EXPERIMENTAL STUDY FOR PV GRID CONNECTED

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"I hereby acknowledge that the scope and quality of this thesis is qualified for the award of the Bachelor of Electrical Engineering (Power Systems)"

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I declare that this project report entitled “*Experimental Study for PV Grid Connected*” is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any degree.

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ABSTRACT

Photovoltaic grid connected system is the development trend of photovoltaic systems. Nowadays, grid connected photovoltaic (PV) generation system is expected more widespread use due to fossil fuel cost. The measured data is used to investigate the effects of PV grid connected system. Result from experimental and research both is compared. To assess the impact on waveform and Total Harmonic Distortion (THD), Single phase motor is used as the load. The measurement technology element of this project pertains to how power quality is being measured in this network environment. Parameter such as input harmonics, input current waveforms, input voltage waveform, voltage (among others) at the input of the network is collected and analyzed.For obtaining high power, numerous PV cells are connected in series and parallel circuits on a panel, which is a PV module. A PV array is defined as a group of several modules electrically connected in series-parallel combinations to generate the required current and voltage. From the experiments, it represents the performance of PV-grid connected system such as the voltage and current in this system. The scale down less than 1kW PV had been connected to 415V distribution feeder. The result consists of 2 part. First part is present the waveform of voltage and current, and the second part is about the harmonic order and percentage of Total Harmonic Distortion. The results that gather are analyzed.

ABSTRAK

Sistem grid photovoltaic yang berkaitan adalah trend pembangunan sistem fotovoltaik. Pada masa kini, grid disambungkan fotovoltaik (PV) sistem penjanaan dijangka penggunaan lebih meluas kerana kos bahan api fosil. Data yang diukur digunakan untuk mengkaji kesan sistem grid PV yang berkaitan. Hasil daripada eksperimen dan penyelidikan kedua-dua dibandingkan. Untuk menilai kesan ke atas bentuk gelombang dan Penyelewengan Jumlah Harmonik (THD), motor fasa tunggal digunakan sebagai beban. Teknologi elemen pengukuran projek ini adalah berkaitan dengan bagaimana kualiti kuasa sedang diukur dalam persekitaran rangkaian ini. Parameter seperti harmonik input, input gelombang semasa, bentuk gelombang voltan input, voltan (antara lain) pada input rangkaian dikumpul dan analyzed.For mendapatkan kuasa tinggi, pelbagai PV sel-sel bersambung dalam siri dan litar selari pada panel, yang adalah satu modul PV. Pelbagai PV ditakrifkan sebagai satu kumpulan beberapa modul elektrik disambung dalam kombinasi selari siri untuk menjana arus dan voltan yang diperlukan. Daripada eksperimen, ia mewakili prestasi sistem PV-grid yang berkaitan seperti voltan dan arus dalam sistem ini. Skala turun kurang daripada 1kW PV telah disambung untuk feeder pengedaran 415V. Hasilnya terdiri daripada 2 bahagian. Bahagian pertama ialah yang hadir bentuk gelombang voltan dan arus, dan bahagian kedua ialah jumlah peratusan harmonik. Keputusan eksperimen dianalisis.

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CHAPTER I

INTRODUCTION

1.1 Introduction of PV grid-connected system

Photovoltaic System (PV) is getting popular by day as the fossil fuel expensive and unstable in the global market. Furthermore with eco-friendly movement, and the awareness of has heightened up regarding green energy, photovoltaic maybe one of the alternative energy for better as well cleaner energy as it is naturally harness from the Sun energy. This is due to the high initial cost, generation efficiency and reliability [1]. On the other hand, alternative energy has made the PV system again popular among the researchers. In addition, the rural areas where the grid connection is extremely expensive, PV Systems have been implied to give hope to these areas, while for the urban life, the PV Water Heater is common and can be found on the roof of the houses. [2] The world production of solar PV cells increased 32% in 2003, compared to the most recent 5-year average of 27% a year. Production increased to 742 MW, with cumulative global production at 3145 MW at the end of year 2003, enough to meet the electricity niche of one million homes. Referring to the EPI, this extraordinary growth is driven to some degree by improvements in materials and technology, but primarily by market introduction programs and government incentives [3]. This fact can clearly conclude that this solar energy (photovoltaic) is a very promising as next generation energy source.

Looking at the grid connected system, whereby the system mainly consists of photovoltaic (PV) modules, inverter, battery, and switching point for the utility [4]. Different types of photovoltaic cell will yield different energy output, meanwhile the controlling technique of inverter is very crucial in championing the PV system. Inverter design should consider the size and capacity of the plant, on the other hand choosing the right controlling technique is needed as well in order to achieve an efficient renewable energy system.There are many types of inverter used in converting the direct current (d.c)produced by the PV to alternating current (a.c). The conversion is a must in order to suit the AC grid system that have been implemented and practiced for so long. Some of the types that can be used are multilevel inverters such as flyback capacitor, neutral point clamped multilevel inverter, diode clamped inverter and many more. Each topology has its own plus point and drawbacks depending on the usage of it.Applying certain controlling techniques to the inverters' such as Pulse Width Modulation (PWM), Space Vector Pulse Width Modulation (SVPWM), Step Modulation etc, the efficiency of the conversion can be obtain up to an optimum level. Hence this is another part for research in the PV Grid-Connected system.

Besides that, it's a common knowledge that, the PV system has different seasonal pattern behavior depending on the temperature as well as the solar irradiation. Due to the different temperature co-efficient of voltage and current the PV system has different output. Yet, to simplify the work of manufacturer mostly, the PV modules are rated at STC (standard test conditions) of solar irradiation as 1000 Wm-2, while the spectrum is fixed and related to a sun-spectrum at air mass of 1.5 (AM = 1.5). The STC temperature operating for the PV cell is at 25oC which does not relate to the practical world especially to Malaysia. Hence this project aims to have some practical simulation work to suit to Malaysian tropical weather and climate.

Renewable energy is no longer just an option nowadays. The renewable energy plays an important role in our live due to rise demand for electrical power. Photovoltaic is one of the renewable energy that has been used for about decade ago. The word "photovoltaic," first used in about 1890, is a combination of the Greek word for light and the name of the physicist and electricity pioneer Allesandro Volta. So, "photovoltaic" can be translated literally as "light-electricity." Photovoltaic or known as solar energy is a renewable resource that is vast and is locally available. It is a clean energy source that allows for local energy independence. The sun's energyflow reaching the earth is typically about 1,000 Watts per square meter (W/m2), although ease of use varies with location and time of year. Simple PV systems provide power for many small consumer items, such as calculators and wristwatches. More complicated systems provide power for communications satellites, water pumps, and the lights, appliances, and machines in some people's homes and workplaces. Many road and traffic signs along highways are now powered by PV. In many cases, PV power is the least expensive form of electricity for performing these tasks .

1.2 Problem Statement

The power quality problem in term of voltage, current of the output on PV grid connected is analyzed by conducted two method of experiment without load and with load (motor) .

1.3 Objective

The objectives of this project are:

i. To investigate the PV grid connected system.
ii. To analyse the waveform of voltage and current at grid, motor and PV system with load.
iii. To compare the THD experimental result of voltage and current at grid, motor, and PV system with load and without load.

1.4 Scope of Project

This project has been divided into few parts. The beginning part, the literature review on the photovoltaic theory, topology and its operation as well grid-connected PV system will be discovered thru to have a better understanding on the system. On the second stage after the understanding of theory, an experimental will be conducted to analyze the result by experimental. From these, the power quality of voltage and current on PV grid connected is investigated by varied the load.

1.5 Outline of Thesis

This thesis is a compilation of many chapters that will elaborate in stages the study work that have been carried out. As in general, it is mainly consist of five main chapters; introduction, literature review and results analysis from the experimental and conclusion

Chapter I This chapter explained the crucial aspect of the research work such as background studies, objectives, research scopes, and methodology as well the thesis outline will also be discussed finally.

Chapter II This chapter includes all the paper works and related research as well as the studies regards to this project. This literature reviews all important studies which have been done previously by other research work.

Chapter III This chapter explains on how the experiment is conducted and illustrated the operation and the parameters involved on the PV grid connected system.

Chapter IV This chapter discussed the results that have been gained from the experimental. The result is analyzed in terms of power quality which is the voltage and current at the system.

Chapter V concludes the overall thesis and provides some recommendations for future work

.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

This chapter gives some idea to the reader regarding the PV grid connected system. Besides that, basic concepts regarding photovoltaic will be reviewed as well as the power electronics converters. On the other hand, the inverters and grid connected PV system also shall be discussed. In addition, related works regarding to this study work also is detailed.

2.2 PV grid connected

In this subtopic the detail explanation on how the solar cell being bring into the big picture of energy generation will be discussed in depth. A grid connected PV system also known as utility interactive PV system, whereby it feed solar electricity directly to a utility power grid. For a general knowledge about we are discussing, kindly refer to Figure 2.1

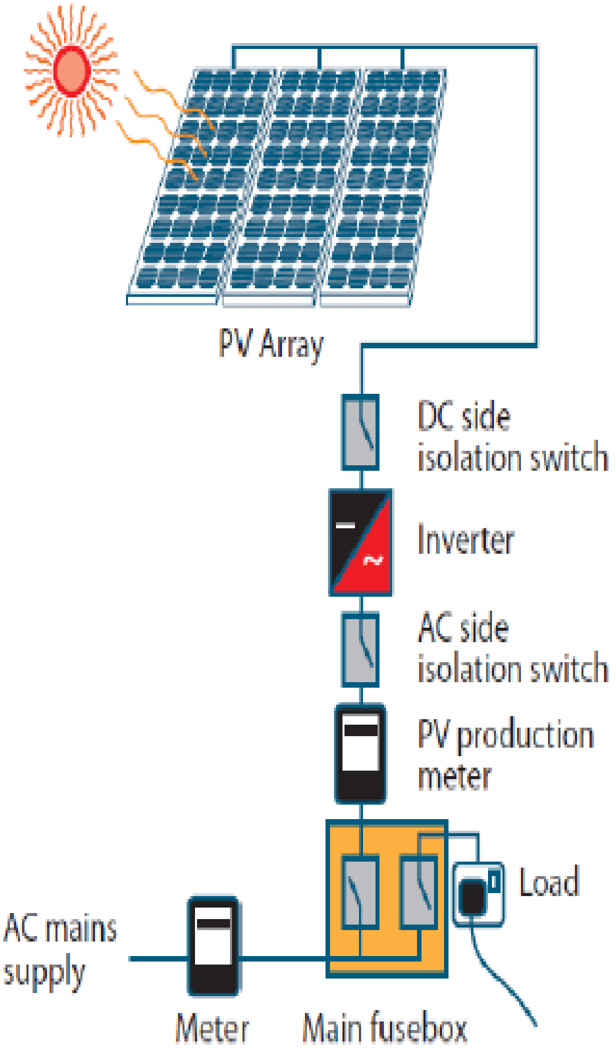

Figure2.1 Grid-connected PV system [6]

This grid connected PV System, consists of a PV Generated, an array of PV modules converting solar energy to DC electricity and an inverter also known as a power conditioning unit that converts direct current generated by PV to alternating current for the grid usage. Surge protector and load are also the grid-connected PV components. Optimization of a Photovoltaic System Connected to Electric Power Grid, the photovoltaic system connected to the electric grid is that it can exercise the double function of active power generator and reactive power compensator. Since it is a type of random generation, dependent on environmental conditions, it can supply reactive power to the electrical grid when there is little or no solar radiation [2].

When the sun shines, the DC power generated by the PV modules is converted to AC electricity by the inverter. This AC electrical power can either be supply the system’s AC load and the excess energy output transmit to the utility grid. Figure 2.2 will give basically the detail component about the grid connected PV system. Referring to Figure 2.2, a first protection level is formed by fuses and blocking diodes between the PV array output and the main DC conductor. Surge protection elements have to be included at the inverter input and output as well. The grid-connected PV system can be classified by its sizing whereby from 1-10kWh is considered as small scale and normally for the domestic usages. While medium size is defined from 10kWh to 100kWh and these kind of system is known as building integrated PV (BIPV). The system with output of 500kWh – 1MWh[1].

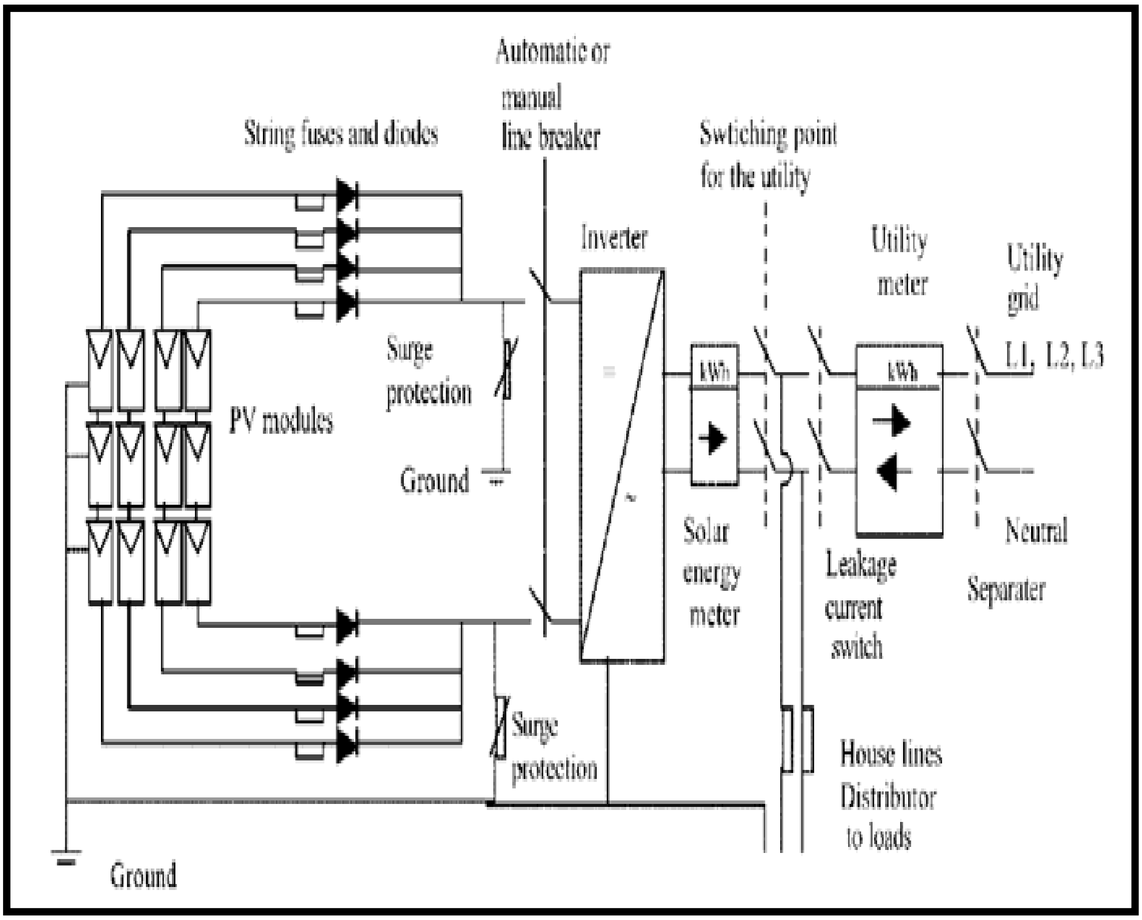

Figure 2.2 A detailed grid-connected PV system [1]

2.3 Converters and Inverters

The rise of power electronics in the industry have always been a factor for the growth in the PV system. As for that, this literature review will be incomplete without the power electronic discussion. As gratitude and to pay some tribute for the works done in the power electronic world some basic power electronics shall be covered here. The role of power electronic converters is to provide power to the user in a suitable form at high efficiency. Power electronic converters are needed in PV systems to convert direct current (DC) voltage to the required values and to convert from DC to alternating current (AC) and vice versa [7]. In addition they control the charging and discharging of batteries in systems where batteries are storage elements especially for the standalone PV system. One of the simplest power electronics circuits is the buck converter and basically consists of an inductor, a power electronic switch (usually a MOSFET or an IGBT) and a diode. It may have a capacitor to smooth the output. Its function is to step down DC voltage as depicted in Figure 2.2.

