USER INTERFACE AND DEVELOPMENT OF FUTURE ACTIVE NETWORK MANAGEMENT SYSTEM FOR MICROGRID

LIM KHIM YAN

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

Faculty of Engineering and Science

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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.

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Name   : _____

ID No.   : _____

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"USER INTERFACE AND DEVELOPMENT OF FUTURE ACTIVE NETWORK MANAGEMENT SYSTEM FOR MICROGRID"** was prepared by **LIM KHIM YAN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronic Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : _____

Supervisor : Mr. Chua Kein Huat

Date : _____

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ABSTRACT

In the Tenth Malaysia Plan (from 2011 to 2015), government had set the renewable energy installation at 98MW which contributes a total of 5.5% of the total electricity generation. Having the advantage of scorching sun throughout the year, Malaysia has a great potential in implementing solar power generation for household and even for industrial usage. Nevertheless, the utility industry is struggling to address numerous challenges such as lack of infrastructure for renewable integration, rise in domestic electricity consumption, increases of power quality issues, aging infrastructure and poor reliability of the existing electrical grid. Nowadays, utilities throughout the world are integrating new technologies towards implementing the new generation electrical grid, namely smart grid. A smart grid provides a wide variety of generation options that enable pervasive control and monitoring.

The high integration of renewable energies could cause problems related to voltage unbalance, voltage rise, thermal limitation of transformer and network power losses. Due to the inherent variation in solar radiation and climate change, the Photovoltaic (PV) systems can cause transients and disturbances to the network and concurrently cause the low power quality of the supply. Besides, the use of switch-mode power supplies (SMPS) in computers, air-conditioning devices, and some home appliances deteriorates the quality of the power supply. Hence, disruption of power will be a common sight for residents. However, the consequences of power interruptions are costly. Therefore, the reliability of power supply is significant in maintaining the growth of economy.

This project presents an algorithm developed to reduce the voltage unbalance problem caused by high penetration of PV systems in LV distribution network. It can record and analyse power quality events, handle the high integration of renewable energies into the electrical network with minimal transients and disturbances. This algorithm also used in peak load clipping and load shifting which used to decrease energy used during the utility's crucial peak period. In this project, an energy storage device is used as buffering agent to deliver power during peak periods and to absorb power during off-peak periods. Experimental results show it can resolve the problem in an orderly manner. An user friendly interface is developed for the ease of control. Hence, an active network management system is developed to address the major shortage of the existing grid.

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INTRODUCTION

1.1   Background

In December 2011, a feed-in tariff (FiT) system has been launched by Malaysia government to allow electricity produced from renewable sources to be sold to utilities at a fixed-premium price. The feed-in tariff is expected to be implemented in December year 2011 (Overview of Policy Instruments for the Promotion of Renewable Energy and Energy Efficiency in Malaysia, 2005). The feed-in tariff will be levied at 1% of consumers' electricity tariff and be managed by the Sustainable Energy Development Authority (SEDA), under the Ministry of Energy, Green Technology and Water. From the offered benefits, solar power will probably become the main gist because this technology is currently the most mature and available technology in this country. Hence the installation rate of solar panels throughout Malaysia will absolutely increase over the next five years (Abdul Rahman Mohamed, 2006). As photovoltaic system becomes the dominant type of renewable energy in Malaysia due to geographically suitable location, the growth of the Building Integrated Photovoltaic (BPIV) system is also increases. As a result, the BPIV system now leads to a sustainable and widespread application of PVs in LV distribution network (Malaysia Building Integrated Photovoltaic Project (MBIPV), 2010).

However, the existing design of the LV distribution networks does not take into account the expected technical issues such as voltage unbalance, power quality, degradation of network efficiency and thermal limitation which caused by the

potential growth of PV system penetration (Cipcigan, L., 2009 and P. F. Lyons, 2009). The load demands are planned to be distributed equally over each phase to minimize the voltage unbalance in the network in the three-phase distribution networks. Nevertheless, PV systems are most likely to be single-phase and connected to the LV distribution networks through "fit and inform" policy by customers. As a result, the three-phase voltage of the LV distribution networks could become unbalance, resulting in a returned current flow through the neutral line which in turn causes increases of power losses in the network and reduction in the efficiency of distribution networks (The Electricity Council, 1990).

