DEVELOPMENT OF DEMAND SIDE MANAGEMENT SYSTEM: DIAGNOSTIC TOOL AND LOAD RECOGNITION

KONG KIE MING

A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical & Electronic Engineering

Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

April 2013

DECLARATION

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

Signature : ____________________________

Name : KONG KIE MING

ID No. : 09UEB07437

Date : ____________________________

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"DEVELOPMENT OF DEMAND SIDE MANAGEMENT SYSTEM: DIAGNOSTIC TOOL AND LOAD RECOGNITION"** was prepared by **KONG KIE MING** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical & Electronic Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : _______________________

Supervisor : Mr Chua Kein Huat

Date : _______________________

Specially dedicated to

my beloved family and friends

supervisor Mr Chua Kein Huat

and project partners Mr Pang Yap Seng and Ms Lim Khim Yan

ACKNOWLEDGEMENTS

I would like to thank everyone who had contributed to the successful completion of this project. I would like to express my gratitude to my research supervisor, Mr Chua Kein Huat for his invaluable advice, guidance and his enormous patience throughout the development of the research.

In addition, I would also like to express my gratitude to my loving parent and friends who had helped and given me encouragement throughout the research. Without their encouragement and support, this project would not have materialized. I am grateful for their unwavering support and guidance.

Finally, I take immense pleasure in thanking my project partners, Mr Pang Yap Seng and Ms Lim Khim Yan who gave me the opportunity to work and learn together as a team in the development of research. Their effort and cooperation was the vital for the success of the project.

DEVELOPMENT OF DEMAND SIDE MANAGEMENT SYSTEM: DIAGNOSTIC TOOL AND LOAD RECOGNITION

ABSTRACT

Electrical supply and demand must remain in balance at all time to ensure the stability on the electrical grid. Demand side management is the ability to maximize the energy usage at the side of consumption from limited electrical supply. It is the modification of customer demand for energy through various methods including energy efficiency, energy controllers, demand response and spinning reserve. Instead of adding more generation to the system, demand side management monitor, reduce and regulate the energy consumption of the users. Smart meter is one of the incentives to improve energy monitoring. However, the smart meter is limited to the energy consumption of a house level. The main challenge is to acquire appliances-level information. The load data obtained is extremely valuable to energy auditors, utilities, public policy makers, and appliance manufacturers, for a broad range of purpose. For example, they can determine the load characteristic of a particular electrical appliance and control it in a way which can reduce maximum energy usage when more loads are added. In this project, a diagnostic tool which is capable of measuring and analyzing the basic parameters of a load is developed. The basic parameters include voltage, current, power factor and so on. The programming is done using LabVIEW 2011 by National Instrument. An algorithm is also developed for load recognition. Lastly, the implementation of energy storage system mitigated the problem of voltage unbalance across the three phase network.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

h	height, m
I	Current, A
Ω	Resistance, Ohm
P	Power, W
s	Time, s
T	temperature, ˚C
V	Voltage, V

AMI	automated meter reading
AMR	advance metering infrastructure
FPGA	field-programmable gate arrays
GUI	graphical user interface
LV	low voltage
NC	normally close
NALM	non-intrusive appliance load monitoring
NO	normally open
VI	virtual instrument
VUF	voltage unbalance factor
UI	user interface
UPS	uninterruptible power supply

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

The utility industries are facing numerous challenges which include fuel diversification, optimizing the deployment of expensive assets, increasing power demand, improving energy conservation and reduction of greenhouse gases (K. Moslehi 2008). Engineers are required to focus on sustainable development which can meet present needs without compromising future generation needs. In power transmission and distribution, the electrical network has become complicated and difficult to manage. In case of any breakdown, this catastrophic effect will cause tremendous losses to the nation. Hence, the electrical energy system must be able to provide a reliable and stable system which can tackle various faults.

The existing electric energy system is unidirectional and up-down oriented. Studies are focused on the Low Voltage (LV) distribution due to the complexity in managing different kind of load. The loads are the culprit which invokes the necessary to perform diagnosis upon them. Different parameters obtained from the load are analysed to sort out the potential predicament that may occur in the future. In some situation, the problem cause by the load does not take into consideration such as voltage unbalance, voltage rise or drop and network power loss.

1.2 Problem Statement

The diagnostic system is found at the different stages from generation, transmission to distribution. Power meter reading device is installed by utilities to monitor the monthly usage of the household and implied charges base on the total usage. This simple meter can only shows the total usage but not the individual devices. It is also attached to distribution board and difficult to remove. Whenever the users want to know about the energy consumption of certain devices, they can only based on the specifications data without knowing the true condition of the device.

Furthermore, the voltage unbalance is a problem usually overlooked in the LV distribution network. In factories which operate numbers of machine, the voltage unbalance has a great effect towards induction motor such as overheating, reduce lifespan and power loss in long run. According the National Electrical Manufacturers Association (NEMA), 1% increase of voltage unbalance factor can cause 6% to 10% temperature rise. This indirectly creates economic loss as the machinery with induction motor has to be replaced more often.

1.3 Aims and Objectives

This project aims to develop a portable diagnostic tool and solve voltage unbalance in the LV distribution network. A graphical interface controlling and monitoring system is developed using a graphical programming language LabVIEW. In interest of this objective, some tasks are set to be fulfilled as following:

- To use the graphical programming language LabVIEW and NI FPGA
- To design and construct the portable diagnosis tool
- To apply present method for demand side management
- To develop an algorithm to perform load recognition
- To implement the Sunny Island 5048 which is a bidirectional inverter into the system for voltage mitigation

1.4 Project Scope

In this project, the aim is to build a diagnostic tool which contains the measurement and automation system. The diagnostic tool is the integration of both hardware and software to measure, monitor and control the system. This device must be portable and easy to carry around. Besides, load recognition and voltage unbalance mitigation are the additional functions of the device besides doing measurement on the LV distribution network. The first part of the project is to construct the diagnostic tool. The design of the structure must be able to cover all the necessary electrical and electronic components. The protection design specification is followed to ensure the safety of the device. In the second part of the project, it focuses on the programming using LabVIEW. A Graphical User Interface (GUI) is constructed which allows the user to monitor the load connected to it. The devices must also be able to perform load recognition with the help of software implementation. When Sunny Island 5048 is added in to mitigate the voltage unbalance, the program must be able to perform the task flawlessly.

CHAPTER 2

LITERATURE REVIEW

2.1 LabVIEW

Over the years, numerous kinds of programming language have been developed to ease the programmers in developing software applications. LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) is a powerful programming tool developed by National Instrument which helps to increase the efficiency and productivity in solving today's problem. This software is unique compare to other programming tools as it is a graphically-based programming language. For engineers, it is used for testing, debugging, optimizing and so on from small to large systems. (Product Information: What is NI LabVIEW 2011)

The simplicity and convenience provided by LabVIEW when constructing and programming is by the Virtual Instrument (VI). A VI consists of the front panel, block diagram, and icons that represent the program. The purpose of the front panel is to show the indicator and allow users to control. Users can either input data or collect data from a virtual instrument which is running. The block diagram is the complete code for the whole VI, which serve as the central core of the programme. Lastly, the icon which is the visual representation of the VI, has connectors for program inputs and outputs.

Figure 2.1: LabVIEW 2012 (National Instrument 2012)

2.1.1 National Instrument FPGA

Field-programmable gate arrays (FPGAs) are made up of reprogrammable silicon chips. By programming an FPGA, it actually rewires the chip itself to implement the user functionality rather than running a software application. It is targeted on NI reconfigurable I/O hardware. LabVIEW is well suited for FPGA programming because it clearly represents parallelism and data flow.

The top 5 benefits of using FPGAs are as below:

- Faster I/O response times and specialized functionality.
- Exceeding the computer power of digital signal processors.
- Rapid prototyping and verification without the fabrication process of custom application-specific integrated circuit (ASIC) design.
- Implementing custom functionality with the reliability of dedicated deterministic hardware.
- Field-upgradable eliminating the expenses of custom ASIC re-design and maintenance.

2.2 Introduction to Smart Grid

The new generation electricity grid, also known as “Smart grid” is no longer a new term in power industries. As the electrical system and its components are getting much more complicated, there is a need to provide the utility companies with full visibility and pervasive control over their system. Utilities need to introduce distributed intelligence into their existing infrastructure to make them more reliable, efficient and capable of exploiting and integrating diverse sources of energy (S. J. Anders 2007). The three significant issues which the electric power industries throughout the world are facing including an aging transmission system, the need for a regulatory framework and an aging workforce (P. Mazza 2005).

The aging transmission system can increase the risk of failure during operation. All the components of the electrical system included in generation, transmission and distribution will degrade over a period of time. While all the utilities have their own maintenance plans for this system, ever-increasing congestion levels in many areas are making it increasingly difficult to schedule circuit outages for routine upgrades. If this is not done well, the impact on utilities in terms of reliability and asset replacement will be significant.

Investment on the electricity infrastructure has been declining over the years. There is a need for a regulatory framework that will encourage more independent investment, ownership, and management on the electrical grid. For the areas which already have restructured framework shows significant increase in funding to develop a new and advance infrastructure to meet the present demand. The aging workforce required a succession plan to ensure the present of next generation of sophisticated workers and engineers in the industry.

Advancement in technology will develop new approaches to improve the functionality and flexibility of the existing electrical system. In other word, smart grid can overcome the shortcomings of the existing grid. Smart grid is more likely to follow an evolutionary trajectory than to involve a drastic overhaul. They will be functioning side-by-sides with existing electricity grid. However, the maturity of the smart grid over time will cause the shifting from old grid to the new grid to improve and enhance their critical services.

One of the common problems faced by most utility companies across the globe is how they can meet the present demand as soon as possible, with minimum cost, and without jeopardizing the critical services they are currently providing. They should come out with strategies which they can achieve the highest return on investment for such undertaking. For any new technology breakthrough, there is a clear advantage for the utility in developing countries to implement it without the need for backward compatibility with their existing network.

The existing electricity grid hierarchy system is arranged from top-bottom in such a way, starting from central generation, transmission system, network of substations, distribution network and finally customer loads. Above the customer loads, the system is centralized and can control with basic data network. When it reaches the customer loads itself, being passive operation, it has no data network. The system is one-way pipeline with no real-time information about the service parameter at the customers' side. Hence, the grid is often over-engineered so that it can withstand the maximum anticipated peak demand which does not occur frequently, causing the system to be inefficient. The system stability is also questioned with any unforeseen surge in demand or anomalies across the distribution network. In the case of any component failures, it can trigger catastrophic blackouts (Amin and Wollenberg 2005).

2.2.1 Smart Grid Evolution

In order to facilitate troubleshooting and protect the expensive upstream assets, various levels of command-and-control functions are introduced. The most widely used system is the Supervisory Control and Data Acquisition (SCADA). It gives limited control for upstream assets while the distribution network remains outside their real-time control.

From statistical report, nearly 90% of all power outages and breakdown have their roots in the distribution network (Moore and McDonnell 2007). The distribution network is the main focus to move toward the smart grid. Due to the increasing cost of fossil fuel, the utility companies choose not to expand their generation capacity with rising demand for electricity. So, there is a need to modernize the distribution network that can help with demand-side management and revenue protection.

In fact, the metering side of the distribution system has been the focus of most recent infrastructure investments. The earliest type of meter is the electromechanical meter which has extremely limited functionality. It has a lot of mechanical moving parts which easily degraded over time. After that, the Automated Meter Reading (AMR) is introduced. It allows the utilities to read the consumption records, alarms, and status from customers' premises remotely. As it is one-way communication system, the AMR does not address the key issue they need to solve: demand-side management. The system can only restricted to reading meter data. The utilities companies realise that the AMR system do not allow the transition to the smart grid where fully control at all levels is a basic premise. The utilities across the globe moved towards Advanced Metering Infrastructure (AMI) instead of investing on AMR. AMI is two-way communication system which allows the utilities to monitor and well as control the service-level parameter. AMI is clearly the next step for transition to the smart grid. Smart grid needs to leverage the AMI infrastructure and implement its distributed command-and-control strategies over the AMI backbone (A. Vojdani 2008).

The pervasive control and intelligence that embodies the smart grid has to reside across all geographies, components, and functions of the system. The smart grid is a grid that consists a wide variety of generation options. It allows consumers to have interaction with the energy management system by adjusting their energy use and reducing their energy cost. The evolution of technologies also leads to the realization of self-healing system in smart grid. A self-healing grid is expected to respond to threats, mal-function of equipment and other destabilizing influences by preventing or containing the spread of disturbances. Since the smart grid requires continuous improvement, Information & Technology is used to optimize the grid. Thus, it is not a replacement for existing electricity grid but a complement to it (Moore and McDonnell, 2007).

2.2.2 Smart Microgrid

In smart micro grid, it is expected that some of the distributed generators and loads can be arbitrarily plugged-in or plugged-out from the microgrid. It is known as the plug and play operation. It consists of interconnected networks of distributed energy system such as loads and resources that can carry out their normal operation whether they are connected to or separated from the electricity grid. In such a plug and play approach, different generators, loads and energy-storage elements are plugged-in or plugged-out arbitrarily. The common AC-bus voltage magnitude and frequency have to be stabilized in the absence of any sort of communication among the elements of the microgrid.

2.2.3 Microgrid Topology

A microgrid can operate both in on-grid as well as islanded modes. During the islanding mode, the distribution generator should be disconnected from the network when the main electric grid continues to energize the distribution line. It incorporates power plant capable of meeting local demand as well as feeding the unused energy back to the electricity grid. It services a variety of loads, including residential, office and industrial loads. It makes use of local and distributed power storage capability to smooth out the intermittent performance of renewable energy sources. It incorporates smart meter and sensors. The communication infrastructures enable system components to exchange information and commands securely and reliably.

2.3 Demand Side Management

Demand side management is a portfolio of measures to improve the energy system at the side of consumption. It can be done in various ways such as improving energy efficiency with the use of better materials, smart energy tariffs with incentives for certain consumption patterns and sophisticated real-time control of distributed energy resources.

The ability of the grid to sustain the increasing demand will soon face its limit. The demand side management is one way to stretch these limits a bit further. The main advantage is that it is require lower capital cost to influence the load than to build a new power plant or install some electric storage device. The demand side management is moving toward the customer driven rather than utility driven. Depending on the timing and the impact of the applied measures on the customer process, it can be categorized into four main points which is Energy Efficiency, Time of Use, Demand Response and Spinning Reserve as shown in Figure 2.2 (Palensky and Dietrich 2011).

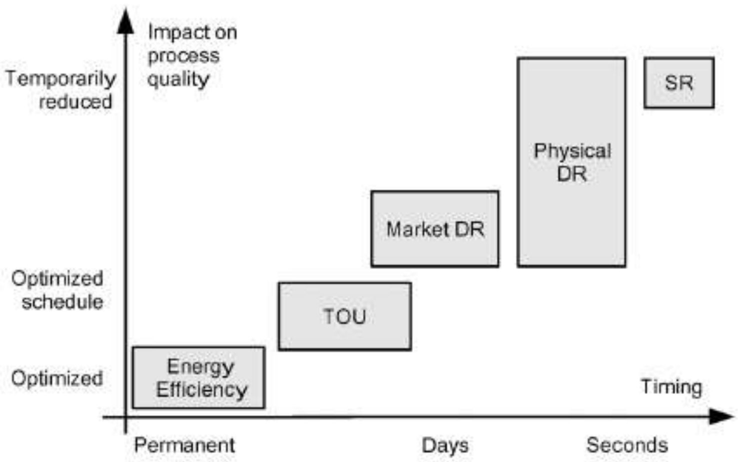


Figure 2.2: Categories of Demand Side Management

The dynamic demand side management does not only reduce energy consumption, the consumption patterns are also influenced. In an ideal case, where energy efficiency takes place, the consumption pattern is lower than the original consumption. When Demand Response is taken into consideration, the normal operation without rebound smoothen the peak of the graph. However, Demand Response will sometimes cause the rebound effect to take place. The energy is typically not saved and maybe a new peak is generated. This effect can be avoided, but it might result in a reduced process quality. For example, when such an ideal “peak shaving” applied to air-conditioning system, if it normally run at 50% and were shed for half an hour, it is restricted to compensate the downtime with half an hour of 100%. In Figure 2.3, the original consumption has a high peak in the middle.

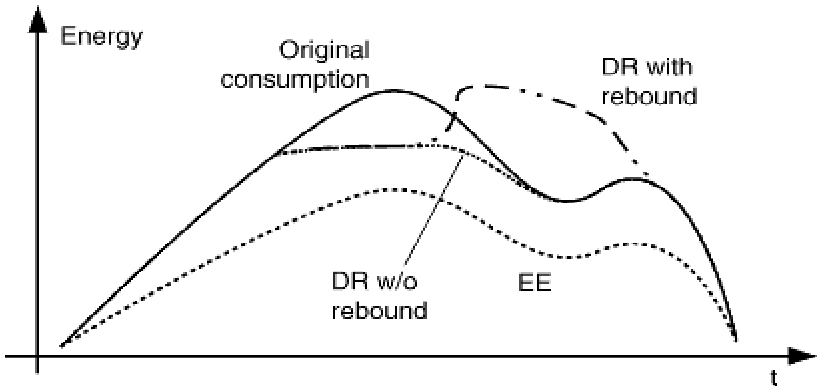


Figure 2.3: Impact of improved energy efficiency versus demand response

2.3.1 Energy Efficiency

Among the various ways to implement demand side management, it is clear that the energy efficiency is most wanted. The goal must be to improve efficiency as it saves energy and emissions. Improving energy efficiency of buildings or industrial sites starts with information and energy auditing into the process involved. In every workplace or site, there are problems that are not noticeable which cause energy wastage. This includes compressed air leakages, misconfigured control, dirty filters, broken equipment, etc. These problems are normally overlooked unless there are tools for analyzing energy efficiency (Palensky and Dietrich 2011).

2.3.2 Energy Controllers

An energy controller is used in the operation of equipments which need consumption-driven adjustment. The device is usually placed at the energy meter to monitor the consumption trend. The controller will automatically switch off the equipments when the consumption trend reaches unwanted levels based on the priorities and other rules set by the user. The energy controller switched device is shown in Figure 2.4. (Palensky and Dietrich 2011)

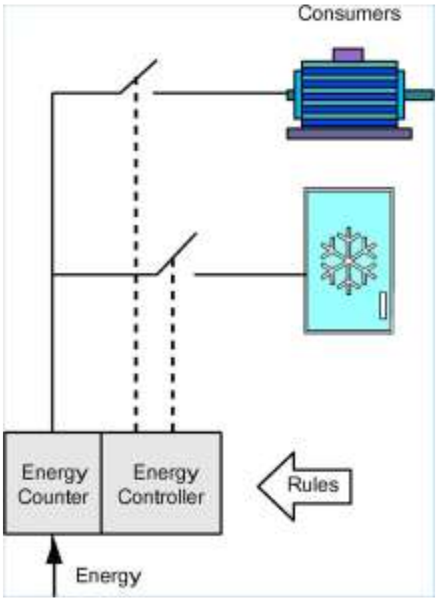


Figure 2.4: An energy controller switches devices

It is extremely complex and complicating to configure such an energy controller. During the adding or removing of consumers, the stability depends on a wise choice of rules. A simple way to determine the priority level is shown in Figure 2.5.

