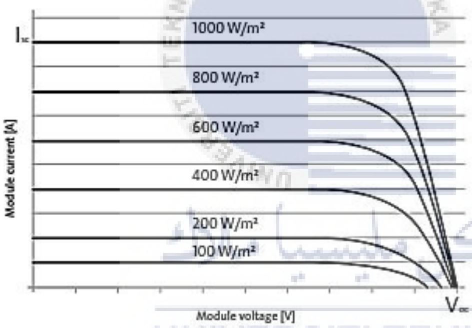
Maximum power	P_{max}	255 Wp
Open circuit voltage	V_{oc}	37.8 V
Maximum power point voltage	V_{mpp}	31.4 V
Short circuit current	I_{sc}	8.66 A
Maximum power point current	I_{mpp}	8.15 A

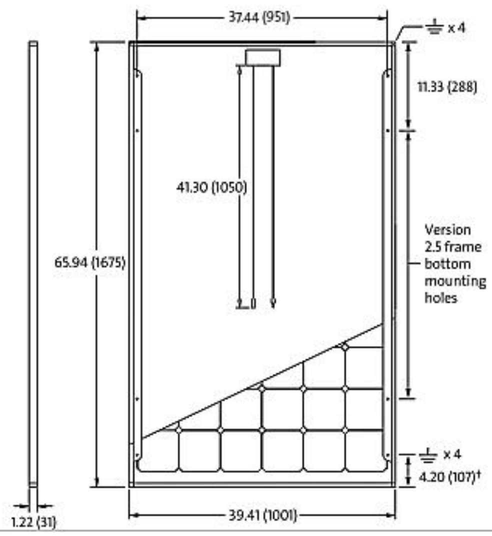
*STC: 1000 W/m², 25°C, AM 1.5

1) Measuring tolerance (P_{max}) traceable to TUV Rheinland: +/- 2% (TUV Power Controlled).

THERMAL CHARACTERISTICS

NOCT	46 °C
TC I_{sc}	0.04 %/°C
TC $_{Voc}$	-0.30 %/°C
TC P_{mpp}	-0.45 %/°C
Operating temperature	-40°C to 85°C





PERFORMANCE AT 800 W/m², NOCT, AM 1.5

Maximum power	P_{max}	184.1 Wp
Open circuit voltage	V_{oc}	34.0 V
Maximum power point voltage	V_{mpp}	28.3 V
Short circuit current	I_{sc}	6.99 A
Maximum power point current	I_{mpp}	6.52 A

Minor reduction in efficiency under partial load conditions at 25°C: at 200 W/m², 100% (+/-2%) of the STC efficiency (1000 W/m²) is achieved.

COMPONENT MATERIALS

Cells per module	60
Cell type	Mono crystalline
Cell dimensions	6.14 in x 6.14 in (156 mm x 156 mm)
Front	Tempered glass (EN 12150)
Frame	Clear anodized aluminum
Weight	46.7 lbs (21.2 kg)

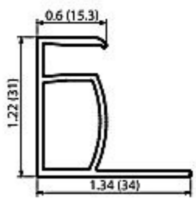
SYSTEM INTEGRATION PARAMETERS

Maximum system voltage SC II		1000 V
Max. system voltage USA NEC		1000 V
Maximum reverse current		16 A
Number of bypass diodes		3
*UL Design Loads**	*Two rail system*	113 psf downward 64 psf upward
*UL Design Loads**	*Three rail system*	170 psf downward 64 psf upward
*IEC Design Loads**	*Two rail system*	113 psf downward 50 psf upward

*Please refer to the Sunmodule installation instructions for the details associated with these load cases.

ADDITIONAL DATA

Power sorting¹	-0 Wp / +5 Wp
J-Box	IP65
Module leads	PV wire per UL4703 with H4 connectors
Module efficiency	15.51 %
Fire rating (UL 790)	Class C
Glass	Low iron tempered with ARC



VERSION 2.5 FRAME
- Compatible with both "Top-Down" and "Bottom" mounting methods
- ⏚ Grounding Locations:
  - 4 corners of the frame
  - 4 locations along the length of the module in the extended flange†

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APPENDIX B

Module Data Sheet Heterojunction with Intrinsic Thin Layer (HIT)

HIT™ Photovoltaic Module

Electrical and Mechanical Characteristics VBHN235SJ18

Electrical data (at STC)

Max. power (Pmax) [W]	235
Max. power voltage (Vmp) [V]	43.0
Max. power current (Imp) [A]	5.48
Open circuit voltage (Voc) [V]	51.8
Short circuit current (Isc) [A]	5.84
Max. over current rating [A]	15
Output power tolerance [%]	+10/-5*
Max. system voltage [V]	600

Note: Standard Test Conditions: Air mass 1.5, Irradiance = 1000W/m², cell temp. 25°C
* All modules measured by Panasonic facility have output with positive tolerance.

