EXPERIMENTAL AND SIMULATION STUDY OF WIND TURBINE GRID
CONNECTED

NURUL IZZATI YUSOP

A Report Submitted In Partial Fulfilments of the Requirement of the Degree of
Bachelor of Electrical Engineering (Power System)

Faculty of Electrical Engineering

University Malaysia Pahang

JUNE 2012

UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS◆

JUDUL: **EXPERIMENTAL AND SIMULATION STUDY OF WIND TURBINE GRID CONNECTED**

SESI PENGAJIAN: _____2011/2012_____

Saya _____NURUL IZZATI BINTI YUSOP (890722-01-5958)_____

(HURUF BESAR)

mengaku membenarkan tesis (Sarjana Muda/~~Sarjana~~ /~~Doktor Falsafah~~)* ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hakmilik Universiti Malaysia Pahang (UMP).
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (√)

☐	**SULIT**	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
☐	**TERHAD**	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
√	**TIDAK TERHAD**	

Disahkan oleh:

_____
(TANDATANGAN PENULIS)

_____
(TANDATANGAN PENYELIA)

Alamat Tetap:

C-1-7 JALAN BELIUNG 6,
TAMAN KERIS LAKSAMANA,
PENJARA MELAKA,76300 SUNGAI UDANG,
MELAKA

PN. SULIANA BINTI AB GHANI
(Nama Penyelia)

Tarikh: _____

Tarikh: _____

CATATAN:
* Potong yang tidak berkenaan.
** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh tesis ini perlu dikelaskan sebagai atau TERHAD.
◆ Tesis dimaksudkan sebagai tesis bagi Ijazah doktor Falsafah dan Sarjana secara Penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

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

Signature   : _____

Name   : <u>PN. SULIANA BINTI AB GHANI</u>

Date   : _____

"All the trademark and copyrights use herein are property of their respective owner

References of information from other sources are quoted accordingly; otherwise the

information presented in this report is solely work of the author."

Signature : _____

Name   : NURUL IZZATI YUSOP

Date   : 1st JUNE 2012

Special dedicated to my beloved

Father, Yusop bin Abdullah,

Mother, Zaiton binti Majuri,

Also to my brothers and sisters. Ainul Syahirah, Nurul Fatehah,

Mohd Nasuha and Mohd Ifwat

ACKNOWLEDGEMENT

First of all, thanks to Allah SWT on His blessing to make this project successful. I wish to express my thankful and appreciation to my supervisor, Puan Suliana Ab Ghani, whose encourage, guide and support from the initial to the final level with her patience and knowledge enabled me to develop an understanding of the project. Her invaluable guidance and advice in this project has been a source of inspiration through the course of this project.

My deepest gratitude goes to my beloved mother, Zaiton Majuri, my adorable father, Yusop Abdullah and also my lovely brothers and sisters for their unconditional support and loving care. I remembered their constant support when I encountered some difficulties. They are my eternal source of inspiration in every aspect and every moment of my life

Finally, I would also like to express my sincere grateful to all my friends especially Nurul Aini Norizan and Irsyarudin for their helping during the time in need and who had directly or indirectly contributed in one way or another towards to accomplish of this project. Last but not least, thank you to all that always supported me in any respect during the completion of the project.

ABSTRACT

At present, it is very common to find renewable energy resources, especially wind power that connected to grid systems. In the growing electricity supply industry and open access market for electricity worldwide, renewable sources are getting added into the grid system. To assess the impact the wind turbine grid connected system, the knowledge of electrical characteristic of wind turbine and associated control equipments are required. This project presents experimental based and simulation for wind turbine by using MATLAB / SIMULINK. The presented control scheme provides the wind power flow to the grid through a converter and inverter. The advantages of using wind generator is environmental friendly refers than portable generator. As practically, wind generator does not use any raw material but portable generator uses the fuel or petrol to generate the electricity. Wind turbine grid connected system will be developed and established for the study. The elements of this project show how the voltage, current and power is being measured in this network environment. Experimental and simulation study on this entire control scheme is carried out by using MATLAB. The experimental and simulation results show the control performance and dynamic behaviour of the wind system it is to assess the impact on the grid system and load was used to simulate the real network environment. Results from experimental and research will be compared.

ABSTRAK

Pada masa ini, kebiasaan untuk mencari sumber tenaga yang boleh diperbaharui terutamanya tenaga angin yang disambungkan pada sistem grid. Dalam industri bekalan elektrik yang semakin meningkat dan akses pasaran terbuka untuk bekalan elektrik di seluruh dunia, tenaga yang boleh diperbaharui untuk digunakan di dalam sistem grid. Untuk mengetahui kesan sistem grid turbin angin, pengetahuan ciri-ciri elektrik turbin angin dan peralatan kawalan yang berkaitan diperlukan. Projek ini menjalankan eksperimen dan simulasi untuk turbin angin dengan menggunakan MATLAB / Simulink. Skema sistem kawalan yang dijalankan menyediakan aliran angin kuasa kepada grid melalui converter. Kelebihan untuk menggunakan penjana angin adalah merujuk mesra alam sekitar daripada penjana mudah alih. Secara praktikal, penjana angin tidak menggunakan mana-mana bahan mentah tetapi penjana mudah alih menggunakan bahan api atau petrol untuk menjana tenaga elektrik. Sistem turbin angin akan dibangunkan dan ditubuhkan untuk kajian. Teknologi elemen pengukuran projek ini menunjukkan bagaimana voltan, arus dan kuasa yang diukur dalam persekitaran rangkaian ini. Kajian eksperimen dan simulasi seluruh skema kawalan ini dijalankan menggunakan MATLAB. Keputusan simulasi menunjukkan prestasi kawalan dan tingkah laku dinamik sistem angin. Untuk menilai kesan ke atas sistem grid dan beban akan diubah untuk mensimulasikan persekitaran rangkaian yang sebenar.

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURE

LIST OF ABBREVIATIONS

AC	Alternating current
DC	Direct Current
PWM	Pulse Width Modulation
PQA	Power Quality Analyzer
GUI	Graphical User Interface
THD	Total Harmonic Distortion
THDv	Total Harmonic Distortion Voltage
THDi	Total Harmonic Distortion Current

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

1.1   Wind Generator and Grid Connected System

Wind generator is commonly used in many windy places. Wind turbines are used to generate electricity from the kinetic power of the wind. Historical they were more usually used as a mechanical device to turn machinery. There are two types of wind generators, those with a vertical axis, and those with a horizontal axis. Wind turbines can be used to generate large amounts of electricity in wind farms both onshore and offshore. Therefore, this type of wind turbine is mainly considered and many diagnostic procedures are proposed from consumer. It will uses in application in a wide costly. Wind energy conversion includes wind energy turn into mechanical energy and then to electrical energy. The conversion will influence the property, efficiency and the power quality. Most of the wind turbines are equipped with synchronous generators (SG). They are simple in construction and offer impressive efficiency under varying operating conditions. Induction machines are relatively not expensive and require minimum maintenance. The characteristics of these generators like the over speed capability make suitable for wind turbine application. Recent advance in Power Electronics have made it possible to regulate the SG in many ways, which has resulted in an increased interest in the use of SG for small scale power generation with wind power.

A grid-connected system allows powering home or small business with renewable energy during those periods when the wind is blowing. Any excess electricity produce is fed back into the grid. When renewable resources are

unavailable, electricity from the grid supplies your needs, thus eliminating the expense of electricity storage devices like batteries. In addition, power providers in most states allow net metering, an arrangement where the excess electricity generated by grid-connected renewable energy systems electricity meter as it is fed back into the grid.

The function of torque is to eliminate the need for converting the alternating current produced by the turbines into direct current and back again before it is fed into the grid. As the rotational speed of the wind turbine, and the generator that is connected to the rotor change depends on the force of the wind, the alternating current it produces must be rectified so that it can be fed into the grid with the correct frequency – usually 50 or 60 hertz.

To accomplish this, the alternating current from the wind turbine generators is transformed into direct current using rectifiers before being transformed back into alternating current of the right frequency. To attain the desired grid frequency of 50 hertz, a generator with the usual two poles pairs must operate at a synchronous speed. The motor allows the power from the rotor to be either boosted or diverted to ensure a constant rotational speed for the generator.

1.2   Problem Statement

This project studied about the performance voltage and current at the grid with wind turbine and without wind turbine. And also power quality disturbance in various condition in wind turbine grid connected.

1.3   Objective

The objectives of this project are:

i.   To simulate the wind turbine grid connected system by simulation and experimental.

ii.   To analyze the impact performance of wind turbine on the grid system.

iii.   To compares results in simulation and experimental.

1.4   Scope of Project

The scopes of this project cover literature reviews on the theory of wind turbine grid connected system based on performance and harmonic distortion in wind turbine grid connected system. In addition, analysis the performance will be made using in MATLAB/Simulink and experimental was setup in small scale at laboratory. The analysis of the performance in wind turbine will be compared with the experimental and simulation.

1.5   Outline of Thesis

Chapter I consists of the overview of the project, which includes the problem statement, objectives and scope.

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 illustrates the operation and the parameters involved in the wind turbine grid connected system. The circuit topology that uses power electronics approach for wind turbine grid connected system is described in detail.

Chapter IV presents the simulation design of the wind grid connected system using MATLAB/Simulink and by the experimental. It also consists of the simulation results, experimental result and discussion based on the performance of the wind turbine grid connected waveforms produced.

Chapter V concludes the overall thesis and for future work.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

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. The related works have been referred carefully since some of the knowledge and suggestions from the previous work can be implemented for this project. Literature review was ongoing process throughout the whole process of the project. It is very essential to refer to the variety of sources in order to gain more knowledge and skills to complete this project. These sources include thesis, journal and also the materials obtained from internet.

2.2 Wind Energy

Wind power energy is the conversion of wind energy into a useful form of energy, such as using wind turbine to make electricity, wind mills for mechanical power, wind pumps for pumping water or drainage, or sails to propel ships. Global wind energy resources are up to 53,000 billion kilowatts, which is equivalent to 2 times of the electrical demand in the world. [1] The annual energy in the wind at a given location depends on the wind-velocity-duration-distribution, which, in general, can be expressed mathematically as a Weibull function, which involves two parameters, i.e. a shape parameter and a characteristic speed. In strong winds, the power output could be limited by only covering part of the blades. With a diameter

typically, of about 25 m, the traditional windmill could deliver a shaft power output of about 30 kW in a wind speed of about 7 m/s (force 4): in a well exposed location, it would give and average power output of about 10 kW, corresponding to an energy output of about 100 kWh per working day. [2]

2.3   Wind Generator

The Electrically Excited Synchronous Generator (EESG) is usually built with a rotor carrying the field system conveys with a direct current (DC) excitation. The stator carries a three-phase winding quite alike to the induction machine. The rotor may have salient poles or may be cylindrical. Salient poles are more common in low-speed machines and may be the most worthwhile version for application to direct-drive wind turbines. [3] To increase the efficiency, to reduce the weight of the active parts, and to keep the end winding losses small, direct-drive generators are usually designed with a large diameter and small pole pitch. Compared with the traditional electrically excited synchronous generator, the necessity of a large pole number can be met with permanent magnets which allow small pole pitch. [4]

2.4   DC and AC Current

In the world today there are currently two forms of electrical transmission, Direct Current (DC) and Alternating Current (AC), each with its own advantages and disadvantages. DC powers supply the appeal of a steady constant voltage across a circuit resulting in a constant current. Most digital circuitry today is run off in DC power as it carries the ability to produce either a constant high or constant low voltage, enabling digital logic to process code execution. [5] The idea is used the DC supply from the battery and any devices that used today is in AC current.

2.5   Inverter

Input inverter has the following advantages which are power from the PV array or the wind turbine can be delivered to the utility grid individually or simultaneously. Second is the maximum power point tracking (MPPT) feature can be realized for both solar and wind energy. Next is a large range of input voltage variation caused by different isolation and wind speed is acceptable. Lastly is a power rating of inverter can be decrease. [6]

2.6   Rectifier

Emulation of the wind turbine is confirmed by running the DC motor to track the theoretical rotational speed of the wind turbine rotor. A dynamic power controller is implemented and tested. The control uses the wind speed and rotor speed information to control the duty cycle of the buck-boost converter in order to operate the wind turbine at the optimum tip-speed ratio. Test results indicate that the proposed system accurately emulates the behaviour of a small wind turbine system. The output of the synchronous generator was first rectified by a 3-phase rectifier and then passed through a DC-DC converter. [7]
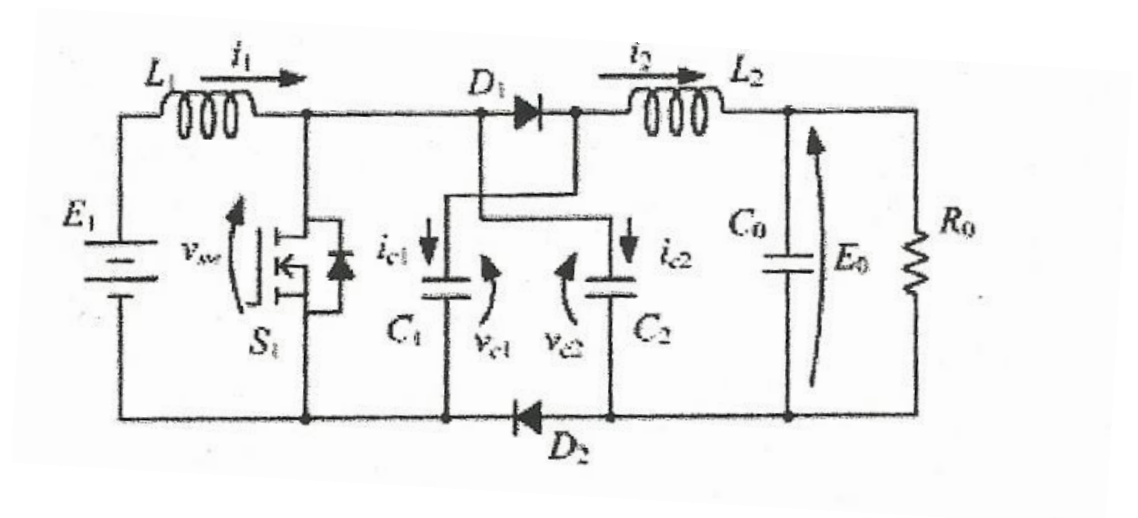

Figure 2.1 Rectifiers [7]

2.7 Wind Power System Used

Wind powered system can be used in two ways which are off-grid or on-grid is when house or buildings is entirely interrupted from electric utility company and wind can generate absolutely all of the electricity. Usually these systems cost about 30% more than an on-grid. A grid tie wind power system sends all of its electricity back into the public electrical network. So it is usually ideal to design a system that very closely offsets how much electricity you consume or just little less, than attempting to make money from the electric company. [8]

2.8 Benefits of Wind Power

Small wind energy systems can be used in connection with an electricity transmission and distribution system which is called grid-connected systems, or in stand-alone application that are not connected to the utility grid. A grid-connected wind turbine can reduce consumption of utility-supplied electricity for lighting, appliances, and electric heat. If the turbine cannot supply the amount of energy require, the utility makes up the difference. When the wind system generates more electricity than the household requires, the excess can be returned to the grid. With the interconnection can be obtained today, switching takes place automatically. Stand-alone wind energy systems can be appropriate for homes, farms, or even whole communities that are far from the nearest utility lines. [8]

2.9 MATLAB/SIMULINK

The most used software for modelling and simulation of dynamic systems is MATLAB/Simulink. Wind turbine systems such as dynamic systems, containing subsystems with different ranges of the time constants which are wind, turbine, generator, power electronics, transformer and grid [9]. There are two principle-connections of wind energy conversion. The first one is connecting the wind-

generator to grid at grid frequency. While connected to grid, grid supplies the reactive VAR required for the induction machines. Often, a DC-link is required to interface the wind-generator system with a certain control technique to the utility grid. The second is connecting the wind-generator system to isolated load in remote areas [10].