Let assumes three device classes, starting from most prominent c1 until c3 which is least important. The dashed line in the middle is the ideal case which leads to the desire goal. The graph increases its gradient when all the devices are allowed to turn on initially. It reaches the “c3 off” line where c3 is required to turn off as it is least important. Although the graph is flattened by a little, it is not sufficient to bring back the graph to the ideal case. So, it will cross the “c2 off” line and the c2 is turned off. The resulting graph is too flat until it crosses “c1 on”. Since c1 is still on, so there is no effect. Crossing “c2 on” will allow the device to turn on again and so forth for the rest of the graph until it reached its goal. Even though the allowed device to on at t_1 and t_2 are the same, the power consumption is different. This allows the devices in one category to switch on at that time. Sometimes, it is not necessary since the devices have their own independent controls and schedules. Figure 2.5 illustrated the selection of priorities in a maximum demand monitor.

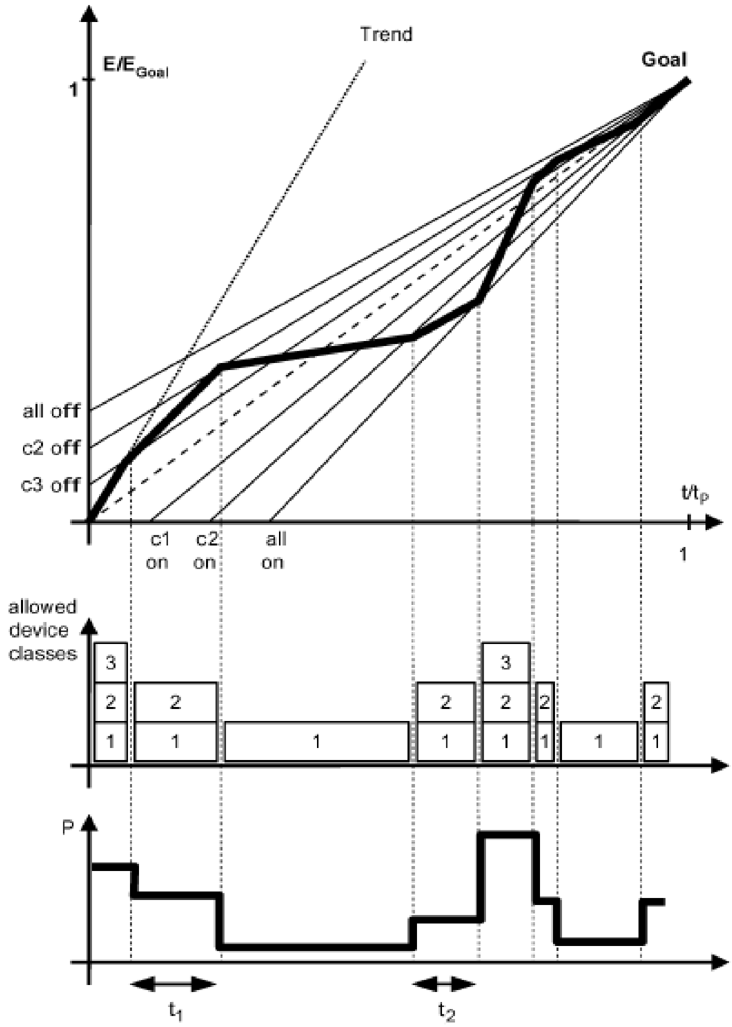


Figure 2.5: Selection of priorities in a maximum demand monitor

2.3.3 Demand Response

Smart grid technologies will further increase the use of demand response in daily operation. It has become an integral part of the power system and market operational practice (NIST 2010). Demand response is the process of controlling end-user (load) from their normal consumption pattern with the objective of decreasing energy demand during peak hours when energy generation is expensive, shifting demand to off-peak times, or balancing demand through load shedding at the time of generation deficit.

The demand response management involves four main participants who are energy balancing authority, demand response provider, utility company and customer. Before any demand response scheduling process starts, it requires the balancing authority to give orders by determining its desired volume, date/time, and duration. The order is submitted to the provider to compare with their demand response availability and select the demand response participating customers. Taking into account each customer's distinct compliance factor, the provider determines expected demand response total and reported back to the balancing authority (Medina, Muller and Roytelman 2010). Figure 2.6 shows the existing demand response scheduling process.

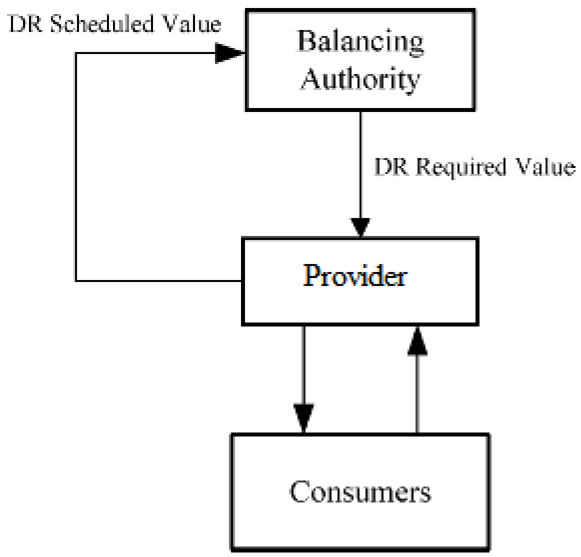


Figure 2.6: Existing Demand Response scheduling process

2.3.4 Spinning Reserve

The spinning reserve is defined as the unused capacity which can be activated on decision of the system operator. It is provided by devices that are synchronized to the network and able to affect its active power. The energy management strategy should accommodate both short-term power balancing and long-term power balancing. An appropriate level of spinning reserve should be maintained to safeguard the power systems without involuntary load shedding. Thus, increasing the spinning reserve can reduce the probability and severity of loss of load (Wang and Gooi 2011).

When the generation cannot meet the demand, the reserved capacity will be used to maintain the balance of the network. The primary control reserve is not part of the spinning reserve because it is not controlled by the transmission system operator. The secondary control reserve is a centralized automatic control that delivers reserve power on short notice in order to bring the frequency back to the target value. The tertiary control reserve provides manual change in the dispatching in order to restore the secondary reserve. It also provides a more permanent solution if the imbalance between consumed power and scheduled power persists. It will react if the secondary reserve does not solve the problem. In Figure 2.7, the normal energy usage is below the scheduled power.

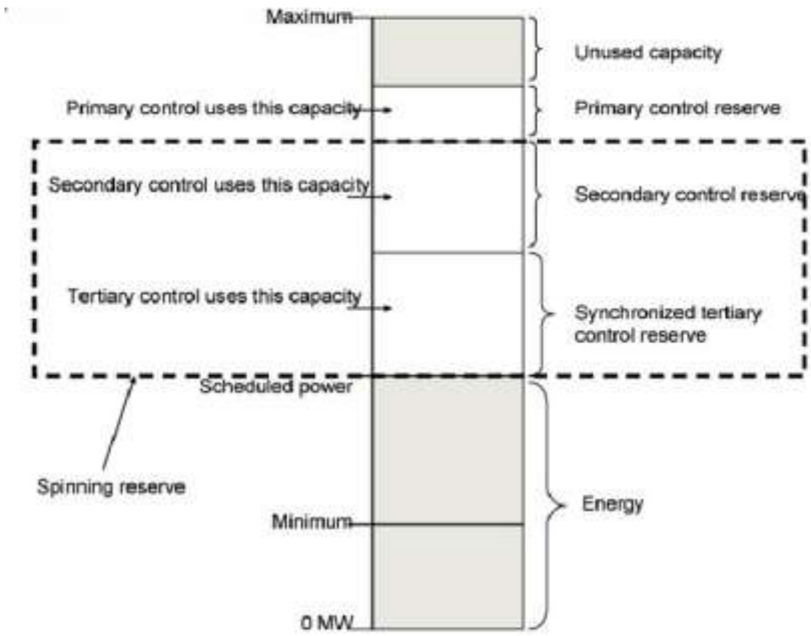


Figure 2.7: Allocation of capacity of generation unit

2.4 Load Recognition

Load recognition is the ability of a system to identify the type of load connected. There are different methods proposed to achieve this specific outcome. In demand side management, it becomes increasingly challenging due to growing energy demands within offices and premises. It is essential to perform automated appliances recognition and monitoring to fully utilize the available resources. Smart meter is one of the incentives to improve energy monitoring. However, it can only measure energy consumption on a house level, providing little information on the breakdown of the energy spent. The main challenge is to acquire appliances-level information. If each load is attached with a meter, the increase in the number of meter will reduce the reliability and cause the system to be much more complicated. Through the load profile, it provides details which appliances have been used, how much they have consumed as well as when and why they are operated. (Zoha et al., 2012)

2.4.1 Non-Intrusive Appliance Load Monitoring

Non-intrusive appliance load monitoring (NALM) is a way to minimize the number of instruments used for monitoring process. It is designed to monitor an electrical circuit that contains a number of devices which switch on and off independently. By a sophisticated analysis of the voltage and current waveform of the total load, the NALM estimates the number and nature of the individual loads, their individual energy consumption and other relevant statistics such as time-of-day variation. (Hsueh-Hsien, Ching-Lung and Hung-Tzer 2008)

This method has no access to the individual components during the installation of sensors or making measurement. It is much more convenient and effective method compare to previous method which by means of placing sensors on each individual components of the load. The load data is extremely valuable to energy auditors, utilities, public policy makers, and appliance manufacturers, for a broad range of purpose. This plug-and-play device is very easy for installation, removal, and maintenance. Figure 2.8 shows the NALM connects with the total load using the standard revenue meter socket interface.

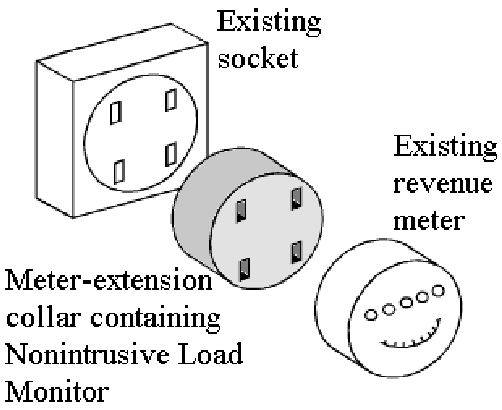


Figure 2.8: NALM devices

The NALM monitors the total load, checking for certain characteristics which provide information about the activity of the appliances which constitute the load. The refrigerator which estimated to consume 250 W and 200 VAR will have a step increase of the characteristic size to indicate that it is turned on, and a decrease of size to indicate that it is turned off. When heater with its own load characteristic is added in, the graph become complicated as there is overlapping between the two loads. However, the loads can be distinguished by knowing the time of each on and off event and the total energy consumption. Furthermore, considering measurement of the reactive power or harmonic current, along with the real power shown, it would reveal even more information about the particular appliances. In Figure 2.9, the power against time graph shows the load characteristic of refrigerator and heater.

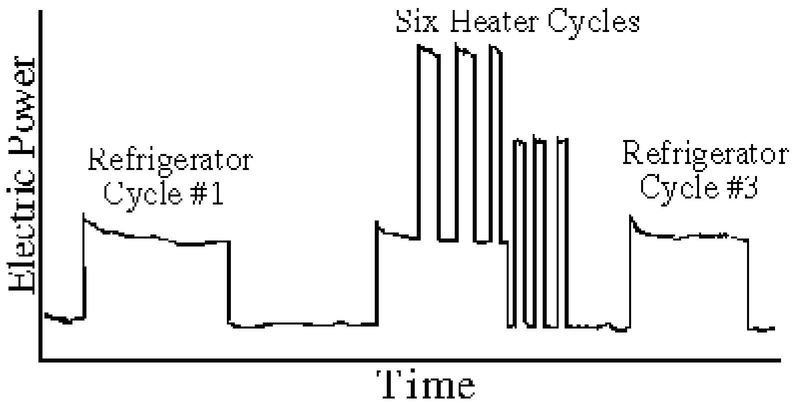


Figure 2.9: Load Characteristic Graph

2.4.2 Electromagnetic Transient Program

Another method of load recognition is through the electromagnetic transient program (EMTP). The idea of EMTP is by analyzing and sampling the transient energy signatures during the start up. Different class of loads has their own characteristic of turn-on transient energy signatures. This method can increase the efficiency and accuracy of load recognition, especially for loads which have same real and reactive power (Hsueh-Hsien, Ching-Lung and Hung-Tzer 2008).

In general, electrical appliances may have more than one load representation due to many physical components are involved. A hair dryer has two loads, a heating coil and a motor while a water boiler has only one load which is the heating coil. These appliances have their own unique power signatures that enable them to be distinguished from one another. It can be observed by voltage and current waveforms of the particular load. Besides, it can also be identified from processed reproductions of these signals including harmonics, real power and reactive power (Laughman et al., 2003).

The transient properties of electrical load are determined by the physical task that the load performs. Transient energy may assume different forms in consumer appliances base on the generating mechanism. Load classes performing physically different tasks are therefore distinguishable by their transient behaviour. Hence, two different appliances which consume similar real and reactive power may have remarkably different turn-on transient currents. For example, a pump has long switching-on transient while electronically fed appliances have short but high amplitude switching-on transient (Leeb et al., 1995).

A sample of time length, Δt is examined to separate transient representatives of a class of loads. Each input waveforms has a set of transient energy values representing a particular transient shape delineated by the separation process. The maximum recognition accuracy, $\hat{\gamma}$ is maximized during the test phase as Δt is adaptively changed based on the factor δ. The flowchart of adaptive algorithm for load recognition is shown in Figure 2.10.

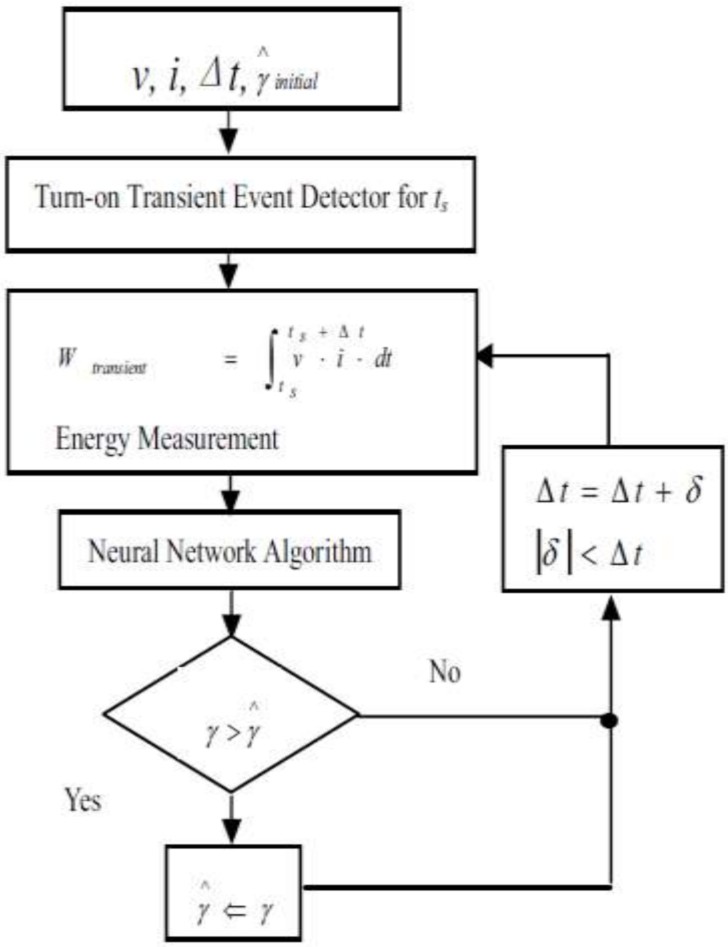


Figure 2.10: Adaptive algorithm for load recognition

2.5 Voltage Unbalance

Among different type of power quality problem, voltage unbalance has significant concern at the LV distribution level. The voltage unbalance at the fundamental frequency is normally present in the supply voltage (Duarte and Kagan 2010). The voltages at the generation and transmission levels are well balanced. When the voltages reach the utilisation and distribution level, they become unbalanced due to various issues such as:

1. Uneven distribution single phase load distribution across the three phase network
2. Continuous changing of instantaneous demand
3. Unbalance or unstable incoming supply

In a balanced network, the three phase's voltage magnitude is equal and the phase angle displaced 120 degree from each other. Any difference that exists in the three voltage magnitudes or shift in phase is known as unbalanced supply. When a balanced three-phase load is connected to an unbalanced supply system, the current drawn by the load also become unbalanced. A balanced system and an unbalanced system are presented in Figure 2.11 and Figure 2.12 respectively.

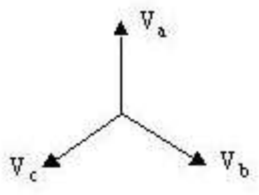


Figure 2.11: A balanced system

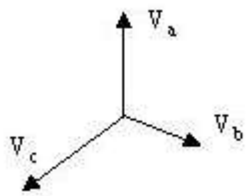


Figure 2.12: An unbalanced system

2.5.1 Voltage Unbalance Factor

Voltage Unbalance Factor (VUF) is resulted by the unequal magnitudes or phase angle which causes unbalanced supply. Based to the European Standards, it is defined as the ratio of negative sequence voltage (V^-) to positive sequence voltage (V^+), as expressed below:

$$\text{VUF}\ (\%) = \frac{V^-}{V^+} \times 100 \tag{2.1}$$

For a perfectly balanced system, both negative and zero sequence system will not be present. As there is no phase displacement between the three voltages in zero sequence system, when it is applied to three-phase induction motor, it will not rotate as there is no rotating magnetic field. The following matrix expression is the negative and positive sequence of the system voltage.

$$\begin{bmatrix} V^0 \\ V^1 \\ V^2 \end{bmatrix} = 3 \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{2.2}$$

where V^0, V^1 and V^2 are the positive, negative and zero sequence voltages and V_a, V_b and V_c are the three phase line voltages components. Figure 2.13 shows different symmetrical components for unbalanced system of voltages.

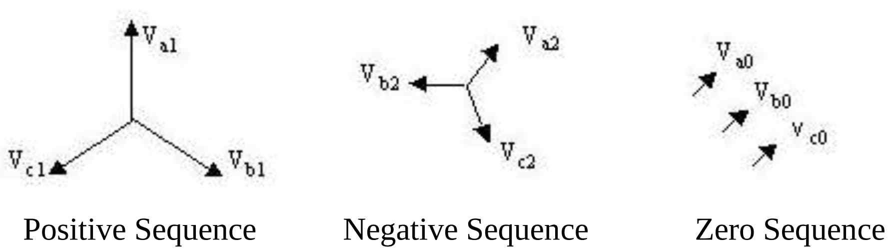


Figure 2.13: Symmetrical components for unbalanced system of voltages

Voltage rise is an issue to be concerned in the three phase power distribution system. The nominal voltage rating delivered by the utilities need to be regulated within the operating tolerance. Malaysia has the voltage unbalance factor has a statutory limit of 1%. For primary distribution with voltage level of 240V, the range is set at +5% and -10%. This ensures that the electrical equipments will perform satisfactorily within the voltage range provided by the utilities.

2.5.2 Effects of Voltage Unbalance

Voltage unbalance will cause several negative effects on induction motors. Overheating, line-current unbalance, derating, torque pulsation and inefficiency are the adverse effects of voltage unbalance. If an excessive level of voltage unbalance occurred, it has serious impacts on the load connected especially induction motors. Although induction motors are designed to tolerate a small level of unbalance, they have to be derated if the unbalance is excessive. This can highly reduce the life span of the induction motor due to overheating in the rotor and stator. Besides, it can cause significant additional power losses resulting in the steady-state temperature rises of the windings. (Siddique, Yadava and Singh 2004).