Temperature characteristics

Temperature (NOCT) [°C]	46.0
Temp. coefficient of Pmax [%/°C]	-0.30
Temp. coefficient of Voc [V/°C]	-0.130
Temp. coefficient of Isc [mA/°C]	1.75

At NOCT

Max. power (Pmax) [W]	179
Max. power voltage (Vmp) [V]	40.5
Max. power current (Imp) [A]	4.41
Open circuit voltage (Voc) [V]	48.9
Short circuit current (Isc) [A]	4.70

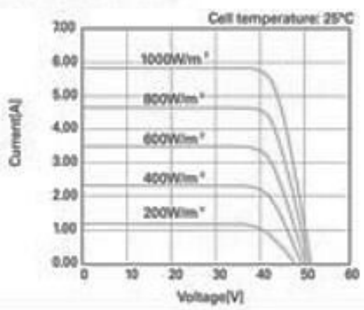
Note: Nominal Operating Cell Temp.: Air mass 1.5 spectrum, Irradiance = 800W/m², Air temperature 20°C; wind speed 1 m/s

At low irradiance

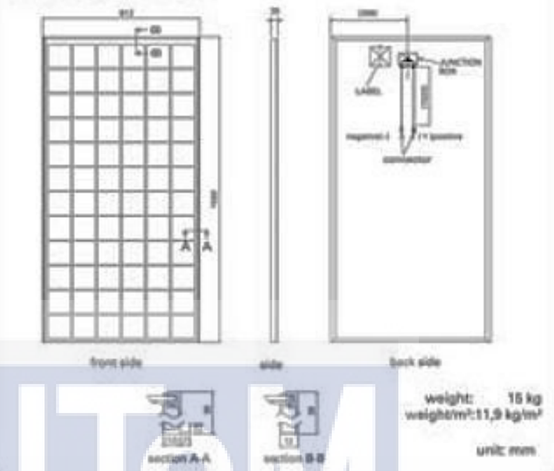
Max. power (Pmax) [W]	44.7
Max. power voltage (Vmp) [V]	41.0
Max. power current (Imp) [A]	1.09
Open circuit voltage (Voc) [V]	48.4
Short circuit current (Isc) [A]	1.17

Note: Low irradiance: Air mass 1.5 spectrum, Irradiance = 200W/m², cell temp. = 25°C

Dependence on irradiance



Dimensions and weight



Guarantee

Power output: 10 years (90% of Pmin), 25 years (80% of Pmin)
Product workmanship: 10 years
(Based on guarantee document)

Materials

Cell material: 5 inch HIT cells
Glass material: AR coated tempered glass
Frame materials: Black anodized aluminium
Connectors type: KITANI

Certificates

Module comply with the requirements of IEC61215, IEC61730-1, IEC61730-2

JET: Japan Electrical Safety & Environment Technology Laboratories

Please consult your local dealer for more information.

APPENDIX C

Module Data Sheet Thin Film (TF)

130 WATT

NS-F130G5

Amorphous Silicon/Microcrystalline Silicon
IEC-Certified for 1,000-volt systems (IEC 61646)

ELECTRICAL DATA		NAMEPLATE VALUES NS-F130G5
Maximum power	Pmax	130 W
Tolerance of Pmax		+7%/-2%
Open-circuit voltage	Voc	60.4 V
Short-circuit current	Isc	3.41 A
Voltage at maximum power	Vpmax	46.1 V
Current at maximum power	Ipmax	2.82 A
Module efficiency	η	9.3%
Temperature coefficient – open circuit voltage	β	-0.3%/°C
Temperature coefficient – short circuit current	α	+0.07%/°C
Temperature coefficient – power	γ	-0.24%/°C

MADE IN JAPAN

The electrical data applies under standard test conditions (STC): Irradiance of 1,000 W/m² with an AM 1.5 spectrum at a cell temperature of 25° C.
Output values are post initial Stabler-Wronski decay; actual measured initial values will be greater than nominal value (by approximately 15% for power).