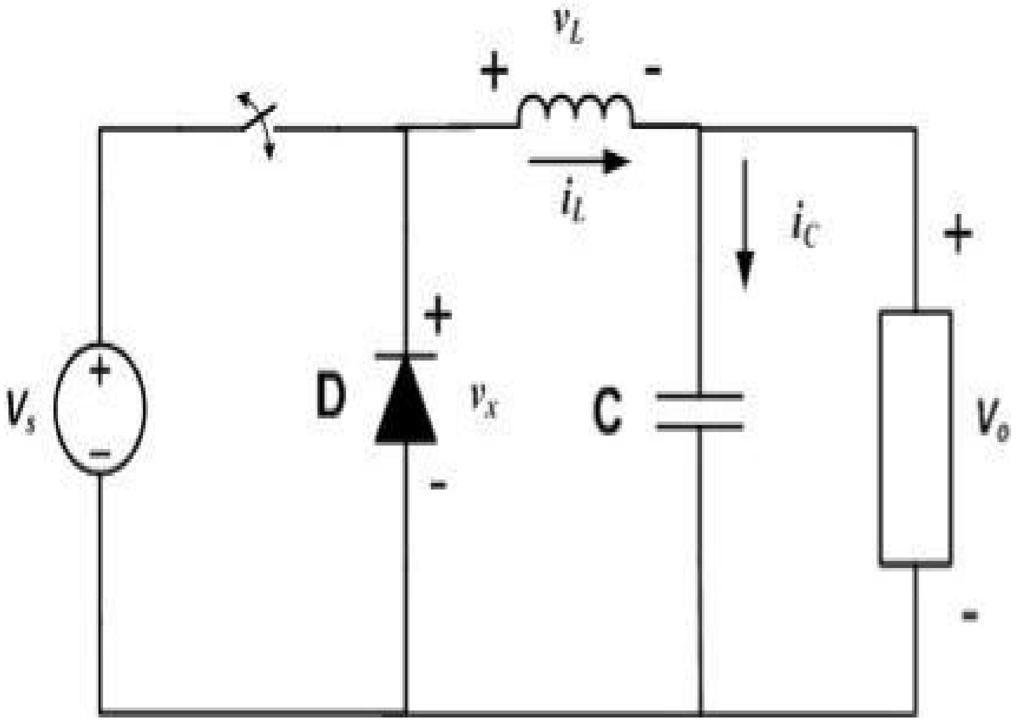

Figure 2.3 The schematic of a buck converter [7]

2.4 Pulse width modulation

Pulse width modulation (PWM) is a powerful technique for controlling analog circuits with a processor's digital outputs. PWM is employed in a wide variety of applications, ranging from measurement and communications to power control and conversion.

An analog signal has a continuously varying value, with infinite resolution in both time and magnitude. A nine-volt battery is an example of an analog device, in that its output voltage is not precisely 9V, changes over time, and can take any real-numbered value. Similarly, the amount of current drawn from a battery is not limited to a finite set of possible values. Analog signals are distinguishable from digital signals because the latter always take values only from a finite set of predetermined possibilities, such as the set {0V, 5V}.

PWM is a way of digitally encoding analog signal levels. Through the use of high-resolution counters, the duty cycle of a square wave is modulated to encode a specific analog signal level. The PWM signal is still digital because, at any given instant of time, the full DC supply is either fully on or fully off. The voltage or current source is supplied to the analog load by means of a repeating series of on and off pulses. The on-time is the time during which the DC supply is applied to the load, and the off-time is the periods during which that supply is switched off. Given a sufficient bandwidth, any analog value can be encoded with PWM [8].

2.5 Power processing system: inverter

The inverter is the electronic device that deals with the conversion of the DC energy supplied by a PV generator into an AC electric energy in a way that it can be injected in the grid. Its finality consists of extracting the maximum available energy from the PV generator and to adequately inject it into the grid. In some studies it has been introduced a parameter called Sizing Factor (SF) and have been developed a procedure for individualizing the Optimal Sizing Factor (SFopt) through which, knowing the power of the PV generator and considering various environmental conditions of influence, the value of nominal power of the inverter that maximizes the yearly energy injected in the grid (YIE) has been drawn [9][10].

2.6 Solar Cell

The solar cell is the fundamental unity of photovoltaic conversion. It is in its inside where the process of transformation happens, therefore, it is the element that fix the maximum value that the output of said transformation can reach and, accordingly, the element that will fix the maximum value of output of the PV generator itself. The electric current being extracted from the solar cell is the difference between the currents produced by the electric carrier couples electron-hole (e-h) that the incidental light produces inside the cell and the current of the couples e-h that recombine inside the cell itself before being able to be drawn out. When a solar cell is in short-circuit the voltage to its terminals is zero and the process of recombination exponentially depends from the value of this voltage, the current that can be extracted will be maximum; when the cell is in open circuit, instead, the number of couples recombining is the same of those couples generated, therefore the voltage to the terminals of the cell will be maximum being zero the current.[11]

2.7 Factors impacting the input harmonic distortions in ASD

Previous studies have shown that the drive load factor and the system impedance at the drive are the two factors impacting the input harmonic distortions in ASD. The current harmonic distortion and lower order harmonic currents in percent of the fundamental vary significantly with the drive load factors. However, the higher order harmonic currents above the 17th do not change much with the drive loading and system impedance [12]. Harmonic currents in Amps will increases with the increase of drive load factors.

2.8 Various loads could affect the magnitude of distortion

One common application for ASD is for variable torque loads under different loading conditions. With multiple drives and multiple motors operating in the system, the harmonics created from various loads could crosstalk and could further positively or negatively affect the magnitude of distortion. However, little has been known about the harmonic interaction between these drives on a single point of common coupling (PCC). There has been a few of attempts done in the past to investigate harmonic distortions. As an example, previous research has been done for a single drive with two induction motors connected to the drive [13]. Besides that, there were also experiments for network of two drive system and two motors connected to each drive [14], network that contain different types of ASD with one motor connected to each drive [15], and system with mixture of ASD and loads connected together at PCC [16]

2.9 Capacitor-Start Induction-Run Motors

We know about the activity of a capacitor in a pure A.C. Circuit. When a capacitor is so introduced, the voltage lags the current by some phase angle. In these motors, the necessary phase difference between the Is and Im is obtained by introducing a capacitor in series with the starter winding. The capacitor used in these motors are of electrolytic type and usually visible as it is mounted outside the motor as a separate unit. During starting, as the capacitor is connected in series with the starter winding, the current through the starter winding Is leads the voltage V, which is applied across the circuit. But the current through the main winding Im, still lags the applied voltage V across the circuit. Thus more the difference between the Is and Im, better the resulting rotating magnetic field When the motor reaches about 75% of the full load speed, the centrifugal switch S opens and thus disconnecting the starter winding and the capacitor from the main winding. It is important to point out from the phasor diagram that the phase difference between Im and Isis almost 80 degrees as against 30 degrees in a split-phase induction motor. Thus a capacitor-start induction-run motor produces a better rotating magnetic field than the split-phase motors. It is evident from the phasor diagram that the current through the starter winding Is leads the voltage V by a small angle and the current through the main winding Im lags the applied voltage. It is to be appreciated that the resultant current I, is small and is almost in phase with the applied voltage V.[17]

2.10 Harmonic distortion is the most common power quality

It is estimated that industrial and digital economy companies collectively lose $45.7 billion a year to outages and another $6.7 billion each year to power quality phenomena [18]. Harmonic distortion is the most common power quality problem and it is found in both the voltage and the current waveform [19]. Current harmonic cause increased loses to customer and utility power system, they produce poor power factor, distorted voltage waveform (causing voltage harmonics). and they could produce dangerous resonant oscillations in the utility power supply.

2.11 Total Harmonic Distortion (THD)

THD is defined as the RMS value of the waveform remaining when the fundamental is removed. A perfect sine wave is 100%, the fundamental is the system frequency of 50 or 60Hz. Harmonic distortion is caused by the introduction of waveforms at frequencies in multiplies of the fundamental ie: 3rd harmonic is 3x the fundamental frequency 150Hz. Total harmonic distortion is a measurement of the sum value of the waveform that is distorted. There is much discussion over the practical harmonic range of a measurement instrument, however study of the harmonic profiles of typically installed equipment can guide the system designer to the practical solution. A typical harmonic profile graph will show a logarithmic decay as the harmonic frequency increases. It is necessary to establish the upper level at which the harmonic content is negligible.[20]

Harmonics emission can have varied amplitudes and frequencies. The most common harmonics in power systems are sinusoidal components of a periodic waveform that have frequencies which can be resolved into some multiples of the fundamental frequency. Power systems also have harmonics that are non integer multiples of the fundamental frequency and have a periodic waveforms.[21]

2.12 Characteristics of Total Harmonic Distortion

A frequency is harmonic if it is an integral multiple of fundamental frequency otherwise it may be interharmonic. The fundamental is the first harmonic. The second harmonic is two times the frequency of fundamental; the third harmonic is three times the fundamental and so on. Distorted waveforms having a Fourier series with fundamental frequency equal to power system frequency and a periodic steady state exists. This is the most common case in harmonic studies. A distorted waveform also having submultiples of power system frequency and a periodic steady state exists. Certain types of pulsed loads and integral cycle controllers produce these types of waveforms. The waveform is a periodic but perhaps almost periodic. A trigonometric series expansion may still exist. Example is arching devices [21]

2.13 Understanding Power Disturbances

Electrical utility company usually provides safe and reliable energy. However, due to the nature of electricity, disruptions and irregularities do occur. Severe storms, lightning, high winds, equipment failures, cars hitting poles, and even animals climbing on utility wires can cause power line disturbances. Electrical equipment within a neighboring facility can also cause power irregularities. Fortunately, most pieces of conventional electrical equipment can tolerate short-term power variances without any noticeable effects, but others cannot. Some solid-state or electrical equipment like computers, industrial process controls, cash registers, security, telephone and fax systems are more sensitive. Power disturbances can cause data or memory losses, altered data and other functional errors, as well as equipment damage. These, in turn may cause scheduling problems, downtime and expensive troubleshooting.[22]

2.14 Cause of disturbances

For the permanent monitoring of network disturbances and power quality, CERN has installed a number of transient recorders (oscillators) in strategic points of the 18 kV network. These oscillators register all voltage and current variations above a certain trigger level. In average there are about 100 to 150 events per year recorded in the 18 kV network. The recordings show that the majority of network disturbances is in the range of 80-120 % of nominal voltage, having an average duration of 50-150 ms.The main causes of these events are sudden load changes, inrush currents of transformers and short-circuits located in remote areas of the power system. There are also a few disturbances of much higher / much lower amplitude, these are mainly caused by short-circuits close to the point of measurement. Unsymmetrical short-circuits severely disturb the voltage balance of the three-phase power system and thus create large under- or over voltages. The typical length of such rare events is about 80-200 ms.[23]

2.15 Power Quality of PV system

Photovoltaic technology provides an attractive method of power generation and meets the criteria of clean energy and sustainability [24]-[27]. Advanced research is still in progress to increase the efficiency of photovoltaic cells and optimize the production of energy through minimization of power losses and better utilization of incident solar irradiance [28]. The efficiency and proper operation of photovoltaic systems depends on a number of factors. Environmental conditions as well as system design constitute the most important factors in the operation of the PV systems and these can have a significant impact on the efficiency and power quality response of the whole system [29]-[31]. The variable power flow due to the fluctuation of solar irradiance, temperature and choice of power semiconductor devices are some of the parameters that affect the power quality of photovoltaic systems. Good power quality translates into obtaining a sinusoidal voltage and current output from a photovoltaic system in order to avoid harmonics, interharmonics and eventually voltage distortion.