CHAPTER 3

METHODOLOGY

3.1 Overview

A microgrid network is developed in a portable heavy duty cabin behind UTAR SE Block. The microgrid consists of supply from utility, switches and protections, bidirectional inverter, batteries and controllable load bank. The National Instrument sbRIO-9632XT is used as a main control unit for controlling, monitoring, and acquiring electrical data of the microgrid through computer. A large system is difficult to manage as things might go haywire during troubleshooting. Thus, it is highly preferred to group the part which can be combined to form an individual device. Figure 3.1 shows the schematic diagram of the microgird.

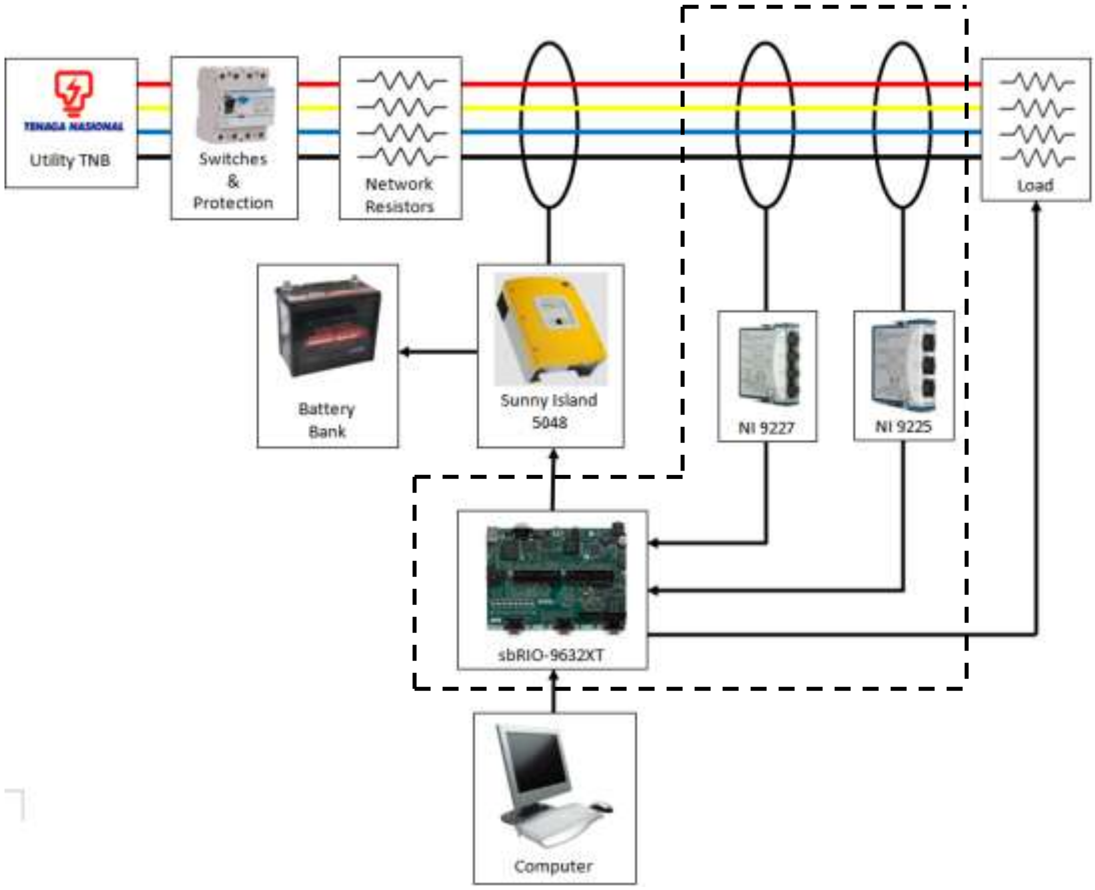


Figure 3.1: Experimental setup of Smart Energy Conditioning System

The first design of the microgrid system is found to be not portable. It is troublesome and difficult to remove when the system needs to move from one place to another. Hence, the improved version of microgrid is developed.

The electrical components within the dotted line in Figure 3.1 can be group together to form a diagnostic tool. During the design of the diagnostic tool, three main parts that bring into consideration are safety, flexibility and portability. Safety which is the paramount of every device is obeyed by selecting the suitable material together with proper protection devices. It must be flexible which act as a plug-and-play device that can connect either single phase or 3-phase load to monitor the necessary data such as power, power factor, voltage and current. Besides, portability is also a consideration so that it can be brought to anywhere which requires energy diagnosis.

Figure 3.2 shows the process flow of load diagnosis. After the separation of the diagnosis part from the existing circuit, there is a need to identify the position of the stand-alone device. The actual position is between the source and the load.

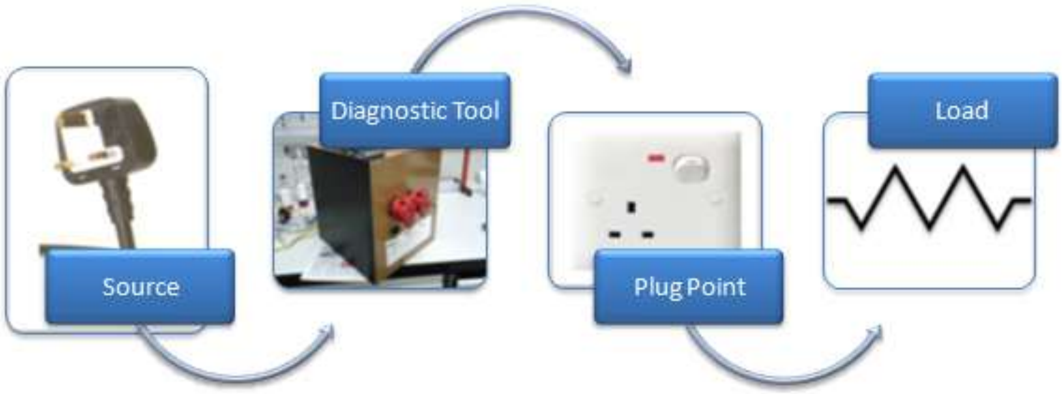


Figure 3.2: Process Flow of Load Diagnosis

3.2 Concept of Diagnostic Tool

The diagnositic tool is actually a detour from the power source to the load. The function is similar to NALM which also place between the power source and the load. The users can monitor and check either the single phase or three phase load. Schneider GC2530M5 contactor is used to separate the two different power sources and to prevent line to line fault. The current is measured by using TABB50C100 100/5A current transformer and collected using the NI9227 current measurement card. The voltage is measured by NI9225 voltage measurement card for each phase by connecting parallel to the output. All the data acquired is passed to the sbRIO-9632XT and will be displayed on the computer. The schematic diagram of the diagnostic tool is shown in Figure 3.3.

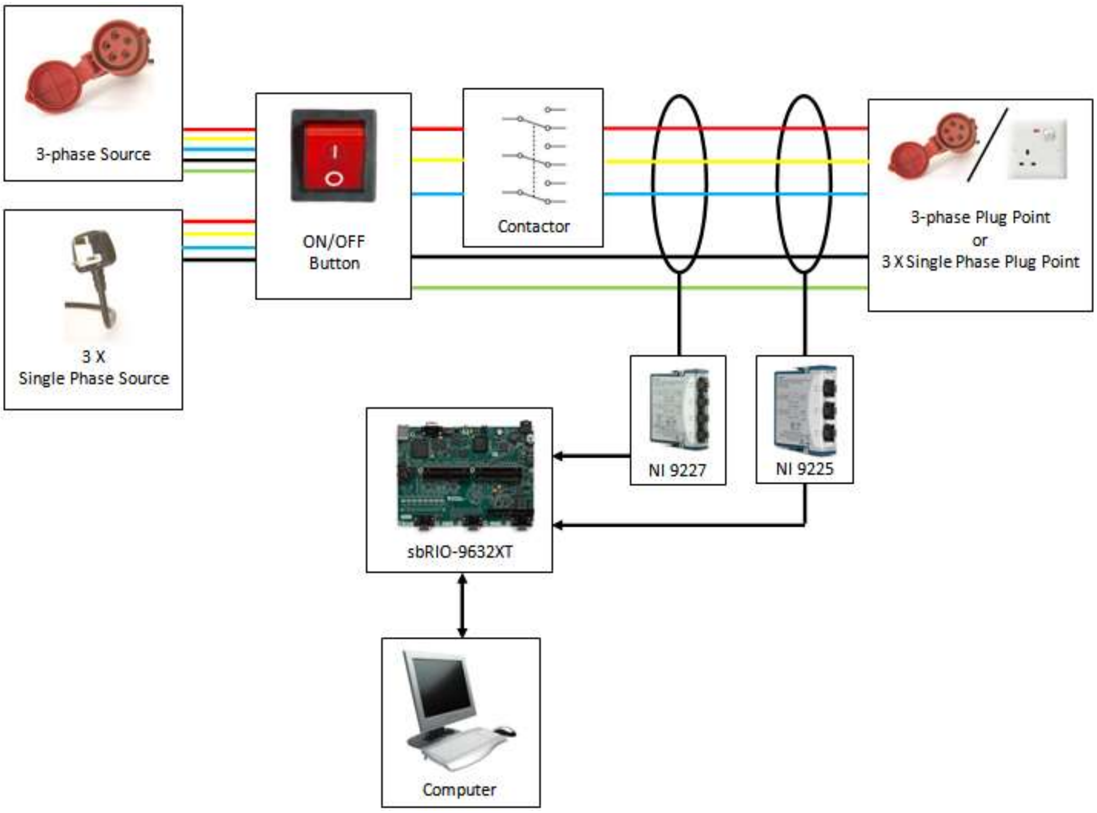


Figure 3.3: Schematic Diagram of Diagnostic Tool

The specification of the prototype 1 is tabulated in Table 3.1.

Table 3.1: Specification of Prototype 1

Specification of Prototype 1	
Type	**Single Phase & 3-Phase Diagnostic Tool**
Material	**1mm^2 Aluminium, 1mm^2 Plywood**
Input / Output Voltage	**Phase voltage of 220 ~ 240 V**
Max Power Rating	**3KW**
Max Current Rating	**14A**
Cable Rating	**32A**
Frequency	**50Hz ±1%**

3.2.1 Prototype 1

The design specifications are listed out and strictly followed to ensure that the diagnostic tool is operating in a safe region. $1mm^2$ of aluminium is chosen due to its light-weight and durable. Another piece of $1mm^2$ plywood is attached at the back to provide insulation. The aluminium can also be used to discharge excessive voltage during fault without damaging the components inside the casing. Figure 3.4 shows the material used to build the casing of the device.

Figure 3.4: $1mm^2$ Plywood and $1mm^2$ Aluminium

3.2.2 Arrangement

The arrangement is important to facilitate the users during the access of plug points and switches. Proper wiring can be done when each item is placed accordingly. The cable used is Copper, PVC insulated, $1.5mm^2$ and voltage rating of 450/750V. The colour code of Red (Phase A), Yellow (Phase B), Blue (Phase C), Black (Neutral) and Earth (Green) are followed to ease the users during troubleshooting. The connection between the point and wire is soldered with lead and insulated using heat shrink tube. It is crucial to prevent any leakage of current during the operation. Figure 3.5 shows the arrangement of the components at the front.

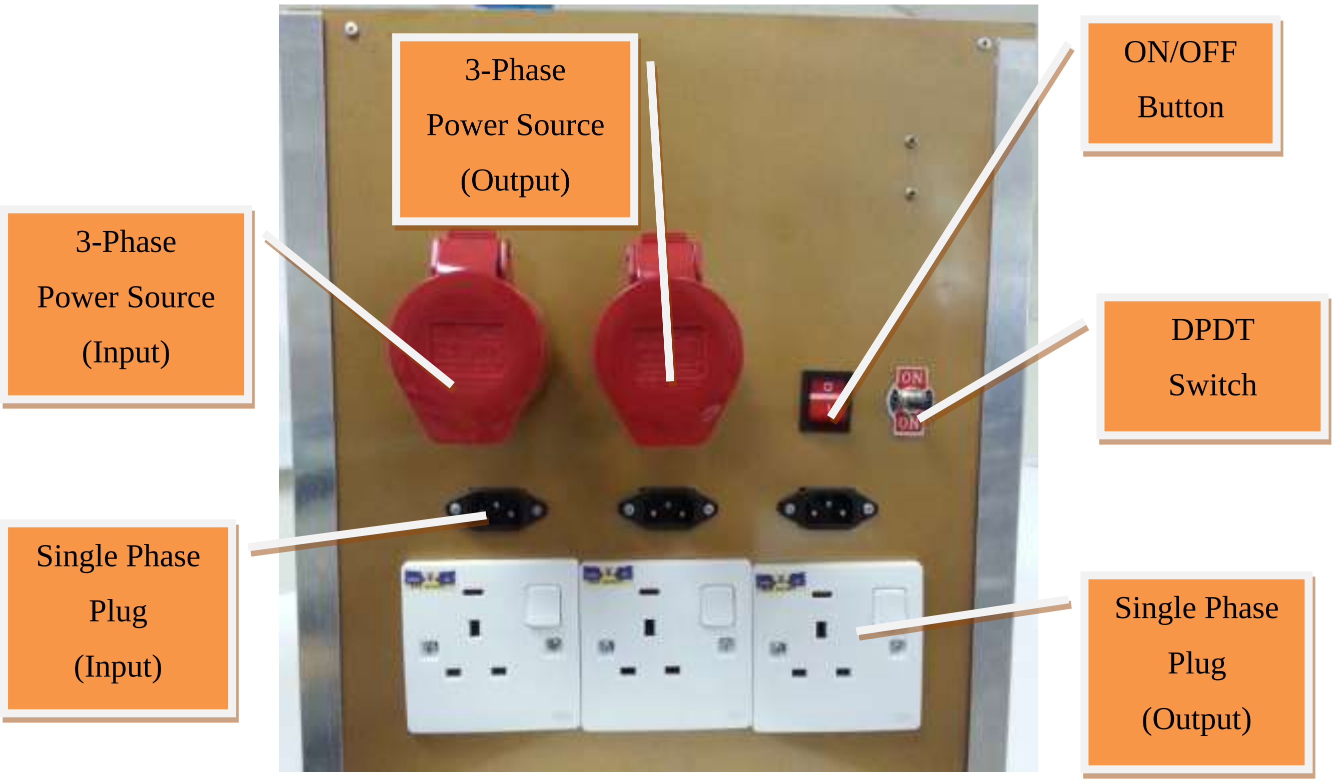


Figure 3.5: Front Arrangement

The arrangement inside the device is shown in Figure 3.6.

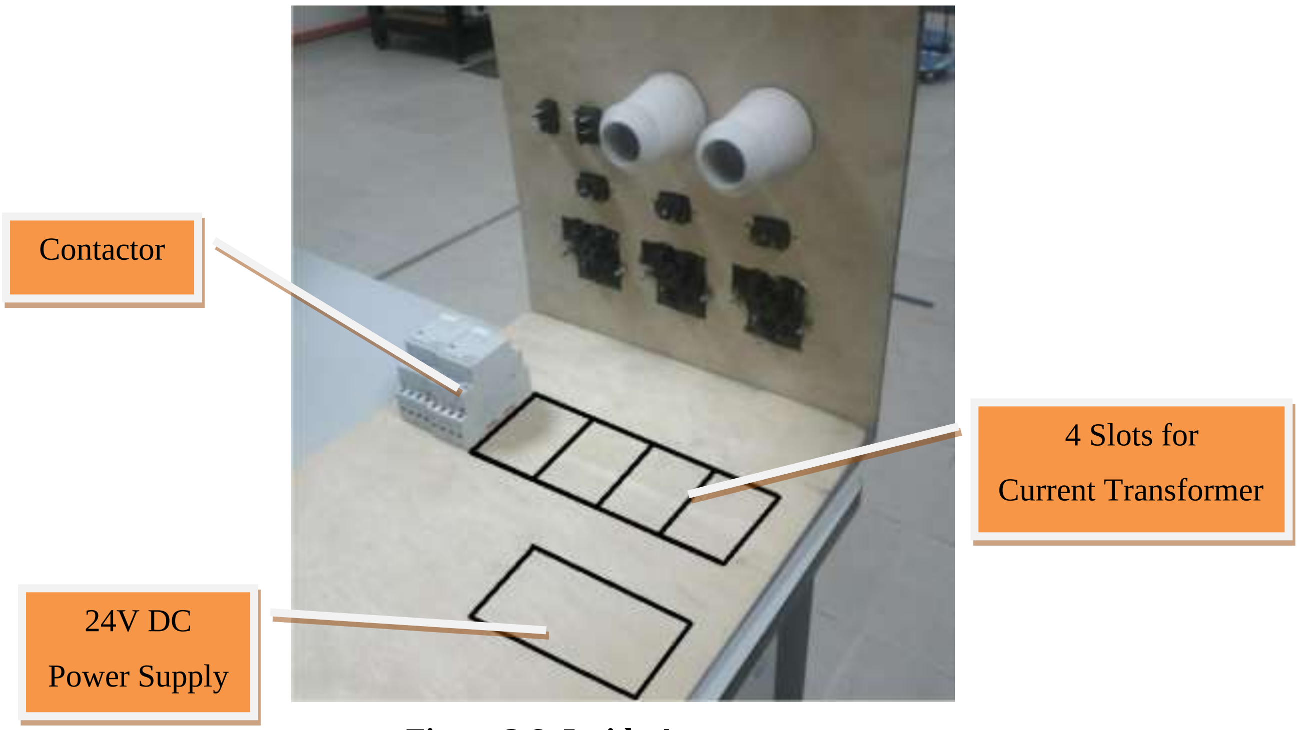


Figure 3.6: Inside Arrangement

3.2.3 Components

In order to match the requirement of the device, studies are carried out to determine the specification of the components. The components include power supply, Contactor and Current Transformer. The specification data sheets are listed as below.

3.2.3.1 Power Supply

The device requires a 100W Single Output Switching power supply NES-100-24 to power up the board and also the contactor. This power supply also has the protection from short circuit, overload and over voltage. The honeycomb design provides an efficient cooling by free air convection. The power supply is shown in Figure 3.7. The specification of the power supply is tabulated in Table 3.2.

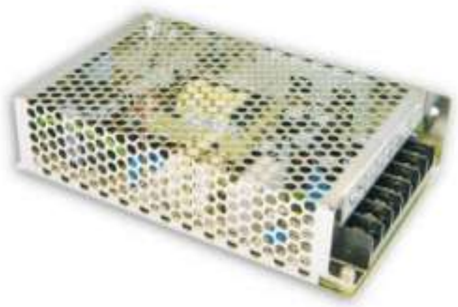


Figure 3.7: Power Supply

Table 3.2: Power Supply NES-100-24

Specification of Power Supply NES-100-24	
Input voltage range	176 ~ 264 VAC
Frequency Range	47 ~ 63 Hz
Output DC Voltage	24 V
Rated Current	4.5 A
Rated Power	108 W

3.2.3.2 Contactor

Contactor can be sued to function as a switch in this device. This contactor has 1 auxiliary contact. When 240V AC is connected, it will trigger the Normally Open (NO) to Normally Close (NC). Two contactors are needed to switch between single phase and 3-phase source. It also provides isolation for input and output when it is not triggered. From specification, it can withstand up to 25A and operate normally under 50˚C. Contactor used in this device is the Schneider Contactor GC2530M5 as shown in Figure 3.8. Table 3.3 shows the specification of the contactor.