SPECIFICATIONS (I)	
Cell	Tandem architecture of amorphous and microcrystalline silicon
Dimensions	1001 x 1402 x 7.4 mm
Weight	26 kg
Front glass	Low iron non-tempered glass
Back glass	Tempered
Connection type	Cable with SMK connector

SPECIFICATIONS (II)		
Maximum system voltage	1,000	V_{DC}
Maximum mechanical load	2,400	Pa
Series Fuse Rating	5	A
Operating temperature (cell)	- 40 to +90	°C
Storage temperature	- 40 to +90	°C
Storage air humidity	Up to 90	%
Installation orientation	Portrait or Landscape	

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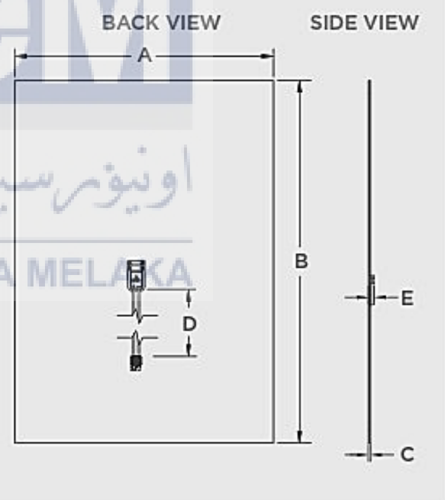
EXTERIOR DIMENSIONS



A	B	C	D	E
1001 mm	1402 mm	7.4 mm	950 mm	24 mm

APPENDIX D

Module Data Sheet Poly Crystalline Silicon (Poly)

Sunmodule™
SW 245 poly / Version 2.5 Frame

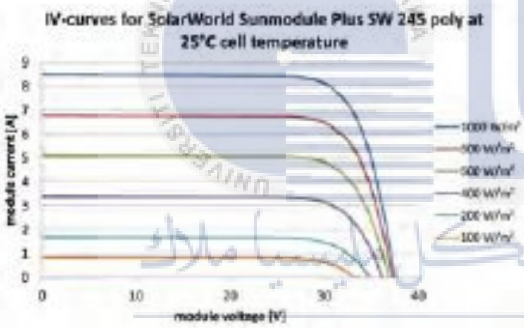
PERFORMANCE UNDER STANDARD TEST CONDITIONS (STC)*

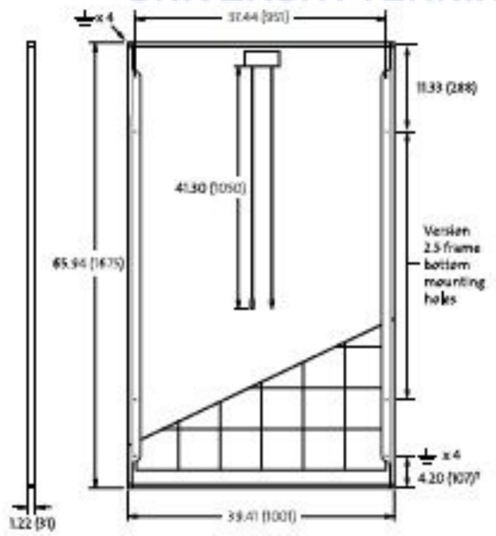
		SW 245
Maximum power	P_{max}	245 Wp
Open circuit voltage	V_{oc}	37.5 V
Maximum power point voltage	V_{mpp}	30.8 V
Short circuit current	I_{sc}	8.49 A
Maximum power point current	I_{mpp}	7.96 A

*STC: 1000W/m², 25°C, AM 1.5

THERMAL CHARACTERISTICS

NOCT	46 °C
TC I_{sc}	0.081 %/K
TC V_{oc}	-0.37 %/K
TC P_{mpp}	-0.45 %/K
Operating temperature	-40°C to 85°C





PERFORMANCE AT 800 W/m², NOCT, AM 1.5

		SW 245
Maximum power	P_{max}	176.4 Wp
Open circuit voltage	V_{oc}	33.7 V
Maximum power point voltage	V_{mpp}	27.7 V
Short circuit current	I_{sc}	6.84 A
Maximum power point current	I_{mpp}	6.37 A

Minor reduction in efficiency under partial load conditions at 25°C: at 200W/m², 95% (+/-3%) of the STC efficiency (1000 W/m²) is achieved.