For modelling, Simulink provides a graphical user interface (GUI) for building models as block diagrams, using click and drag mouse operations. Simulink include a comprehensive block diagram of sinks, sources, linear and non linear components, and connectors. Simulink also customize and create own blocks. [11]

Using a choice integration method either from the Simulink menus or by entering commands in MATLAB's command window, after a model is defines, it can simulate the command. For running a batch simulation, the menus are particularly convenient for interactive work, while the command-line approach is very useful. The parameters can be change and immediately see what happen, for exploration. The MATLAB workspace for post processing and visualization can be put in the simulation result. [11]
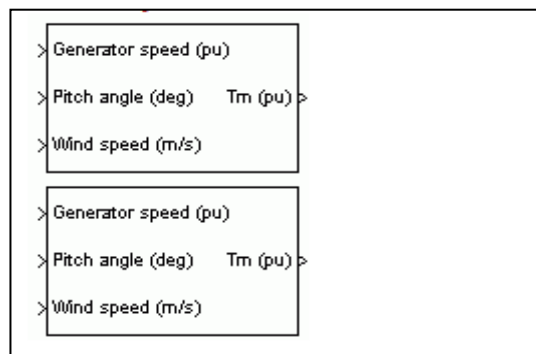
Figure 2.2   Description of wind turbine model
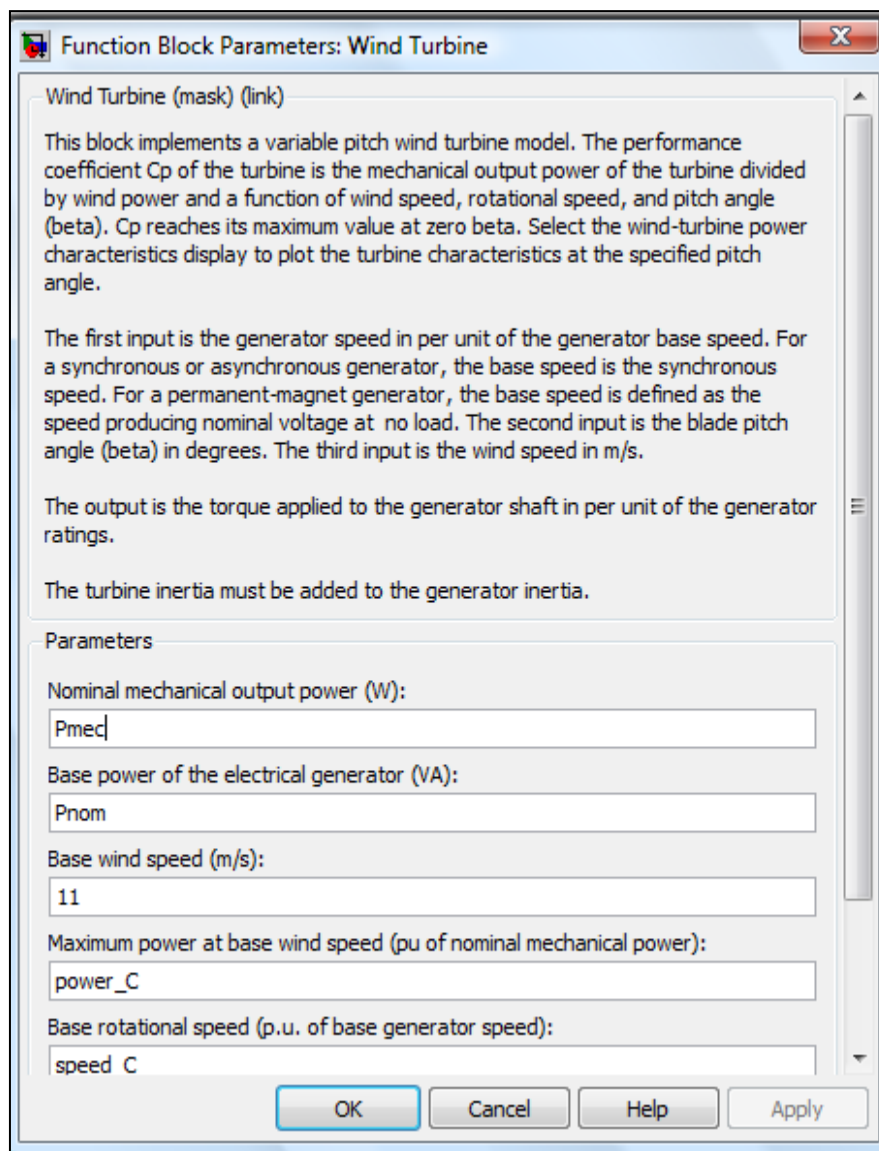
Figure 2.3   Function block parameter in wind turbine

2.10   Pulse Width Modulation

Pulse Width Modulation (PWM) is a capable technique for controlling analog circuits with a processor's digital outputs [12]. The applications of PWM are wide variety used like ranging from measurement and communications to power control and conversion. PWM is a way of digitally encoding analogue signal levels. The duty cycle of a square wave is modulated to encode a specific analogue signal level by using the high resolution centre. 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 analogue 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 off-time is the period during the supply is switched off. Given a sufficient bandwidth, any analogue value can be encoded with PWM [9]. Control of the switches for the sinusoidal PWM output requires a reference signal (modulating or control signal) which is a sinusoidal wave and carrier signal which is a triangular wave that control the switching frequency [12].

One reference signal is needed to generate the pulses for a single- or a two-arm bridge, and three reference signals are needed to generate the pulses for a three-phase, single or double bridge. The amplitude (modulation), phase, and frequency of the reference signals are set to control the output voltage (on the AC terminals) of the bridge connected to the PWM Generator block. [12]

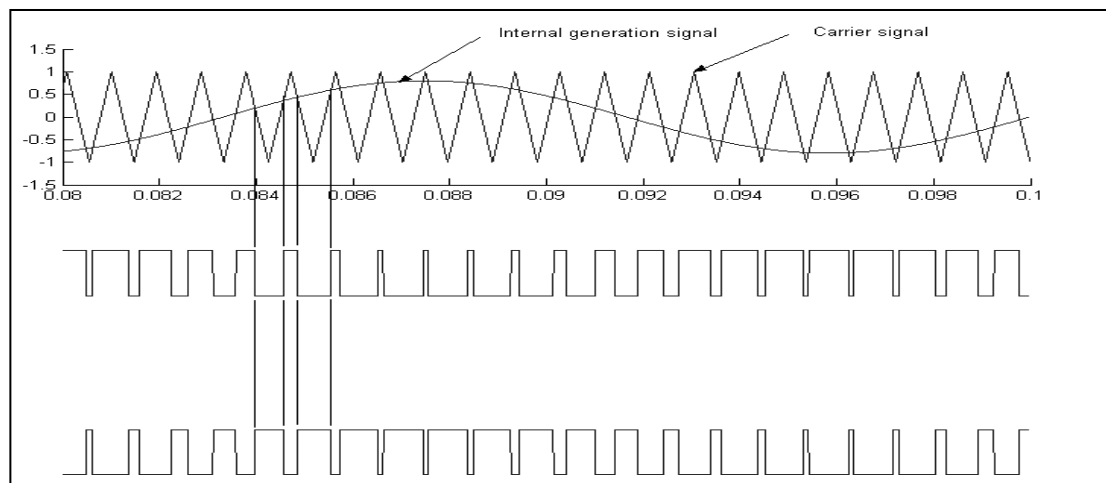**Figure 2.4**   Pulse width modulation [12]

2.11   Harmonic and Total Harmonic Distortion (THD)

Harmonic distortion is a term represents the condition that occurs when waveform is changed from the original shape by addition of harmonic frequency. Harmonics cause distortion of the voltage and current waveforms, which have awful effects on electrical equipment. Harmonic are one of the major power quality

concerns. The estimation of harmonics from nonlinear loads is the first step-in a harmonic analysis and this may not be straightforward. There is an interaction between the harmonic producing equipment, which can have varied topologies and the electrical system. Over the course of recent years, much attention has been established for permissible harmonic current and voltage distortion.

Harmonics emission can have varied amplitudes and frequencies. The most usual 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. [13]

2.12   Definition of Harmonic Distortion

Harmonic:

Harmonic are sinusoidal voltages or current having frequencies that are integer multiples of the fundamental frequencies. [13]

Distortion:

Qualitative term indicating the deviation of a periodic wave from its ideal waveform characteristics. [13]

2.13   Characteristics of 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. [13]
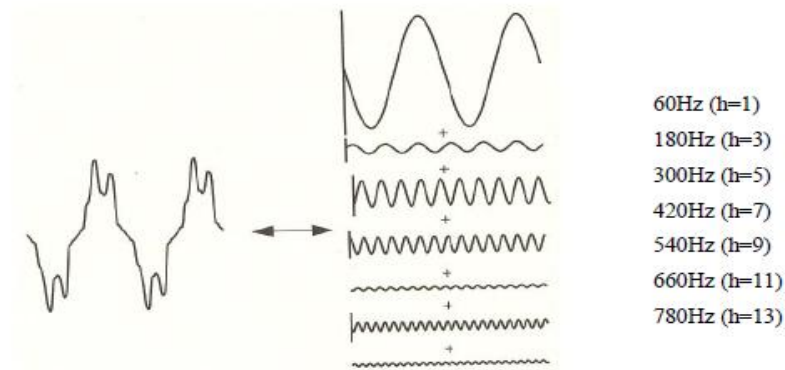

Figure 2.5   Harmonic generation [13]

2.14   Load Producing Harmonic

The generation of harmonics in power system occurs from two distinct types of loads:

1. Linear loads are characterized so that an application of a sinusoidal voltage results in a sinusoidal flow of current. These loads display constant steady state impedance during the applied sinusoidal voltage. If the voltage is increased, the current is also increase in direct proportion. Tooth ripples and slotting can produced forward and reverse rotating harmonics. Magnetic circuit can saturate and produce harmonics. Synchronous generators in power system produce sinusoidal voltage and the loads draw nearly sinusoidal currents. The harmonic pollution produced due to these load types for applied sinusoidal voltages is small. [14]

2. The second category of loads is described as nonlinear. In a nonlinear device the application of sinusoidal voltage does not result in a sinusoidal flow of current. These loads do not demonstrate constants impedance during the entire cycle of applied sinusoidal voltage. Nonlinearity is the same as the frequency dependence of

impedance such as the impedance of a reactor change in proportion to applied frequency but it is linear at each applied frequency. On the other hand, nonlinear loads draw a current that may even be discontinuous or flow in pulses for a part of the sinusoidal voltages cycle. [14]

The loads producing harmonic distortion are:

1. Electronic lighting ballasts
2. Adjustable speed drives
3. Electric welding equipment
4. Solid state rectifiers
5. Industrial process controls
6. Uninterruptible Power Supplies (UPS)systems
7. Saturated transformers
8. Computer system
9. Cycloconverter
10. Switching mode power supply
11. HVDC transmission
12. Battery charging and fuel cells
13. Wind and solar power generation
14. Slip recovery schemes of induction motor
15. Electric traction [15]

2.15   Impacts of Wind Farms on Power Quality

Currently power quality standard for wind turbines, approached by the International Electrotechnical Commission (IEC), IEC 61400-21: "Measurement and assessment of power quality characteristics of grid connected wind turbines", defined the parameters that are characteristic of the wind turbine behaviour in terms of the quality of power, and also provides recommendations to carry out measurements and assess the power quality characteristics of grid connected wind turbines. Although the standard mainly describes measurement methods for characterizing single wind turbines. [16]

Since voltage variation and flicker are caused by power flow changes in the grid, operation of wind farms may affect the voltage in the connected network. On the local level, voltage variations are the main problem associated with wind power. This can be the limiting factor on the amount of wind power which can be installed. If necessary, the appropriate methods should be taken to ensure that the wind turbine installation does not bring the magnitude of the voltage at PCC outside the required limits. [17]

2.16 Grid Disturbances

When the response to grid disturbances is of interest, it is mainly the generator description that affects the response of the turbine. For assessing the stability margin of the wind farm-grid integration, small-signal dynamic model of the system must be formed in simulation platforms. Wind speed, pitch control and input torque to generator are usually assumed constant for transient analysis, since mechanical system time steps are too larger than time constant of electrical system. The worst case scenario must be defined, like maximum wind speed and minimum load conditions. [18]

2.17 Variable Speed of Wind Turbine

Wind turbine operating within a narrow speed range normally has a double feed induction generator with a converter connected to the rotor circuit. Since the rotational speed of the generator varies around 1000 or 1500 rpm a gearbox is required. Wind turbines operating within a broad variable-speed range are equipped with a frequency converter. The use of a frequency converter makes it possible to use direct-driven generator. A direct-driven generator with a large diameter can operate at a very low speed and does not need a gearbox. [19]

2.18 Power Quality of Wind Turbines

Perfect power quality means that the voltage is continuous and sinusoidal having a constant amplitude and frequency. Power quality can be expressed in terms of physical characteristics and properties of electricity. It is most often described in terms of voltage, frequency, and interruptions. The quality of the voltage must fulfil requirements in national and international standards. In these standards, voltage disturbance are subdivided into voltage variations, flicker, transients and harmonic distortion. Figure 2.8 shows a classification of different power quality phenomena. Grid connected wind turbines do affect power quality. The power quality depends on the interaction between the grid and wind turbine. The frequency of large system is normally very stable. A wind turbine normally will not cause any interruption on a high voltage-grid. [20]
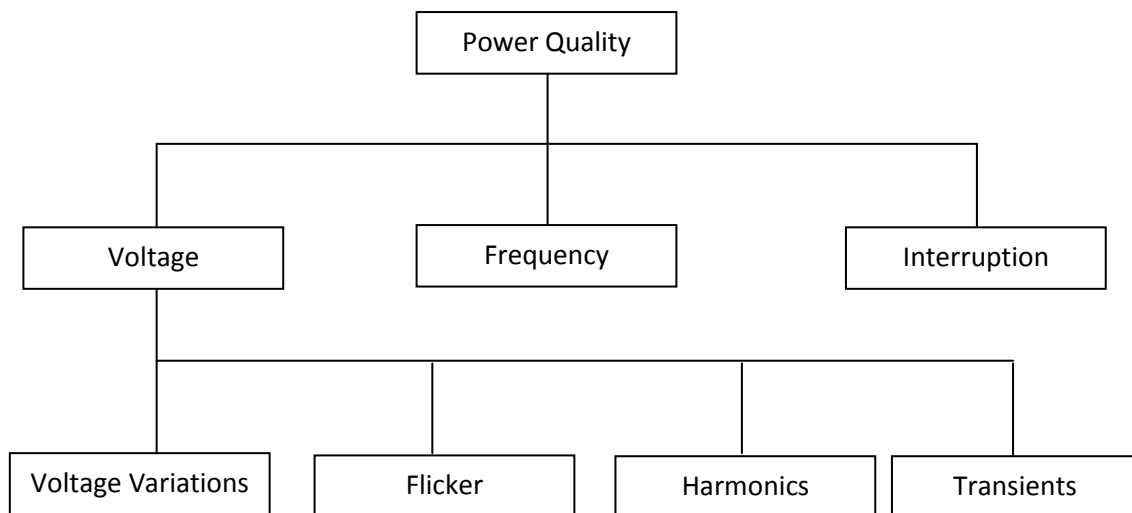

Figure 2.6   Classification of different power quality phenomena

2.19 Real and Reactive Power Capability

With the increased penetration level of wind power in the power system, grid utilities want wind turbine generator system to behave like a conventional synchronous generator in terms of real and reactive power settings. [21] In other words, wind turbines have to contribute not only to active power generation but also

to the reactive power. Hence, wind turbines should have extended reactive power capability not only during voltage dips but also in steady state operation. [22] Although, the wind turbines are able to control active and reactive power independently of one another by virtue of ac/dc/ac power electronic converter present on it. [23] The grid side inverter reactive power capability can be taken into consideration, but in commercial system, this converter usually works with unity power factor, i.e. zero reactive power, so the total reactive power capability of the generator is equal to the stator reactive power capability [23].

2.20   Harmonics in Wind Turbine

Harmonics are only noticeable in the turbine with electronic power converters or at switching events. Switching events can generate noticeable transitory harmonics. Power converters of turbine produce high frequency harmonics in voltage during continuous operation. Current THD can be noticeable at low output powers because it is a measure relative to fundamental current. However, absolute values of distortion are not very dependent on power output in continuous operation. The main effect of these harmonics is related to interference with signals and electronic devices. The high frequency harmonics, corresponding to the switching of IGBT, are only of importance inside the turbine, because they are largely filtered by the high impedance of transformers [24]. These harmonics are not in phase from one turbine to another, so they partially cancel and they don't affect the grid in the analyzed grids. However, electronic converters based on slower devices can generate harmonics of lower frequencies and hence, harder to block, allowing the excitation of resonances at farer points.

2.21   Effect Wind Turbine Connected to Weak Grid

Wind turbines, when connected to a weak grid, or a large amount of wind power connected to a more robust grid, may give rise to stability problems. The time

variation of power output due to wind speed variations needs to be assessed. This variation, giving rise fluctuations in voltage, frequency and phase angle, could lead to interference and problems with grid. The doubly-fed induction generator can supply power at constant voltage and constant frequency while the rotor speed varies. Constant frequency control is one of the main techniques used in variable speed wind energy conversion system. [25]

2.22 Impact Wind Turbine to Nanogrid System

In conventional electrical power systems, the dynamics of generation, distribution, and consumption are fully coupled, and the system stability is in the ac systems achieved with the constant frequency electromechanical sources (synchronous generators), while in dc systems with constant voltage electrochemical sources (batteries).[26] Rerouting of energy is only ensured through high redundancy, over-design, and electromechanically controlled devices considered to be dynamically slow and unreliable. [27] It can be seen that some of the components in the ac-nanogrid system such Wind are actually interfaced to the grid through the power converters because of their different dynamic characteristics, and thus dynamically completely decoupled from it. [28] These systems include multiple energy sources and redundant energy storage for back-ups, in addition to the numerous active loads. [29] In these applications, majority of energy sources are interfaced to the power system through power electronics converters because of their very different dynamic characteristics.

2.23 Control of Wind Turbine System

With the increase in wind turbine size and power, its control system plays a major role to operate it in safe region and also to improve energy conversion efficiency and output power quality. The main objectives of a wind turbine control system are the wind turbine is operated to extract the maximum amount of wind

energy considering the safety limits like rated power, rated speed. Next objective is conditioning the generated power with grid interconnection standards. The various control techniques used in wind turbines are pitch control, yaw control and stall control. [30]

CHAPTER III

METHODOLOGY

The methodology of this project consist four main steps as shown in Figure 3.1. This project begins with a through literature review on the basic concept of wind turbine generator using simulation and experimental. These include a study the impact of wind turbine grid connected system and harmonic distortion. The theory of the wind turbine grid connected very important in this project in order to get clear understanding on what the project is all about.

Firstly, the experimental wind turbine grid connected was set up. The wind turbine was installed in the grid connected system to study and analyzed on the performance and harmonic distortion in grid connected system. Wind turbine consists of shaft, bearing, frame, vane and gear. This wind turbine already connected to the rectifier and produce DC (direct current) power directly. Then, the DC power will flow through the inverter and convert to AC (alternating current). The characteristic and datasheet of wind turbine was learned to get more understanding about the wind turbine and the inverter.