CHAPTER III

METHODOLOGY

3.1 Introduction

The approach that has been applied in this study can be divided into two major parts. The first part is the literature review and the second part is on the PV grid connected experimental. In the beginning, the literature review will help to understand the photovoltaic cell by understanding their types, and identifying all the PV system components. Later on the literature review continues up to grid components as well studies on the inverter models in the grid systems. On the other hand, the result is also gathered in order to make this study work to be specific on power quality. On the second part, the PV grid connected experimental is done and the result obtain is analyzed in waveform.. The result of the current and voltage obtained is compared to between with load and without load. PV grid connected system was installed at laboratory. In this experiment consist of PV, grid connected, inverter, power supply, loads, power quality analyzer, and hydraulic pump (using for varied the load)

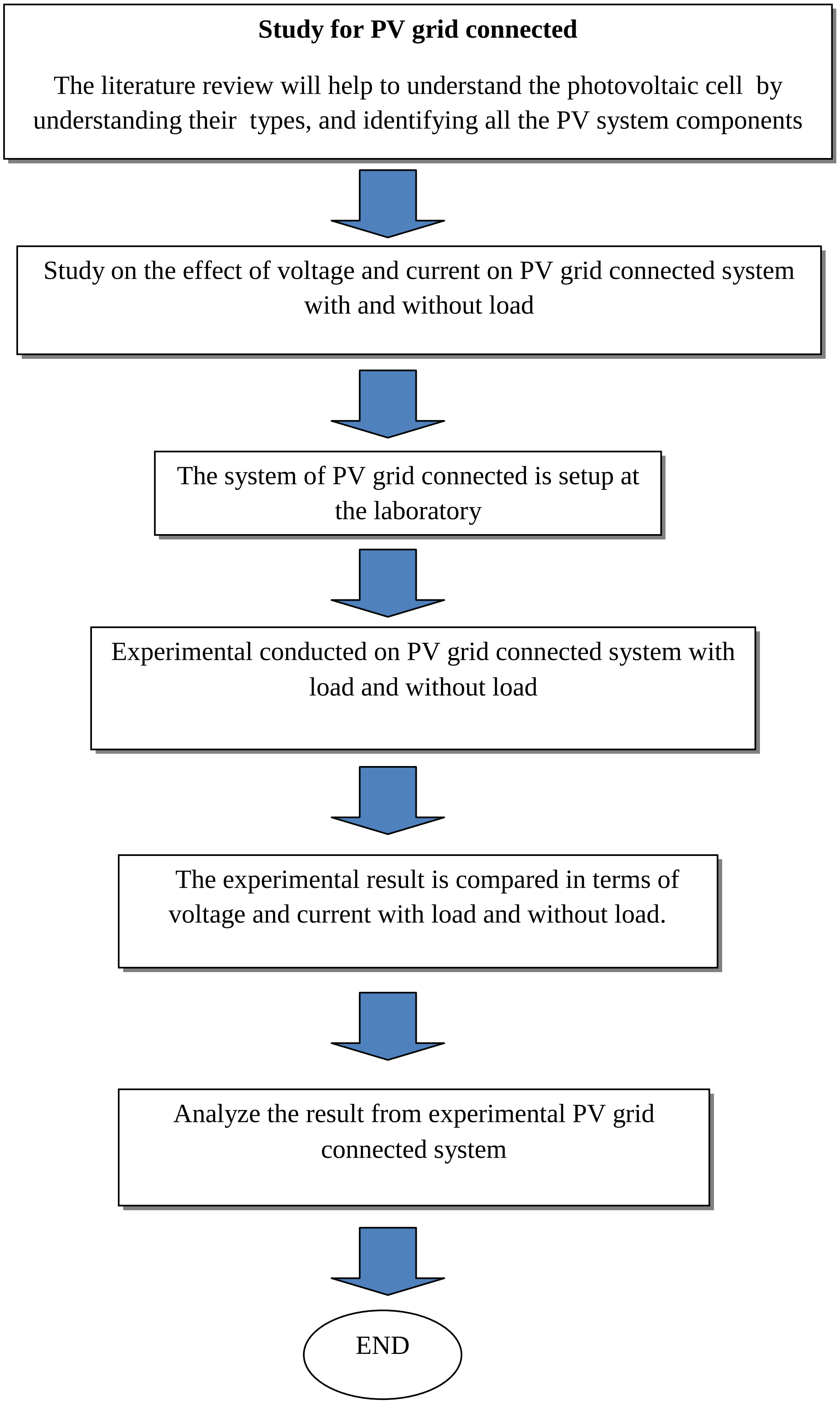

Figure 3.1.1 Methodology flow chart

3.2 Circuit Topologies

Tie to the grid supply. Grid supply must be present at all time. The PV grid connected system is also called grid-interactive, grid-intertie, utility connected are built onto our building that transfers DC power from the PV array to the utility supply through grid inverter. There are five major component involves namely PV array, array junction box (AJB), DC and AC cables, inverter and export/import energy meters.

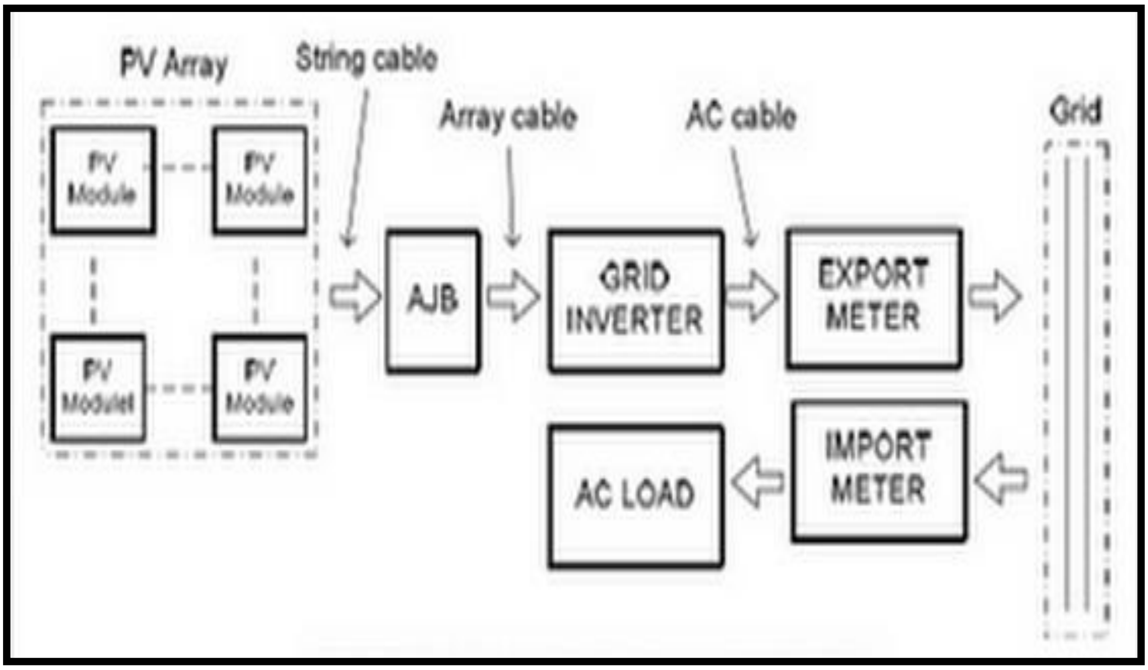

Figure 3.2.1 Block diagram of PV grid connected[32]

3.3 Experimental Method

The Figure 3.2.1 shows that operation of the system for a day light start from morning till evening. This experiment starts at 11 am and end at 6 pm. In this experiment, both supply which is supply from PV and grid was used. PV array 1.5 kW was used and motor 0.7 hp used as load and this motor was setup at 1500rmp. The measurement was recorded at the measurement points which shown in Figure 1. Data Total Harmonic Distortion (THD) for voltage and current was measure by using fluke power quality analyser. In PV supply side, the measurement point is situated between inverter and switch box. Meanwhile, in Grid supply side, the measurement point is situated between main supply and switch box. Figure 3.2.2 shows the .PV grid connected system was installed at laboratory. In this experiment consist of PV array, grid connected system, inverter, power supply, non-linear loads, linear loads, power quality analyzer, and hydraulic pump (as variable load). An experiment on power quality will be analysis of a network of one motor (figure 3.2.3) connected to PV and grid system. System impedance at the drive input is considered to be constant and the input harmonic distortions are determined by drive load factors only. Experimental results from this research will be important to further understand the interaction and hence reveal how the drives interact with each other.

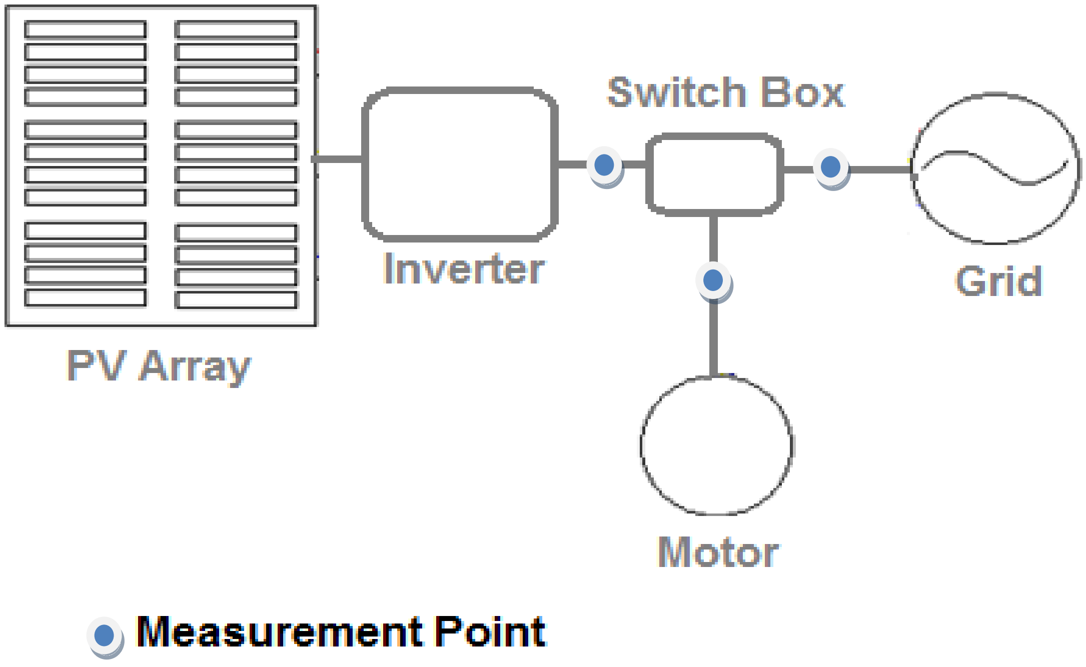

Figure 3.3.1 Measurement point in diagram system

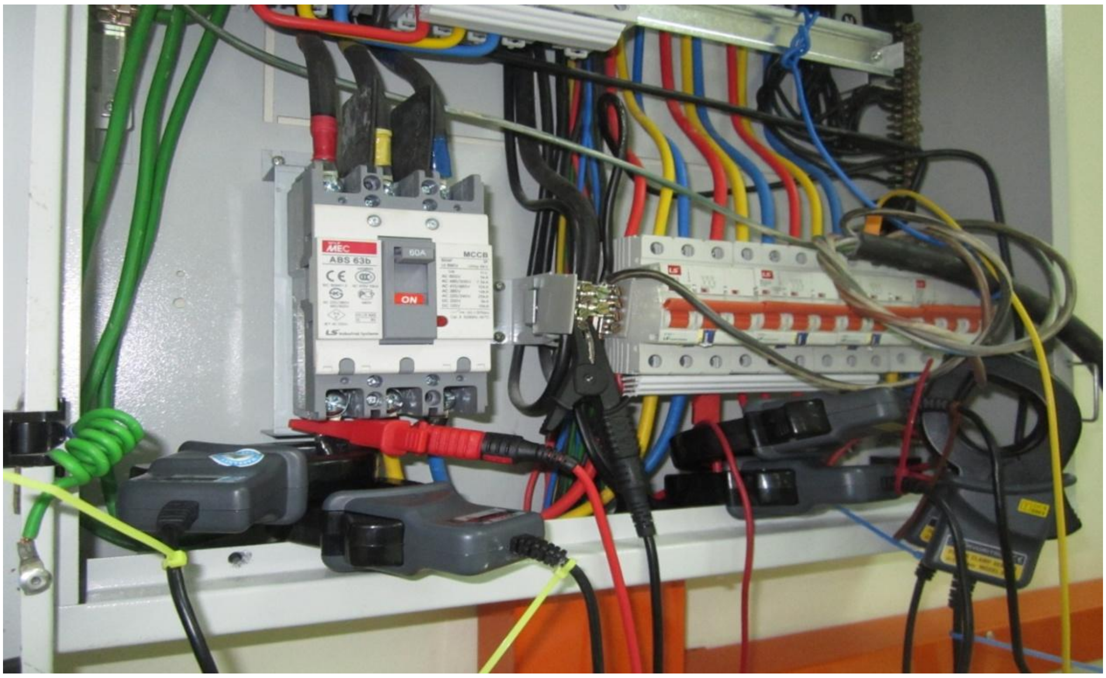

Figure 3.3.2 Grid Connecter System

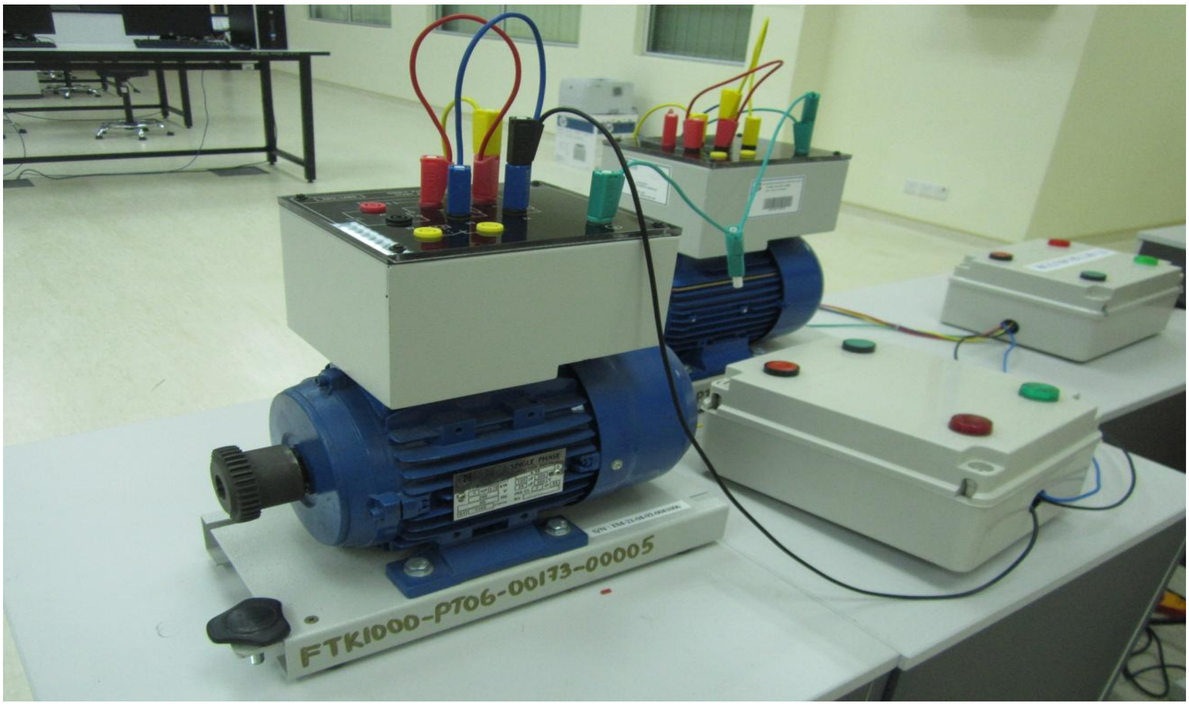

Figure 3.3.3 Motor Start Run Capacitor

CHAPTER IV

RESULT AND DISCUSSION

This chapter discussed about the results gained from the experiment on PV grid grid connected system. The voltage and current at PV grid connected system is overall covered thru this part. The THD and waveform form power quality analyzer is collected. Result from experimental demonstrate without load and with load(the load is varied by hydraulic pump)

4.1. Total Harmonic Distortion(THD) Of Voltage (without varied load)

a) THDv at PV side

The graph in Figure 4.1.1 shows the characteristic of Total Harmonic Distortion (THD) at PV side for this experiment.