Figure 3.8: Contactor

Table 3.3: Contactor GC2530M5

Specification of Contactor GC2530M5	
Coil Voltage	240V ac
Contact Current Rating	25 A
Contact Voltage Rating	415 V ac
Maximum Operating Temperature	+50 ˚C
Number of Auxiliary Contact	1
Number of Contacts	3

3.2.3.3 Current Transformer

Current Transformer is used to obtain the current when there is load connected to the output of plug point. A low-voltage measuring current transformer is used to measure the current flowing through it. The current induced will be stepped-down by the current transformer. The advantage of using open core current transformer is that the current is obtained by induction rather than direct current flow in series across the NI9227 Current Measurement Card. When the current is large, it is highly possible to damage any device which is connected in series. The current transformer is shown in Figure 3.9.The specification of current transformer is shown in Table 3.4.

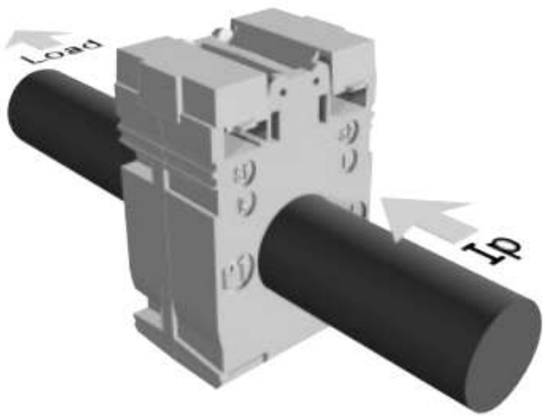


Figure 3.9: Current Transformer

Table 3.4: Current Transformer 100/5A

Specification of Current Transformer TAIBB 100/5A	
Primary Current	40 ~ 300A
Secondary Current	1 ~ 5A
Operating Frequency	47 ~ 63 Hz
Insulation Class	Class B (CEI EN 60044-1)
Terminal Protection	IP200 with sealable terminal cover
Weight	180g

3.2.4 Prototype 2

Some modifications are made to prototype 1 to improve the overall functionality by removing the unnecessary part. Few drawbacks of prototype 1 are listed as below:

1. The size is too big and bulky.
2. The 3-Phase Power Source is hardly used as this diagnostic tool is for low-voltage measurement.
3. The casing is difficult to dissemble and reassemble.

Previously, the 3-phase power input and output require a large space within the device. It also requires an additional contactor for selection between single phase and 3-phase. The removal of 3-phase related components has highly decreases the size and weight of the device. The casing is also redesign to two combination of U-shape which can be easily access during troubleshooting. The new schematic diagram for prototype 2 is shown in Figure 3.18.

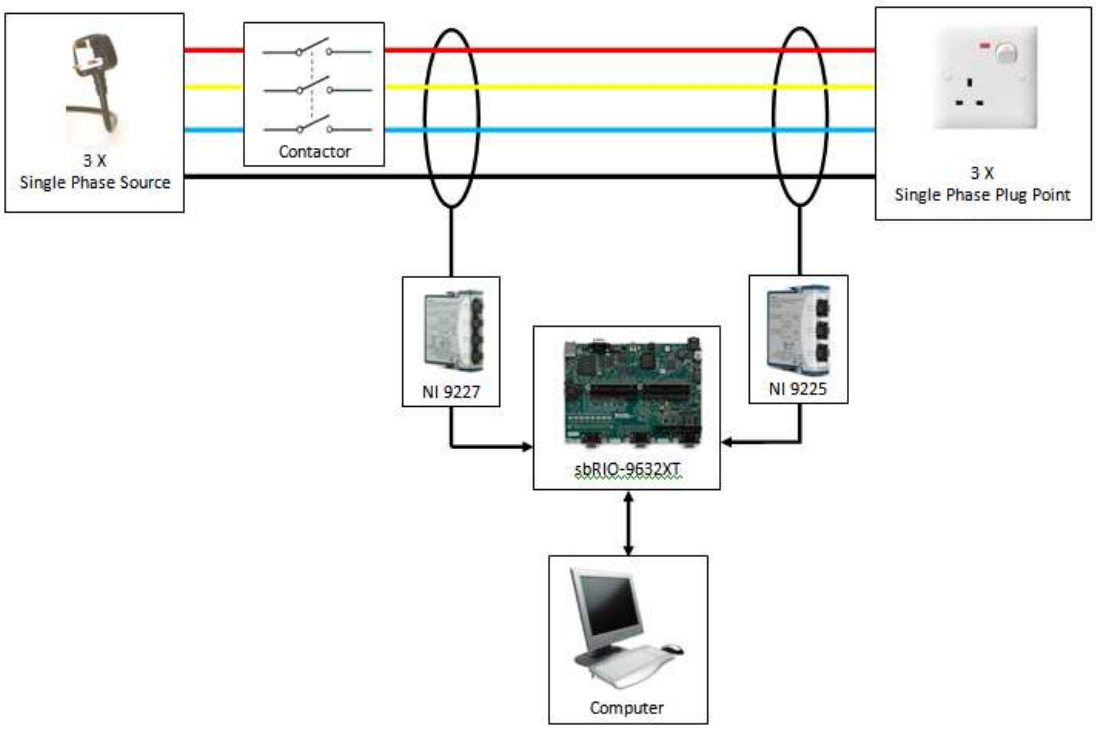


Figure 3.10: Schematic Diagram of Prototype 2

3.2.5 Load Recognition

Load recognition can be done by comparing the amplitude of the waveform and the maximum and minimum current. The NI9227 Current Measurement card has the ability to measure up to 50kS/s per channel sampling rate with 24 bits resolution. This allows the measurement to be more accurate and differentiate the distinction between each kind of load.

For higher-speed control, sbRIO-9632XT incorporate a FPGA that can be programmed with LabVIEW software allows a silicon-speed processing on I/O data from National Instrument C Series Module. With the integration of both hardware and software, the flowchart to perform load recognition is shown in Figure 3.11.

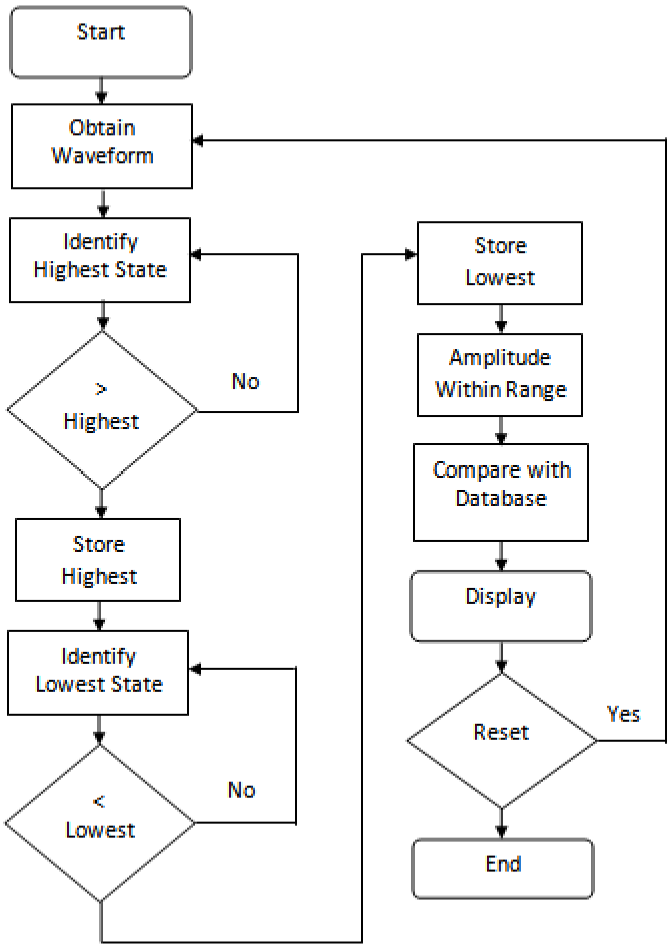


Figure 3.11: Flowchart of Load Recognition

3.2.5.1 Programming on LabVIEW

The graphical programming in Labview is user-friendly and easy to construct the program. The information contained in the program can be extracted out or displayed by using proper indicators. In Figure, sbRIO-9632XT acquired the data from the NI9227 Current Measurement card and passed through the electrical power measurement, the data is converted into AC current waveform. Then, the waveform is multiplied with 20 to get the RMS current. Finally, it can be tapped out to perform necessary analysis. The Convert to Waveform.vi is shown in Figure 3.12.

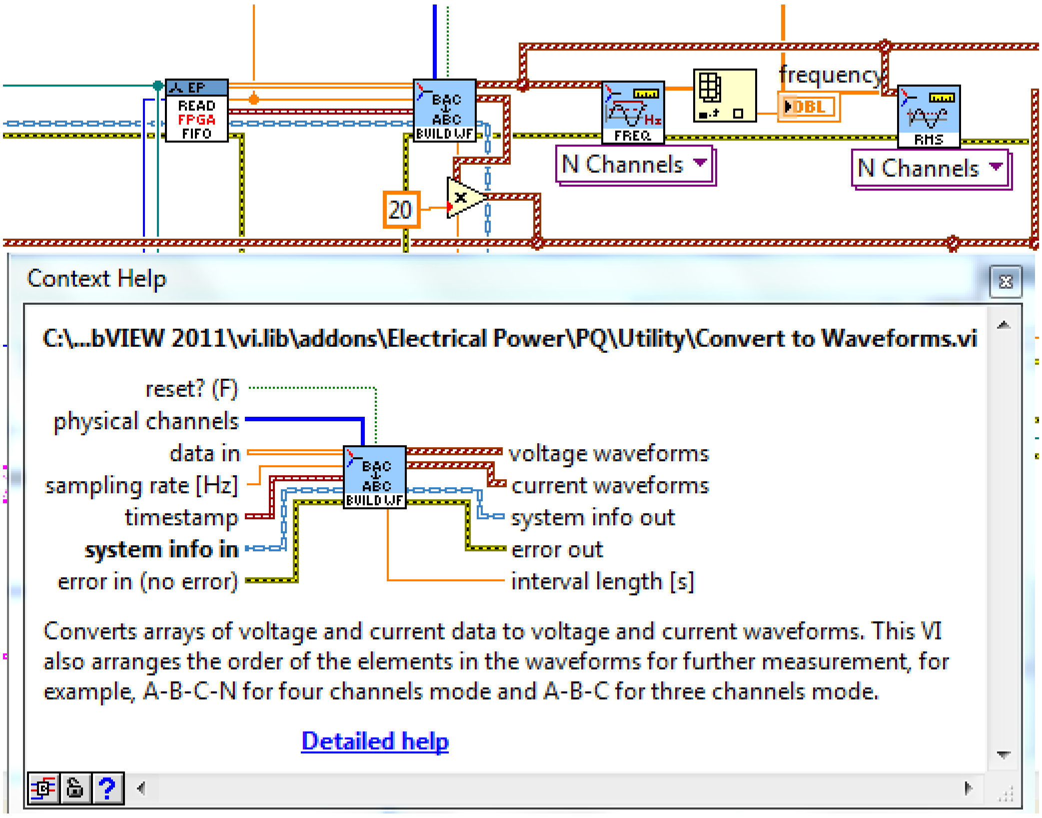


Figure 3.12: Electrical Power Tools (Convert to Waveform.vi)

Further analysis can be done by breaking down the complex data source into individual simple indicator. A current waveform consists of combination of current Phase A, Phase B, Phase C and Neutral. The experiment is done using only Phase A which is expected to have the same result for Phase B and Phase C. The amplitude of the waveform is the first condition to determine the type of load. After that, the highest and lowest current values are compared to make sure they fall within the range. For example, the water boiler maximum state and minimum state in the current waveform is 4.6 and - 4.5 respectively. The graphical programming is shown in Figure 3.13.

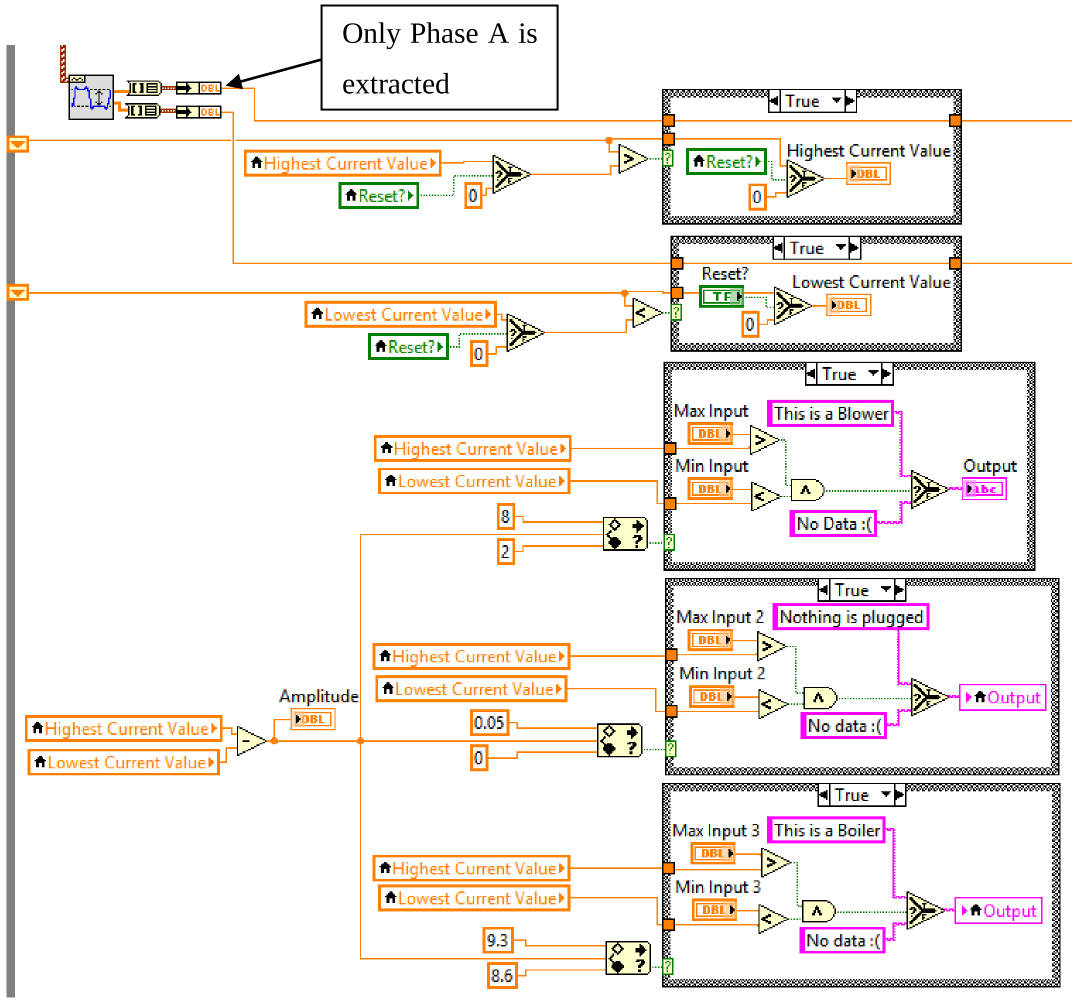


Figure 3.13: Block Diagram for Load Recognition

3.3 Voltage Unbalance Mitigation Experimental Setup

In this project, NI Single-Board RIO 9632XT is chosen because it is an embedded control and acquisition device with the integration of FPGA, real-time processor, and I/O port on a single printed circuit board. All these features allow it to be used as the main control system. The I/O port can supply up to 3.3V which is sufficient to trigger the solid state relay connected to the load bank. The ability to connect with C Series Module, both NI 9225 Voltage Measurement and NI 9227 Current Measurement, enhance the functionality of the board.

The network resistors with different set of values are used to emulate the transmission line. Besides, the power resistor is constructed into a controllable load bank which emulates the power consumer. The solid state relay is controlled by the sbRIO-9632XT to on or off the load bank.

The Sunny Island 5048, which is a bidirectional inverter, is connected to Phase A and Phase B respectively in the system. It can either absorb or deliver power to the electrical network. Meanwhile, this bidirectional inverter also acts as an uninterruptible power supply (UPS) which enable the gird to continue running even when there is no supply from the utilities. The energy conditioning system is set up as in Figure 3.14.

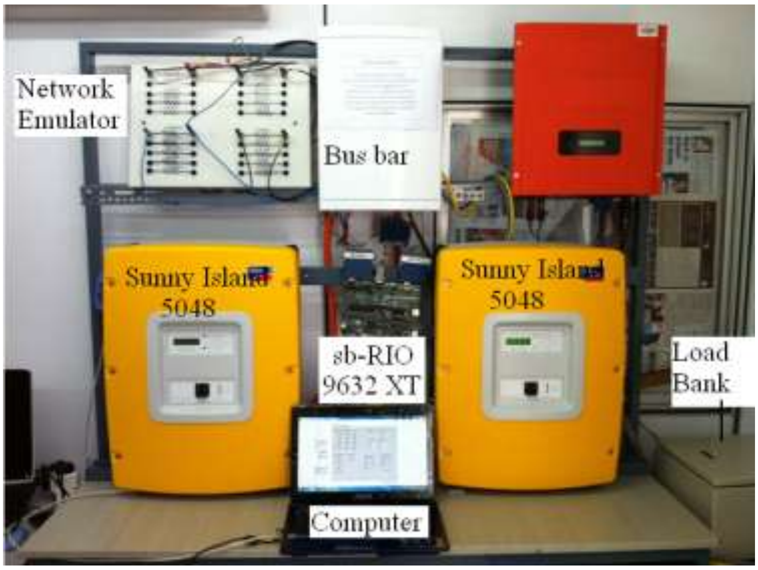


Figure 3.14: Experimental setup of Energy Conditioning System

3.3.1 Measurement and Automation System

sbRIO-9632XT is the central processing unit in this device. The users are able to test, control and monitor the whole system through interaction between computer and the board. It also has I/O port with can produce an output voltage of 3.3 V for different purposes. The C series modules which are used in this project are the NI-9225 voltage measurement card and NI 9227 current measurement card. Figure 3.15 shows the sbRIO-9632XT along with the NI9225 and NI9227.

Figure 3.15: sbRIO-9632XT with C Series Module

3.3.2 Transmission Line Model

There are altogether 4 set of resistors varies from 0.11 Ω to 0.33 Ω. The three phases plus the neutral line is connected to 0.33 Ω in order to create a more significant value for voltage unbalance. From calculation, 0.33 Ω representing 600 m of transmission cable in length. Figure 3.16 shows the transmission line model which emulates the resistance presence in the line.