The next procedure is a general study on the various types of wind turbine generator that have been proposed for grid connected system. It will be made with focus on performance and harmonic distortion in wind turbine grid connected system. The variation of the circuits in MATLAB is explored based on their advantages and disadvantages which consist of the design circuitry and wave shapes. The new circuit topology that will fulfil the specifications of wind turbine grid

connected system will be designed based on the features of circuit topologies that have been proposed by previous researchers.
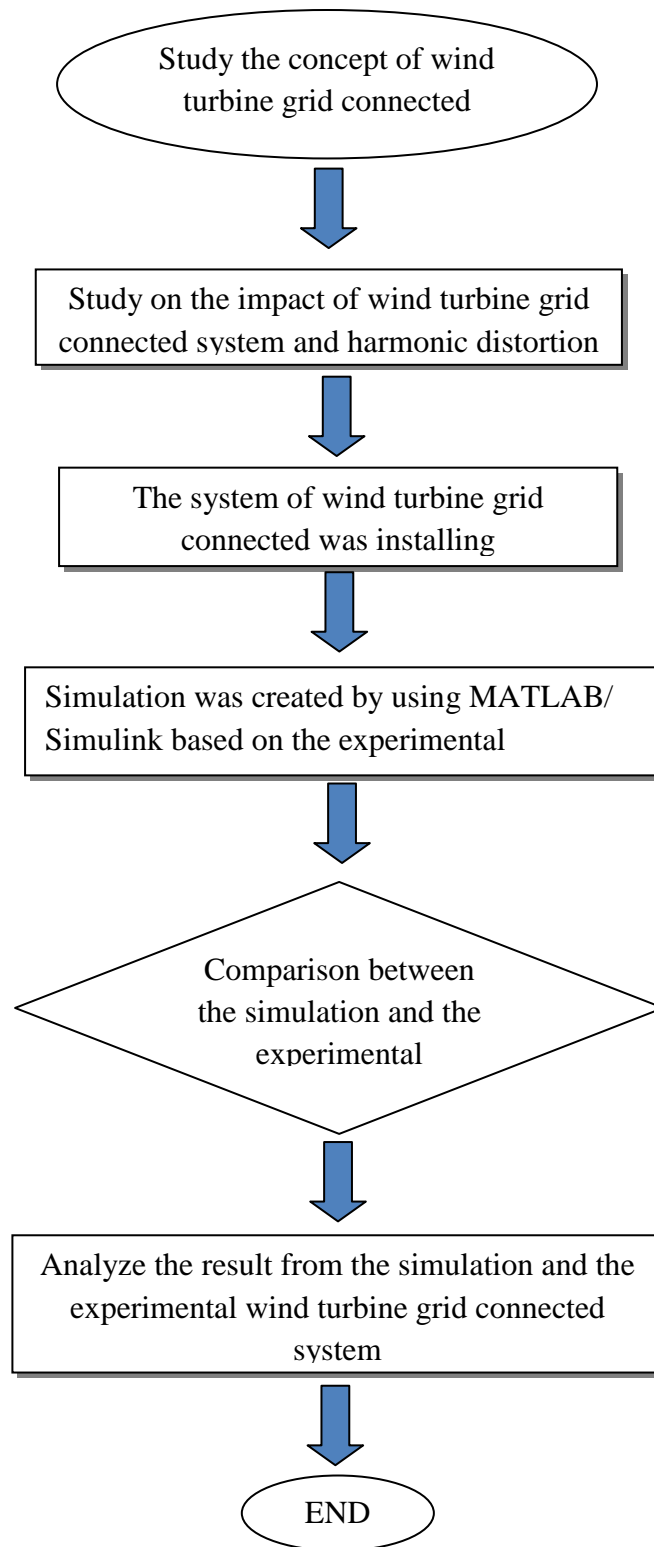

Figure 3.1   Flow of the project development

3.1   Design Procedures and Configurations

3.1.1   Circuit Topologies

A basic topology of a wind turbine grid connected system as shown in Figure 3.2 is chosen. The complete circuit diagram is illustrated in Figure 3.3. This system consists of wind turbine, rectifier, inverter, load, grid system, generator and transformer.

Block diagram is a diagram of a system, in which the principle parts of functions are represented by blocks connected by lines. For the block diagram of wind turbine system is connection by all main part of the system.

Waveform in wind turbine produces AC when kinetic energy converts to electrical energy. The rectifier is to convert AC to DC. The function of capacitor at Common DC Link between the rectifier and inverter is to reduce the output voltage variation. The inverter will convert the waveform from DC to AC. The type of waveform receives at grid connected system is AC.
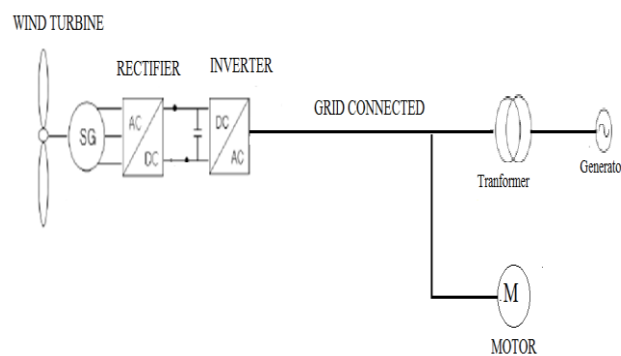
Figure 3.2   Block diagram of the wind turbine grid connected system [31]

3.2   Experimental Method

Wind turbine grid connected system was installed at laboratory. In this experiment consist of wind turbine, grid connected, inverter, power supply, non-linear loads, linear loads, power quality analyzer, and hydraulic pump. The experiment was carried out with four sessions which are when the all system was generated. Then followed by the load was cut off from the grid and wind turbine. Then the wind turbine is off and only grid connected the data was taken. Lastly, the wind turbine was off and the grid connected and motor is on.

3.2.1   Wind Turbine

The wind turbine that was used in this experimental is air breeze which are the most powerful wind generator. The rated capacity produce by wind turbine is 160 watts at 12.5m/s. This wind turbine diameter is 1.17 meter and the weight of wind turbine is 5.9kg. This turbine is control by microprocessor based smart internal regular with peak power tracking. Wind turbine generates power 38 kWh per month.

Small changes in wind speed can have significant impact on power production. Air breeze technical specification was showed at table below:

Table 3.1: Voltage regulation set point (factory setting) [32]

12 Volt Systems	14.1 Volts
24 Volt System	28.2 Volts
48 Volt System	56.4 Volts

Table 3.2: Regulator adjustment range[32]

12 Volt Systems	13.6 to 17.0 Volts (approximately)
24 Volt System	27.2 to 34.0 Volts (approximately)
48 Volt System	54.4 to 68.0 Volts (approximately)

Table 3.3: Recommended fuse size [32]

12 Volt Systems	20 amp (slow below)
24 Volt System	10 amp (slow below)
48 Volt System	5 amp (slow below)

Fuses, circuit breaker and ammeter were needed in wind turbine. Air breeze is capable producing high amperages. Fuse and circuit breaker can protect the wind turbine. An ammeter is allows to monitor the current output of turbine. The ammeter was placed between turbine and the battery on the positive lead. It will give the instantaneous readings output in amps.

Proper grounding of the air breeze provides protection to human and equipment by eliminating the possibility of dangerous voltage potentials. In a typical air breeze installation grounding one of the conductors is accomplished by connecting the air breeze negative (black) conductor to an earth ground close to battery bank.

3.2.2 Operational Wind Turbine

Wind turbine operates by capturing the kinetic energy of moving air. It converts it to rotational motion to turn an alternator that produces electrical power. The electrical power must be regulated to a voltage to charge the system batteries, and there must be a system to prevent overcharging batteries and resume charging as the battery voltage drops. From extreme wind damage the protection of wind turbine also are provided.

Operating modes when air breeze connected to batteries with the voltage below the voltage regulation set point, the blades will spin in response to the wind. The blades will continue to spin until the batteries voltage the regulation set point.
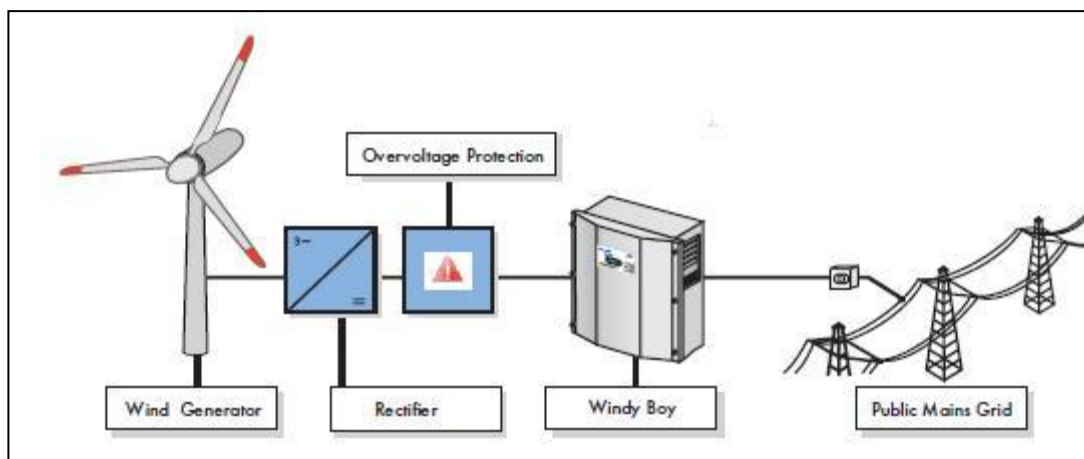
Figure 3.3   Diagram of the wind turbine grid connected system [33]

3.2.3   Inverter (Windy Boy 1100LV)

The Windy Boy 1100LV is the smallest wind power systems: turbines with a nominal voltage of 24 or 48 V can be connected without an additional voltage converter. The programmable polynomial curve gives full flexibility for choosing the turbine, while its weatherproof enclosure and the wide temperature range allow for installation at nearly any location. The Windy Boy is optimally adjusted to fast and frequent load changes. Its minimum self-consumption during calm periods also increases the yield, which can be monitor at any time using the display. The Windy Boy 1100LV is design for the conversion of DC voltage from a wind turbine (permanent magnet generator) into AC voltage for feeding into the main supply.
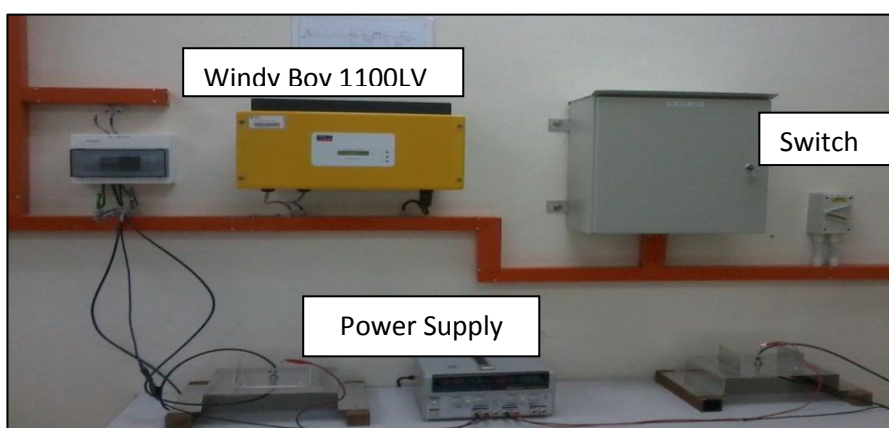
Figure 3.4   Inverter Windy Boy 1100LV

3.2.4 Characteristic of Windy Boy 1100LV

The table below showed the characteristic of the inverter:

Table 3.4: Technical data Windy Boy 1100LV [33]

Technical data	Windy Boy 1100LV
Input DC	
Max. DC power (cosϕ=1)	1240W
Recommended generator power at 2500/5000 full load hours	1000W/900W
Max. Input voltage/nominal DC voltage	60V/25V
Min. Open circuit voltage or activating "Turbine mode"	25V
Voltage range in "Turbine mode"	21V-60V
Max input current	62A
Output (AC)	
Rated output power (@ 230V, 50Hz)	1000W
Max. Apparent AC power	1100VA
Nominal AC Voltage/range	220V,230V,240V/180V-260V
Power line frequency/range	50Hz,60 Hz/-4.5Hz...+4.5 Hz
Rated power frequency/rated power voltage	50Hz/230V
Max. Output current	5A
Power factor at rated output	1
Fixed in phases/connection phases	1/1
Efficiency	
Max. Efficiency/ European Efficiency	92%/90.4%
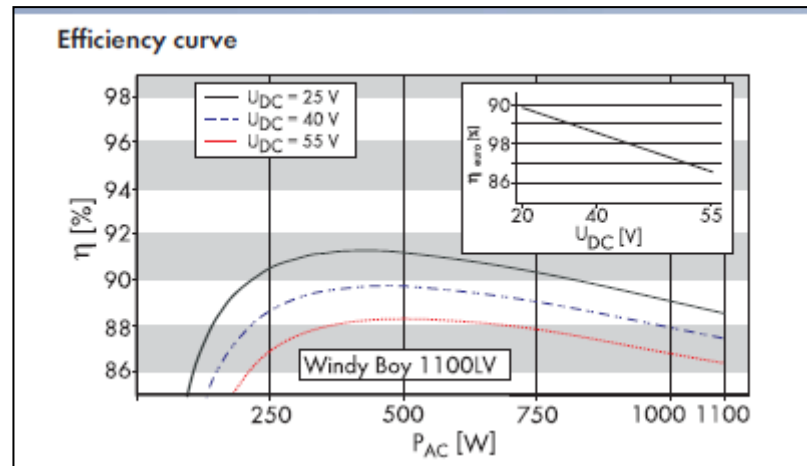
Figure 3.5   Efficiency curve Windy Boy 1100LV [33]

3.2.5   Operating Modes of Windy Boy 1100LV

The operational status is displayed using three light emitting diodes in the cover of Windy Boy 1100LV. To allow the device signal it's operational, the Windy Boy 1100LV must be connected to the DC side of the system. As long as the green control LED is on or blinking the Windy Boy 1100LV is operating normally.

3.2.6   Grid Connected System

For a grid-connected system, the alternative energy sources in the grid can supply power both to the local loads and the utility grid. In addition to real power, these DG sources can also be used to give reactive power and voltage support to the utility grid. The capacity of the storage device for these systems can be smaller if they are grid-connected since the grid can be used as system backup. However, when connected to a utility grid, important operation and performance requirements, such as voltage, frequency and harmonic regulations, are imposed on the system.

In figure 3.5 show the distribution board that have load, wind turbine and grid system. In this figure, the cable from the grid is connected to wind turbine. Blue and

yellow cable is for wind turbine. Only one wind turbine was used in this experiment. From the wind turbine is connected to load which are lamp, socket outlet and the single phase motor.
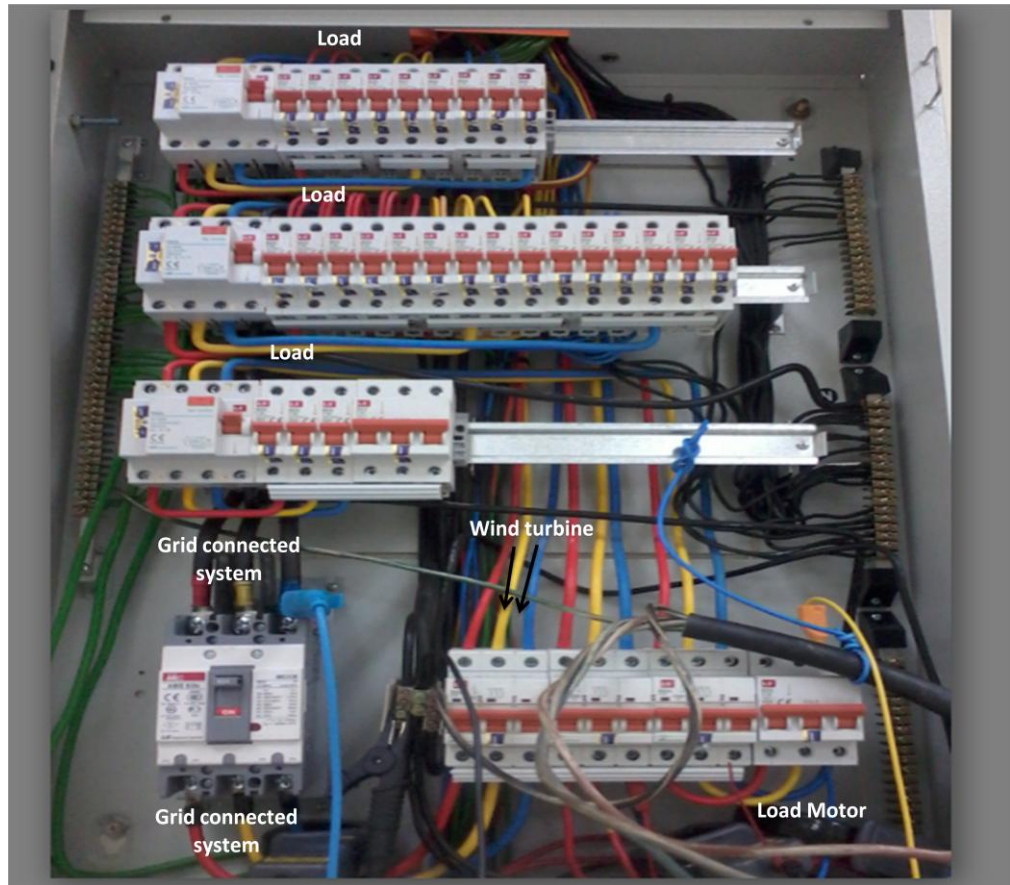
Figure 3.6   Grid connected system

3.2.7   Load

The synchronous capacitor start-run was used in this experiment to see the impact on grid and wind turbine. Instead of the motor single phase that was used in this experiment, the lamp at the laboratory also connected at the grid system. This table was showed the characteristic of the motor single phase capacitor start run.

Table 3.5: Characteristic of single phase motor

Type ML 802-4
1HP 0.75kW
240V
50 Hz
1400 r/min
100μF 300V
4.79A
25μF 450V
INS.GL F IP 5S
No. 0510157

Figure 3.7   Single phases asynchronous capacitor start run

3.2.8   Power Quality Analyzer

Power quality analyzer was used in this experimental to take the data of total harmonic distortion and waveform. The Kyoritsu 6310 Power Quality Tester is full of functions for power quality analysis and power consumption. This power quality analyzer can analyse and store measurements from both single phase and three phase systems. Power quality analyzer can control 12 kinds of power measurements for

power control and applicable to power quality control including harmonics analysis for voltage, current, active power, reactive power, apparent power, power factor, frequency, current flowing on the neutral line and many more. The power quality analyzer (PQA) was tagged at the wind turbine, grid and motor single phase to record the data of waveform and total harmonic distortion (THD).

3.3 Simulation Using MATLAB/SIMULINK

The circuit is simulated using MATLAB/SIMULINK. The advantage of SIMULINK is that it is straightforward and user friendly for analysis and design purpose. MATLAB involves many high instructions and tools for some systems designing applications and developing power system analysis. Furthermore, since the MATLAB/SIMULINK contains Power System Toolbox, the software turns into a powerful power systems simulation and analysis tool.