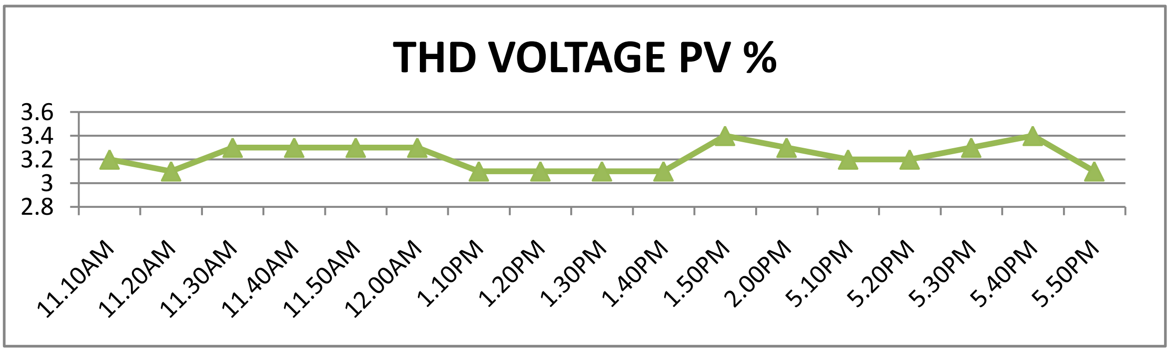

Figure 4.1.1 Total Harmonic Distortion (THDv) at PV side

This graph is the function of Total Harmonic Distortion(THD) in percentage versus time. The measurement was conducted for 3 hours started from 11 am till 6.00 pm on 10/3/2012.

In this experiment, THDv for PV-Grid Connected with motor as a load is shown in graphs as in figure 4.1.1. In general, for measurements at PV measurement point show the result less than 4%.

b) THDv at grid side

The graph in Figure 4.1.2 above shows the characteristic of Total Harmonic Distortion(THD) at grid side for this experiment

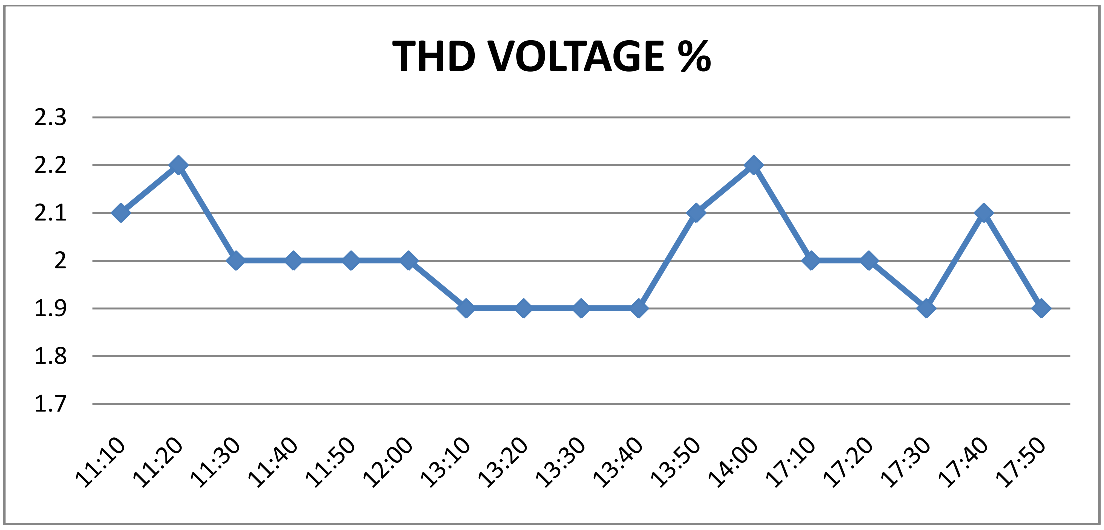

Figure 4.1.2 Total Harmonic Distortion(THDv) at grid side

This graph is the function of Total Harmonic Distortion(THD) in percentage versus time. The measurement was conducted same as the THDv of PV is taken.

In this experiment, THDv for Grid with motor as a load is shown in graphs as in figure 4.1.2. In general, for measurements at grid measurement point show the result less than 2.2%.

c) THDv at motor side

The graph in Figure 4.1.3 above shows the characteristic of Total Harmonic Distortion (THDv) at motor side for this experiment.

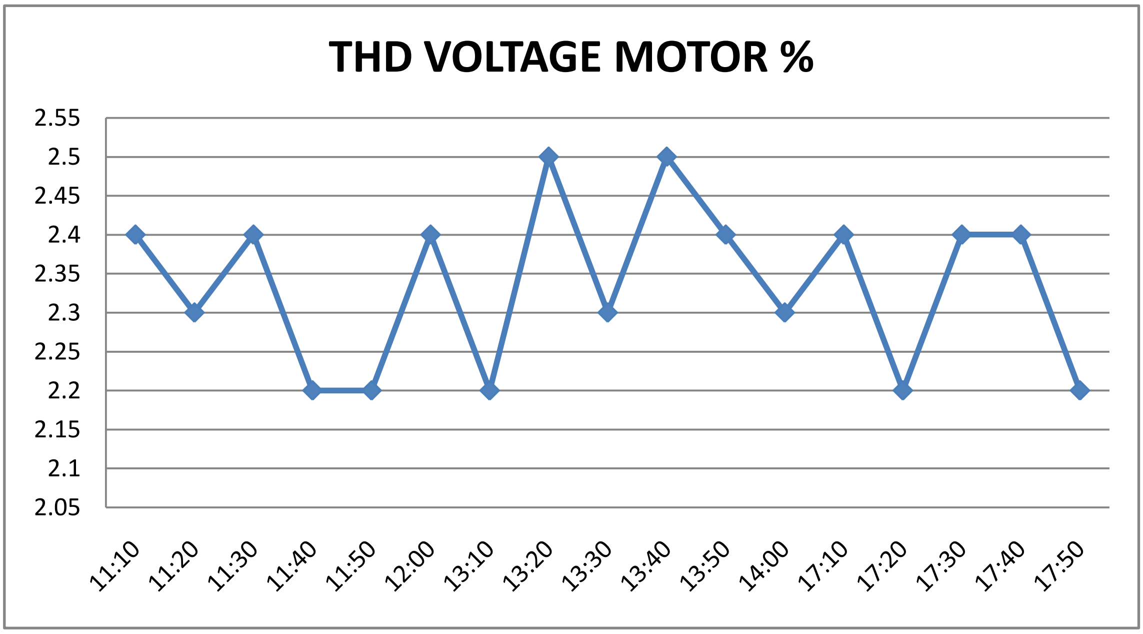

Figure 4.1.3 Total Harmonic Distortion(THDv) at motor side

This graph is the function of Total Harmonic Distortion(THD) in percentage versus time. The measurement was conducted same as the THDv of PV is taken. In this experiment, THDv for Grid with motor as a load is shown in graphs as in figure 4.1.3. In general, for measurements at motor measurement point show the result less than 2.5%.

In general, for measurements at each measurement point show all result not more 4%. THDv for PV system is high compare to THDv grid and THDv motor. This is because by power electronics equipment which generates more harmonic distortion. The equipment such as inverter will produce harmonic distortion to the system

4.2 Total Harmonic Distortion(THD) Of current (without varied load)

a) THDi at PV side

The graph in Figure 4.2.1 above shows the characteristic of Total Harmonic Distortion (THDi) at PV side for this experiment.

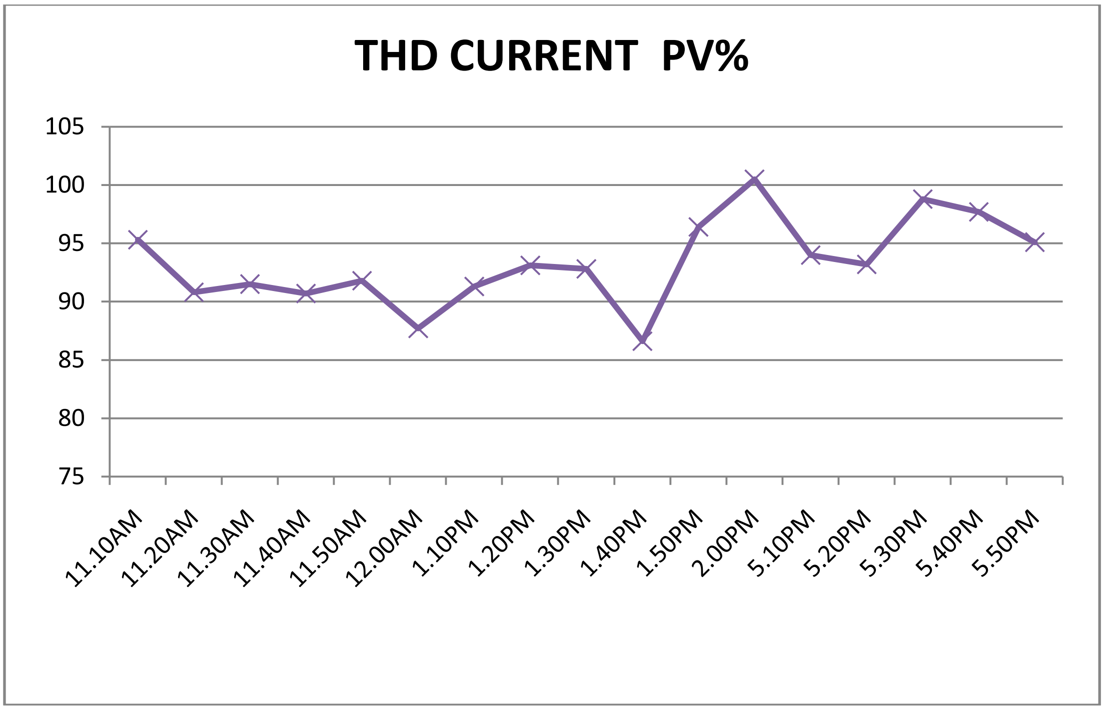

Figure 4.2.1 Total Harmonic Distortion (i) at PV side

The analysis of current distortion is important, especially since the power quality issues relating to harmonic distortion of the current waveform are the responsibility of the customer compared to voltage distortion in which much of the responsibility of maintaining a clean voltage waveform lies on the utility [3].

For analysis of the current distortion, the THDi for grid connection is shown in graphs as in figure 4.2.1. From the graph, THDi of PV for measurements at PV measurement point shows the result less than 100%.

b) THDi at grid side

The graph in Figure 4.2.2 shows the characteristic of Total Harmonic Distortion (THDi) at grid side for this experiment.

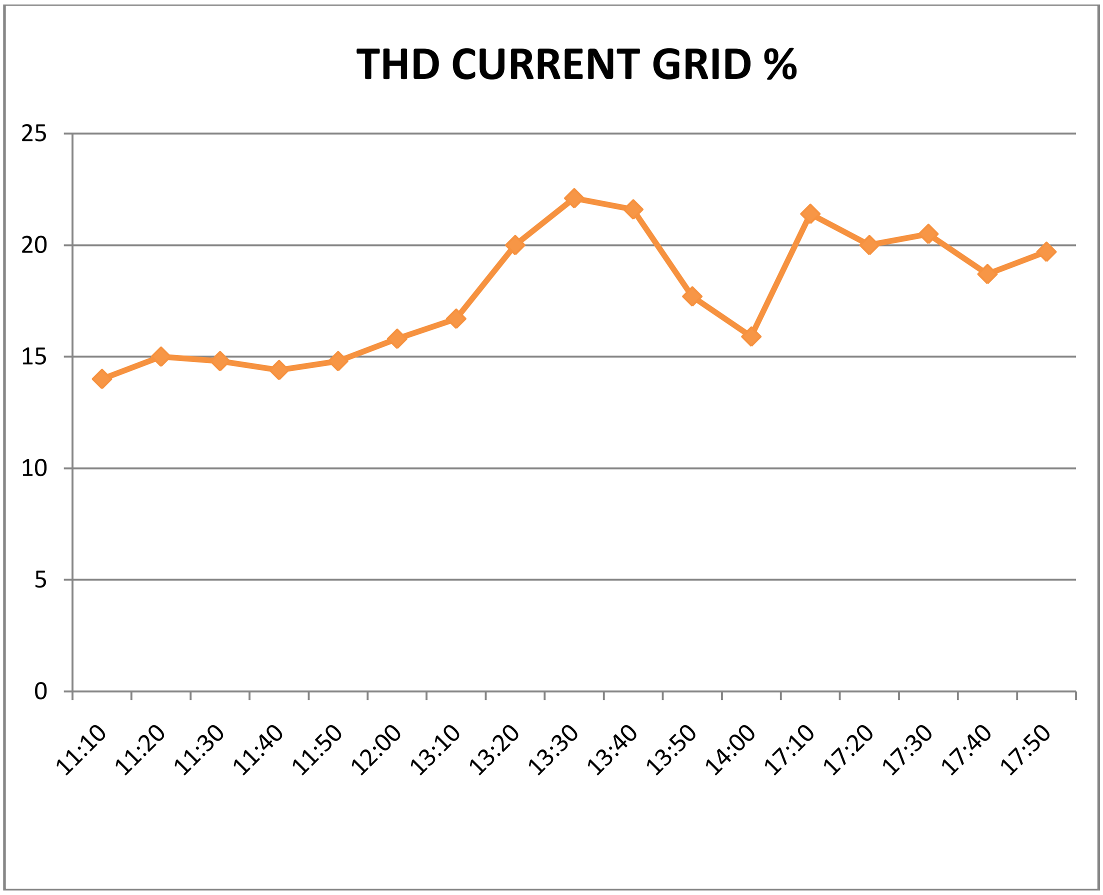

Figure 4.2.2 Total Harmonic Distortion(i) at grid side

This graph is the function of Total Harmonic Distortion (THD) in percentage versus time. The measurement was conducted same as the THDi of PV is taken

In this experiment, THDi for Grid with motor as a load is shown in graphs as in figure 4.2.2. In general, for measurements at motor measurement point show the result less than 25%.

c) THDi at motor side

The graph in Figure 4.2.3 shows the characteristic of Total Harmonic Distortion (THDi) at grid side for this experiment.