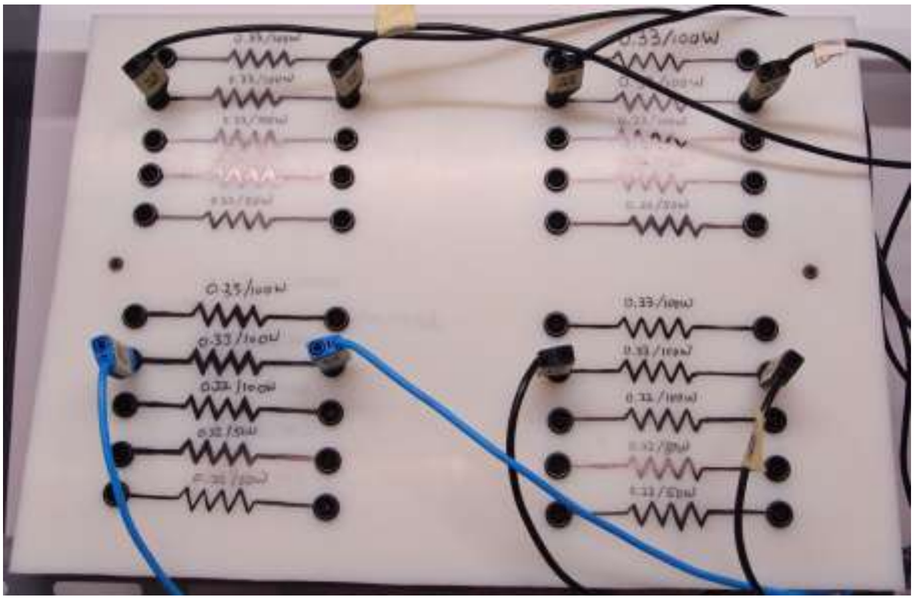


Figure 3.16: Transmission line model

3.3.3 Controllable Load Bank

The controllable load bank is built from a series of power resistor and solid state relay. Each phase has five 200 W power resistor connected in series. The total load can go up to 1000 W in each phase. The solid state relay is triggered by the signal output from the sbRIO-632XT to turn on the power resistor. Figure 3.17 shows both the resistor bank together with the solid state relay.

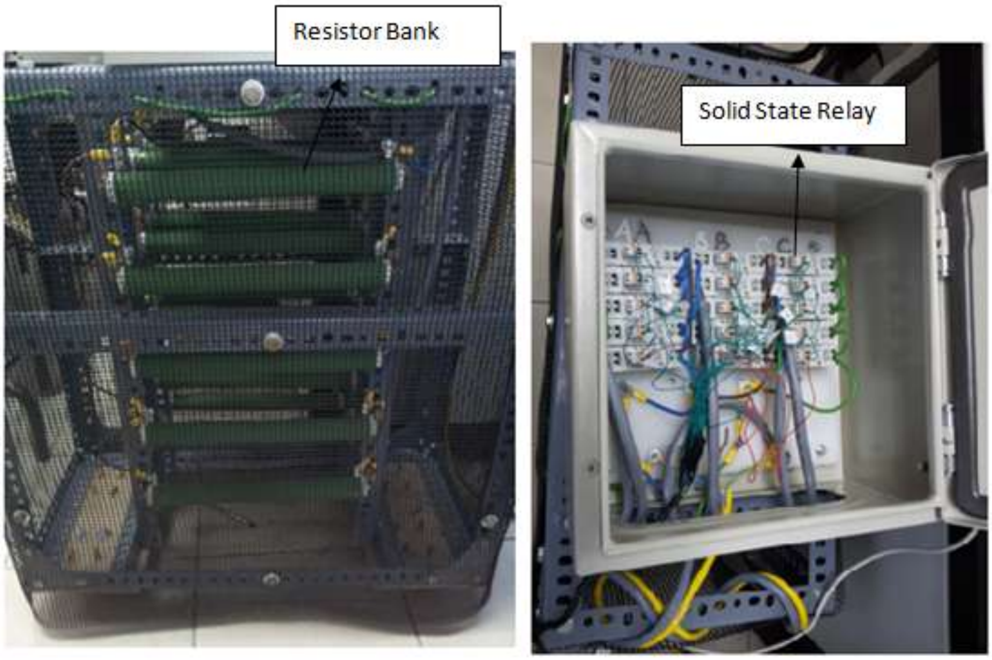


Figure 3.17: Controllable Load Bank

3.3.4 Sunny Island 5048

Four batteries are required to power up Sunny Island 5048 and the batteries provide energy storage up to 5760 Wh. This device is able to charge the excessive power from utilities into the battery bank or supply to load when the supply from the grid is low. The network condition programmed in LabVIEW will determine the bidirectional inverter either inject or absorb power. This can maintain the VUF within the statutory limit. Besides, the Sunny Island can also be used as the Uninterruptible Power Supply (UPS) which can supply the load during power outage. The Sunny Island 5048 which is a bidirectional inverter is shown in Figure 3.18.

Figure 3.18: Sunny Island 5048

3.4 Graphical User Interface

A graphical user interface (GUI) is developed in LabVIEW. The front panel of the user interface (UI) consists of several tabs which allow the users to access base on their preference. There are also indicators to display the value of the voltage, current, power and energy. The users can glance through all the information at the monitor tab. The load recognition UI is shown in Figure 3.19.

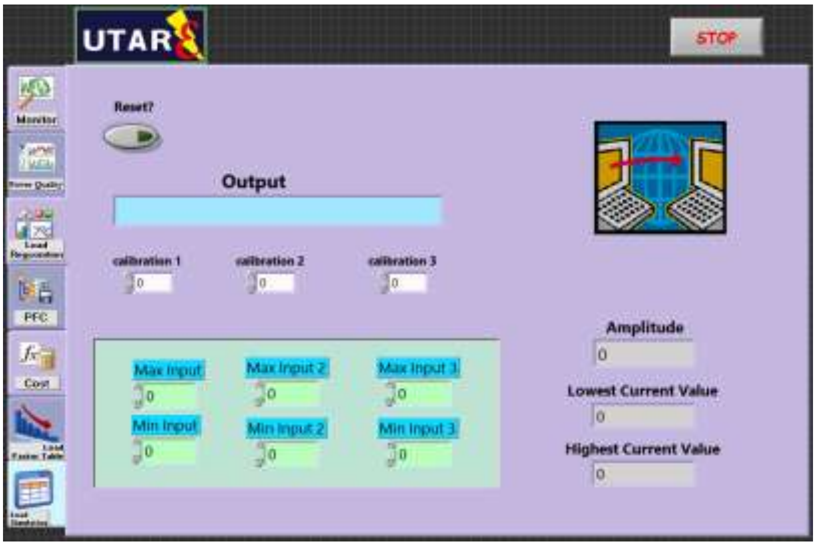


Figure 3.19: Load Recognition UI

The UI for mitigation of voltage unbalance is shown in Figure 3.20.

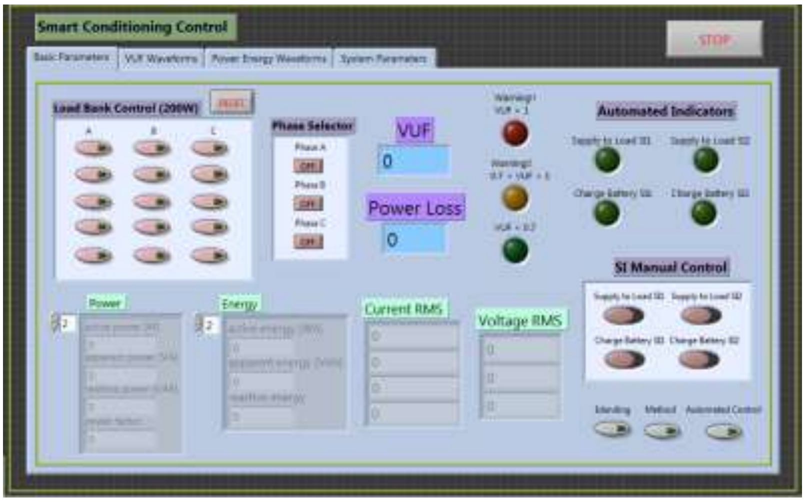


Figure 3.20: Energy Conditioning System UI

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Comparison of Prototype 1 and 2

The major difference between prototype 1 and prototype 2 is the reduction in size. The portability is highly increased when the device become smaller. Less material is required to build which can highly save the cost during mass production. The power rating, current rating and cable rating remain unchanged to make sure the device is well protected. The prototype 1 and prototype 2 are shown in Figure 4.1 and Figure 4.2 respectively.

Figure 4.1: Prototype 1

Figure 4.2: Prototype 2

The changes that have been made between the Prototype 1 and 2 are listed in Table 4.1.

Table 4.1: Comparison between Prototype 1 and 2

Model	Prototype 1	Prototype 2
Type	Single Phase & 3-Phase Diagnostic Tool	Single Phase Diagnostic Tool
Material	1mm^2 Aluminium, 1mm^2 Plywood	1mm^2 Aluminium, 1mm^2 Plywood
Input/ Output Voltage	Single phase/ Three phase, 220 ~ 240 V	Phase Voltage, 220 ~ 240 V
Output Socket	3 single phase outlet and 1 3-phase socket	3 single phase outlet
Max Power Rating	3KW	3KW
Max Current Rating	14A	14A
Cable Rating	32A	32A
Frequency	50Hz ±1%	50Hz ±1%
Dimension (W×L×H)	35cm × 40cm × 38cm	35cm × 38cm × 20cm

The actual device in action is shown in Figure 4.3 where a blower is connected for load analysis. The detail is displayed through the Graphical User Interface (GUI) which consists of several tabs for users to access.

Figure 4.3: Diagnostic Tool Connected with Hair Blower

4.2 Functions of Diagnostic Tool

The functions of the diagnostic tool are related to load analysis and load recognition. The ability of measuring different parameters of the load including, power, voltage, current, power factor and frequency has invoke the idea of load recognition.

Notice that the Voltage Waveform has only 1 red-coloured waveform. Phase B and Phase C remain approximately at zero because there is only Phase A connected with load. Further detail of the load is displayed by the indicators under the waveform graph. Figure 4.4 shows the User Interface (UI) of the voltage waveform.

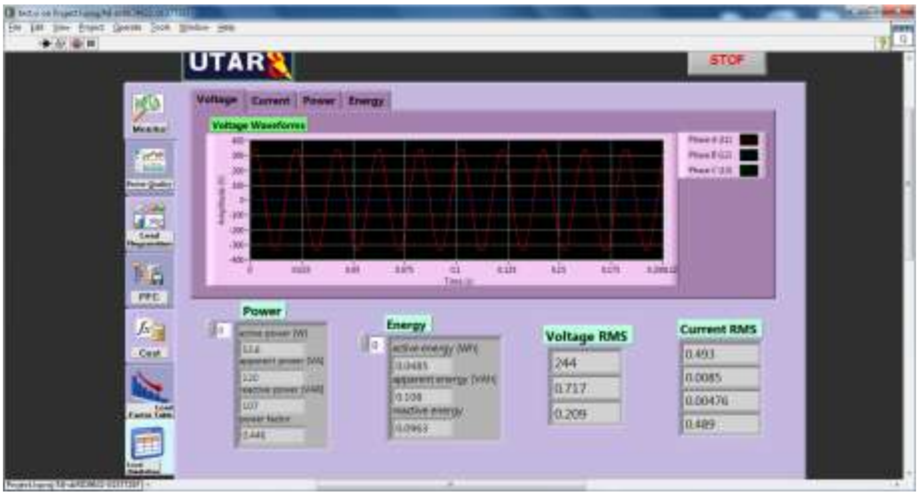


Figure 4.4: Voltage Waveform

Current Waveform graph has two waveforms which is the Phase A and Neutral. The amount of current flow in and out must be equal. If the electrical current is not balanced between the incoming and returning neutral conductor, it will cause the Residue-Current Device (RCD) to trip. This allow the users to monitor the load connected through it is functioning normally. Figure 4.5 shows the interface of the current waveform.

Figure 4.5: Current Waveform

The power waveform is the outcome of multiplication between voltage and current. The active power is displayed in unit W. The load measured using this device has power less than 2KW. The power waveform is displayed to users as in Figure 4.6.

Figure 4.6: Power Waveform

The energy waveform is the accumulation of active power per hour. It can be used to calculate the cost of electricity bill for particular load. It is presented by an increasing line as in Figure 4.7.

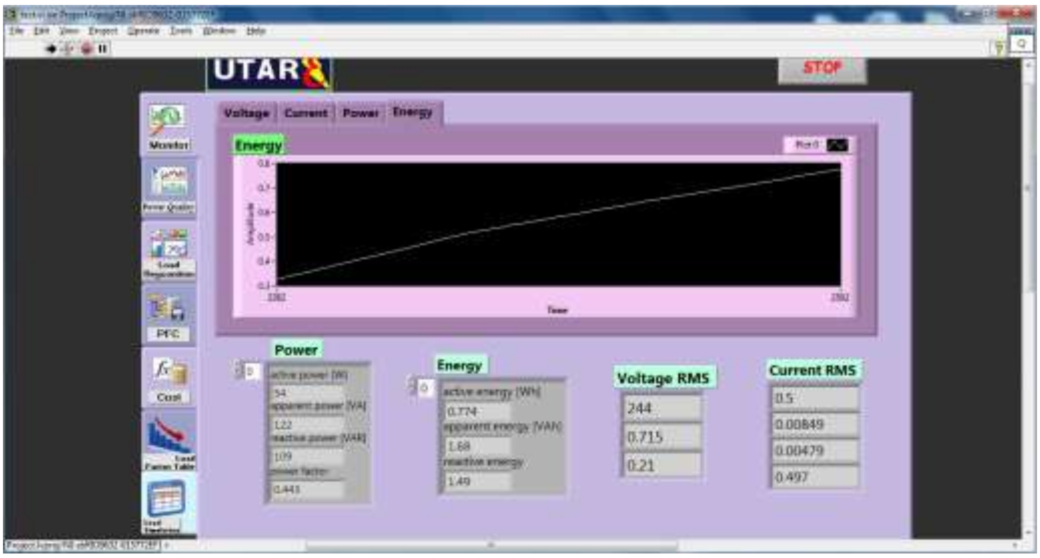


Figure 4.7: Energy Waveform

4.2.1 Load Recognition at Idle State

When no load is connected, the device should be able to identify it is in the idle state. The small changes in the current values vary the range from 0.042 to 0.047. The ideal state when no load is connected should be 0 A current. The small offset value is cause by the internal resistor. A negative value of amplitude is not possible to occur. Hence, the range where no load is plugged in is set from 0 to 0.05. The range of the amplitude without any load is shown in Figure 4.8 and Figure 4.9.

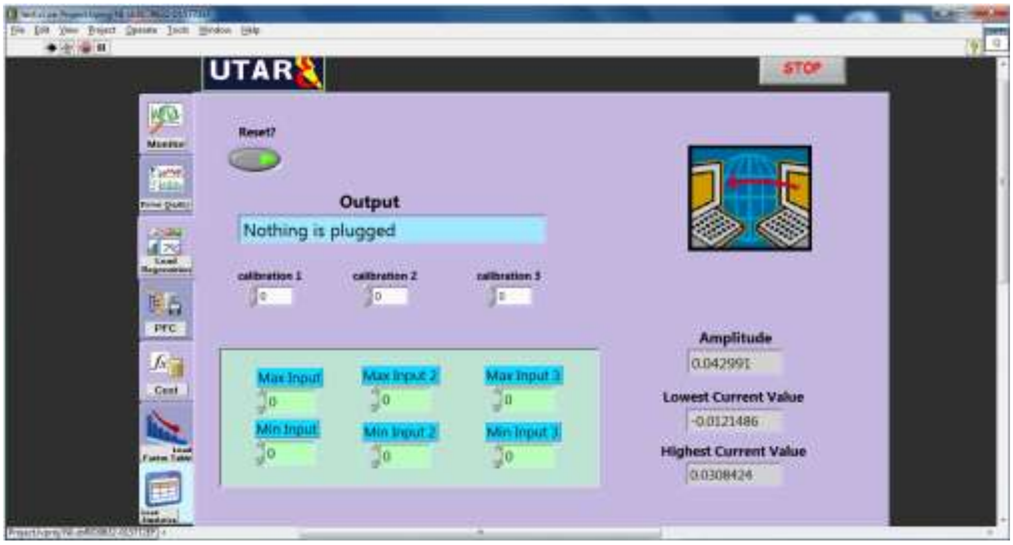


Figure 4.8: Idle State 1

Figure 4.9: Idle State 2

Once the idle state has been determined, the range beyond can be categorize into different load by proper measurement. In order to prove that this concept can function, hair blower and water boiler are chosen to use as load.

4.2.2 Hair Blower

A hair blower has both the characteristic of inductive load and resistive load. This can be proven by observing the current values and the amplitude of the waveform. When the hair blower is turn on without heating up the coil, it is pure inductive load. The amount of current draw is used to turn the motor as shown in Figure 4.10.

Figure 4.10: Hair Blower (Inductive)

When the motor and heating coil are turned on, it consumes more power. The highest and lowest current values will change depending on the power consumption. The inductive and resistive load of the hair blower is shown in Figure 4.11.

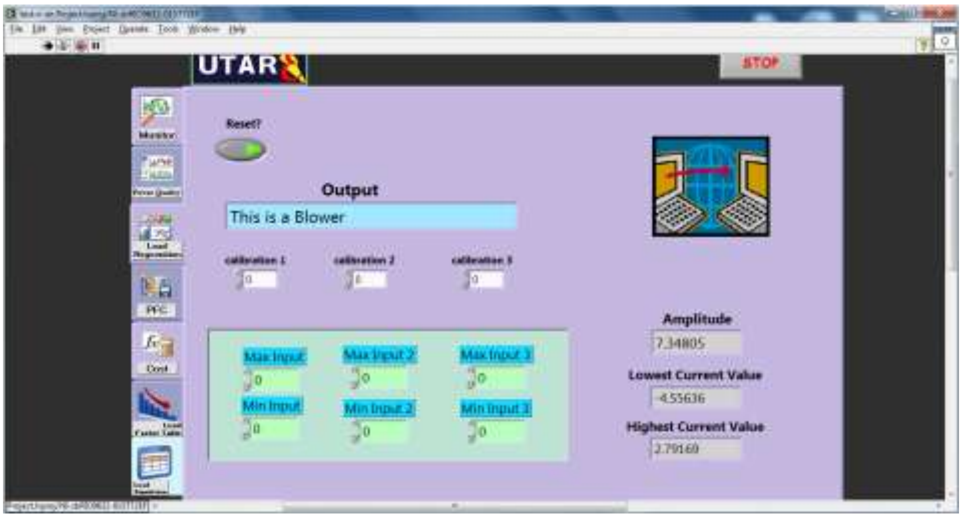


Figure 4.11: Hair Blower (Resistive)

The load characteristic of the hair blower is recorded and discussed. The power graph shows the process when operating the hair blower. Initially, the hair blower is not turned on. When it is switched to cool fan mode without heating coil, the power consumed is around 560 W. Once it is switched to drying mode, additional power around 460 W is needed due to heat up the coil. The amplitude of current waveform varies from 2.5 to 7.5 during the operation. The maximum current and minimum current are 2.8 and - 4.6. With all the detail available, the process to identify and recognize the load can be carried out. Figure 4.12 shows the load characteristic of a blower.