Power quality has believed increasing significance due to the widely use of power electronic equipment. Notwithstanding people discuss about power quality commonly, they are actually referring to "voltage quality". This is because most of the time voltage will be the controlled quantity. In a three phase balance power distribution system, the three line-neutral voltages are equal in magnitude and are 120 degrees phase displaced from each other in a balanced sinusoidal supply. It is said to be unbalanced supply or known as Voltage Unbalance Factor (VUF) if there is any differences that present in the three voltage magnitudes and/or a shift in the phase separation from 120 degrees (Vic Gosbell, 2002).

Therefore, a system should be used to cope with these power quality problems in order not disturbing the routine of the equipment. As changes of quality of supply have put significant stress on the supply system to be efficient and meanwhile provided unreliable supply causing many breakdown or failures. It is costly as in some factories, following a cut-off of power supply, clearing the lines of spoilt work, restarting of boilers, and reprogramming automatic controls at a usual cost of $50,000 per incident may be required by the restarting of assembly lines.

1.2   Aims and Objectives

The aim and objective of this project is to develop a microgrid by using the smart energy conditioning system to mitigate the power quality problems including voltage unbalance issue with high penetration of PV system. Besides, it also can analyze the power quality events in order for the user to monitor the variation of power supplied to the grid. In order to achieve this objective, a powerful conditioning system built. The system comprises of NI-single board RIO 9632XT, NI 9225-voltage measurement unit, NI 9227- current measurement unit, LV network emulator, Sunny Island 5048, load bank, PV system and selector. A graphical interface controlling and monitoring system is developed using a graphical programming language LabVIEW. Figure 1 interprets the block diagram of energy conditioning system. Figure 1.1 shows the block diagram of energy conditioning system.
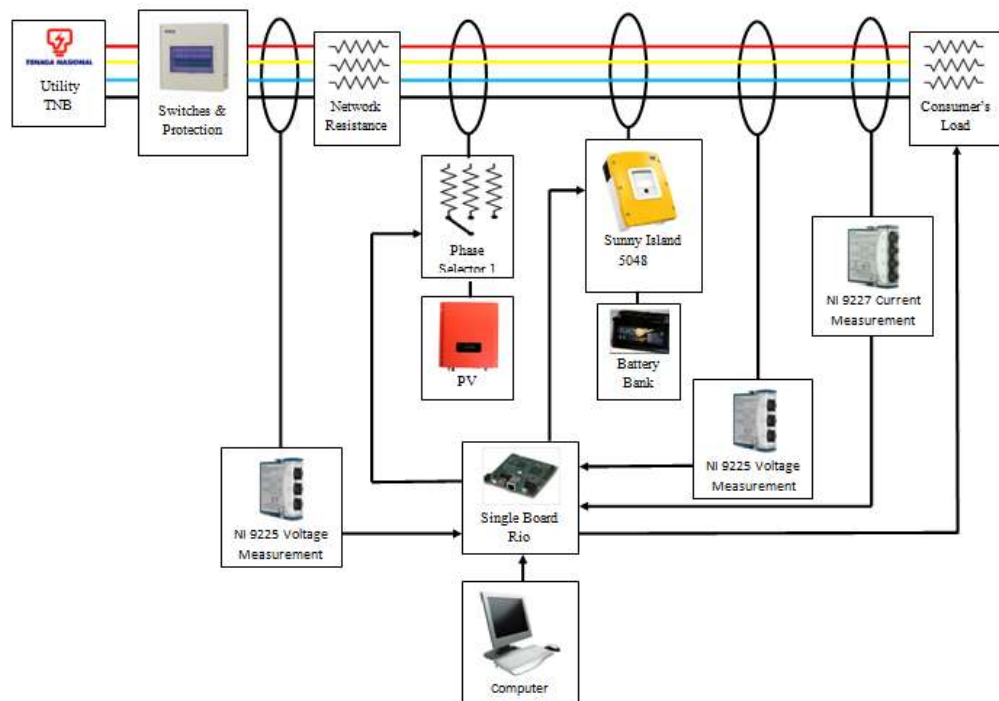
Figure 1.1: Block diagram of energy conditioning system

1.3 Scope of Project

For the project flow, we study journals, articles and papers relevant to this topic at the beginning. After we have the knowledge on this topic, we start brainstorming. How to develop a system with what resources and equipment? Where should we build the system? We figure out these questions and try to understand the functions of the equipment used and get to know the way of operation of that equipment. Then, we start to design our system. We design the system which can mitigate the VUF with the limited equipment and budget. After that, we build the system with the equipment. Here come to the heart of our project, with the master piece (NI-single board RIO 9632XT), we create our own program with the powerful graphical programming language LabVIEW. After all are ready, we run the program with equipment and do troubleshooting until the system meet the condition needed. Next, we will make our system in automated control. For the improvement part, we study other power quality of the power supplied such as harmonics, flicker, voltage sag and swell and do some analysis. After all, we realised we are having high electricity bill due to high peak demand charges and power factor surcharge. So, we do some research and find out the way to solve this problem as well. Finally, we developed Dr. Energy which is also an electric power diagnosing tool. It is a customizable system which can add on due to your requirement.