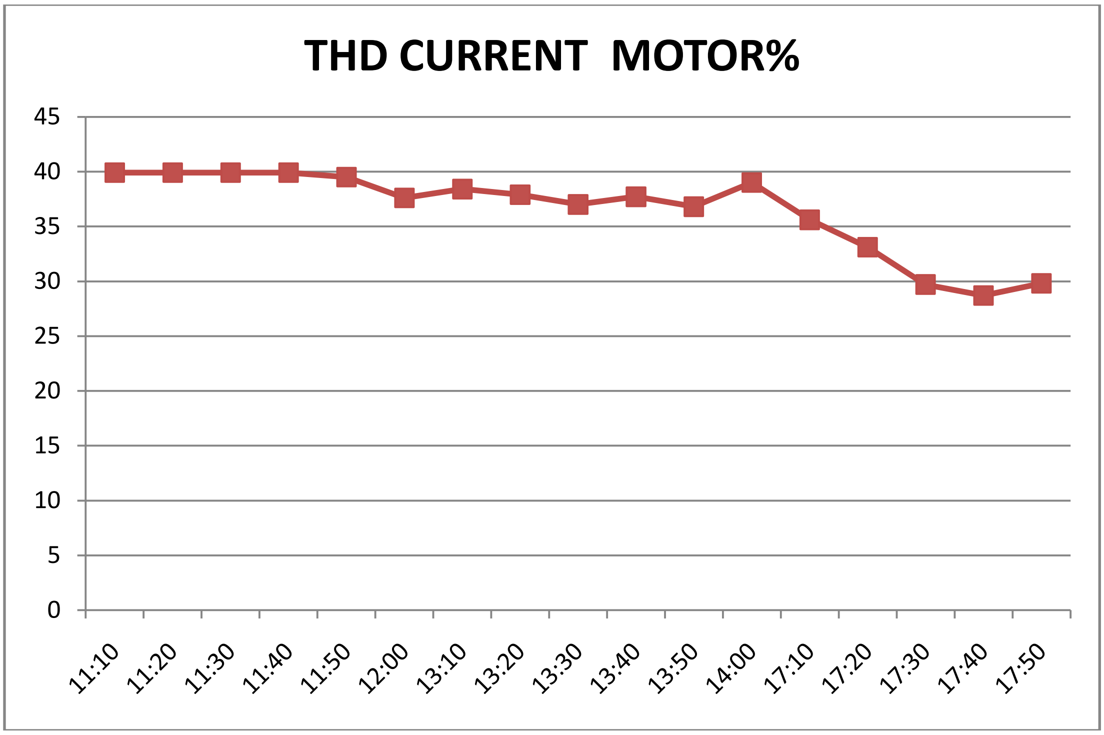

Figure 4.2.3 Total Harmonic Distortion(i) at motor side

This graph is the function of Total Harmonic Distortion (THD) in percentage versus time. The measurement was conducted same as the THDi of PV is taken.

In this experiment, THDi for Grid with motor as a load is shown in graphs as in figure 4.2.3. In general, for measurements at motor measurement point show the result less than 40%.

4.3 Total Harmonic Distortion(THD) Of Voltage (with varied load in condition PV off ,motor on)

a) THDv at PV side

The graph in Figure 4.3.1 shows the characteristic of Total Harmonic Distortion (THDv) at PV side for this experiment.

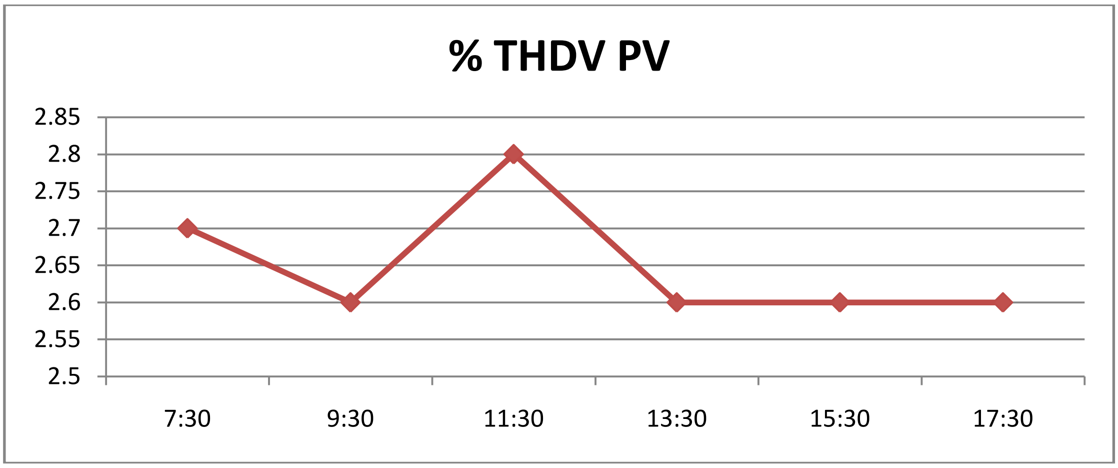

Figure 4.3.1 Total Harmonic Distortion(v) at PV side

b) THDv at grid side

The graph in Figure 4.3.2 shows the characteristic of Total Harmonic Distortion (THDv) at grid side for this experiment.

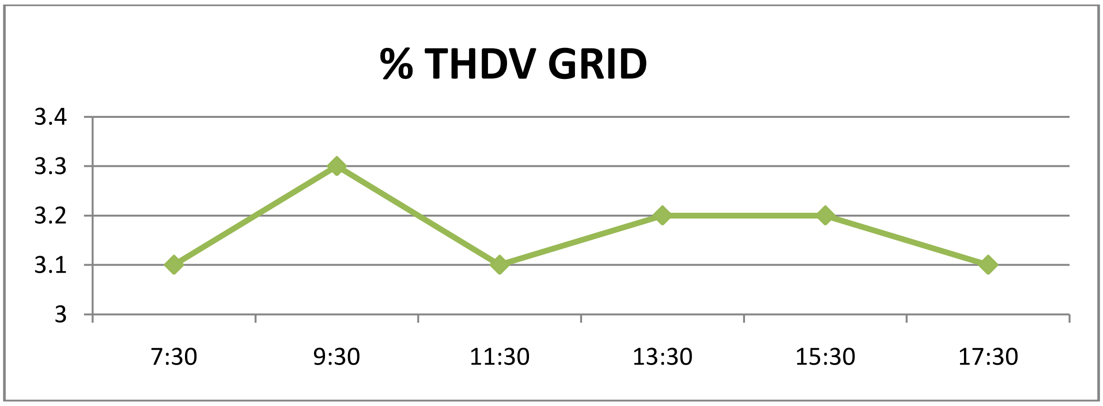

Figure 4.3.2 Total Harmonic Distortion(v) at grid side

c)THDv at motor side

The graph in Figure 4.3.3 shows the characteristic of Total Harmonic Distortion (THDv) at motor side for this experiment

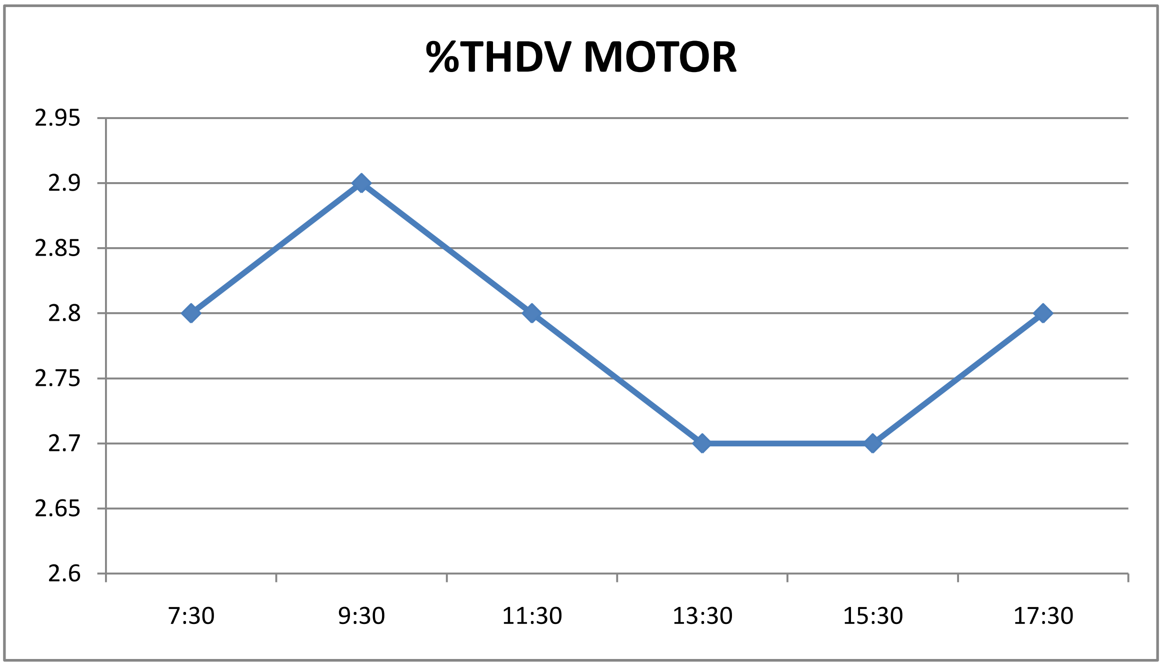

Figure 4.3.3 Total Harmonic Distortion(v) at motor side

The graph in Figure 4.3.1.4.3.2,and 4.3.3 above shows the characteristic of Total Harmonic Distortion(THDv) at PV,grid,motor side for condition PV is off and motor is on. This graph is the function of Total Harmonic Distortion (THD) in percentage versus time.

The measurement was conducted with variation of load at different time. At 7.30 a.m the current motor load is varied to 2.3A.At 9.30 am, turn the current to 2.5A.At 11.30 a.m, turn the current to2.8 A. At 13.30 pm, the current is turned to 2.9 A.At 15:30 and 17:30,the current of motor is turned to 2.9A and 3.1 A. When the load is changed, the voltage at PV,grid and motor side is also affected.

4.4 Total Harmonic Distortion(THD) Of current (with varied load in condition PV off motor on)

a) THDi at PV side

The graph in Figure 4.4.1 shows the characteristic of Total Harmonic Distortion (THDi) at PV side for this experiment.

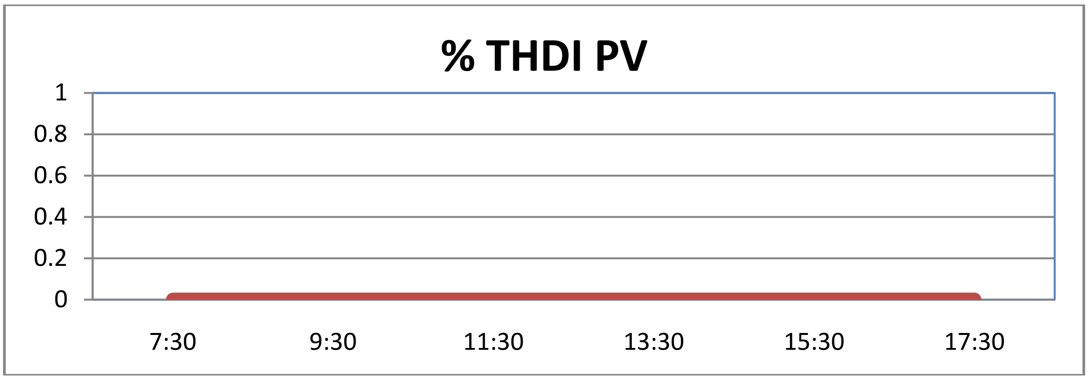

Figure 4.4.1 Total Harmonic Distortion (i) at PV side

b)THDi at grid side

The graph in Figure 4.4.2 shows the characteristic of Total Harmonic Distortion (THDi) at grid side for this experiment.

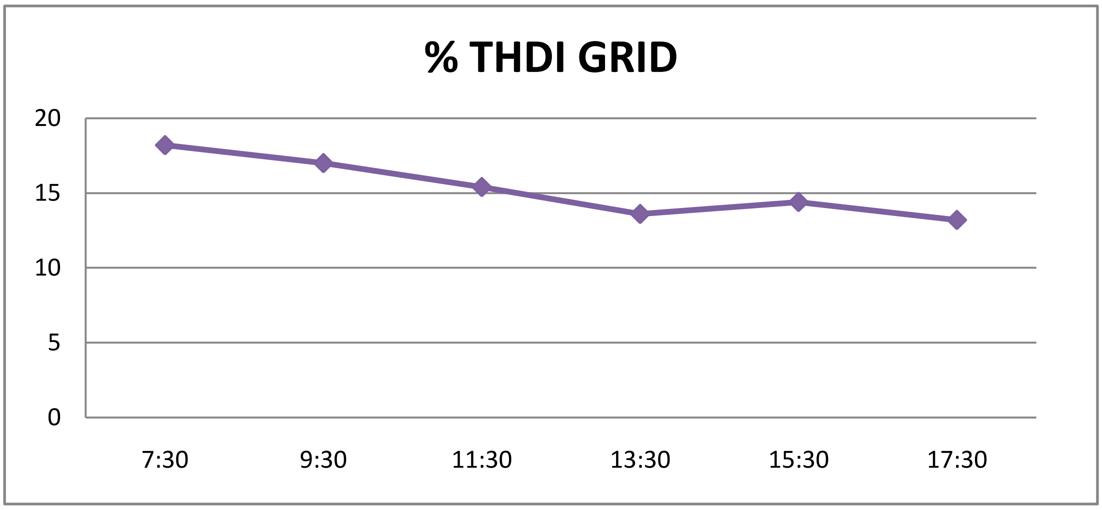

Figure 4.4.2 Total Harmonic Distortion (i) at grid side

c)THDi at motor side

The graph in Figure 4.4.3 shows the characteristic of Total Harmonic Distortion (THDi) at motor side for this experiment.