Other than that, this software is very helpful because it comes with demos of some power electronics circuit that student can refer to as references for circuit designing and simulation. It also provides help topics for students to refer to. It is very easy to create power system in SIMULINK environment, which allows users to build a model by simple "click and drag" procedures. In addition, the simulation system of block component can set relation electrical parameters from MATLAB commands. The results of the simulation work will be analyzed to determine the performance and power quality in wind turbine grid connected system.

3.3.1 Simulation of Wind Turbine Grid Connected System

The simulation of wind turbine grid connected system was used MATLAB to simulate and analyzed the performance and harmonic distortion of wind turbine grid connected system. The wind turbine, grid and load were rebuilding in simulation based on the experimental. The simulation also was carried with four condition same

as the experimental. The data from simulation and experimental was compared their accuracy and appropriateness.

3.3.2 Powergui Block

Powergui block was used in this simulation. The Powergui block provides useful graphical user interface (GUI) tools for the analysis of Power System Block set models. The Powergui block allows to presented steady state values of measured current and voltages as well as all state variables in a circuit. The Powergui block can generate a report containing steady state values of the measurement blocks, the sources, the nonlinear models, and the states of your circuit.

3.3.3 Circuit Description Wind Turbine

A 600W wind turbine connected to a 25kV distribution system exports power to a 120kV grid through feeder which the length is 21 km. The wind turbine presented in this simulation consists of synchronous generator connect to rectifier, a DC-DC based PWM boost converter and a DC/AC based PWM converter. Wind turbine that was used in simulation allows to extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed. In this simulation the wind speed is maintained constant 20 m/s. The control system of the DC-DC converter is used to maintain speed at 1 pu.

Figure 3.8 display the block set wind turbine. The wind turbine consists of rectifier, inverter and synchronous generator. The synchronous generator must set in positive value to make the synchronous generator action as generator otherwise the synchronous generator can function as motor if the negative value was setting. This figure 3.9 below show the simulation of wind turbine grid connected when all system was operated. Then, the simulation was conducted with the other three conditions that are second condition disconnecting load from the grid system, third is

disconnecting the wind turbine system while the motor was running and lastly the simulation was running by the grid only without motor and wind turbine.

Figure 3.8   Wind turbine systems
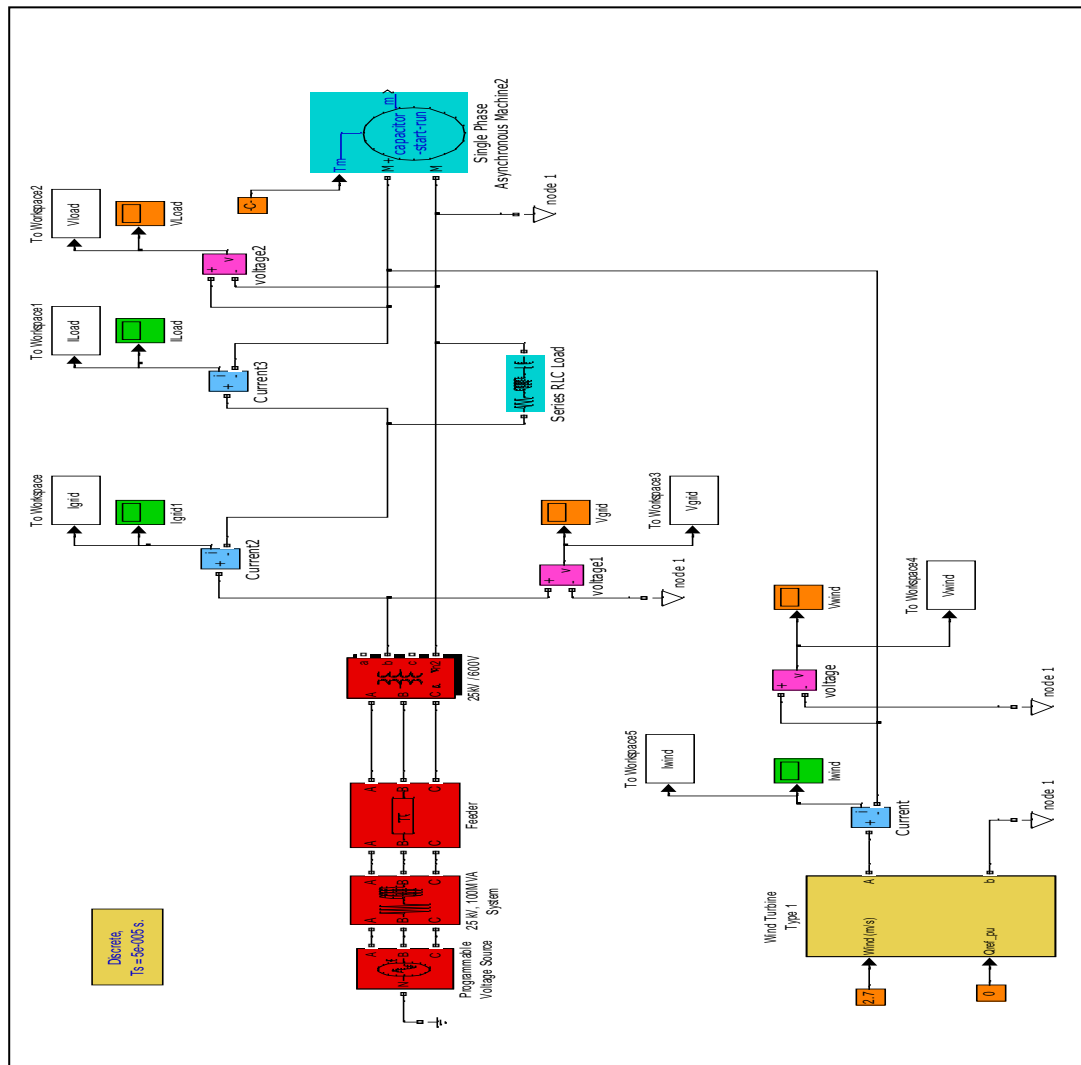
Figure 3.9   Simulation of wind turbine grid connected system

3.3.4   Grid System in Simulation

The grid system was setting by the programmable voltage source, feeder and transformer. The programmable voltage source was implemented three phase voltage and harmonic. The programmable was setting with amplitude 50Hz. Next, the feeder was used to perform the balance three phase transmission line and the transformer to make the circuit complete. Three phase transformer that was used in this simulation and the transformer was produce neutral line because the system is single phase system. The transformer is step down transformer.

3.3.5 Single Phase Motor

An improvement in the operation mode of the single phase asynchronous machine occurs when the auxiliary winding is still connected in series with a capacitor after starting. In this simulation the motor was setting same as motor at experimental. The motor was connected to line neutral and life.

3.4 Experimental and Simulation

The experimental and simulation was conducted at the same parameter to and same conditions which are the whole system is connected (wind on motor on), the load was disconnect from the wind turbine and grid, wind turbine was cut off from the system and lastly at the grid only. The value of voltage and current was compared from the experimental and simulation. The waveform from the experimental and simulation was taken to see the harmonic distortion at wind turbine and grid.

CHAPTER IV

RESULT AND DISCUSSION

This chapter discuss about the result for experimental and simulation of wind turbine grid connected system. This includes all result designing circuit by using MATLAB and also result from the experimental. The design circuit in MATLAB and the experimental result of wind turbine and power quality problem such as the voltage and current at wind generator and at grid system was included in this chapter.

This project will using simulation software which is MATLAB to rebuild the wind turbine grid connected system. The circuit for wind turbine grid connected system was consists of wind turbine block, rectifier, inverter, motor, transformer, generator and etc. The experimental was divide by four sections which are wind on motor on, wind on motor off, wind off motor on and wind off motor off. The THD and waveform form power quality analyzer was collected. The result illustrates in two part which are experimental and simulation result.

4.1   Experimental Result

Result from experimental demonstrates three analyses that has been cover. The analysis consists of voltage, current and total harmonic distortion. The experimental was done by four conditions which are wind and motor on, wind on motor off, wind off motor on and lastly at the grid only because want to see the impact of the these conditions to voltage and current.

4.1.1 Voltages and Currents at Grid

This part describes about the values of the voltage and current that obtains from the result by doing experimental. The table below indicate the values of voltage and current at grid system based on four conditions state above.

The values of voltages at the grid were slightly differences because there were synchronized of voltages. The values of voltages for wind turbine and motor on is 234Vrms, wind turbine on and motor off is 230Vrms, for wind turbine off motor on is 230Vrms and lastly for the grid only is 234Vrms. The value of voltage was approximately to 245Vrms because this system was used single phase (245Vrms). Voltage variations can be defined as changes in the RMS value of the voltage occurring in a time span of minute. The voltage for the standard voltage is 230/400 V for frequency 50Hz system. The voltage must not differ more than +/-10% from the rated voltage. The results of voltages for all conditions show that the values at range standard voltage.

The value of current at the grid is the highest when all system was operating (wind turbine and motor on). The current was produce at grid connected system is 6A. When the wind turbine was on and motor was off the current generate at the grid system is 3.5A. While the wind turbine was off and the motor was on, the current is 4.9A.However, the current at grid only generate 3A. Since the wind turbine and motor was operate, the current was increased because the grid, wind turbine and the load was operating simultaneously and caused the value of current increase compared to others condition. At fourth condition which is at the grid system only, the current indicate the little amount than the other conditions because the usage load was small. Table 4.1 displays the data of load and each current. As shown as below, the non linear load is the highest affect of current compare to other loads.

Table 4.1: Data of currents consumption

Loads	Current (A)
Asynchronous machine	2
Non Linear load (lighting and socket)	2.5-3.5
Wind Turbine	0.5

4.1.2 Voltages and Currents at Wind Turbine

The operation of wind turbine has an impact on the power quality of the connected grid. Depending on the grid configuration and the type of wind turbine used, different voltage and current may arise when wind turbine was connected to the grid system.

All the system was operated; the value of voltages at wind turbine is 235Vrms. It same as when motor as load was disconnected from this system, the value for voltage is 231Vrms. When the wind turbine was cut off from the system and load was connected to the system, the voltage is 235Vrms and eventually the whole system was disconnected from grid the voltage is also 235Vrms. The results show the voltages at wind turbine more or less than same with the values of voltage at grid. It is because of the grid side converter for wind turbine system is 230Vrms. Voltage variations on the grid are mainly caused by variations in load power production units. When wind power is introduced, voltage variations also emanate from the power produced by the turbine. The power production from wind turbines may vary widely and not only due to variations in the wind. It may also momentarily go from full to zero power production in the event of an emergency stop or vice versa at a start under high wind conditions.

The data from the experimental indicate the value of output current that produce from wind turbine system. The maximum output current inverter in wind turbine system 5A. The technical specifications of wind turbine represent that this wind turbine can produce maximum power and current are 1240W and 62A. After

through the inverter (Windy Boy 1100LV) the rate output power (AC) is 1000W. The highest value of current that was record in experimental was only 0.49A. It means that the wind speed at that time is slow. The percentage of the output current only 10.4% than the maximum current that can be produced by wind turbine generator. It may be at that time the wind is too slow. Next, when the wind turbine was cut off from this system the current produce at wind turbine is 0.006A. The current at wind turbine when all system was disconnecting from the grid is also 0.006A. The current produce at wind turbine was smaller because the wind was disconnecting from the system.

4.1.3   Total Harmonic Distortion (THD) at Grid

Grid connected wind turbines do affect power quality. The power quality depends on the interaction between the grid and the wind turbine. Inverter does inject harmonic currents into the grid and will due to the grid impedance, cause harmonics voltages. As a result, voltage harmonic does not affect much than harmonic currents. The advancement and wide application of adjustable speed drivers, electronic devices, microprocessors, etc. in many areas have significantly contributed to the voltage and current waveform distortion in power and distribution system

The THDv at the grid when the whole system generates only 2%. When the load was cut off from this system, the THD at grid also same as when the whole system was operated which are 2%. At the same time the wind was disconnecting form the grid the THD for voltage also same as the two conditions above. But, THD voltage is 2.1% at the grid only. The figures below show the harmonic voltage when wind on motor on, wind on motor off, wind off motor on and wind off motor off. V1 stands for wind turbine, V2 is grid system and V3 is motor as load. The percentage of THDv at grid connected in range 1% until 3%. This show the low order harmonic distortion occurs in voltage. The THDv does not effect by all conditions.

The results below show the percentage of THD in the variation of all conditions that was applies in experimental. The THD currents at grid are 14% at that the whole system was on. When the load was chopping from the wind turbine, the THD currents were increased until 20%. The experimental was continued with the wind turbine was disconnecting from the grid and the load still connected to grid, the THD currents is 18%. Lastly, the data was taken at the grid only. Value for THD current at the grid is the highest which are 25%.The percentage of THD is high due to wind turbine connected to the grid, it is because wind turbine in this experimental produces the harmonic distortion that distorted the THD current in grid system. This was proven after disconnecting the wind turbine THD current was decreased. Harmonic distortion comes from the power electronic devices in wind turbine system that is inverter. Electronic devices such as rectifiers and inverters which are sensitive to the zero-crossing point of the voltage waveform can obviously be affected by harmonic distortion.

4.1.4   Total Harmonic Distortion (THD) at Wind Turbine

The renewable energy such as wind turbine produces the harmonic distortion. When the wind turbine was connected to the grid, it will affect the harmonic distortion in grid system. Wind speed uncertain at the random speed, it is caused wind turbine produce the unstated power.

The data from the experimental displays when the whole system was generate the percentage of the THD voltage is 3.2. Motor was cut off from the grid and wind turbine, the value of harmonic distortion also same with the wind turbine was disconnect and the load was connected which is 3.2%. The percentage of the voltage at wind turbine when all the system was cut off slightly different which is 3.3%.

An experiment was conduct to observe the value of total harmonic distortion at the wind turbine. There are differences when the value of THDi at grid and wind

turbine. The values of THD current at wind turbine when the system was operated is 52% and the highest is 81%. While the harmonic distortion at the wind turbine when the load was disconnect, the range of harmonic distortion is 56% to 72%. When the wind turbine was cut off from the grid system either has the load or not the values of THD are 0%. Harmonic is higher when the current is smaller via versa when the current is higher the harmonic distortion is lower. Therefore, condition wind speed is unstable and the production of current is not static produce difference harmonic distortion. Harmonic distortion happen in wind turbine will affect at the grid system. It is not suitable for the certain devices that need the pure sine wave of voltage and current.

The data was taken every five minutes and for one hour. At table 4.5 the data was taken for 24 hours. It is because to observe the current through the grid. From table 4.5, data after 5.00 pm until 8.30 am was low because there is no usage of load such as lighting and socket. From the data, it shows clearly that current consumption during office hour higher than outside office hour. The current flow during office hour is 2.6A up to 2.7A but when the off the official time, the current is around 0.5A. This is caused by the lighting and socket at the laboratory not used at that time and that is why the current is low compared to official time.