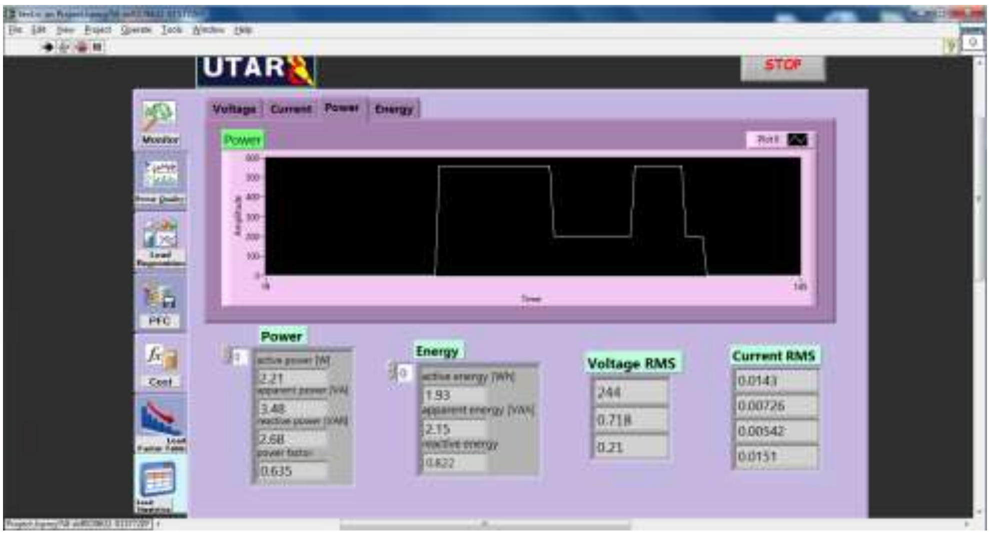


Figure 4.12: Power Waveform of Hair Blower

4.2.2.1 Data Recording and Storing

The data can also be recorded and extracted to Microsoft Excel for verification. The way to record the data is by using Write to Spreadsheet File.vi. The data is bundled and converted from cluster to array and stored in the C:\<File path>. The block diagram for data recording and storing is constructed as in Figure 4.13.

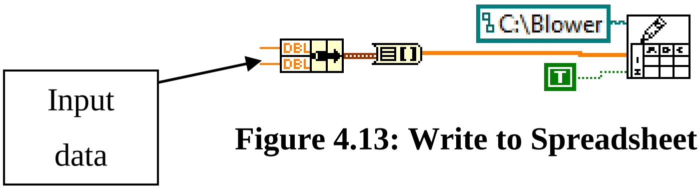


Figure 4.13: Write to Spreadsheet File.vi

4.2.2.2 Export to Microsoft Excel

Both current and power have approximately the same characteristic graph. The small different are caused by the inconsistence value of voltage. This information is useful for demand side management for different purposes. The current against the time is shown in Figure 4.14.

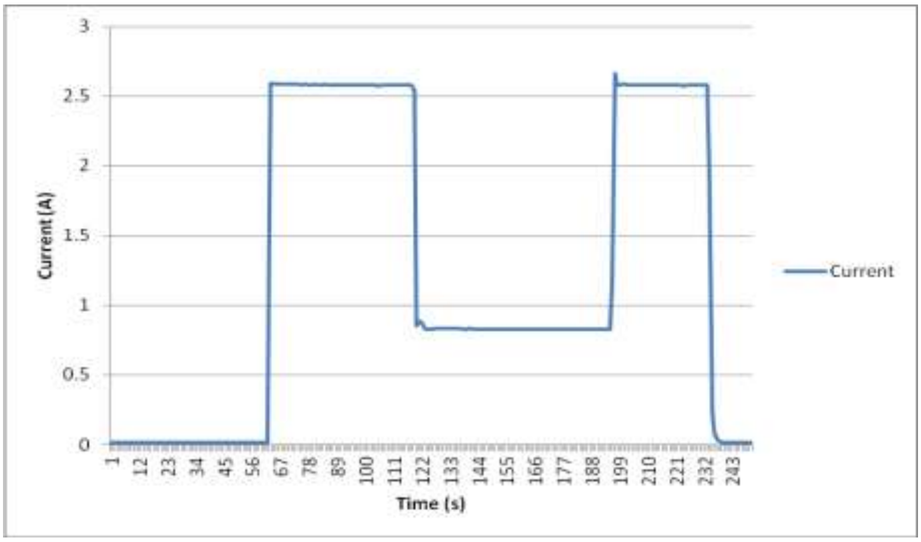


Figure 4.14: Current vs Time (Hair Blower)

The power against time graph is shwon in Figure 4.15

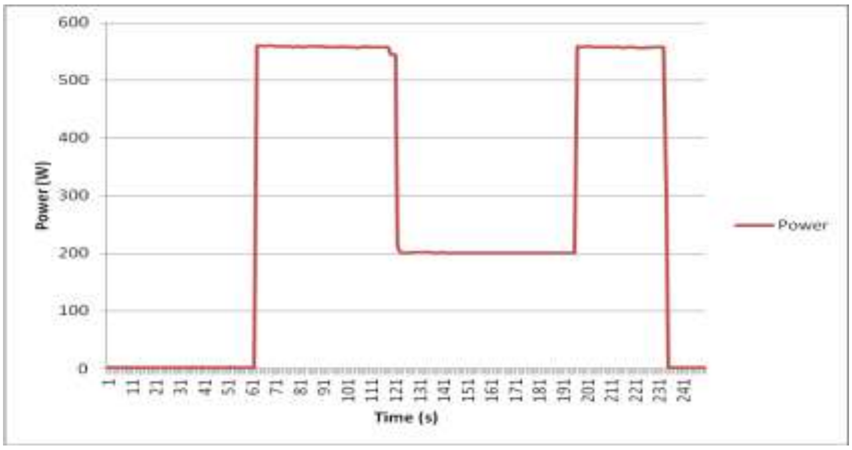


Figure 4.15: Power vs Time (Hair Blower)

4.2.2.3 Creating Database

When the detail of the type of load is determined, it is required to store the data in the database. This can create a list of data which can recognize different type of electrical equipment. The value of current obtained at real-time from the current waveform is compared with the database. When the amplitude is in range and within the current value, the type of electrical equipment will be displayed. A simple way to build the database is shown in Figure 4.16.

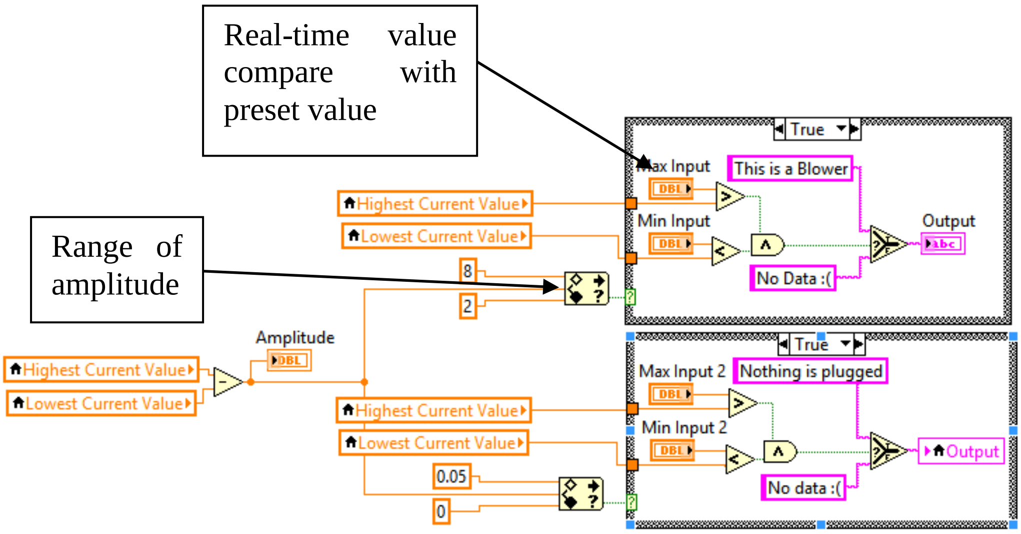


Figure 4.16: Database

4.2.3 Water Boiler

Water boiler has only the characteristic of resistive load. The power consumption of water boiler is higher compare to hair blower. When a water boiler operates, it is either at “Keep Warm” mode or “Boiling” mode. The voltage waveform of water boiler is shown in Figure 4.17.

Figure 4.17: Voltage Waveform of Water Boiler

The current waveform of the water boiler has a sinusoidal waveform as it is purely resistive as indicated in Figure 4.18.

Figure 4.18: Current Waveform of Water Boiler

The load characteristic of a water boiler is either low or high as there are only two states. This characteristic is commonly found on those electrical appliances which repeat the same process such as refrigerator, rice cooker and so on. In the case of water boiler, “Keep Warm” mode only consumes around 33.9W while “Boiling” mode consumes around 774W. The power waveform is obtained as in Figure 4.19.

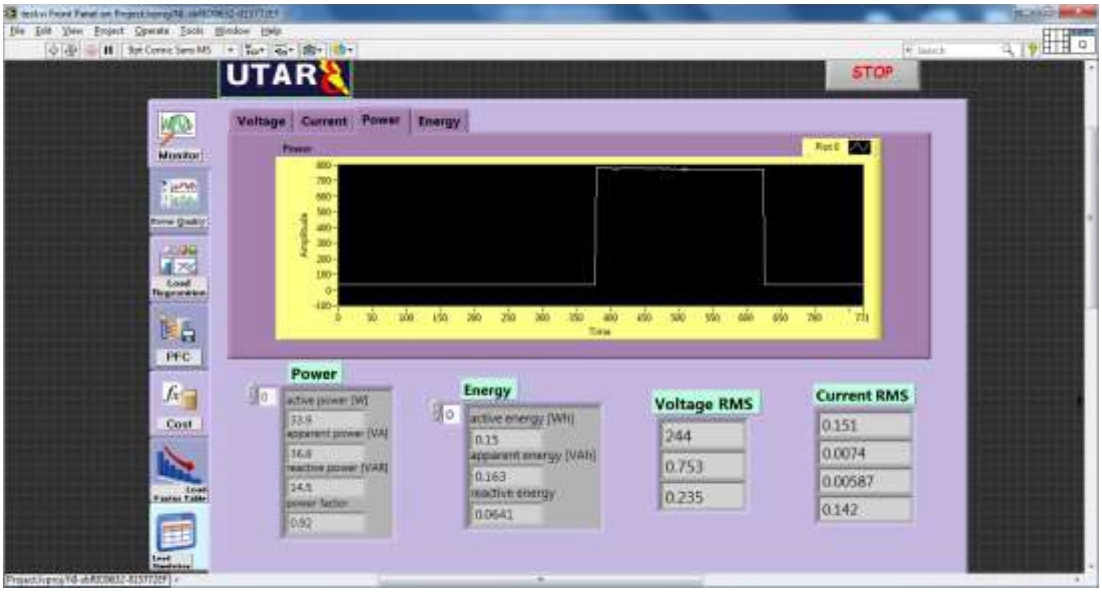


Figure 4.19: Power Waveform of Water Boiler

The current against time graph for "Keep Warm" mode to "Boiling" mode and finally OFF is shown in Figure 4.20.

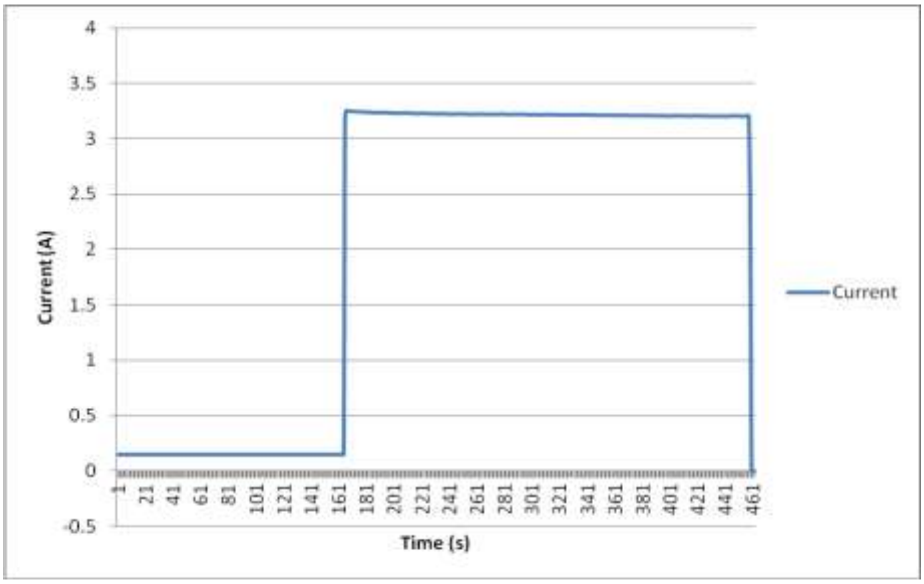


Figure 4.20: Current vs Time (Water Boiler)

The power consumption of the water boiler can also be determined through the data saved in the sbRIO-9632XT. The approximation of power consumption against time is shown in Figure 4.21.

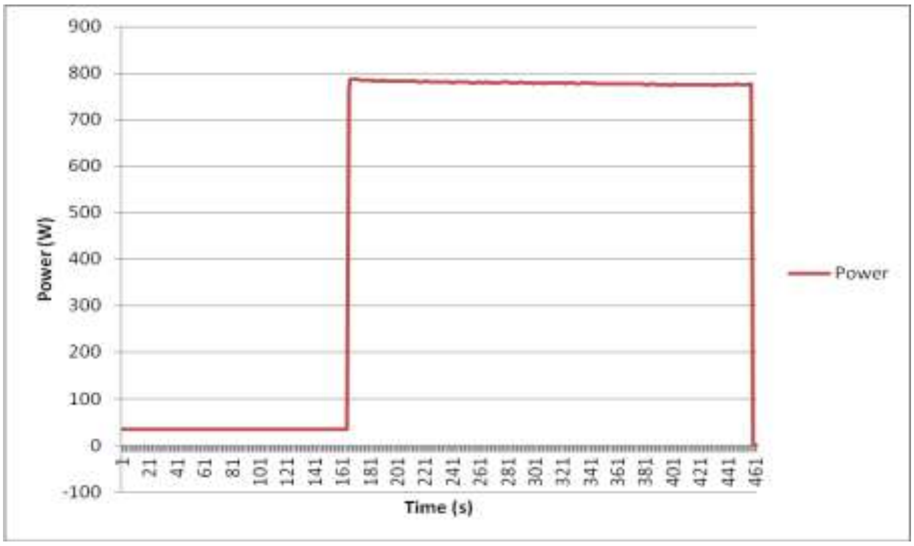


Figure 4.21: Power vs Time (Water Boiler)

4.2.3.1 Database Expansion

The database can be expanded by acquiring more load characteristic of different electrical appliances. The newly determined data of water boiler is created and included in the previous database. The dotted line in Figure 4.22 shows the newly created data in the database to determine a new load.

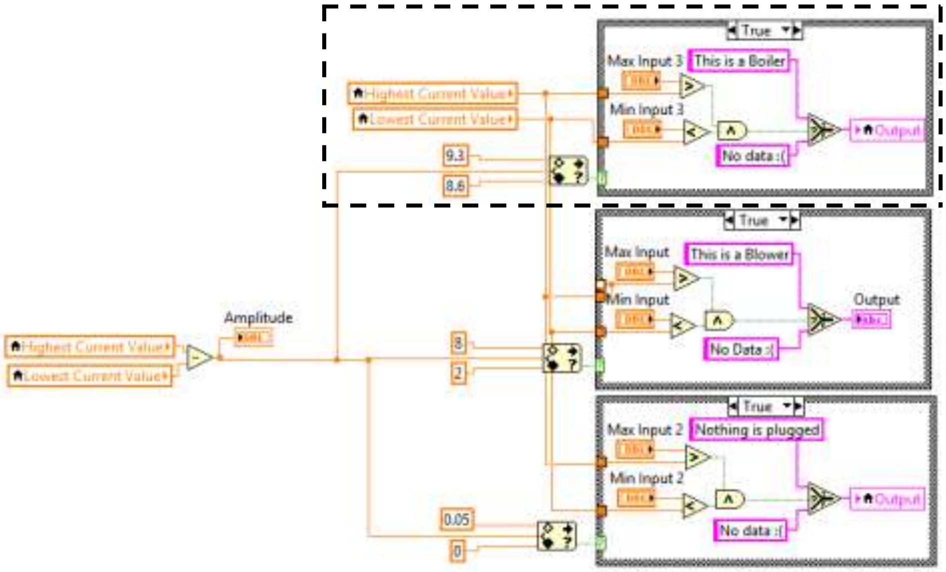


Figure 4.22: Creating New Data

The water boiler has now become one of the electrical appliances that can be recognized by the diagnostic tool. The interface is shown in Figure 4.23.

Figure 4.23: Load Recognition User Interface

4.2.4 Load Characteristic

The load characteristic shows the consumption trend of a load when it is turned on. When both of the loads operate together, each of them will have different load characteristic. The duration is also different depends on how long the users operate them. As water boiler continues to turn on at “Keep Warm” mode, its power consumption does not remain at zero. During the “Boiling” mode, the power consumption will increase instantaneously to a high level. Meanwhile, the hair blower only turns on during usage. The power consumption is zero when it is not operating. The two types of load present in the hair blower have different level of power consumption. Figure 4.24 illustrate the load characteristic of water boiler and hair blower.

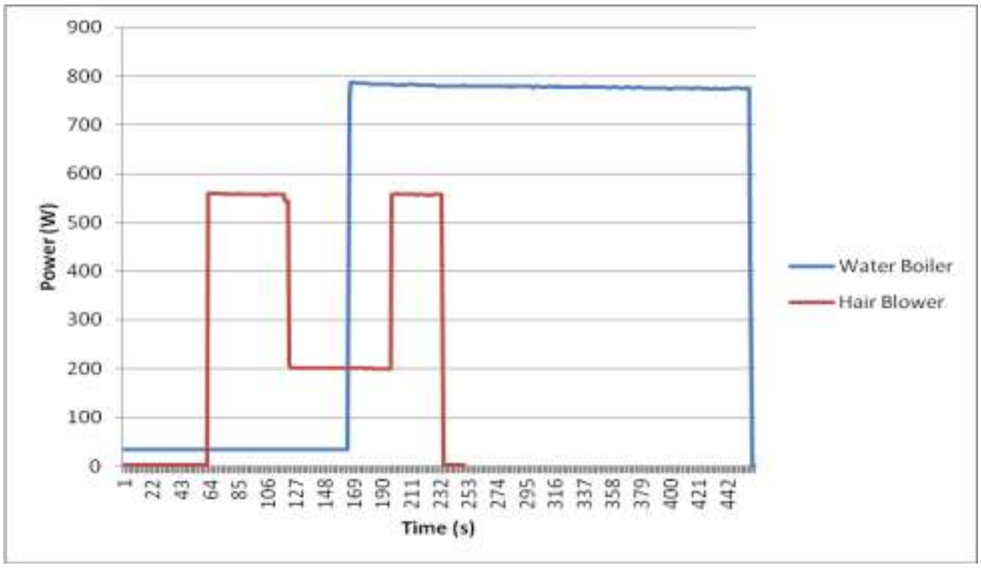


Figure 4.24: Load Characteristic

When two load characteristics are combined, the power consumption trend will increase. At 169 s, the water boiler is turned to “Boiling” mode with hair blower running only the induction motor without heating coil. The power consumption is around 1 KW. After 194 s, the hair blower turned on both induction motor and heating coil. The power consumption by adding both of the load yields around 1350 W. Hence, when two or more loads operate simultaneously, the power consumption trend will have high peak. In demand side management, such peak is unfavorable and most likely will be “shaved” to conserve energy. If different loads run at the same time, this will increase the burden of the electrical network. Additional power plant has to operate to meet the power demand. The combination of hair blower and water boiler power characteristic produce a high peak as shown in Figure 4.25.