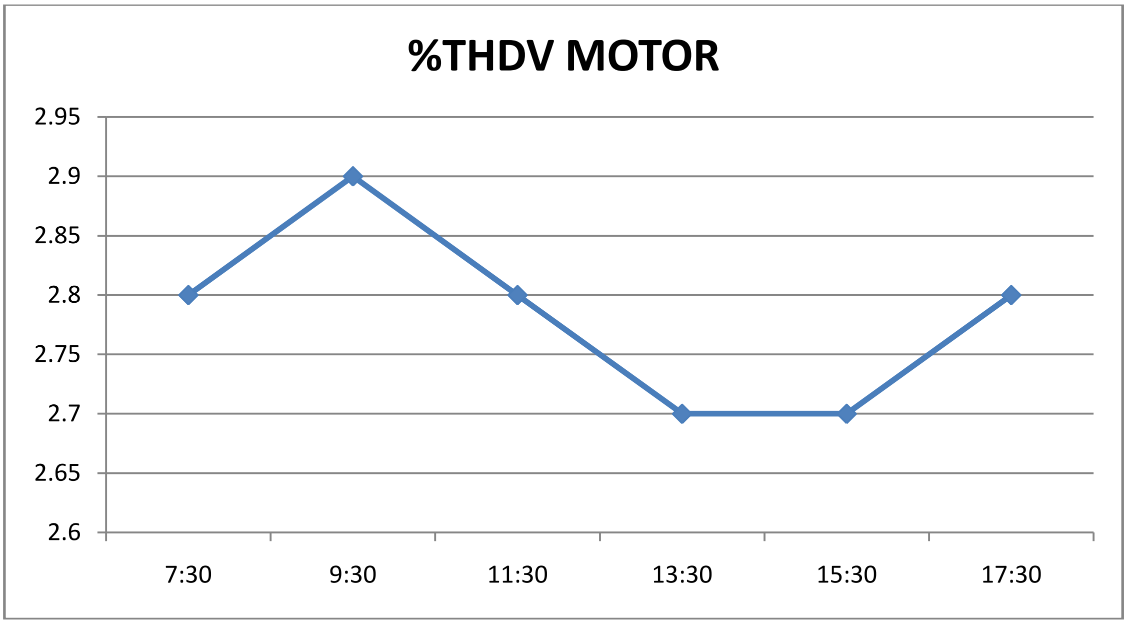

Figure 4.4.3 Total Harmonic Distortion(i) at motor side

The graph in Figure 4.4.1.4.4.2,and 4.4.3 above shows the characteristic of Total Harmonic Distortion(THDi) at PV,grid,motor side for condition PV is off and motor is on. This graph is the function of Total Harmonic Distortion(THD) in percentage versus time. The measurement was conducted with variation of load at different time.At 7.30 a.m the current motor load is varied to 2.3A.At 9.30 am,turn the current to 2.5A.At 11.30 a.m,turn the current to2.8 A.At 13.30 pm,the current is turned to 2.9 A.At 15:30 and 17:30,the current of motor is turned to 2.9A and 3.1 A. When the load is changed,the current at grid and motor side is also affected.But it is not affected the current at PVside.

4.5 Total Harmonic Distortion(THD) Of voltage (with varied load in condition PV on motor on)

a) THDv at pv side

The graph in Figure 4.5.1 shows the characteristic of Total Harmonic Distortion (THDv) at PV side for this experiment.

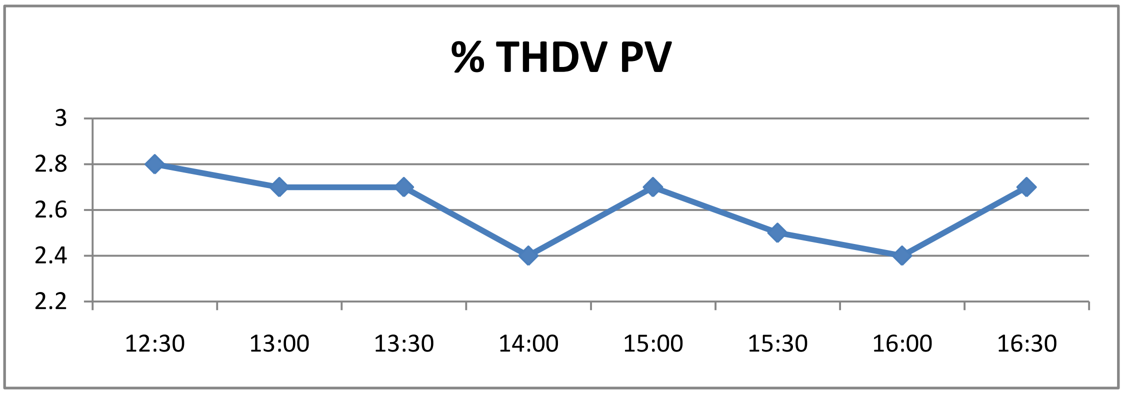

Figure 4.5.1 Total Harmonic Distortion(v) at PV side

b) THDv at grid side

The graph in Figure 4.5.2 shows the characteristic of Total Harmonic Distortion (THDv) at grid side for this experiment.

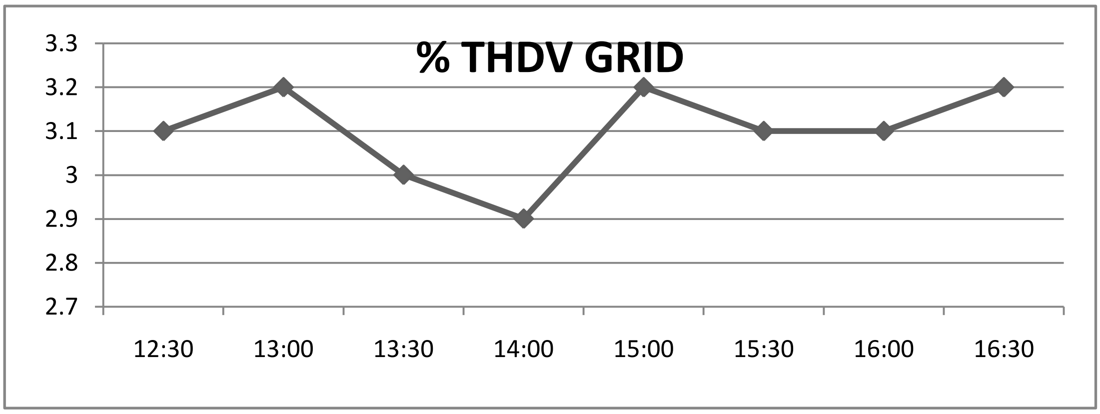

Figure 4.5.2 Total Harmonic Distortion(v) at grid side

c)THDv at motor side

The graph in Figure 4.5.3 shows the characteristic of Total Harmonic Distortion (THDv) at motor side for this experiment.

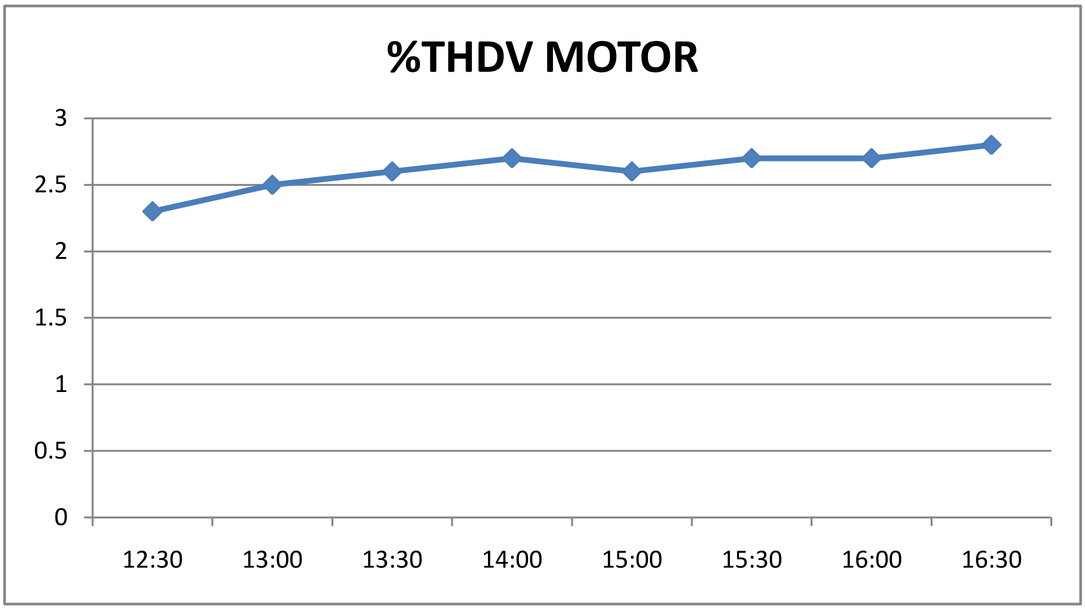

Figure 4.5.3 Total Harmonic Distortion(v) at motor side

The graph in Figure 4.5.1.4.5.2,and 4.5.3 above shows the characteristic of Total Harmonic Distortion(THDv) at PV,grid,motor side for condition PV is on and motor is on. This graph is the function of Total Harmonic Distortion(THD) in percentage versus time. The measurement was conducted with variation of load at different time.At 12.30 p.m the current motor load is varied to 2.5A.At 13.00 pm,turn the current to 2.7A.At 13.30p.m, the current is turned to 2.8 A.At 14.00 pm,the current is turned to 2.9 A.At 15:00 and 15:30,the current of motor is turned to 2.9A and 3.1 A. When the load is changed,the voltage at PV,grid and motor side is also affected.But it seems really affected at PVside and grid side.

4.6 Total Harmonic Distortion(THD) Of current (with varied load in condition PV on motor on)

a)THDi at pv side

The graph in Figure 4.6.1 shows the characteristic of Total Harmonic Distortion (THDi) at PV side for this experiment.

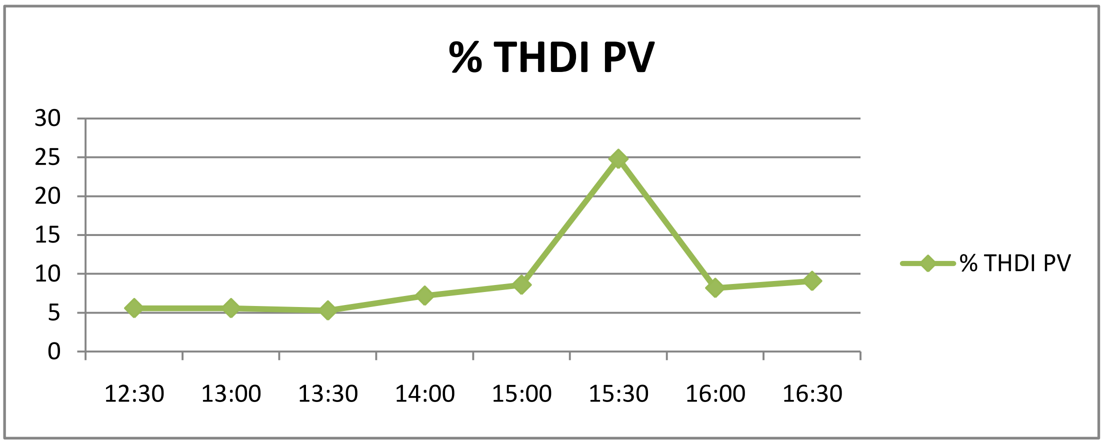

Figure 4.6.1 Total Harmonic Distortion(i) at PV side

b)THDi at grid side

The graph in Figure 4.6.2 shows the characteristic of Total Harmonic Distortion (THDv) at grid side for this experiment

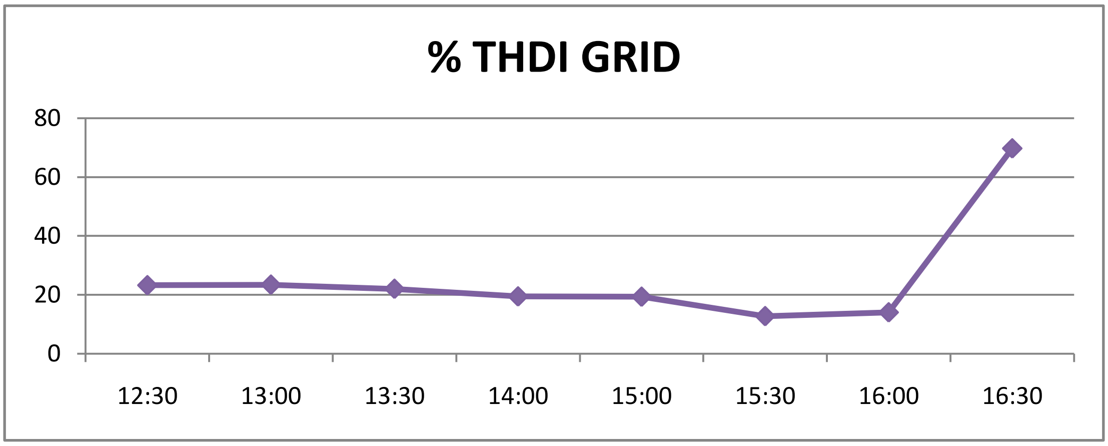

Figure 4.6.2 Total Harmonic Distortion(i) at grid side

c) THDi at motor side

The graph in Figure 4.6.3 shows the characteristic of Total Harmonic Distortion (THDi) at motor side for this experiment.

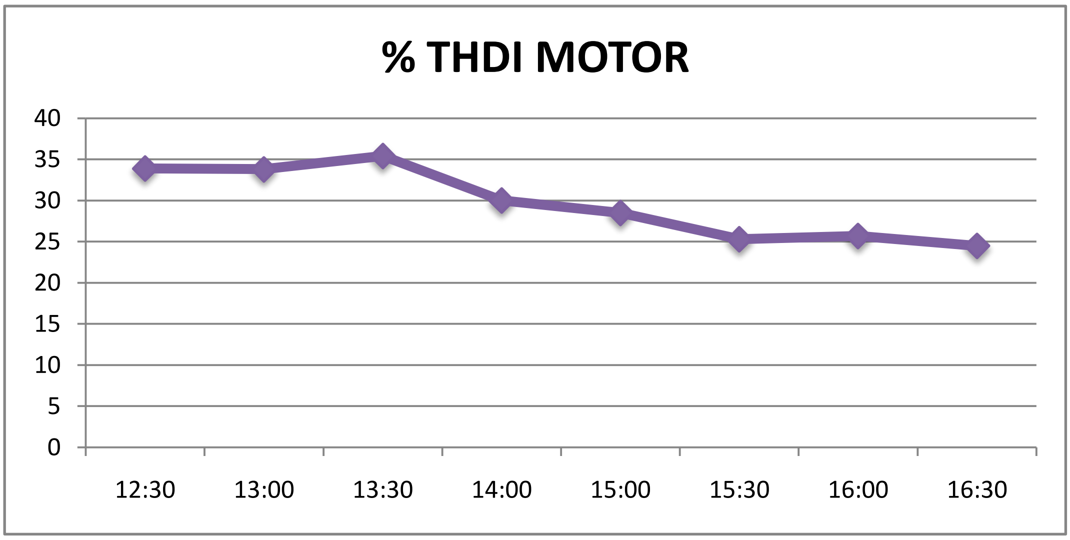

Figure 4.6.3 Total Harmonic Distortion(i) at motor side

The graph in Figure 4.6.1.4.62,and 4.6.3 above shows the characteristic of Total Harmonic Distortion(THDi) at PV,grid,motor side for condition PV is on and motor is on. This graph is the function of Total Harmonic Distortion(THD) in percentage versus time. The measurement was conducted with variation of load at different time.At 12.30 p.m the current motor load is varied to 2.5A.At 13.00 pm,turn the current to 2.7A.At 13.30p.m, the current is turned to 2.8 A.At 14.00 pm,the current is turned to 2.9 A.At 15:00 and 15:30,the current of motor is turned to 2.9A and 3.1 A. When the load is changed,the current at PV,grid and motor side is also affected.But it seems really affected at PVside and grid side.