1) <u>Wind On Motor On</u>
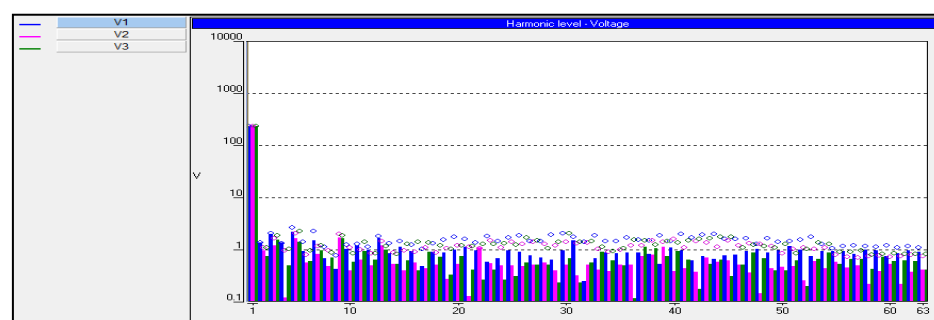
Figure 4.1   Harmonic distortion of voltage at wind turbine, grid and load
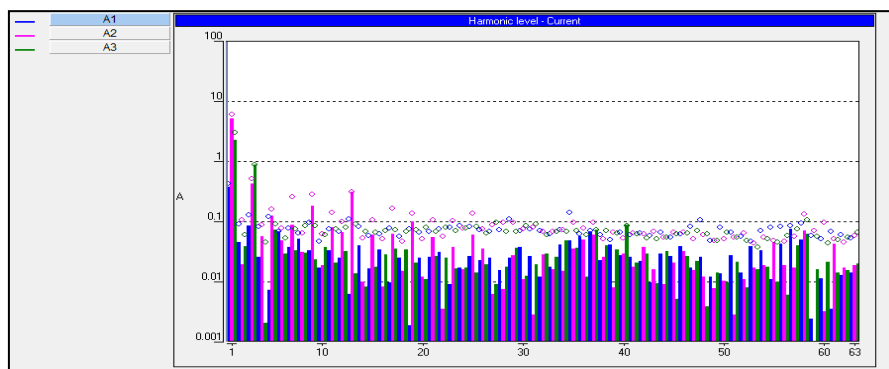
Figure 4.2   Harmonic distortion of current at wind turbine, grid and load
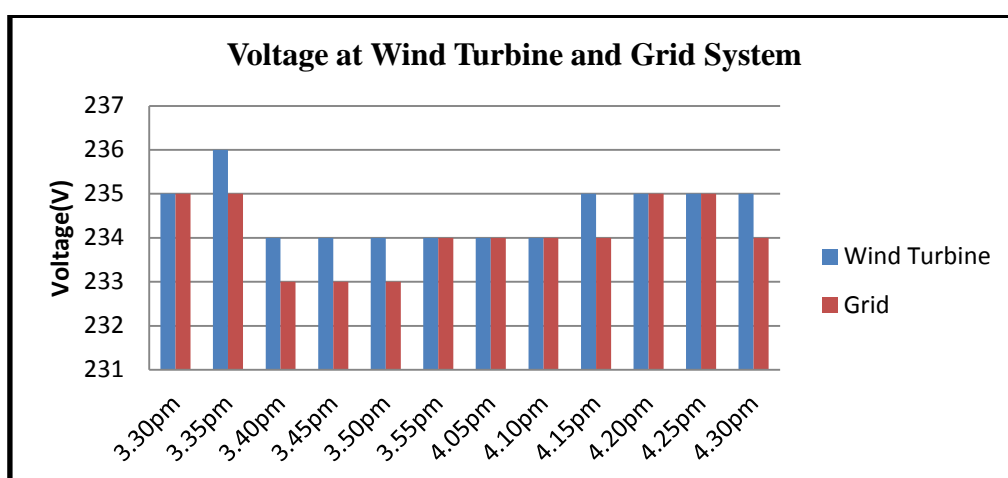
Figure 4.3   Voltage at wind turbine and grid
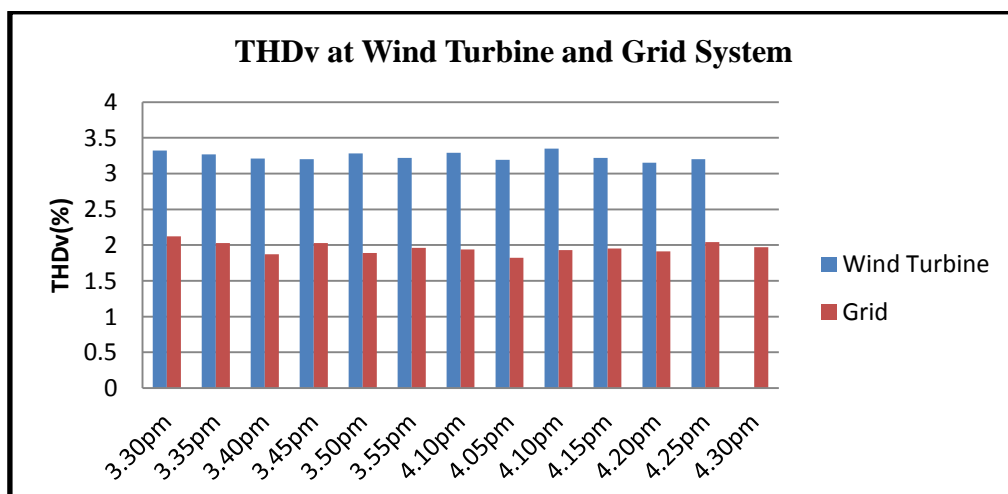
Figure 4.4   THD at wind turbine and grid
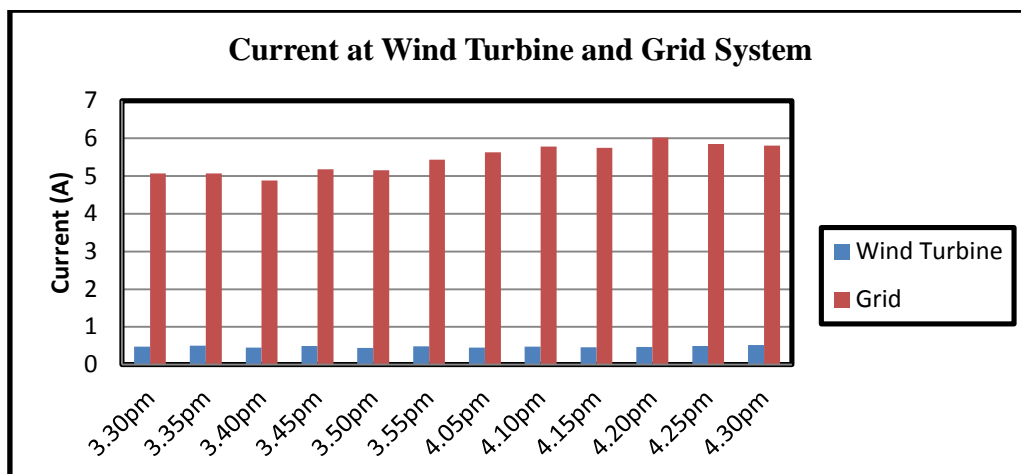
Figure 4.5   Current at wind turbine and grid
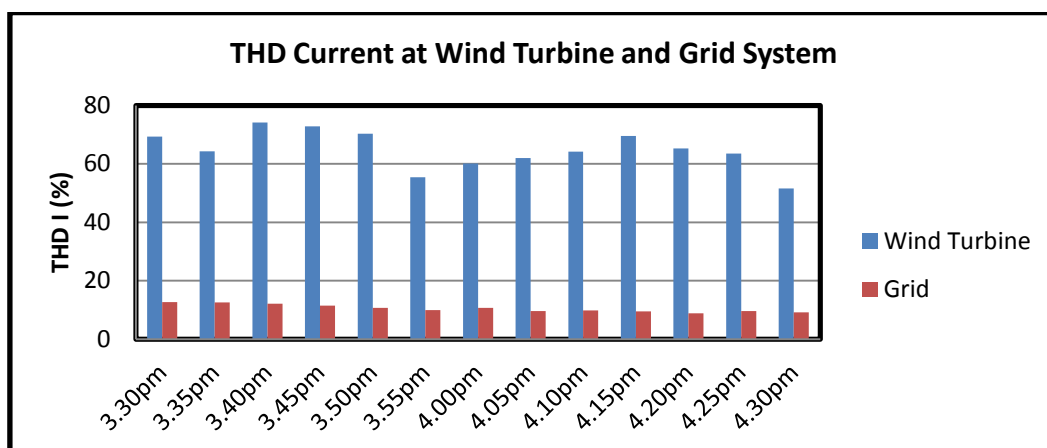
Figure 4.6   THD current at wind turbine and grid

2)   <u>Wind On Motor Off</u>
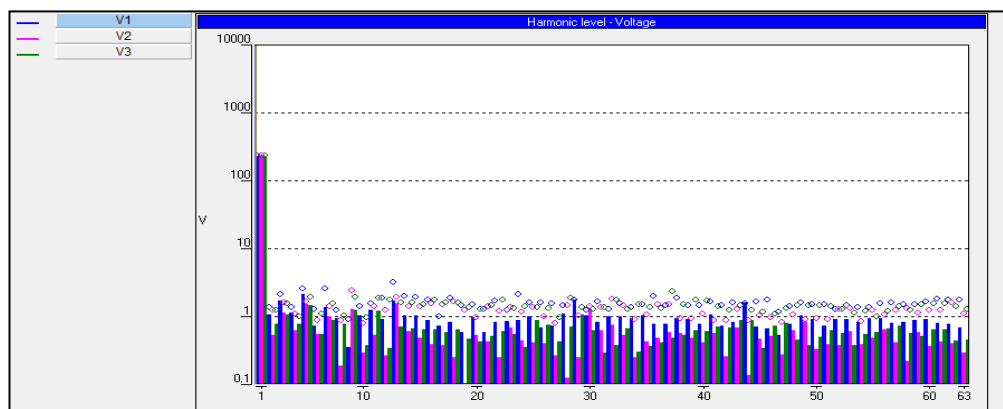
Figure 4.7   Harmonic distortion of voltage at wind turbine and grid
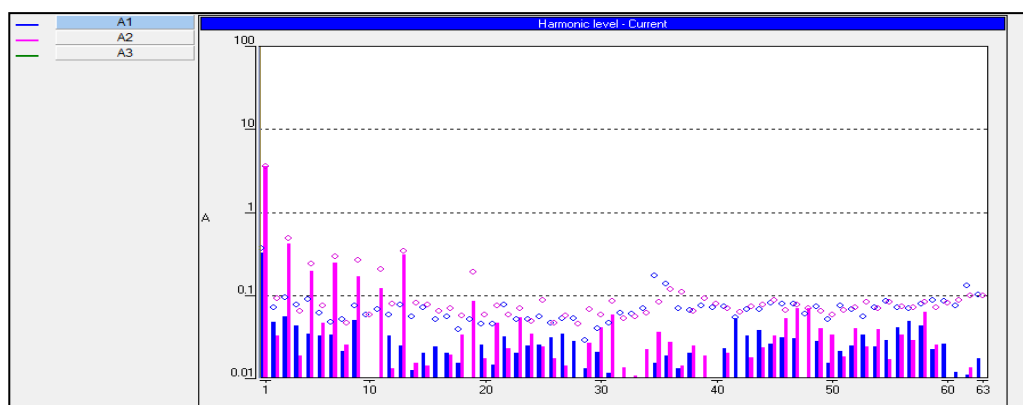
Figure 4.8   Harmonic distortion of current at wind turbine and grid
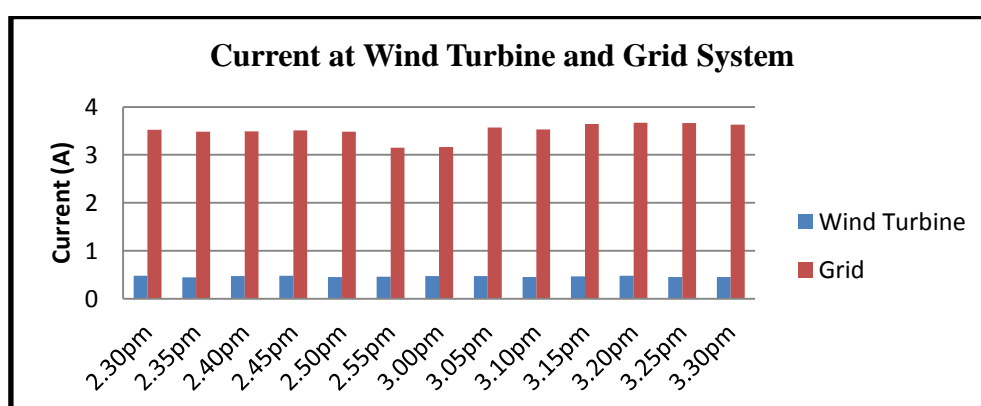
Figure 4.9   Current at wind turbine and grid
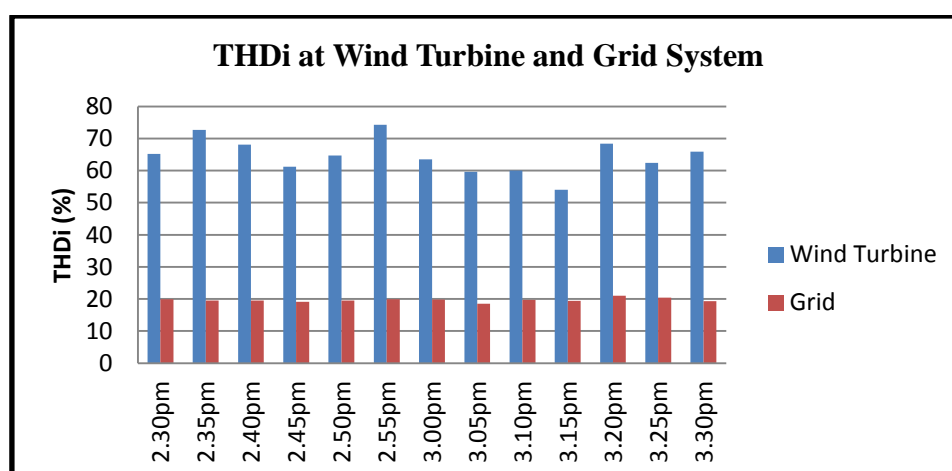
Figure 4.10   THD current at wind turbine and grid
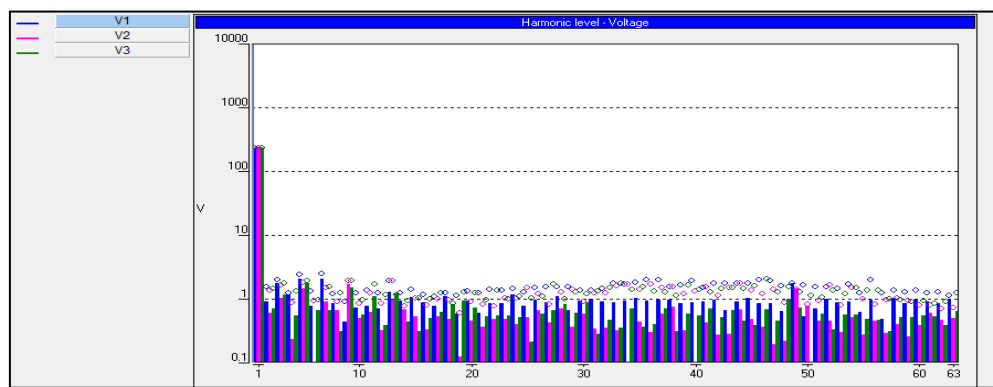
3) <u>Wind Off Motor On</u>

Figure 4.11   Harmonic distortion of voltage at grid and load
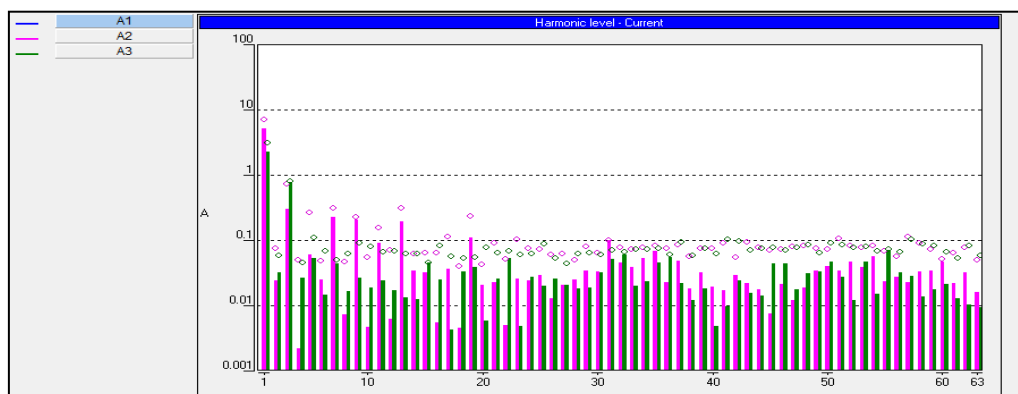
Figure 4.12   Harmonic distortion of current at grid and load
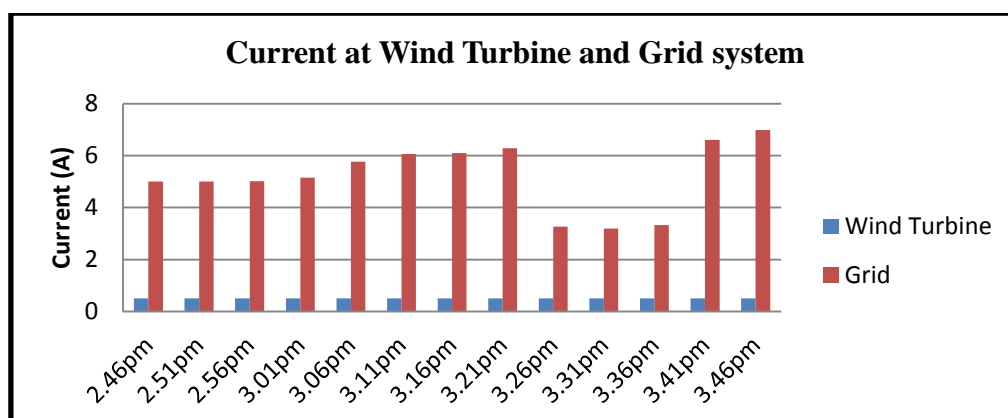
Figure 4.13   Current at wind turbine and grid system
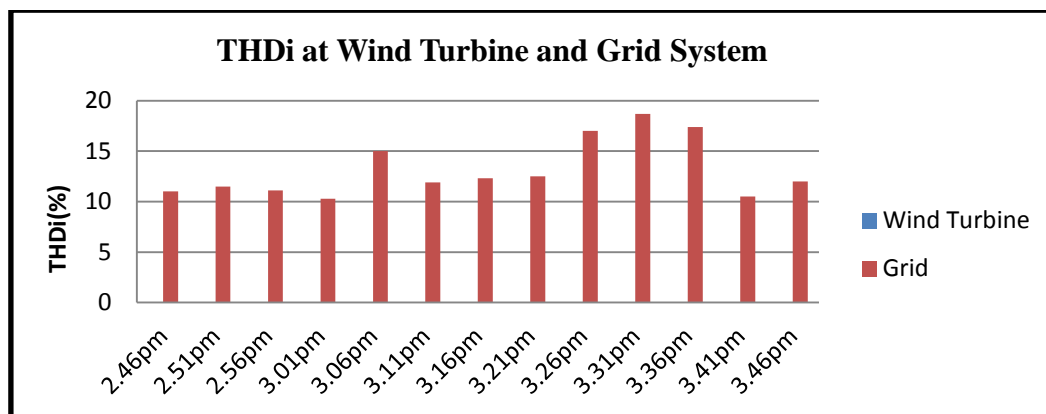
Figure 4.14   THD current at wind turbine and grid system