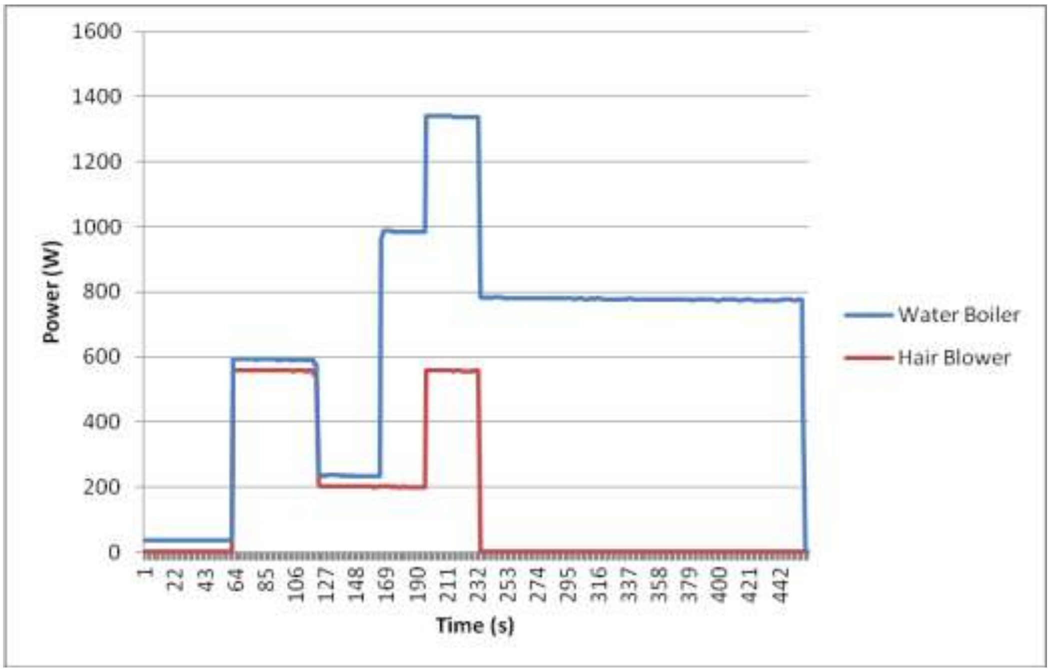


Figure 4.25: Combination of Load Characteristic

4.2.5 Voltage Unbalance Mitigation

This diagnostic tool is able to perform a wide range of function when Sunny Island 5048 is integrated into the system. The functionalities included are peak clipping, mitigation of voltage unbalance, power factor correction, provide uninterruptible power supply and energy measurement.

Voltage unbalance can be mitigated when all the three phases have well balanced voltage. The diagnostic tool has the ability to integrate with Sunny Island 5048 to mitigate the voltage unbalance. In this project, Sunny Island 5048 acts as an energy storage device. It is able to channel excessive power to charge batteries and supply power to the load to lower the burden of utilities. When the system has balance load among the three phases, the Voltage Unbalance Factor (VUF) does not rise beyond the statutory limit of 1%. When a balanced load is connected to the three phases, the increase or decrease in load still maintain the phase voltage close to each other. The balanced load varies the VUF in the range of 0.4% to 0.6% as in Figure 4.26.

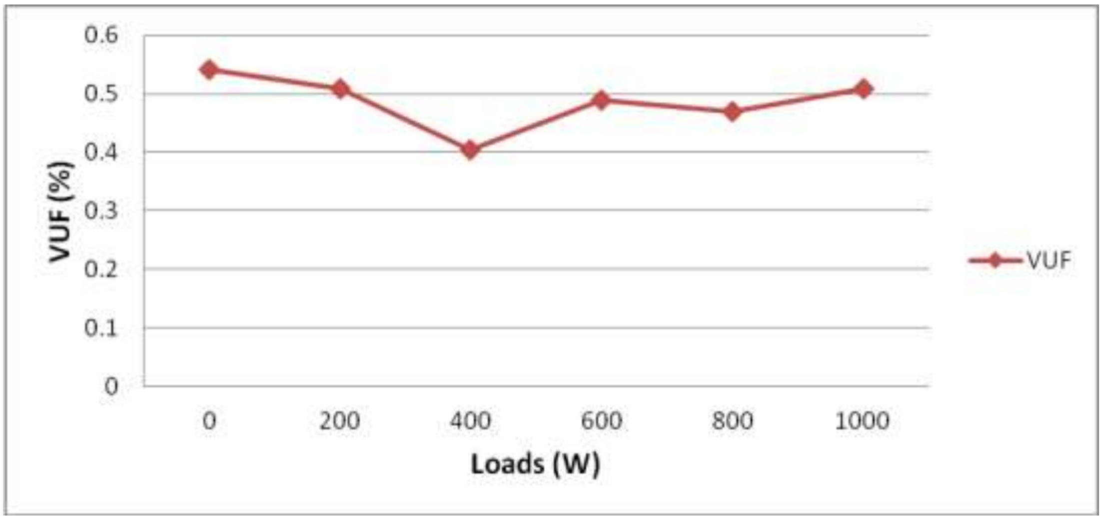


Figure 4.26: VUF with balanced load

In order to generate a significant voltage unbalance, the load at phase A is loaded in a step of 200W for 5 steps. The loading condition can be expressed as [LOAD 0 0]. This means that phase B and phase C are at no-load condition. When the load at phase A keeps on increasing, the voltage at phase A will drop. This causes the phase A to have lowest voltage among the three phases. Hence, the VUF rises and exceed the statutory limit of 1%. The highest VUF recorded is 1.45% as indicated in Figure 4.27.

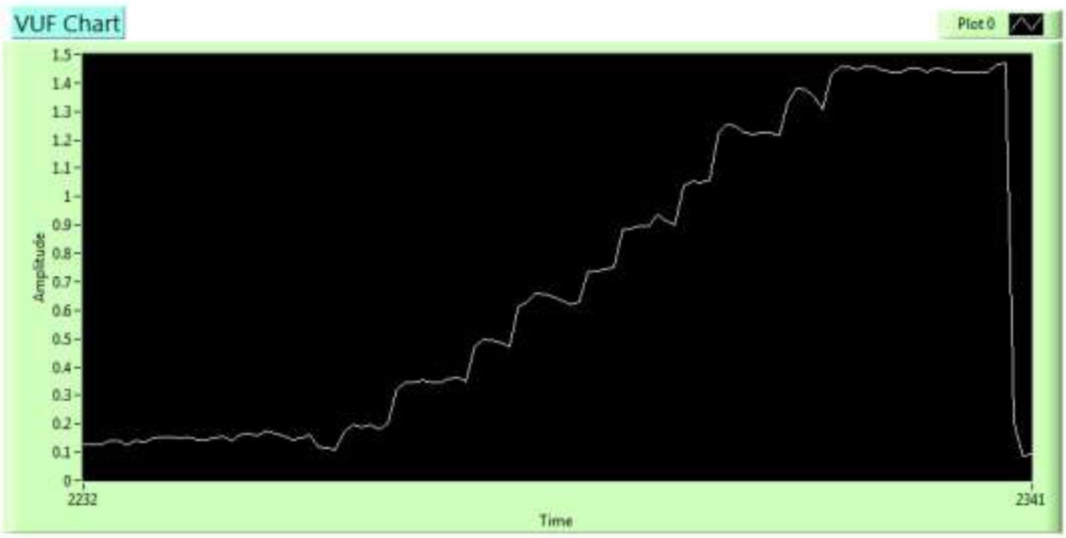


Figure 4.27: VUF with unbalanced load at Phase A

This voltage unbalance problem is always overlooked and it will result in overheating, reduce in lifespan, power loss and decrease in efficiency of induction motor.

When the Sunny Island 5048 is added into the system, the voltage unbalance can be significantly mitigated. The energy conditioning system is able to detect and take action when the VUF exceed 1%. After the condition is fulfilled, it takes action by either supplying power to the phase with lower voltage or channelling the power of highest phase to charge battery. In previous scenario where phase A is highly loaded, the Sunny Island will supply the load to lower down the burden of phase A. This solution successfully mitigated the VUF to 0.3%. The VUF waveform with loading condition of [LOAD 0 0] and Sunny Island 5048 connected to phase A is shown in Figure 4.28.

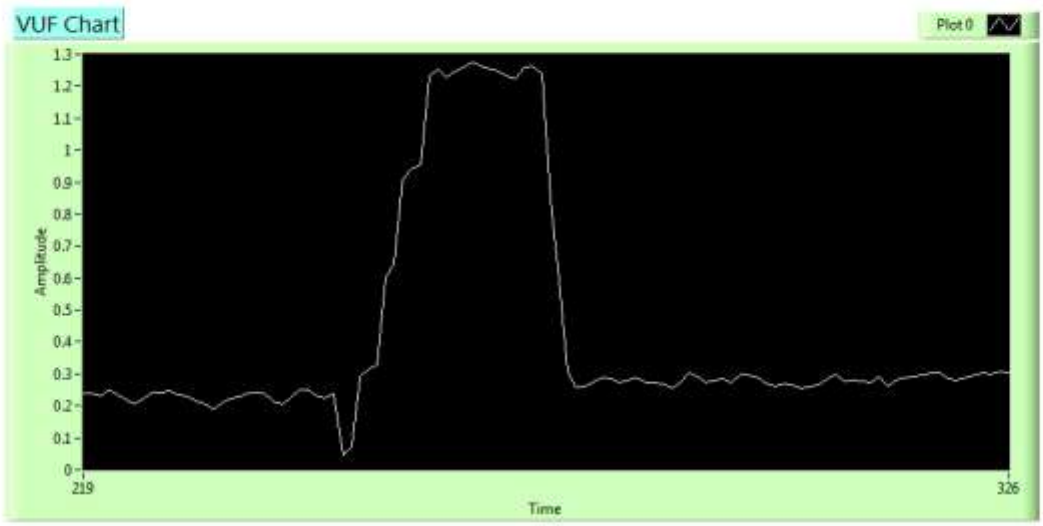


Figure 4.28: VUF with Load and Sunny Island at Phase A

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the objectives of the project have been met. The diagnostic tool has been built and improved from prototype 1 to prototype 2. The device is programmed with LabVIEW to conduct several experiments and the result proved that the device is functioning. The development of the diagnostic tool allows the users to obtain the load characteristic and further enhance the system to perform load recognition. Load recognition can be used to provide information about particular load which helps in developing the demand side management strategy.

The energy conditioning system developed has also successfully mitigated the voltage unbalance in the network with the integration of Sunny Island 5048. Unbalance load in a network may cause the violation of voltage unbalance statutory limit. With the energy conditioning system, the excess power can be channelled to the energy storage system for future use at the same time the voltage unbalance can be kept at minimal value.

5.2 Future Improvement

There are few limitations found on the diagnostic tool which can be improved. The size of the device can be decreased to improve portability by rearranging the components. The location of input plug can be moved to the rear part of the device so that it is easier for the users to access. The device can further improve by having external voltage measurement clip and clamp-type current transformer. This allows the users to access different kind of load even in a compact area.

Moreover, the programming part can also be improved. Whenever a new load is detected, the programme can create and store the new data in database. The load recognition can increase its reliability and accuracy of identifying different load by comparing their turn-on transient signatures.

On the other hand, the mitigation of voltage unbalance is now limited to Phase A and Phase B as there are only two Sunny Island 5048 available. The additional Sunny Island 5048 installed to Phase C enable the energy conditioning system to operate effectively. The Uninterruptible Power Supply (UPS) is more reliable with all the three phases connected to the bidirectional inverter.

REFERENCES

A. Vojdani, “Integration challenges of the smart grid— Enterprise integration of DR and meter data,” in Proc. IEEE Electrical Power System Conf. (EPEC’08), Vancouver, Canada, Oct. 2008, p. 21.

D. Moore and D. McDonnell, "Smart grid vision meets distribution utility reality," *Elect. Light Power*, pp. 1-6, Mar. 2007

Duarte, S.X.; Kagan, N.; , "A Power-Quality Index to Assess the Impact of Voltage Harmonic Distortions and Unbalance to Three-Phase Induction Motors," *Power Delivery, IEEE Transactions on* , vol.25, no.3, pp.1846-1854, July 2010

Hsueh-Hsien Chang; Ching-Lung Lin; Hong-Tzer Yang, "Load recognition for different loads with the same real power and reactive power in a non-intrusive load-monitoring system," *Computer Supported Cooperative Work in Design, 2008. CSCWD 2008. 12th International Conference on* , vol., no., pp.1122,1127, 16-18 April 2008

K. Moslehi, “Intelligent infrastructure for coordinated control of a self-healing power grid,” in Proc. IEEE Electrical Power System Conf. (EPEC’08), Vancouver, Canada, Oct. 2008, pp. 3–7

Laughman, C.; Kwangduk Lee; Cox, R.; Shaw, S.; Leeb, S.; Norford, L.; Armstrong, P., "Power signature analysis," *Power and Energy Magazine, IEEE* , vol.1, no.2, pp.56,63, Mar-Apr 2003

Leeb, S.B.; Shaw, S.R.; Kirtley, J.L., Jr., "Transient event detection in spectral envelope estimates for nonintrusive load monitoring," *Power Delivery, IEEE Transactions on* , vol.10, no.3, pp.1200,1210, Jul 1995

M. Amin and S. Wollenberg, “Toward a smart grid: Power delivery for the 21st century,” IEEE Power Energy Mag., vol. 3, no. 5, pp. 34–41, Sept.–Oct. 2005.

Medina, J.; Muller, N.; Roytelman, I.; , "Demand Response and Distribution Grid Operations: Opportunities and Challenges," *Smart Grid, IEEE Transactions on* , vol.1, no.2, pp.193-198, Sept. 2010 doi: 10.1109/TSG.2010.2050156

National Institute of Standards and Technology, NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0, Special Publ. 1108, Jan. 2010, 145 pp.

Palensky, P.; Dietrich, D.; , "Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads," *Industrial Informatics, IEEE Transactions on* , vol.7, no.3, pp.381-388, Aug. 2011(REAL)

P. Mazza, “Powering up the Smart Grid,” Climate Solutions, July 2005, pp. 25–26.

Product Information: What is NI LabVIEW, 2011. [Online]. Available at: http://www.ni.com/labview/whatis/ [Accessed 16 March 2013]

Siddique, A.; Yadava, G.S.; Singh, B.; , "Effects of voltage unbalance on induction motors," *Electrical Insulation, 2004. Conference Record of the 2004 IEEE International Symposium on* , vol., no., pp. 26- 29, 19-22 Sept. 2004

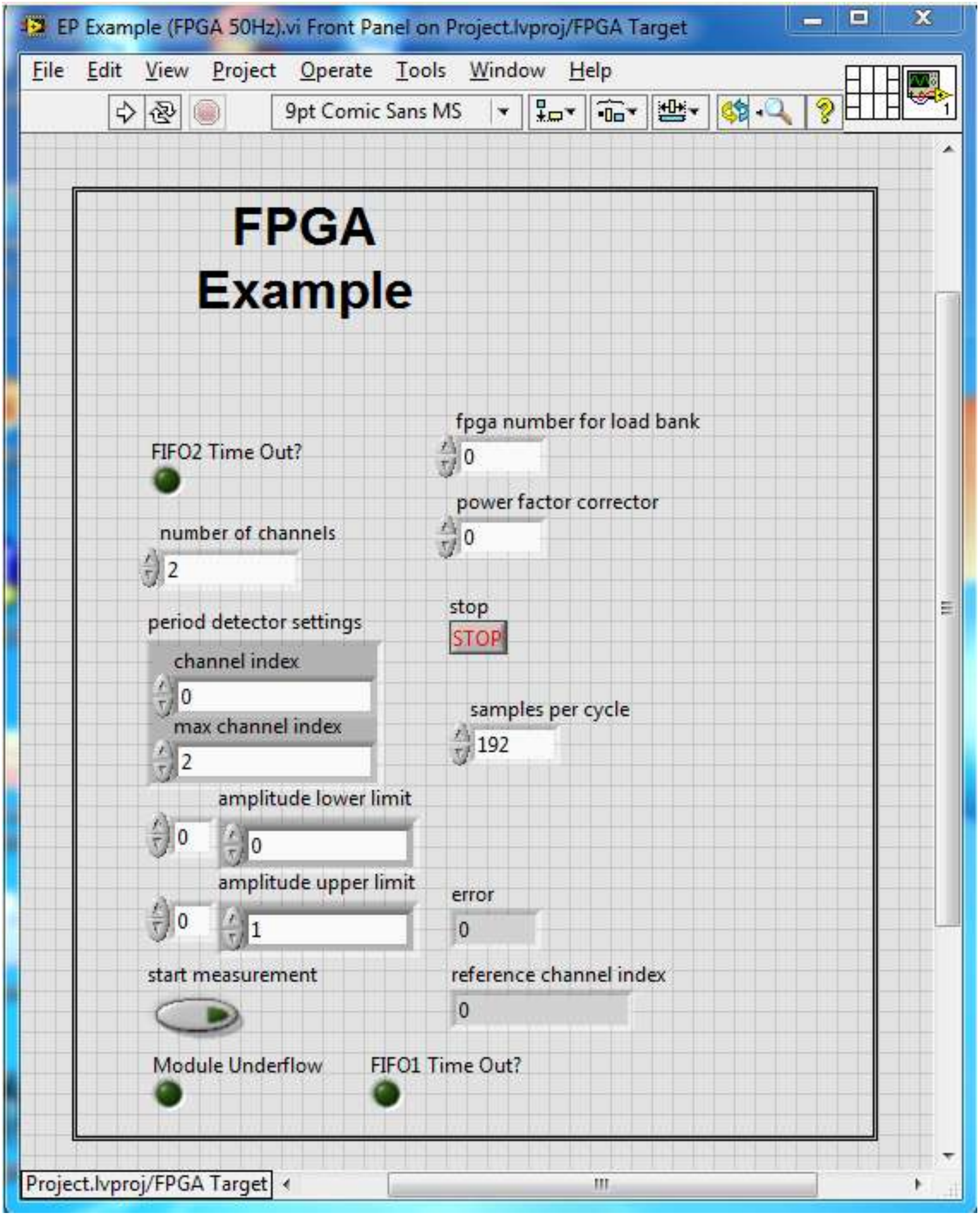
S. J. Anders, “The emerging Smart Grid”, Energy Policy Initiative Center, University of San Diego School of Law, Octo 2007, pp.4–8.