COMPONENT MATERIALS

Cells per module	60
Cell type	Poly crystalline
Cell dimensions	6.14 in x 6.14 in (156 mm x 156 mm)
Front	tempered glass (EN 12150)
Frame	Clear anodized aluminum
Weight	46.7 lbs (21.2 kg)

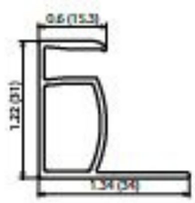
SYSTEM INTEGRATION PARAMETERS

Maximum system voltage SC II		1000 V
Max. system voltage USA NEC		600 V
Maximum reverse current		16 A
Number of bypass diodes		3
UL Design Loads*	Two rail system	113 psf downward 64 psf upward
UL Design Loads*	Three rail system	170 psf downward 64 psf upward
IEC Design Loads*	Two rail system	113 psf downward 50 psf upward

*Please refer to the Sunmodule installation instructions for the details associated with these load cases.

ADDITIONAL DATA

Power tolerance²	-0 Wp / +5 Wp
J-Box	IP65
Connector	MC4
Module efficiency	14.61 %
Fire rating (UL 790)	Class C



VERSION 2.5 FRAME
- Compatible with both "Top-Down" and "Bottom" mounting methods
- Grounding Locations:
  - 4 corners of the frame
  - 4 locations along the length of the module in the extended flange*

APPENDIX D

Raw Recorded Data From Fluke 43B

Title	Record 1	Title	Record 2
ID	1	ID	1
Type	MinAvgMax	Type	MinAvgMax
Date	11/3/2015	Date	11/3/2015
Time	8:32:28	Time	8:32:28
X Scale	3.60E+03	X Scale	3.60E+03
X At 0%	0.00E+00	X At 0%	0.00E+00
X Resolution	2.81E+01	X Resolution	2.81E+01
X Size	240	X Size	240
X Unit	s	X Unit	s
X Label	1 h/Div	X Label	1 h/Div
Y Scale	5.00E+00	Y Scale	1.00E+01
Y At 50%	1.25E+01	Y At 50%	1.50E+01
Y Resolution	5.00E+01	Y Resolution	1.00E+03
Y Size	65536	Y Size	65536
Y Unit		Y Unit	A
Y Label		Y Label	A

0.00E+00	1.18E+01	1.21E+01	1.24E+01	0.00E+00	1.19E+01	1.20E+01	1.21E+01
1.28E+02	1.13E+01	1.16E+01	1.20E+01	1.28E+02	1.21E+01	1.23E+01	1.24E+01
2.56E+02	1.09E+01	1.13E+01	1.17E+01	2.56E+02	1.23E+01	1.25E+01	1.26E+01
3.84E+02	1.06E+01	1.09E+01	1.17E+01	3.84E+02	1.24E+01	1.27E+01	1.29E+01
5.12E+02	1.00E+01	1.03E+01	1.07E+01	5.12E+02	1.28E+01	1.30E+01	1.31E+01
6.40E+02	9.30E+00	9.70E+00	1.03E+01	6.40E+02	1.30E+01	1.32E+01	1.34E+01
7.68E+02	9.00E+00	9.20E+00	9.50E+00	7.68E+02	1.34E+01	1.35E+01	1.36E+01
8.96E+02	8.50E+00	8.80E+00	9.30E+00	8.96E+02	1.36E+01	1.38E+01	1.40E+01
1.02E+03	8.00E+00	8.30E+00	8.60E+00	1.02E+03	1.40E+01	1.41E+01	1.43E+01
1.15E+03	7.70E+00	8.00E+00	8.30E+00	1.15E+03	1.42E+01	1.44E+01	1.45E+01
1.28E+03	7.40E+00	7.70E+00	8.00E+00	1.28E+03	1.45E+01	1.46E+01	1.48E+01
1.41E+03	7.20E+00	7.40E+00	7.80E+00	1.41E+03	1.48E+01	1.48E+01	1.50E+01