4)   <u>Wind Off Motor Off</u>
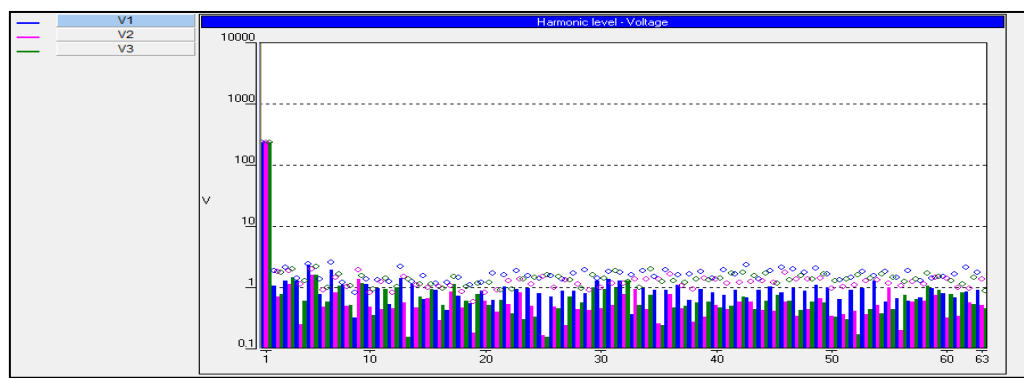
Figure 4.15   Harmonic distortion of voltage at grid
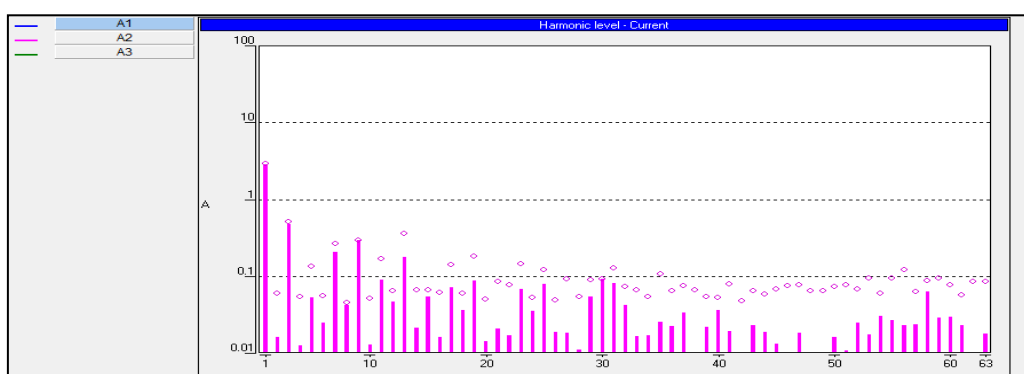
Figure 4.16   Harmonic distortion of current at grid
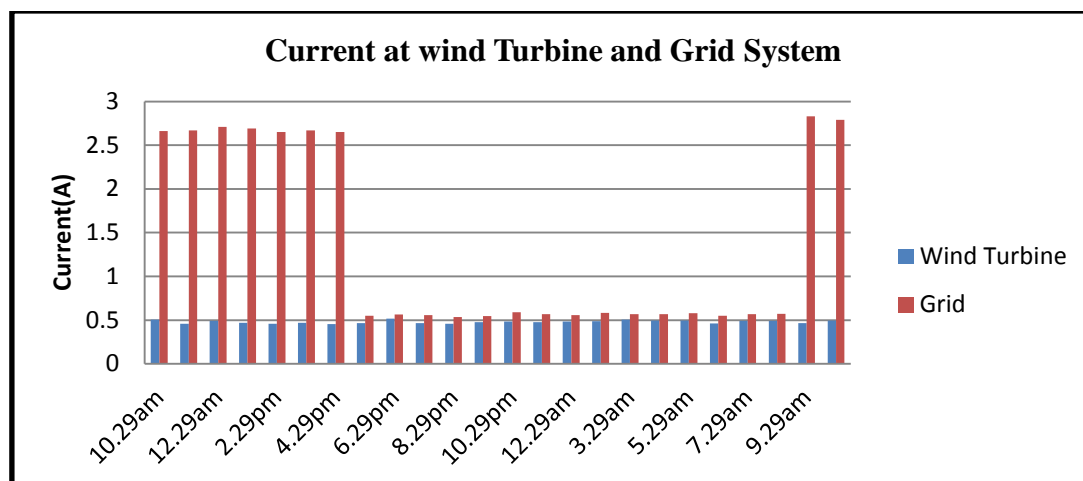
Figure 4.17 Current at wind turbine and grid system
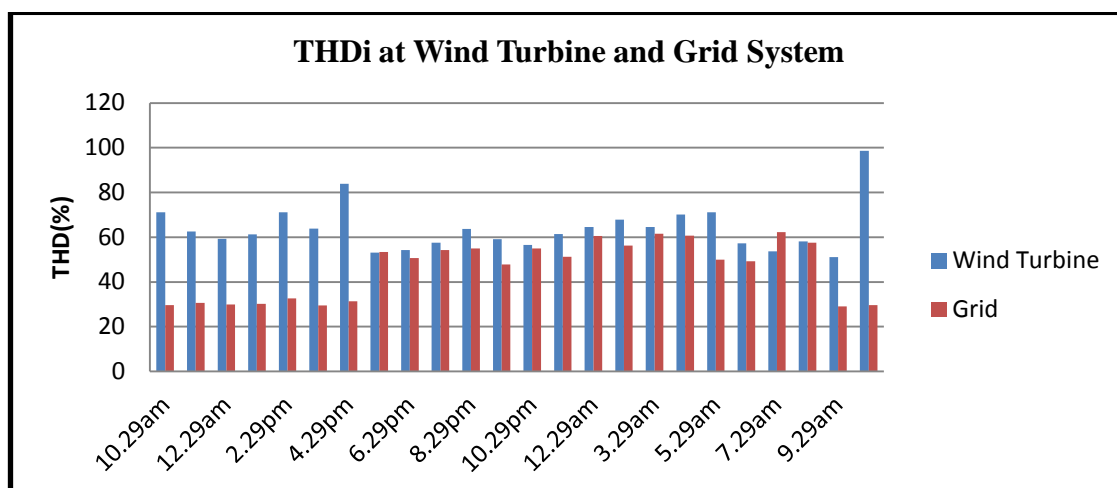
Figure 4.18 THD current at wind turbine and grid system

4.1.5 Waveform

Figure below indicated waveform for voltage and current when there is wind turbine system and motor was running, the data of waveform was recorded by power quality analyzer from 8.36am until 9.36am that is equal to 1 hour. This data was recorded because to observer and analyzer the waveform of voltage and current that occurs in grid system and wind turbine system. The figure shows the different pattern of waveform for current. As can see in the figure 4.9, it show that the waveform for voltage still the same pastern of waveform in this 1 hours. It is because of the

harmonic distortion that occur in voltage was very little of distortion. So, it doesn't affect the waveform of voltage as can see the waveform it is in pure sin wave. Compare to waveform of current, the figure 4.26 show that there are high distortion in current. As indicated in figure the harmonic distortion that occurs in the current was high and affects the pattern of pure sin wave waveform.

Figure below show the waveform of voltage and current in four conditions. It indicate when the condition different it effect the waveform of voltage and current. But, for voltage it stills the same waveform because the harmonic distortion does not affect the voltage at grid and at wind turbine system. The waveform of current is different cause of harmonic distortion. As shown below, the line preview the waveform of current at wind turbine system, it shows wind turbine produce the unstable waveform of current.

The harmonics of the supply voltage and current cause some supplementary losses in the machines. Some of these losses may be core losses. Core losses due to harmonic main fluxes. These core losses occur at high frequencies, but the fluxes are highly damped by induced secondary currents.

1) <u>Wind On Motor On</u>
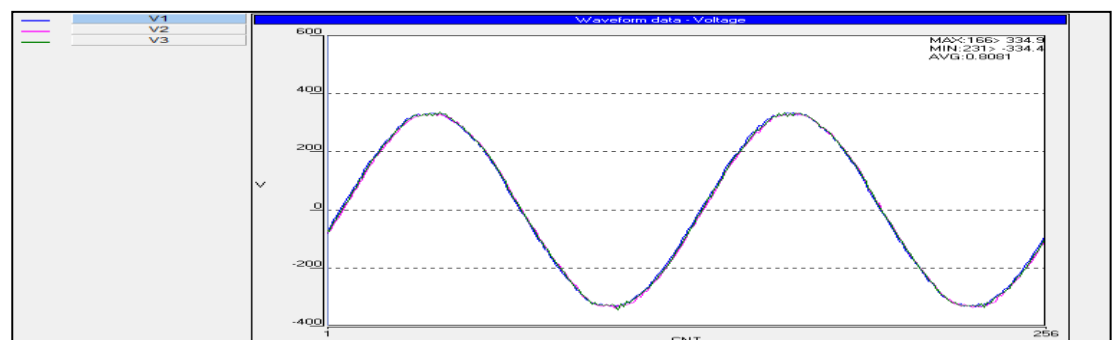
Figure 4.19   Waveform of voltages at wind turbine, grid and load
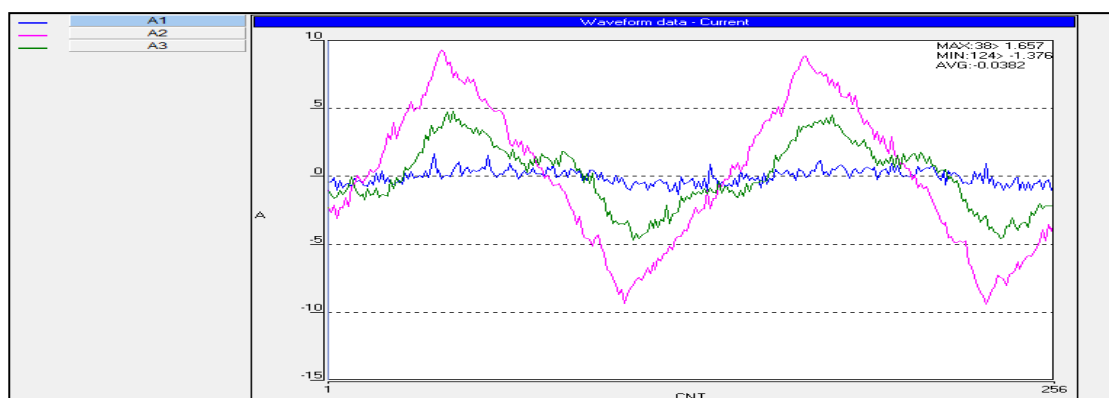
Figure 4.20   Waveform of currents at wind turbine, grid and load

2)   <u>Wind On Motor Off</u>
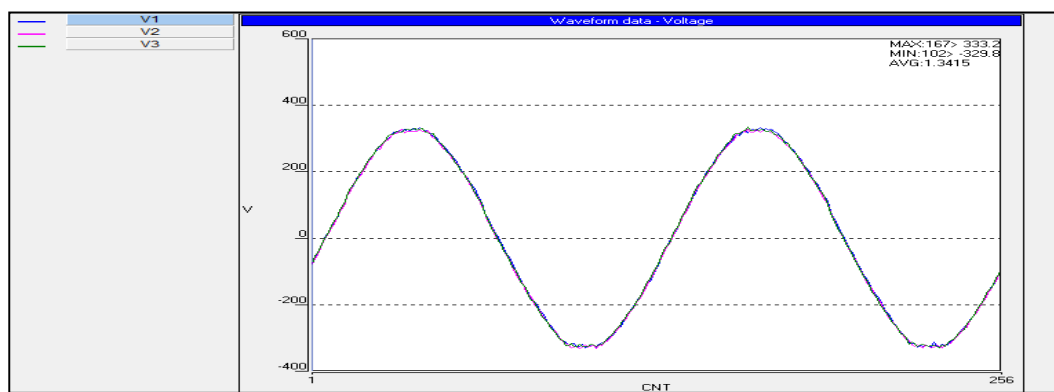
Figure 4.21   Waveform of voltages at wind turbine and grid
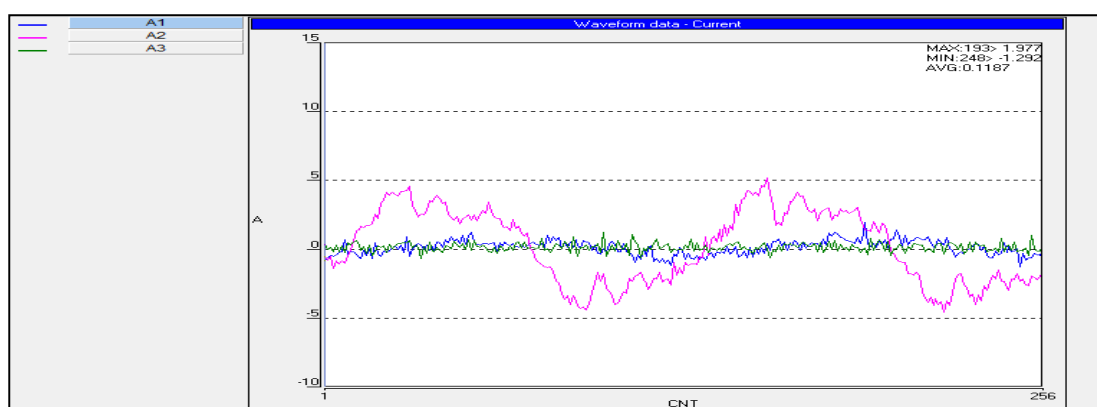
Figure 4.22   Waveform of currents at wind turbine and grid
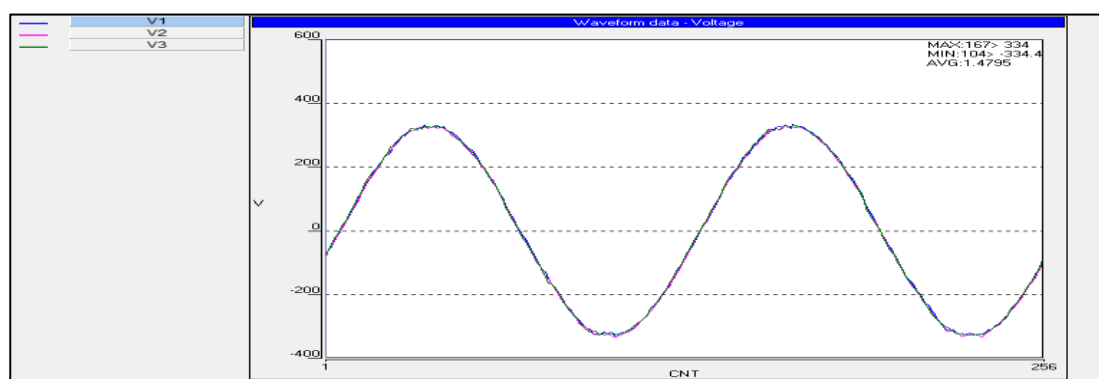
3) <u>Wind Off Motor On</u>

Figure 4.23   Waveform of voltages at grid and load
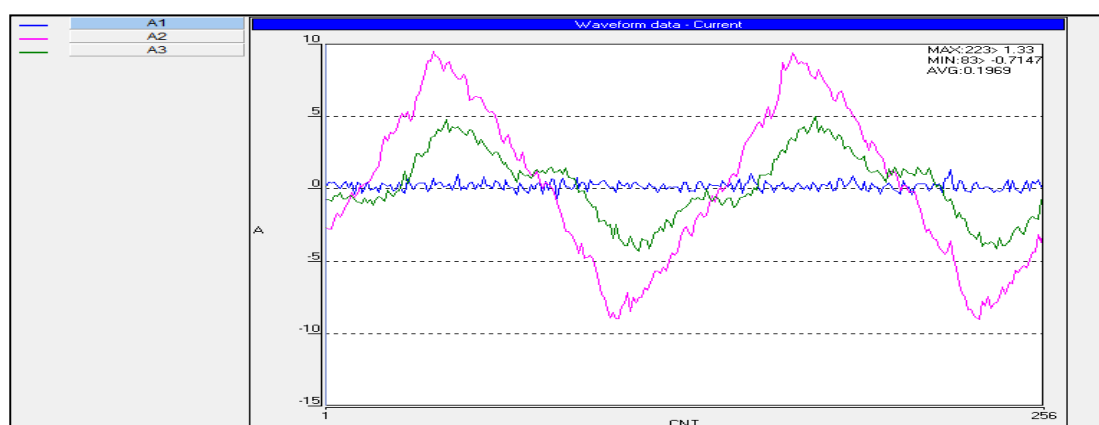
Figure 4.24   Waveform of currents at grid and load

4) <u>Wind Off Motor Off</u>
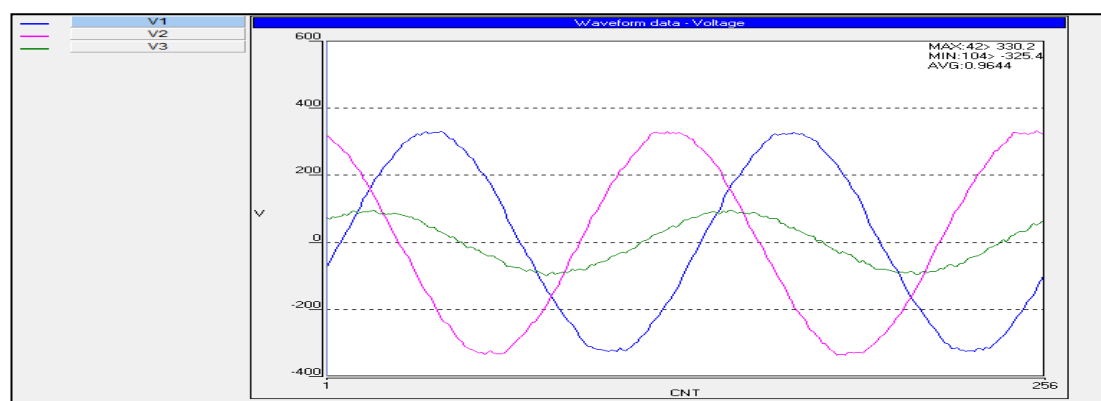
Figure 4.25   Waveform of voltages at grid
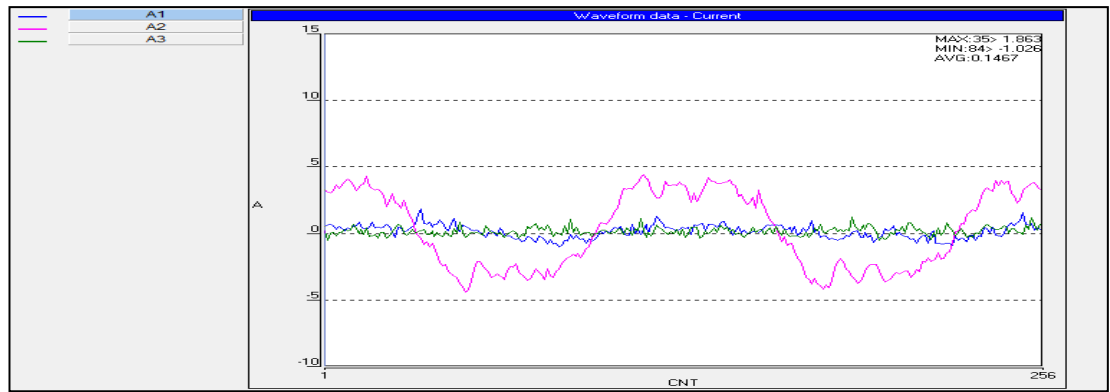
Figure 4.26   Waveform of currents at grid

4.2   Simulation Results

In this part briefly explain about the simulation results of the wind turbine grid connected system. The simulation was conducted same as the experimental to observe the voltage, current and total harmonic distortion in simulation. The simulation and the experimental was compared their accuracy and appropriateness.

4.2.1   Voltages and Currents at Grid

This simulation was developed exactly same with the experimental environment. Simulation was developed by four simulations. This section will explain about the result of voltage and current at grid system.