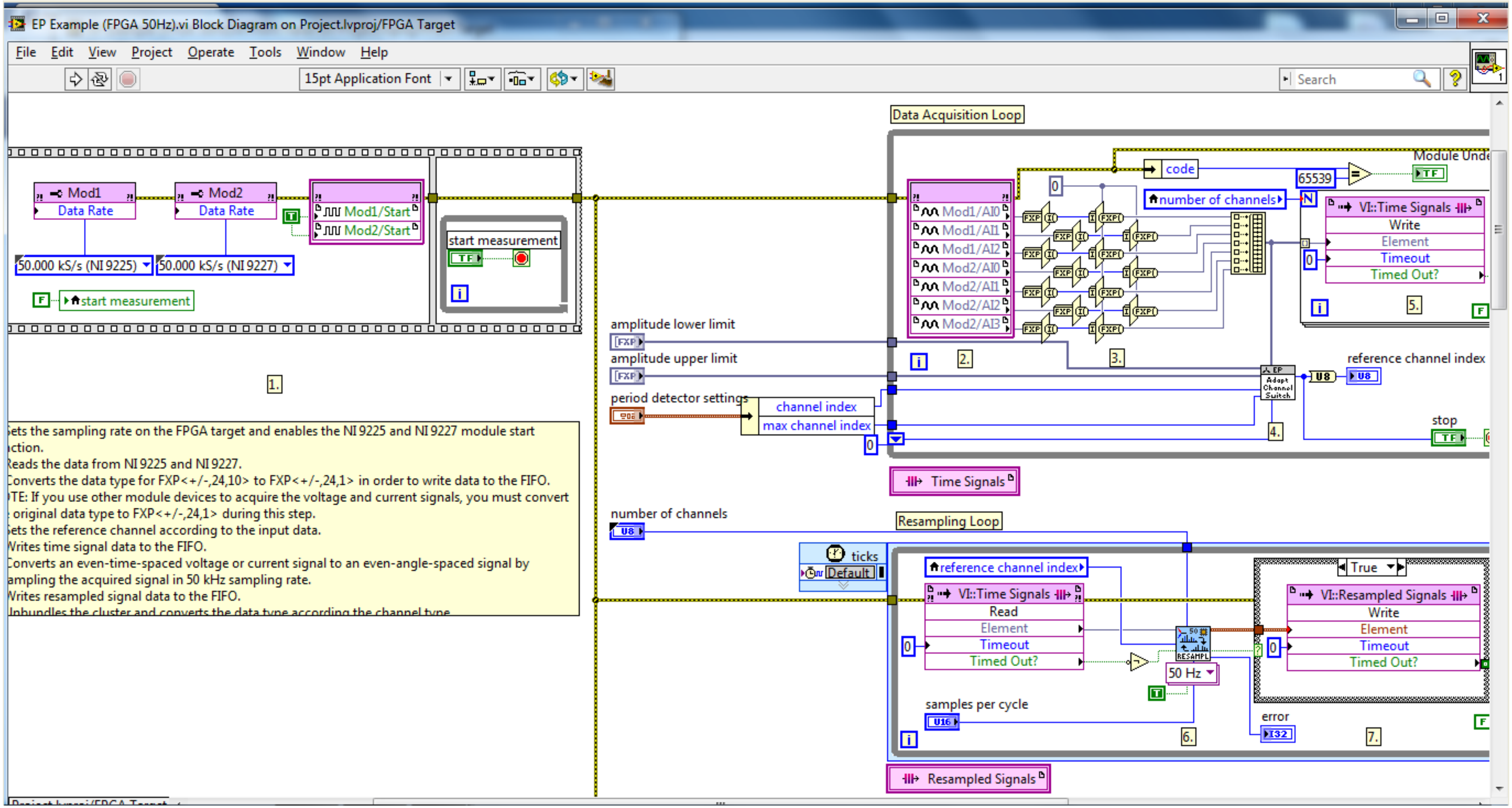
Wang, M. Q.; Gooi, H.B., "Spinning Reserve Estimation in Microgrids," *Power Systems, IEEE Transactions on* , vol.26, no.3, pp.1164,1174, Aug. 2011

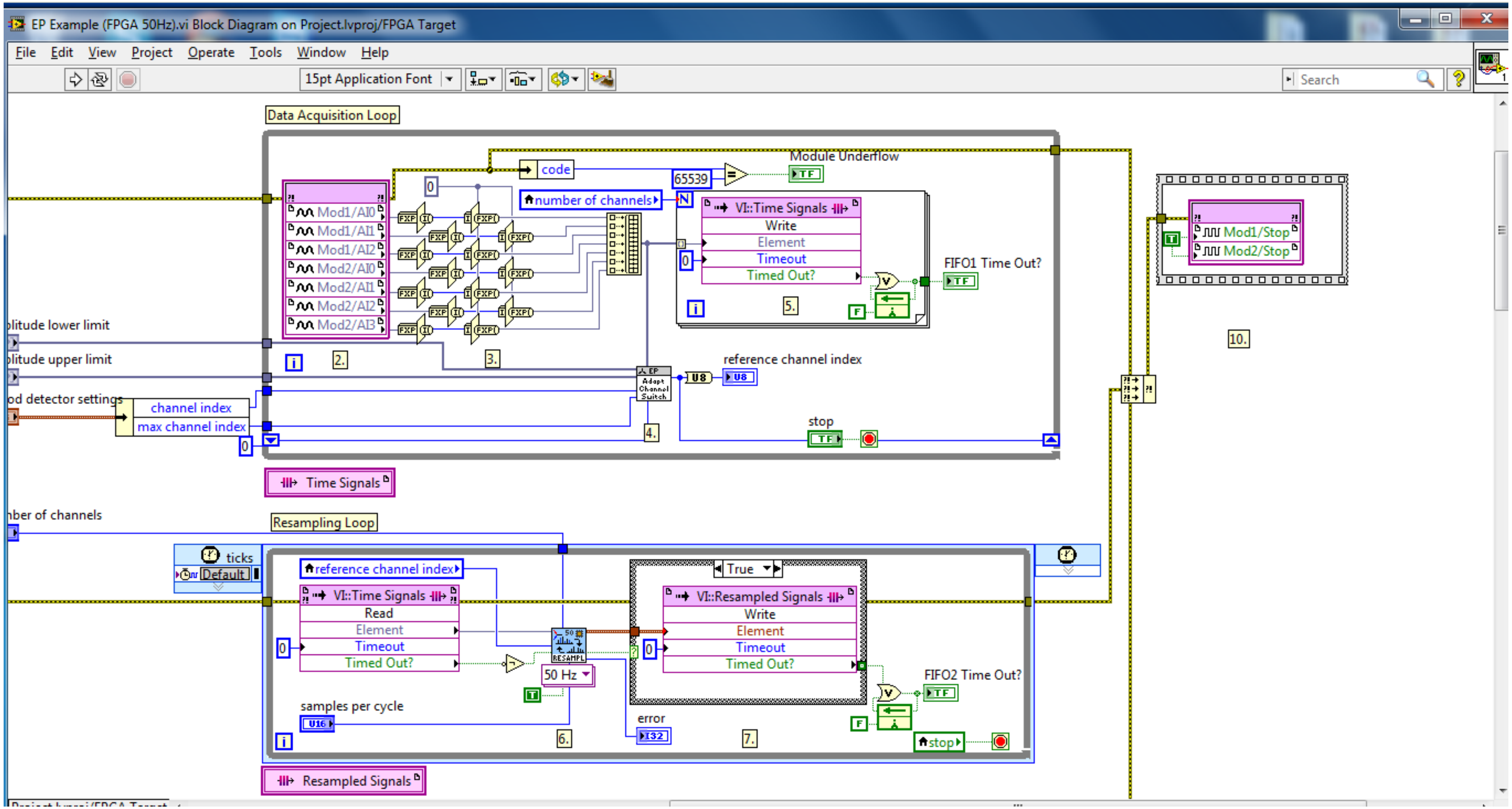
Zoha, A.; Gluhak, A.; Nati, M.; Imran, M.A.; Rajasegarar, S., "Acoustic and device feature fusion for load recognition," *Intelligent Systems (IS), 2012 6th IEEE International Conference* , vol., no., pp.386,392, 6-8 Sept. 2012

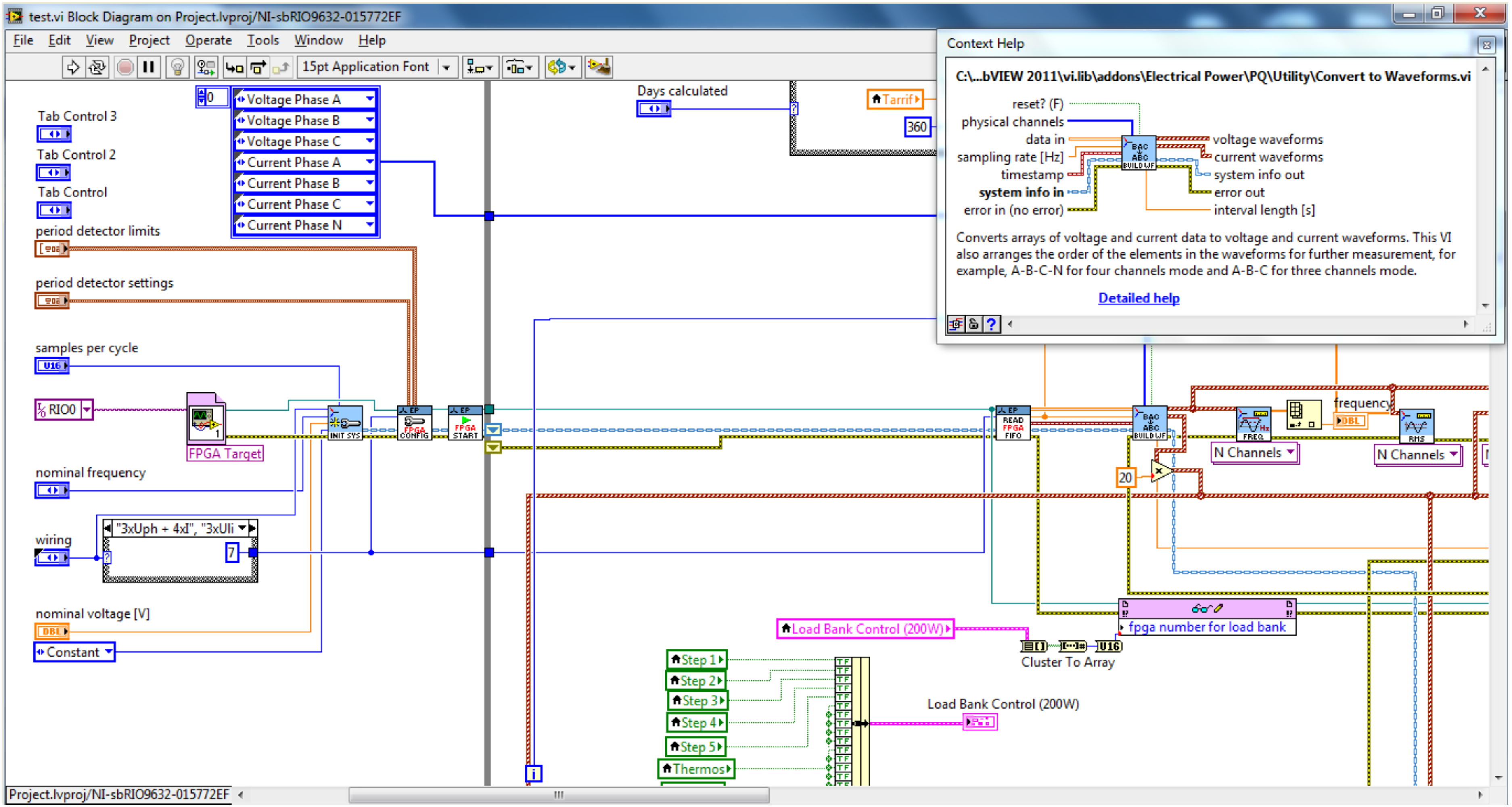
APPENDICES

APPENDIX A: Graphical Programming (LabVIEW)

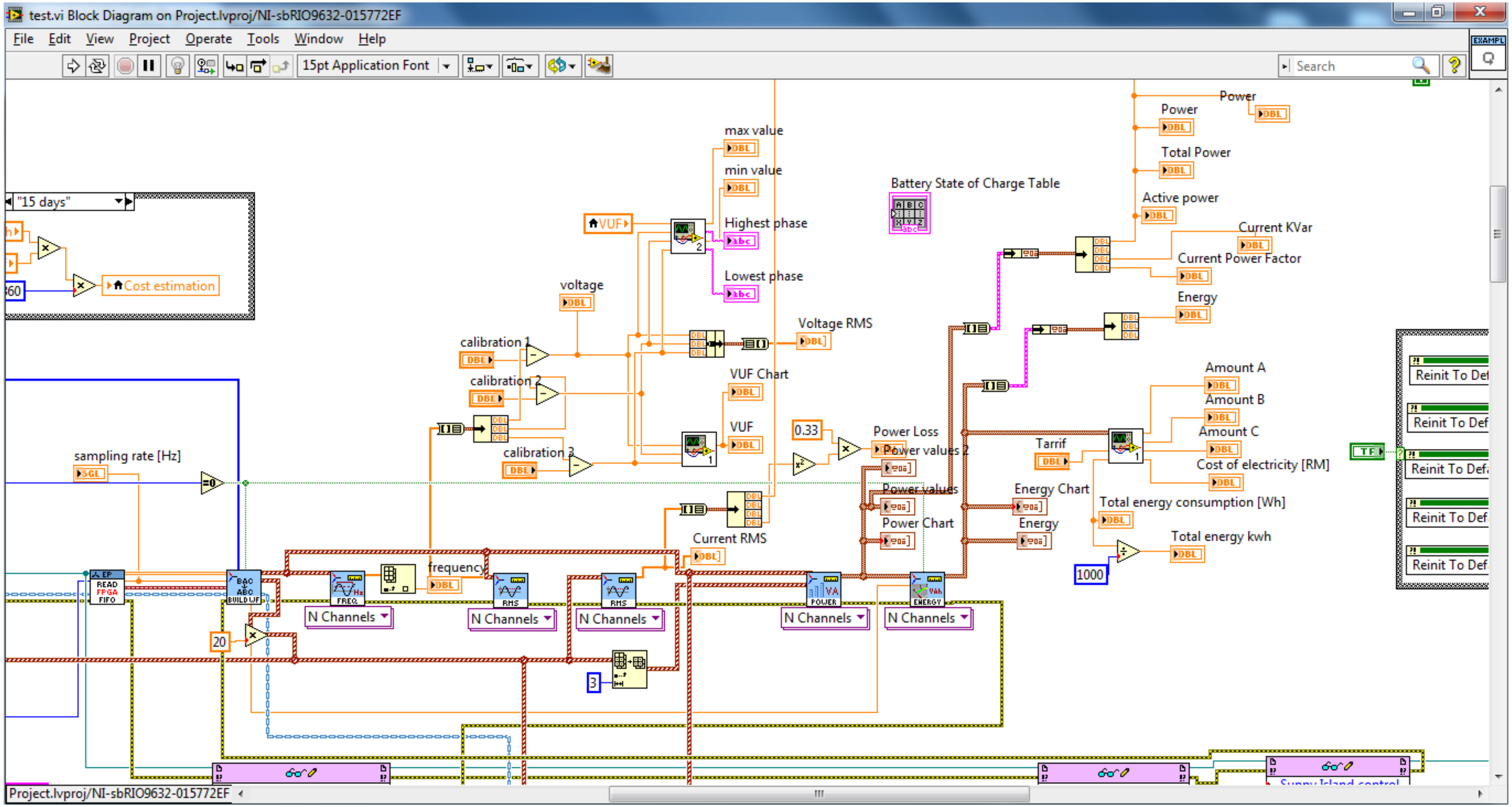



EP Example (FPGA 50Hz).vi Block Diagram on Project.lvproj/FPGA Target
File Edit View Project Operate Tools Window Help
15pt Application Font
Search
Data Acquisition Loop
Mod1
Data Rate
Mod2
Data Rate
Mod1/Start
Mod2/Start
50.000 kS/s (NI 9225)
50.000 kS/s (NI 9227)
start measurement
start measurement
1.
ets the sampling rate on the FPGA target and enables the NI 9225 and NI 9227 module start
ction.
eads the data from NI 9225 and NI 9227.
onverts the data type for FXP<+/-,24,10> to FXP<+/-,24,1> in order to write data to the FIFO.
TE: If you use other module devices to acquire the voltage and current signals, you must convert
original data type to FXP<+/-,24,1> during this step.
ets the reference channel according to the input data.
Vrites time signal data to the FIFO.
onverts an even-time-spaced voltage or current signal to an even-angle-spaced signal by
ampling the acquired signal in 50 kHz sampling rate.
Vrites resampled signal data to the FIFO.
amplitude lower limit
amplitude upper limit
period detector settings
channel index
max channel index
number of channels
ticks
Default
code
number of channels
Module Unde
65539
Mod1/AI0
Mod1/AI1
Mod1/AI2
Mod2/AI0
Mod2/AI1
Mod2/AI2
Mod2/AI3
VI::Time Signals
Write
Element
Timeout
Timed Out?
2.
3.
4.
5.
reference channel index
stop
Time Signals
Resampling Loop
reference channel index
VI::Time Signals
Read
Element
Timeout
Timed Out?
True
VI::Resampled Signals
Write
Element
Timeout
Timed Out?
50 Hz
samples per cycle
error
6.
7.
Resampled Signals


EP Example (FPGA 50Hz).vi Block Diagram on Project.lvproj/FPGA Target
File Edit View Project Operate Tools Window Help
15pt Application Font
Search
Data Acquisition Loop
Module Underflow
code
65539
number of channels
VI::Time Signals
Write
Element
Timeout
Timed Out?
FIFO1 Time Out?
Mod1/AI0
Mod1/AI1
Mod1/AI2
Mod2/AI0
Mod2/AI1
Mod2/AI2
Mod2/AI3
plitude lower limit
plitude upper limit
od detector settings
channel index
max channel index
reference channel index
stop
2.
3.
4.
5.
Mod1/Stop
Mod2/Stop
10.
Time Signals
nber of channels
Resampling Loop
ticks
Default
reference channel index
VI::Time Signals
Read
Element
Timeout
Timed Out?
50 Hz
True
VI::Resampled Signals
Write
Element
Timeout
Timed Out?
FIFO2 Time Out?
samples per cycle
error
stop
6.
7.
Resampled Signals



test.vi Block Diagram on Project.lvproj/NI-sbRIO9632-015772EF
File Edit View Project Operate Tools Window Help
15pt Application Font
Context Help
C:\...bVIEW 2011\vi.lib\addons\Electrical Power\PQ\Utility\Convert to Waveforms.vi
reset? (F)
physical channels
data in
sampling rate [Hz]
timestamp
system info in
error in (no error)
voltage waveforms
current waveforms
system info out
error out
interval length [s]
Converts arrays of voltage and current data to voltage and current waveforms. This VI also arranges the order of the elements in the waveforms for further measurement, for example, A-B-C-N for four channels mode and A-B-C for three channels mode.
Detailed help
Tab Control 3
Tab Control 2
Tab Control
period detector limits
period detector settings
samples per cycle
RIO0
FPGA Target
nominal frequency
wiring
"3xUph + 4xI", "3xUI
nominal voltage [V]
Constant
Voltage Phase A
Voltage Phase B
Voltage Phase C
Current Phase A
Current Phase B
Current Phase C
Current Phase N
Days calculated
Tarrif
360
frequency
N Channels
20
Load Bank Control (200W)
fpga number for load bank
Cluster To Array
Step 1
Step 2
Step 3
Step 4
Step 5
Thermos
Project.lvproj/NI-sbRIO9632-015772EF


test.vi Block Diagram on Project.lvproj/NI-sbRIO9632-015772EF
File Edit View Project Operate Tools Window Help
15pt Application Font
Search
"15 days"
Cost estimation
60
max value
min value
Highest phase
Lowest phase
VUF
voltage
calibration 1
calibration 2
calibration 3
Voltage RMS
VUF Chart
VUF
0.33
Power Loss
Power values 2
Power values
Power Chart
Current RMS
sampling rate [Hz]
frequency
N Channels
20
3
Battery State of Charge Table
Power
Power
Total Power
Active power
Current KVar
Current Power Factor
Energy
Amount A
Amount B
Amount C
Tarrif
Cost of electricity [RM]
Energy Chart
Energy
Total energy consumption [Wh]
Total energy kwh
1000
Reinit To Def
Project.lvproj/NI-sbRIO9632-015772EF