4.7 Total Harmonic Distortion(THD) Of voltage (without load in condition PV on motor off)

a)THDv at PV side

The graph in Figure 4.7.1 shows the characteristic of Total Harmonic Distortion (THDv) at PV side for this experiment.

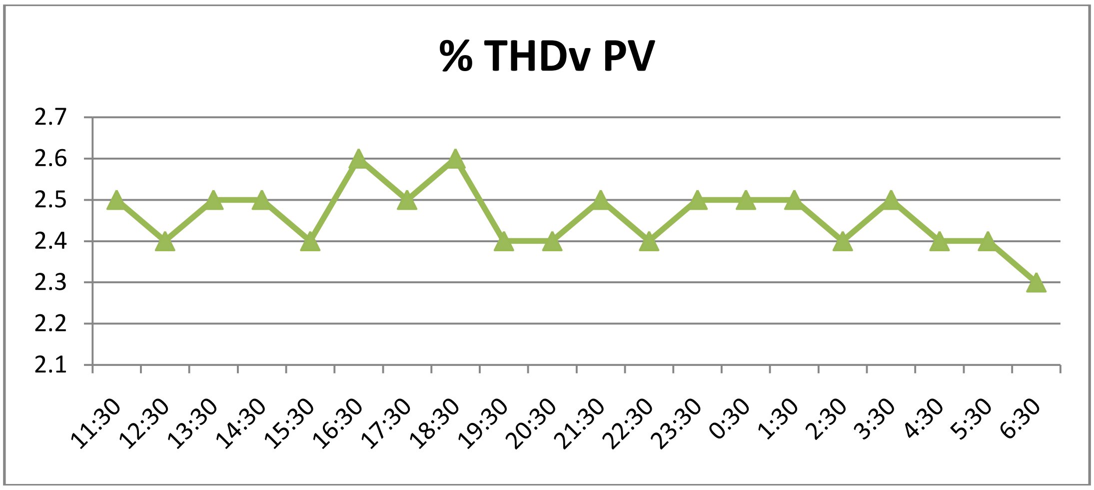

Figure 4.7.1 Total Harmonic Distortion(v) at PV side

b)THDv at grid side

The graph in Figure 4.7.2 shows the characteristic of Total Harmonic Distortion (THDv) at grid side for this experiment.

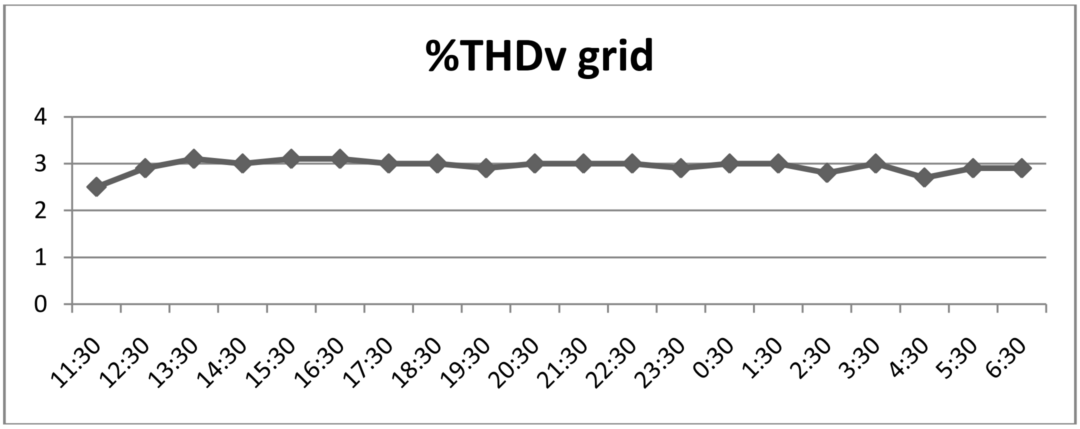

Figure 4.7.2 Total Harmonic Distortion (v) at grid side

c)THDv at motor side

The graph in Figure 4.7.3 shows the characteristic of Total Harmonic Distortion (THDv) at motor side for this experiment.

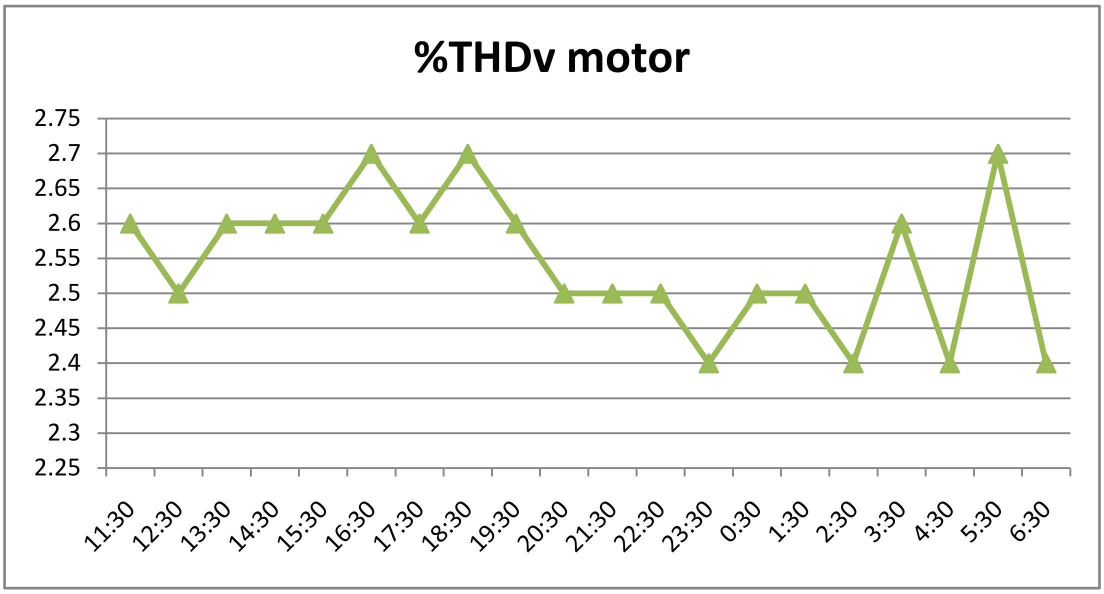

Figure 4.7.3 Total Harmonic Distortion(v) at motor side

The graph in Figure 4.7.1.4.7.2,and 4.7.3 above shows the characteristic of Total Harmonic Distortion(THDv) at PV,grid,motor side for condition PV is on and motor is on. This graph is the function of Total Harmonic Distortion(THD) in percentage versus time. The measurement was conducted without load .Generally,the THDv at PV and motor site changed very drastically due to the time.The THDv of PV is getting lower at the evening. But the THDv of grid does not show so much changes.

4.8Total Harmonic Distortion(THD) Of current (without load in condition PV on motor off)

a)THDi at pv side

The graph in Figure 4.8.1 shows the characteristic of Total Harmonic Distortion (THDi) at PV side for this experiment.

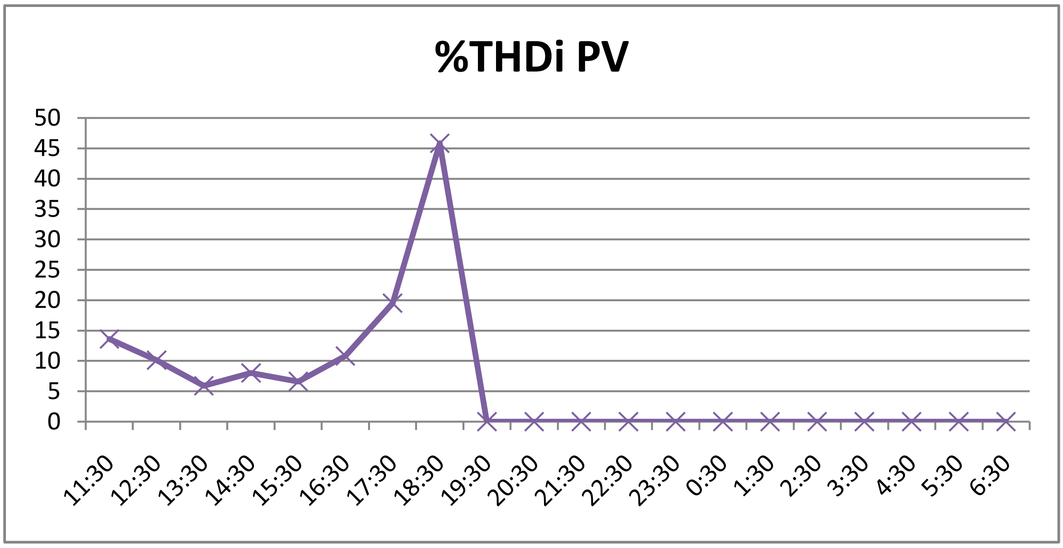

Figure 4.8.1 Total Harmonic Distortion(i) at PV side

b)THDi at grid side

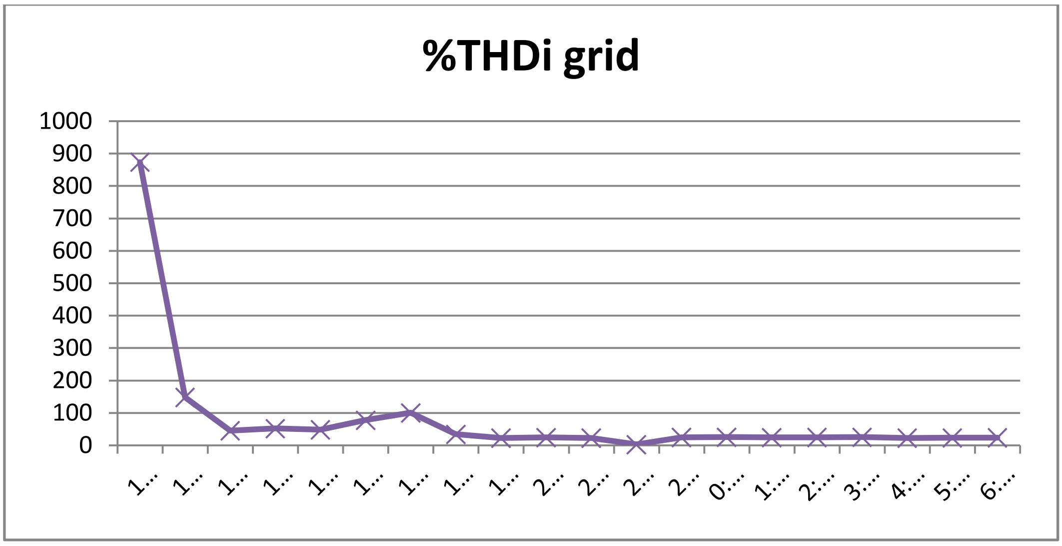

Figure 4.8.2 Total Harmonic Distortion(i) at grid side

c)THDi at motor side

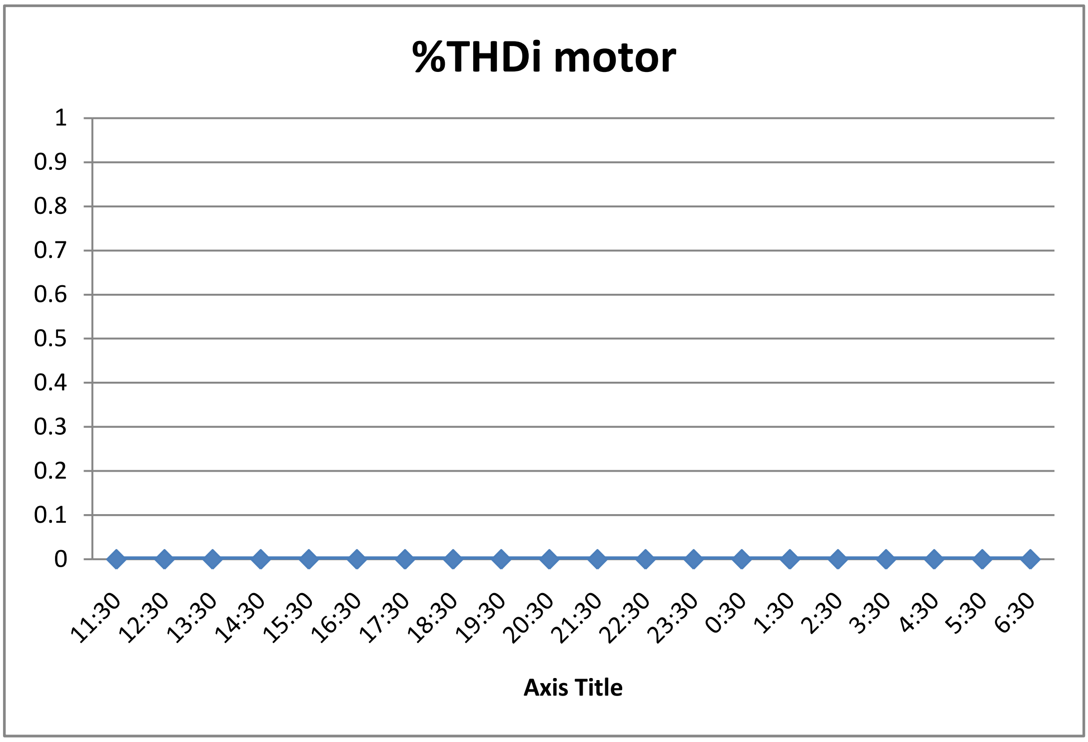

Figure 4.8.3 Total Harmonic Distortion(i) at motor side

The graph in Figure 4.8.1.4.8.2,and 4.8.3 above shows the characteristic of Total Harmonic Distortion(THDi) at PV,grid,motor side for condition PV is on and motor is on. This graph is the function of Total Harmonic Distortion(THD) in percentage versus time. The measurement was conducted without load .It seems THDiat PV , site changed very drastically at 19:30.While the THDi of grid at 11:30am drop to 150%.Maybe due to the usage of electricity at 11:30 am is the peak hour and is getting lower at the evening. But the THDi of motor remain zero.