Value for voltage at grid system when all system was generated is 256.8V. From the simulation the data is 365. Then, the voltage has to convert to rms voltage which is $365/\sqrt{2}$, therefore the Vrms is 256.8V. When doing the other cases, the result for voltage is same this is 256.8V. It is because the connection between load grid and wind turbine are parallel.

There is a different for current at the grid system among four cases. The current at the grid was effect by motor as load and wind turbine. From the simulation, the current passes through when the whole system was operated are 4.9A. While, the current when wind turbine was operated, the current is 3.76A. The current when there is no wind turbine and load was disconnected is 4.29A. Lastly, the current passes through the grid when no other sources was connected to the grid is 3.34A. Result current at the first situation when the grid is connected to the wind turbine and load show the higher current because at that time the current consumption was high and also wind turbine produce current and supply to the grid. This figures below show the waveform of voltage and current at all situation.

1) <u>Wind On Motor On</u>
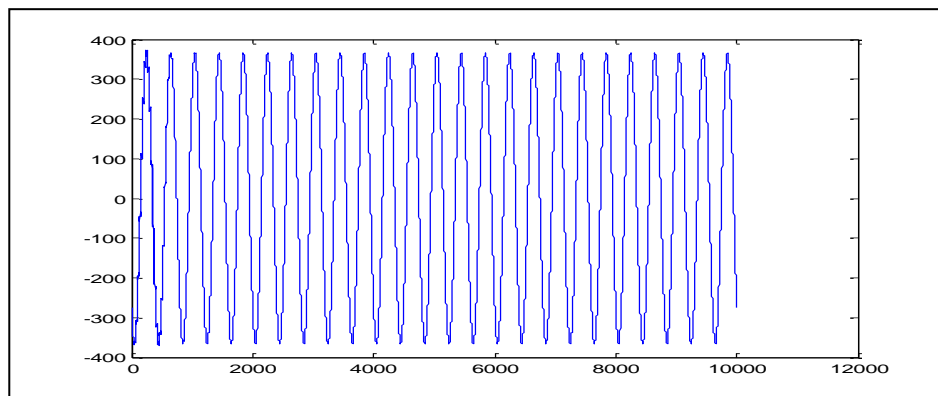
Figure 4.27   Waveform of voltage at grid
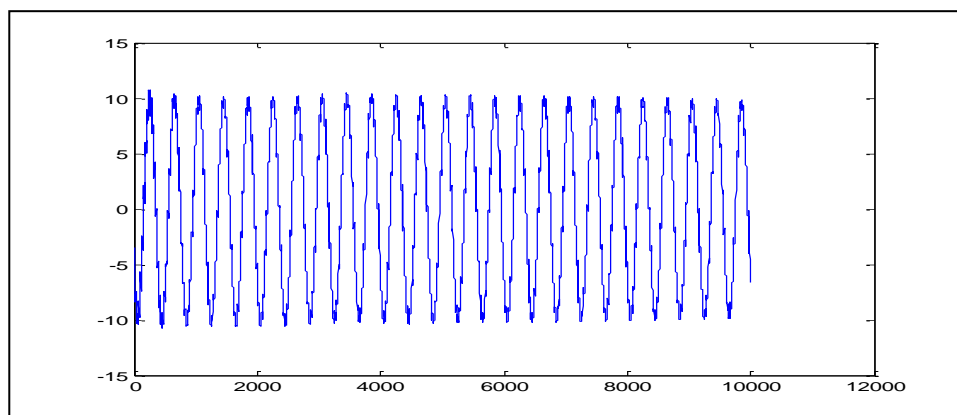
Figure 4.28   Waveform of currents at grid

2) Wind On Motor Off
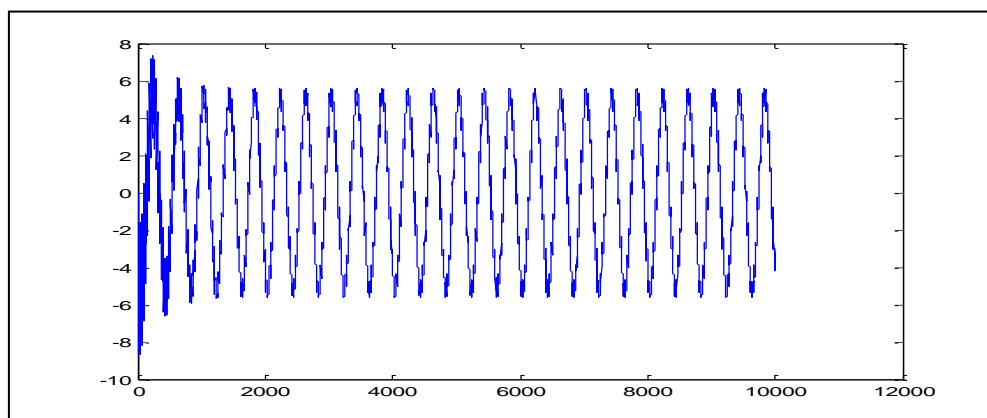
Figure 4.29   Waveform of currents at grid

3) Wind Off Motor On
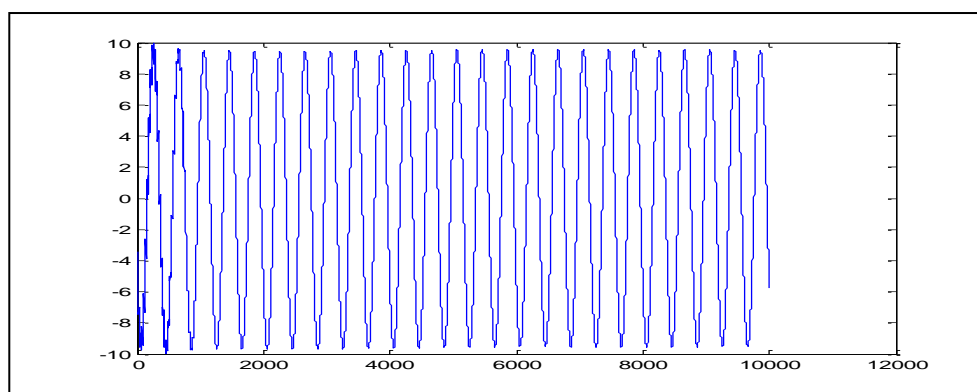
Figure 4.30   Waveform of currents at grid

4) Wind Off Motor Off
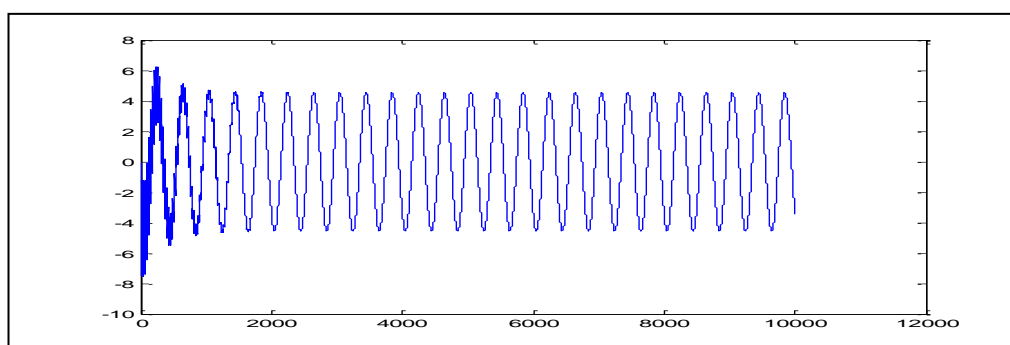
Figure 4.31   Waveform of currents at grid

4.2.2   Voltages and Currents at Wind Turbine

Wind turbine is renewable energy that produces current to generate the electricity. When the wind system produces more electricity than the household requires, the excess can be returned to the grid.

The voltage of wind turbine is almost same with the grid system. The voltage in wind turbine connected in parallel when the whole system was connected, therefore the readings of voltage at wind turbine is same with grid which is 256.8Vrms. The voltage when the load was cut off from the system also 256.8Vrms. But, when the wind turbine was disconnect, the voltage produce is zero whether there is no load or have load.

From the readings that take from the MATLAB, the current passes through in wind turbine are 0.52A. Currently, the current for wind turbine was connected to the grid is same either there is motor was connected or disconnect from the grid which are 0.52A. When the wind turbine was cut off from this system, the current is 0A. It is because from the simulation, the line from wind turbine was disconnecting and no current flow from wind turbine. The figures below show the voltages and current passes through in wind turbine. The figure only show when the wind turbine was connected to the grid. There is no figure when wind turbine was disconnected from the system.

1)   Wind On Motor On
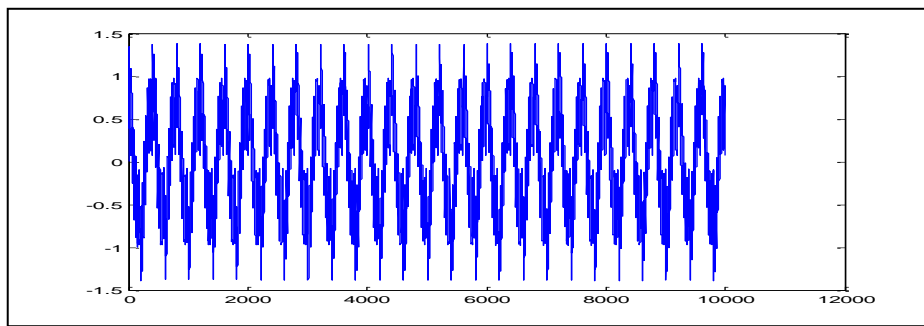
Figure 4.32   Waveform of currents at wind turbine

2)   <u>Wind On Motor Off</u>
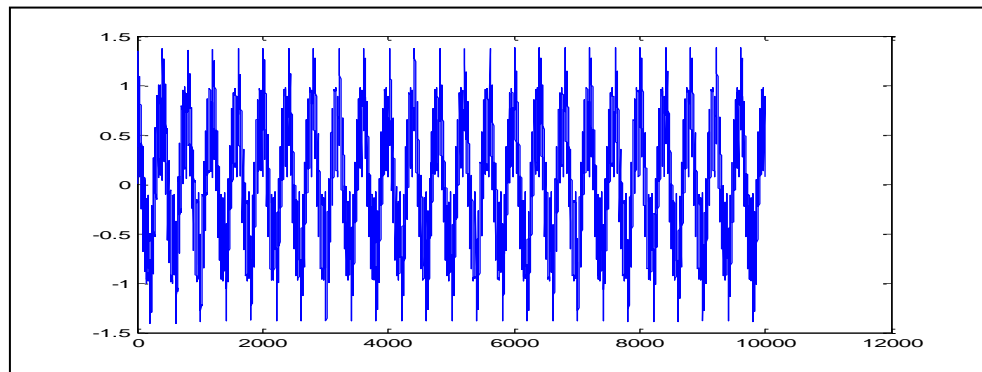
Figure 4.33   Waveform of currents at wind turbine

4.2.3   Total Harmonic Distortion (THD) at Grid

Power sources act as non-linear loads, drawing a distorted waveform that contains harmonics. The summation of all harmonics in a system is known as total harmonic distortion (THD). THD happen due to the current draw of each type of load. Linear loads draw current that is sinusoidal in nature so they generally do not distort the waveform. Non-linear loads, however, can draw current that is not perfectly sinusoidal. Since the current waveform deviates from a sine wave, voltage waveform distortions are.

THD voltage at grid is low at all condition that can be seen in this figure below. THD voltage in simulation does not affect much because the system in simulation was stabilization. From the simulation show that THD voltage performs in grid system is 0.24% when the whole system was generates. This case is similar with the percentage THD when the wind turbine off and motor was operated which are 0.24%. When the motor was disconnect either the wind turbine was on or off, THD voltage is around 0.26%.It show the inverter in simulation create more harmonic distortion. As can be observed from the waveform in figure below, waveform distortions can drastically alter the shape of the sinusoid. However, no matter the level of complexity of the fundamental wave, it is actually just a composite of multiple waveforms called harmonics.

Indeed the THD current is higher because the harmonic distortion effect at current waveform. As shown in result from simulation, THDi when the all system was generated is 12.01%. In second condition where the motor was disconnect from the system, percentage THD current is 21.5%. It is two times higher than first case. Next, the wind turbine was disconnecting from the method, THDi is 11.02%. On the other hand, THDi at the grid was 22.4% if the wind turbine and motor were not use in this simulation. Inverter produce harmonic in different order, the line commutated inverter is equipped with thyristor which must be connected to the grid in order to operate. Figure below were shown the THD voltage and current at grid.

1) Wind On Motor On
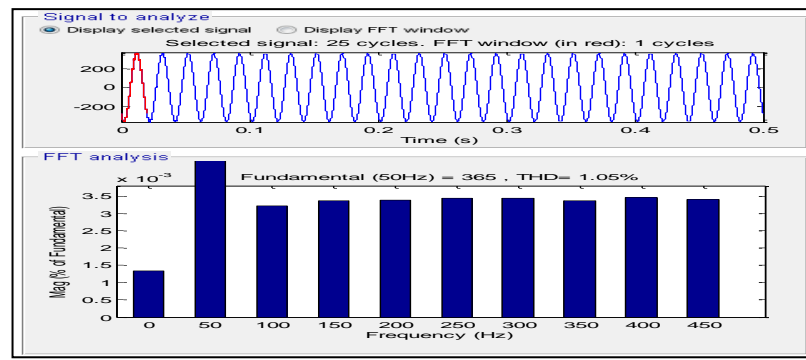
Figure 4.34 THD voltages at grid
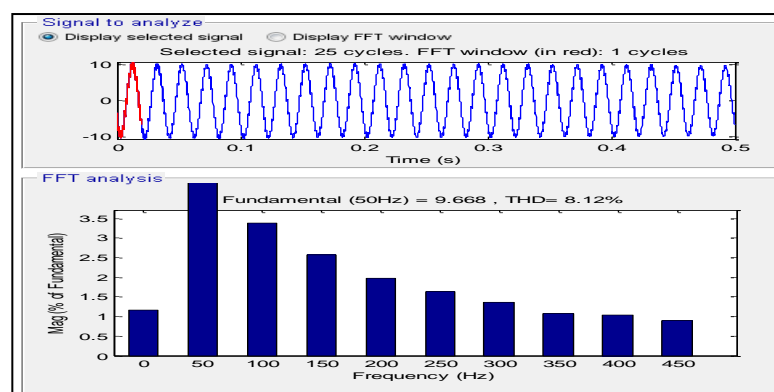
Figure 4.35 THD current at grid

1)   <u>Wind On Motor Off</u>
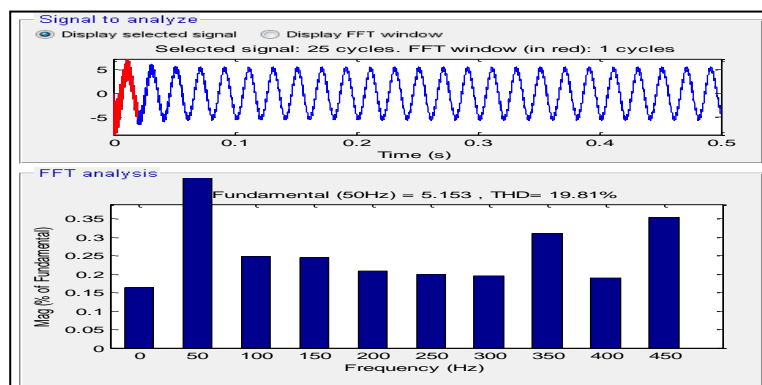
Figure 4.36   THD current at grid

2)   <u>Wind Off Motor On</u>
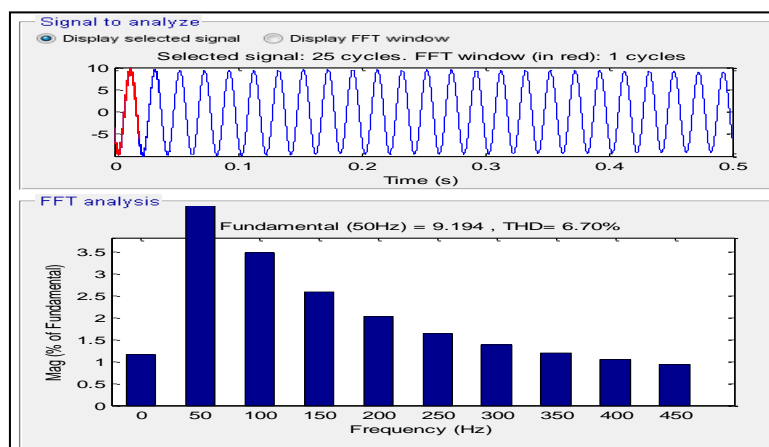
Figure 4.37   THD current at grid

3)   <u>Wind Off Motor Off</u>
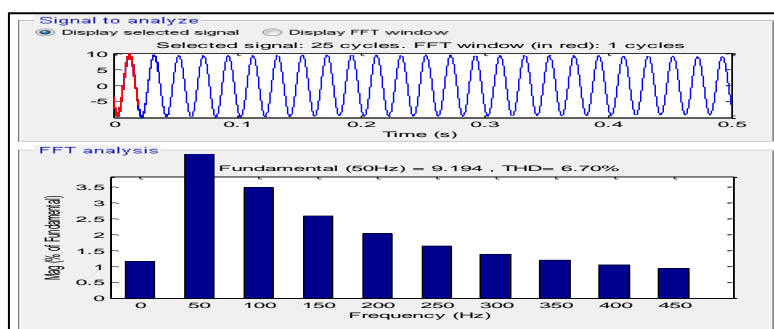
Figure 4.38   THD current at grid

4.2.4   Total Harmonic Distortion (THD) at Wind Turbine

Power quality relates to factors which describe the variability of the voltage level, as well as the distortion of voltages and current waveform. The various power quality parameters in the simulation such as harmonic distortion are observed in this part.

There is no difference percentage of THD voltage at wind turbine and grid system. THDv when the all system was operated is 0.24%. When the motor is not connected to the grid and wind turbine, the value of THDv is 0.26%. However, when the wind turbine was not generated either the motor was connected or disconnect, the percentage of THD is zero. It is because there is no connection between the wind turbine and grid. Harmonic distortion can have detrimental effects on electrical equipment. Unwanted distortion can increase the current in power systems. The higher the percentage, the more distortion that is present on the mains signal.