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The analysis of PV-inverter system connected to a motor as a load has been presented. As results, the optimum operating condition based on the worst and best case operating scenarios has been obtained. The analysis of the data shows trends in the harmonics behavior in the system which connected to induction motors and can be used to analyze power quality impact to the grid system. Additionally, this research can be used to reduce the higher total harmonic distortion in power system with a network of adjustable speed drives based on worst case operating scenarios.

5.2 Recommendation

For future, the analysis part where the efficiency of the PV system also can be studied by using more than one load with different type of motor. Other than that, the smart PV panel is another interesting part to work on as the maximum power point changes according to cell temperature and solar radiation. The maximum power point tracking system can be studied using the artificial intelligence to have better yield of energy output. As grid connected project concerns the power electronics, the use of multiple inverters also can be studied to see the effects on power network with multiple inverters.

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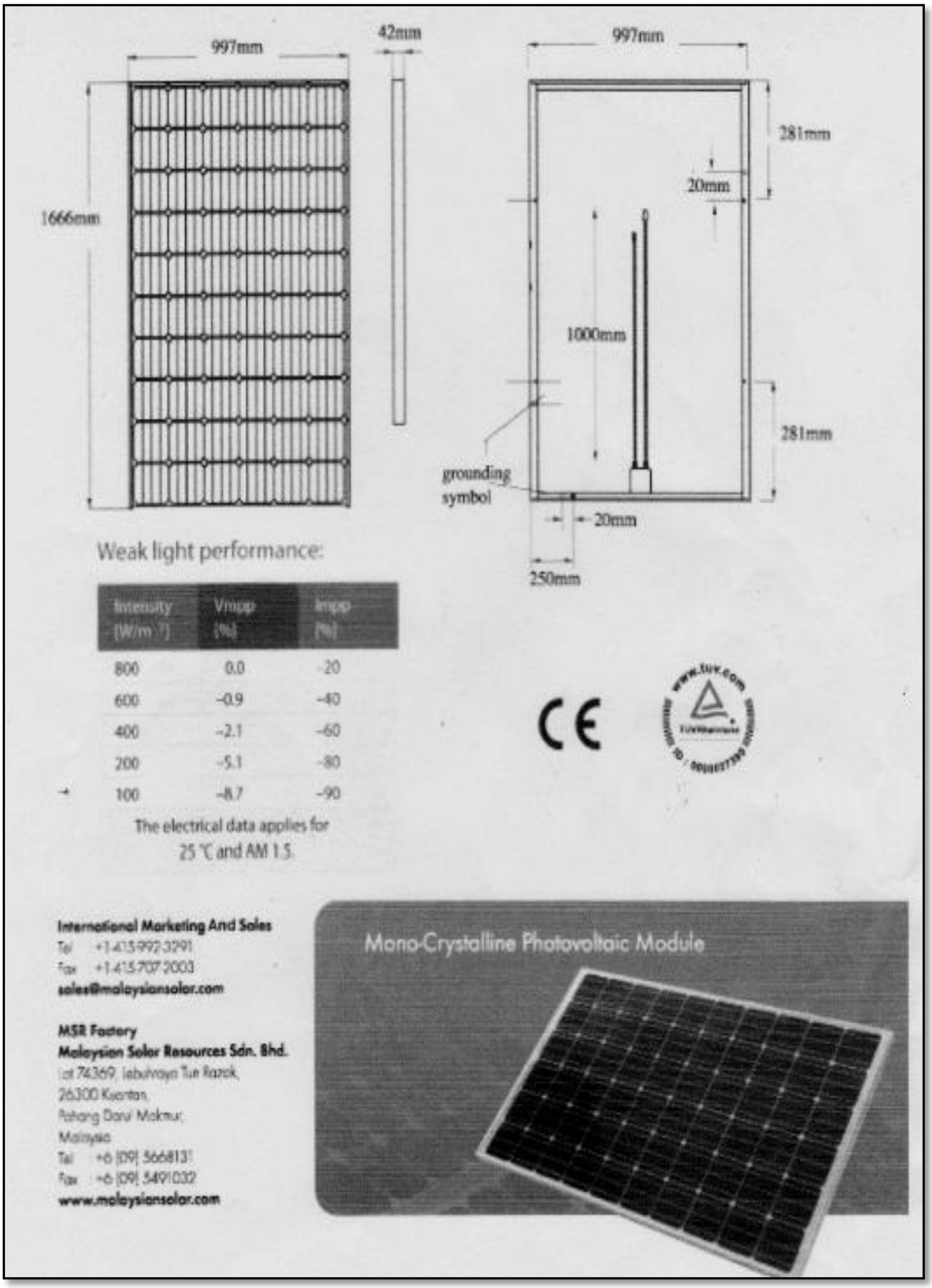
APPENDIX A



Weak light performance:

Intensity (W/m²)	Vmpp (%)	Impp (%)
800	0.0	-20
600	-0.9	-40
400	-2.1	-60
200	-5.1	-80
100	-8.7	-90

The electrical data applies for 25 °C and AM 1.5.

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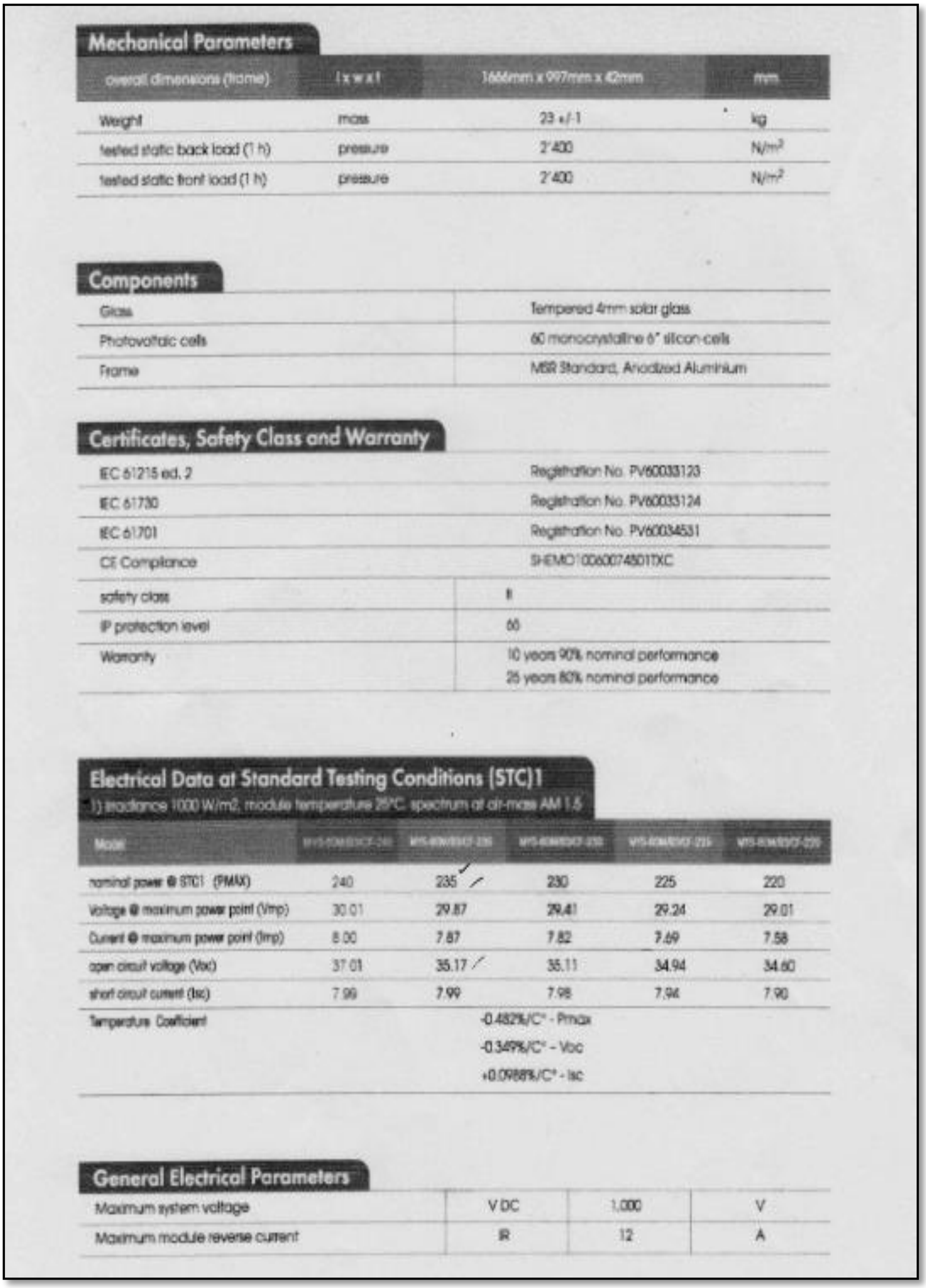
26300 Kuantan,
Pahang Darul Makmur,
Malaysia
Tel +6 (09) 5668131
Fax +6 (09) 5491032
www.malaysiansolar.com

Mono-Crystalline Photovoltaic Module

Figure A.1 Datasheet A for PV Array Module



Mechanical Parameters

overall dimensions (frame)	l x w x t	1666mm x 997mm x 42mm	mm
Weight	mass	23 +/-1	kg
tested static back load (1 h)	pressure	2'400	N/m²
tested static front load (1 h)	pressure	2'400	N/m²

Components

Glass	Tempered 4mm solar glass
Photovoltaic cells	60 monocrystalline 6" silicon cells
Frame	MSR Standard, Anodized Aluminium

Certificates, Safety Class and Warranty

IEC 61215 ed. 2	Registration No. PV60033123
IEC 61730	Registration No. PV60033124
IEC 61701	Registration No. PV60034531
CE Compliance	SHEMO10060074501TXC
safety class	II
IP protection level	65
Warranty	10 years 90% nominal performance 25 years 80% nominal performance

Electrical Data at Standard Testing Conditions (STC)1

1) irradiance 1000 W/m2, module temperature 25°C, spectrum at air-mass AM 1.5

Model	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
nominal power @ STC1 (PMAX)	240	235 ✓	230	225	220
Voltage @ maximum power point (Vmp)	30.01	29.87	29.41	29.24	29.01
Current @ maximum power point (Imp)	8.00	7.87	7.82	7.69	7.58
open circuit voltage (Voc)	37.01	35.17 ✓	35.11	34.94	34.60
short circuit current (Isc)	7.99	7.99	7.98	7.94	7.90
Temperature Coefficient		-0.482%/C° - Pmax -0.349%/C° – Voc +0.0988%/C° - Isc			

General Electrical Parameters

Maximum system voltage	V DC	1,000	V
Maximum module reverse current	IR	12	A

Figure A.2 Datasheet B for PV Array Module

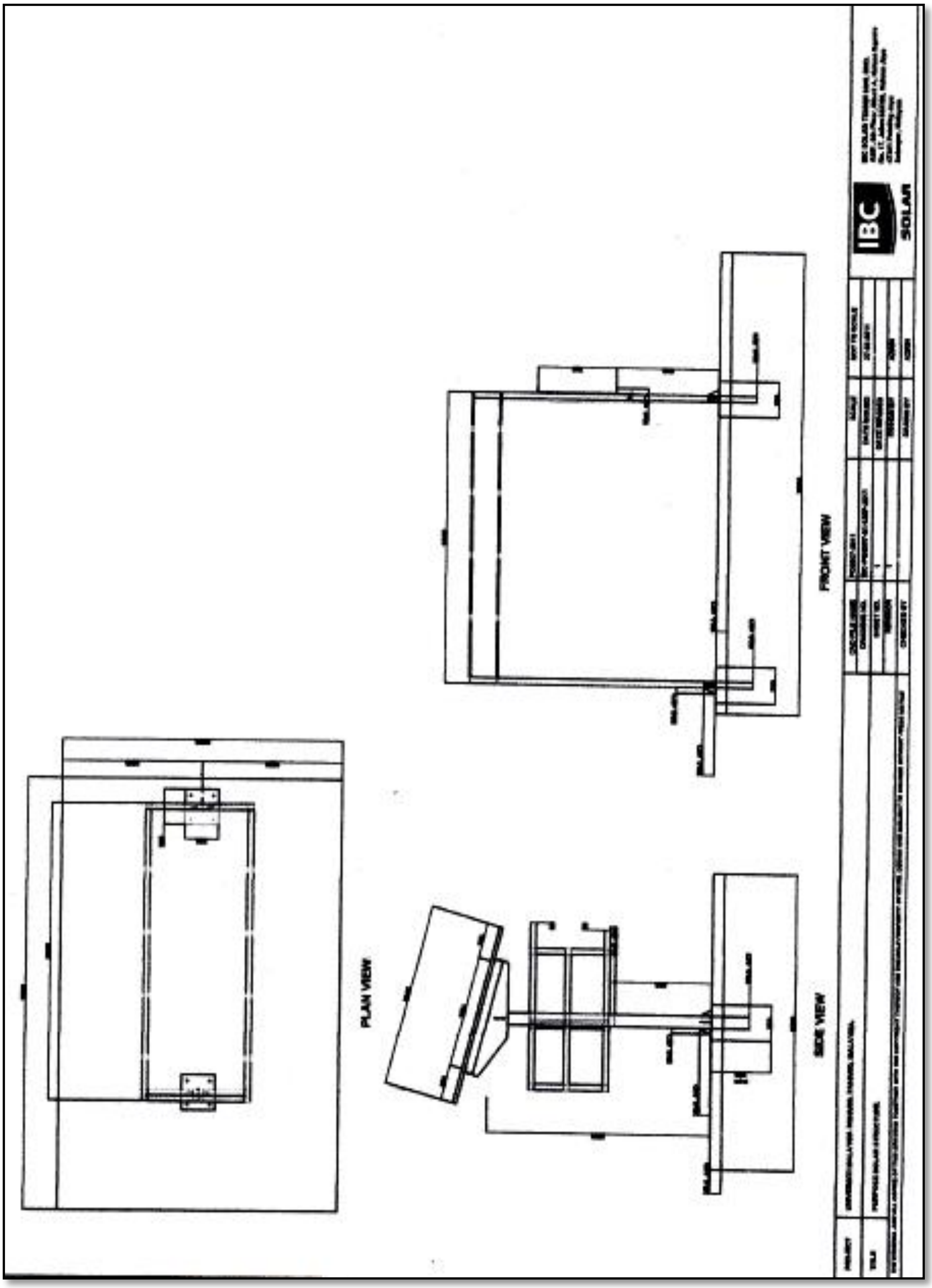


Figure A.3 Alignment of PV Array