Wind turbine produce more harmonic distortion current compared to grid. The THD current in wind turbine in a state of all system was operating is 61.7%. Secondly, when the motor was cut off from the system the value for THD is 61.7% and lastly the wind was off if there have motor or not THDi is 0%. Power electronic devices might be able to cause harmonics. The capacitive coupling seen by the DC bus through the wind turbine is composed of the path between the rectifier side and ground can cause high harmonic current. Figure below were shown the percentage of THD current and voltage at wind turbine. The figure does not include when the wind turbine was off because there is no harmonic distortion in that cases.

1) <u>Wind On Motor On</u>
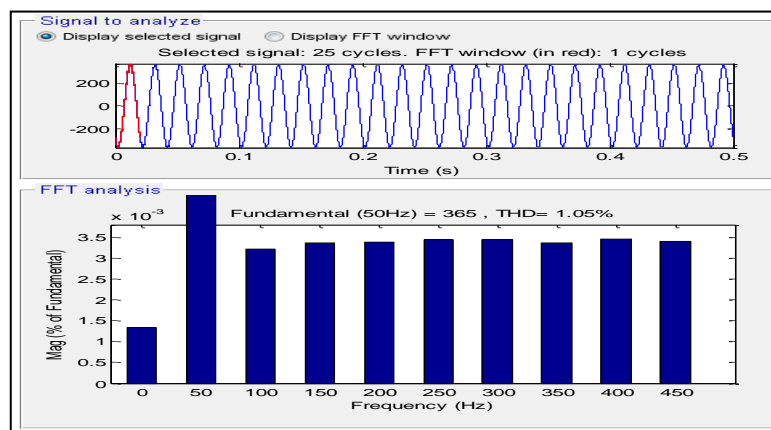
Figure 4.39   THD voltages at wind turbine
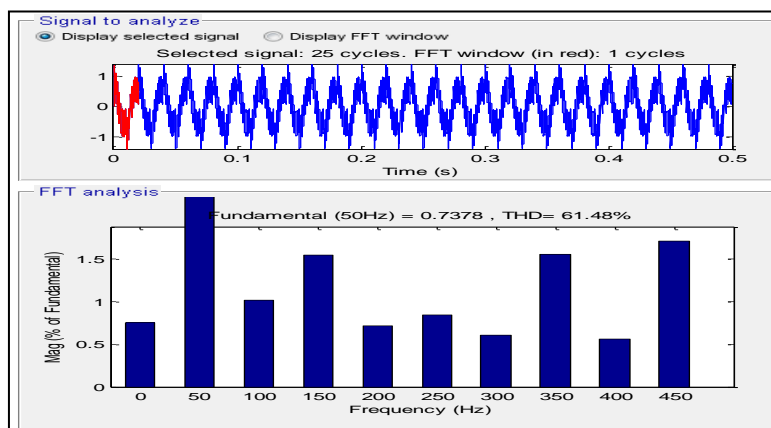
Figure 4.40   THD current at wind turbine

2) <u>Wind On Motor Off</u>
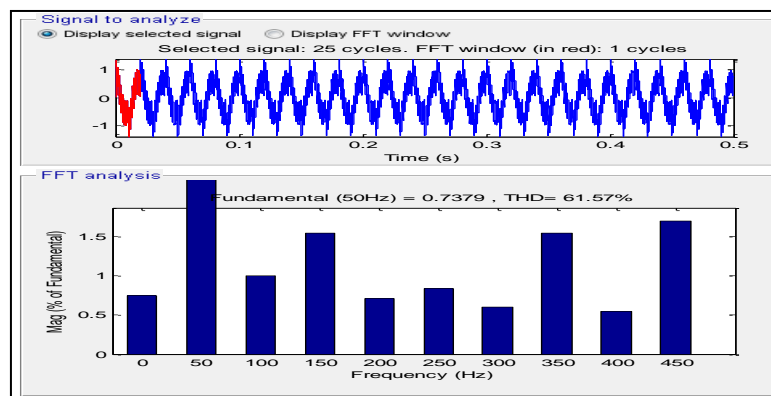
Figure 4.41   THD current at wind turbine

4.3   **Comparison between the Experimental and Simulation**

After the experimental and simulation, result from the experimental and simulation was compared to their accuracy and appropriateness. The results from both experimental and simulation are not exactly same because there are the environment factors such as heat losses, resistance of cable and etc are occur in this experimental. Although the result not exactly same but the data is approximately both experimental and simulation. It is because the parameters in certain system are same. The result is acceptance when there are differences below +/-50%.

Table below preview the comparison for voltage, current and THD for all condition. As shown as below, the values of voltage for all conditions in experimental and simulation are below than 10%. While for THDv the difference of both experimental and simulation is +/-50%. This difference is too highest perhaps for the experimental THDv effect from the source of generation. For other result such as current at grid, output current at wind turbine, THDi at grid and THDi at wind turbine show the percentage approximate are less than 40%.

1)   <u>Wind On Motor On</u>

Table 4.2: Comparison in grid system

Grid	Experimental	Simulation
Voltage(V)	234	256.8
Current(A)	4.8-6	4.9
THDv (%)	2	0.24
THDi(%)	10-14	12.01

Table 4.3: Comparison in wind turbine

Wind turbine	Experimental	Simulation
Voltage(V)	235	256.8
Current(A)	0.44-0.52	0.52
THDv (%)	3.2	0.24
THDi(%)	63.58	61.7

2)   Wind On Motor Off

Table 4.4: Comparison in grid system

Grid	Experimental	Simulation
Voltage(V)	231	256.8
Current(A)	3.1-3.5	3.76
THDv (%)	2	0.26
THDi(%)	18-20	21.5

Table 4.5: Comparison in wind turbine

Wind Turbine	Experimental	Simulation
Voltage(V)	231	256.8
Current(A)	0.44-0.49	0.52
THDv (%)	3.2	0.26
THDi(%)	56-72	61.7

3) <u>Wind Off Motor On</u>

Table 4.6: Comparison in grid system

Grid	Experimental	Simulation
Voltage(V)	230	256.8
Current(A)	3.1-4.9	4.24
THDv (%)	2.1	0.24
THDi(%)	11.02	11.02

4)   <u>Wind Off Motor Off</u>

Table 4.7: Comparison in grid system

Grid	Experimental	Simulation
Voltage(V)	234	256.8
Current(A)	2.8-3	3.34
THDv (%)	2.1	0.26
THDi(%)	21-25	22.4

CHAPTER V

CONCLUSION

5.1   Conclusion

The objectives of the wind turbine grid connected system are to assess the impact on grid system. Then the data from simulation and experimental will be compared. As conclusion, after studies wind turbine and power quality were complete, experimental was set up and also the simulation was developed according to the parameter that set up in experimental. The result was recorded by PQA in four conditions. It is to observe the various power quality effects in various conditions. Simulation of the wind turbine grid connected system was developed in four conditions same as in experimental. Wind turbine has a great impact in grid connected system. Wind turbine produces the harmonic distortion because of the function of inverter in wind turbine system. The load consumption effect at the current and harmonic distortion in grid system. Wind energy gives the positive and negative impact at grid. A wind turbine was support the grid in term of current but also increases the harmonic distortion. The impact from a wind turbine on the utility grid is determined from a wind turbine power quality test. The test results shall contain information regarding the effect of wind turbine and grid system. The results from the experimental and simulation are approximate.

5.2   Future Recommendation

For the future recommendation, the project could use other type of renewable energy such as hydro energy, fuel cells and other sustainable energy. So, the performance of all type renewable energy at grid system will observer in this

project. Other recommendation is the experimental were carried out in large scale system. The power quality disturbance and effect at high voltage system would recognize by carried out this experimental.

REFERENCES

[1] Haiyan Liu, Chuanglin Fang, Yanli kuai, Maoxun Li "Wind Energy Resources Exploitation and Large-scale Non-grid-connection Wind-Powered Industrial Bases Construction in China Northwest Territories"' Chemical Industry Press 2005,page 78.

[2] P.J. Musgrove, B.Sc(Eng.),Ph.D.,C.Eng.,M,.R.Ae.S. "Wind energy conversion-an introduction", Paper 2912A form 31st October 1983.

[3] H.Li, Z. Chen, "Optimal Direct-Drive Permanent Magnet Wind Genarator System for Different Rated Wind Speeds" Senior Member, IEEE.

[4] H.Li, Z. Chen, "Overview of different eind genarator systems and their comparisons" Senior Member,IEEE 23rd August 2007.

[5] Robert P. Fuller, Larry A. Nordstrom, Lamp Circuit,http://www.freepaternt.com 17 Dec 1985.

[6] Y.-M Chen, S.-C Hung,(2.4.C heng, and Y.-CL.i u "Multi-Input Inverter for Grid-Connected Hybrid PV/Wind Power System",IEEE 2005.

[7] Hiroshi Nomura , Kenichiro Fujiwara, Masanobu Yoshida, " A New DC-DC Converter Circuit with Larger Step-up/down Ratio", 783-8508.

[8] Heier S., "Grid Integration of Wind Energy Conversion Systems", 1998, ISBN 0 471 97143.

[9] Florin Iov et. al.," Wind Turbine Blockset in Matlab/Simulink", UNI.PRINT Aalborg University, Denmark, March 2004.

[10] Ezzeldin. S. Abdin and X. Wilson, "Control design and dynamic performance analysis of a wind turbine-induction generator unit" IEEE Trans. On Energy Conversion, Vol. 15, No. 1, pp 91-96, March 2000.

[11] http://www-ccs –ucsd.edu/matlab/toolbox/simulink/simulink.html.

[12] Daniel W.Hart, "Introduction to Power Electronic", Valparaiso University Valparoisa Indiana, 2010.

[13] Henderson, R.D., and Rose, P.J., "Harmonics: The Effects on Power Quality and Transformers," *IEEE Trans, on Ind. Apps.,* Vol. 30, No. 3., pp528-532, May/June 1994.

[14] Ashton, R.W., *Harmonic andPower Factor Correction By Means ofActive Line Conditioners With Adaptive Estimation Control,* Ph.D. Dissertation, Worcester Polytechnic Institute, Worchester, MA 1991.

[15] Lundquist, Johan. Harmonic Distortion in Power Systems. Chalmers University of Technology: Department of Electrical Power Engineering, 2001.

[16] International Electrotechnical Commission (IEC), IEC 61400-21: "Measurement and assessment of power quality characteristics of grid connected wind turbines"

[17] Mutlu, Ö.S., Akpınar, E. and Balıkcı, A. Power Quality Analysis of Wind Farm Connected to Alaçatı Substation in Turkey. Renewable Energy 34 (2009) 1312–1318.

[18] Mutlu, Ö.S. and Akpınar, E. Assessing the Grid Codes For Wind Power Plants in Turkey. Proc. of 9th World Wind Energy Conference 15-17 June 2010 Istanbul-Turkey.

[19] Johnson,G.L., Wind Energy System,Prentice Hall Intenational Inc., New Jersey USA, 1985,360p

[20] Tande,J.O.G, "Impact of wind Turbines on Voltage Quality", 8th International Conference of Harmonics and Quality of Power, Greece, October 14-16,1998

[21] Mustafa Kayıkc¸ı and Jovica V. Milanovi´c, "Reactive Power Control Strategies for DFIG-Based Plants," *IEEE Trans. on Energy Conversion*, vol. 22, no. 2, pp. 389-396, June 2007.

[22] Stephan Engelhardt, Istvan Erlich, Christian Feltes, J¨org Kretschmann, and Fekadu Shewarega, "Reactive Power Capability of Wind Turbines Based on Doubly Fed Induction Generator," *IEEE Trans. on Energy Conversion*, vol. 26, no. 1, pp. 364-372, March 2011.

[23] Torsten Lund, Poul Sorenson and Jarle Eek, "Reactive Power Capability of a Wind Turbine with Doubly Fed Induction Generator," *Wind Energy*, vol. 10, iss. 4, pp.379-394, Apr. 2007.

[24] Heier, Siegfried. "Grid integration of wind energy conversion systems". John Wiley & Sons Ltd.

[25] P. Rosas, "Dynamic influences of wind power on the power system," Risø-R-1408(EN) 2003. 152 p.

[26] D. Boroyevich, I. Cvetkovic, Dong Dong, R. Burgos, Fei Wang, Fred Lee, "Future Electronic Powers Distribution Systems – A Contemplative view," presented at the OPTIM Conference, Brasov, Romania, May 2010.

[27] T. G. Wilson Sr., "The evolution of power electronics," *IEEE Trans. Power Elec.*, vol. 15, no. 3, pp. 439-446, May 2000.

[28] *Electricity Technology Roadmap, 2003*. Palo Alto, CA: Electric Power Research Institute (EPRI), Inc.

[29] R. Strzelecki, G. Benysek (editors), *Power electronics in smart electrical energy networks*, London: Springer-Verlag Ltd., 2008.

[30] Jianzhong Zhang, Ming Cheng, Zhe Chen and Xiaofan Fu, "Pitch Angle Control for Variable Speed Wind Turbines," *Electric Utility Deregulation and Restructuring and Power Technologies*, pp. 2691-2696, 6-9 April 2008.

[31] Abram Perdana, Technology Wind Turbine Models for Power System Stability Studies: Chalmers University, 2006.

[32] Datasheet Wind Turbine Air Breeze Southwest Wind Power Dealer

[33] Datasheet Inverter Windy Boy 1100LV SMA Technologies AG

SMALL WIND. BIG ENERGY.

The most powerful wind generator in its class.

The all-new Air Breeze. Quieter, more efficient, and precision engineered to deliver more energy at lower wind speeds than any other wind generator in its class.[1] The Air Breeze is the latest generation of AIR with more than 100,000 sold in 120 countries the world's most popular small wind generator.

- 3 year warranty
- Injection-molded composite blades
- Microprocessor-based smart internal regulator with peak power tracking
- Aircraft-quality aluminum alloy castings
- Brushless neodymium alternator
- Maintenance-free — only two moving parts

Technical Specifications

Rated Capacity	200 watts at 28 mph (12.5 m/s)
Rotor Diameter	46 in (1.17 m)
Weight	13 lb (5.9 kg)
Shipping Dimensions	27 x 12.5 x 9 in (686 x 318 x 229 mm) 17 lb (7.7 kg)
Mount	1.5 in schedule 40 1.9 in (48 mm) OD pipe
Start-Up Wind Speed	6 mph (2.68 m/s)[3]
Voltage	12, 24 and 48 VDC
Turbine Controller	Microprocessor-based smart internal regulator with peak power tracking
Body	Cast aluminum (Marine is powder coated for corrosion protection)
Blades	(3) Injection-molded composite
Overspeed Protection	Electronic torque control
Kilowatt Hours per Month	38 kWh/mo at 12 mph (5.4 m/s)
Survival Wind Speed	110 mph (49.2 m/s)
Warranty	3 year limited warranty

Power all of this with Air Breeze

Your Southwest Windpower Dealer:

Next Generation Turbines Ltd.
Skyrrid Farm, Pontrilas, Hereford. HR2 0BW
0845 094 9488 nextgenerationturbines.com

[1]Wind generators with the same swept area as Air Breeze.
[2]Data collected by the North Carolina Small Wind Initiative/Appalachian State University Small Wind Research and Demonstration Facility, Beech Mountain, NC, USA.

APENDIX A Air breeze technical data

SMA

WB 1100LV

Maximum yield
> Specially designed for small wind energy systems
> Optimized for best yields in both weak as well as strong wind regions

Easy Installation
> Free choice of turbine due to programmable power curve
> Free choice of mounting location

Safe operation
> Electric separation
> Certified for the most important countries of installation (SMA grid guard)
> Worldwide SMA service and SMA Service Line
> Comprehensive SMA warranty program

WINDY BOY 1100LV
The Low Voltage Device

The Windy Boy 1100LV is the perfect solution for the smallest wind energy systems with low generator voltage: turbines with a nominal voltage of 24 or 48 V can be connected without an additional voltage transformer. The programmable power gives you full flexibility for choosing the turbine, its weatherproof housing and the wide temperature range allow for installation at nearly any location. As an inverter for wind energy systems, the Windy Boy is optimally adjusted to fast and frequent load changes. Its minimum internal consumption during a calm also increases the yield, which you can monitor at any time using the display and different communication interfaces.

Technical Data
WINDY BOY 1100LV

	WB 1100LV	
Input (DC)		
Max. DC power	1210 W	
Recommended generator power at 2500 full-load hours per year	1000 W	
Recommended generator power at 5000 full-load hours per year	900 W	
Max DC voltage	60 V	
Min. open circuit voltage for activating "Turbine Mode"	25 V	
"Turbine Mode" operating range	21 V – 60 V	
Max. input current	62 A	
Output (AC)		
Nominal AC output power	1000 W	
Max. AC output power	1100 W	
Max. output current	5 A	
Nominal AC voltage / AC operating range	220 V – 240 V / 180 V – 260 V	
AC grid frequency (self-adjusting) / range	50 Hz / 60 Hz / ± 4.5 Hz	
Power factor (cos φ)	1	
AC connection	single-phase	
Efficiency		
Max. efficiency	92.0%	
Euro ETA	90.0%	
Protective equipment		
DC reverse polarity protection	●	
AC short-circuit protection	●	
Ground fault monitoring	●	
Grid monitoring (SMA grid guard)	●	
Electric separation	●	
General data		
Dimensions [W / H / D] in mm	434 / 295 / 214	
Weight	29 kg	
Operation temperature range	-25 °C ... +60 °C	
Internal consumption: Operation / standby	< 5 W / 0.1 W	
Topology	Low frequency transformer	
Cooling concept	Convection	
Installation location: indoor / outdoor (IP65)	● / ●	
Features		
DC connection: screw terminal	●	
AC connection: plug connector	●	
LCD display	●	
Cover color: red	●	
Interfaces: RS485 / radio	○ / ○	
Warranty: 5 years / 10 years	● / ○	
Certificates and approvals	www.SMA.de	

● Standard   ○ Optional   Values apply for nominal conditions – Version: February 2009

Efficiency curve

Accessories

APPENDIX C   Schematic diagram of wind turbine system