The scope of this project is shown in the flow chart below:
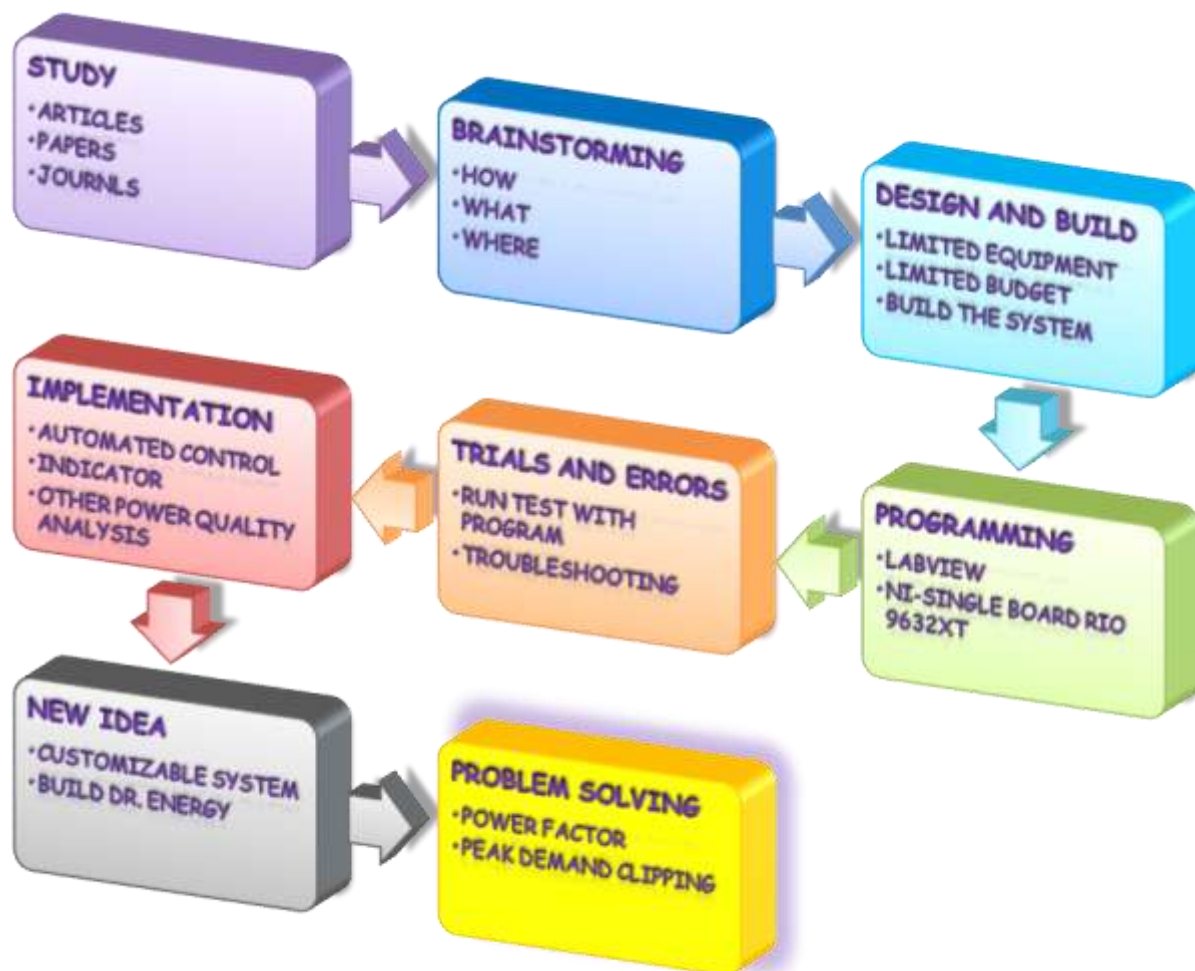
Figure 1.2: Flow of this project

1.4 Schedule

For this project, it is distributed it into 3 parts. For the first part, it will be covered until experiments which is the end of first semester. While for the second part, it will cover the implementation. And the third part is about the new idea until April. Below shows a Gantt chart for the milestone of this project.
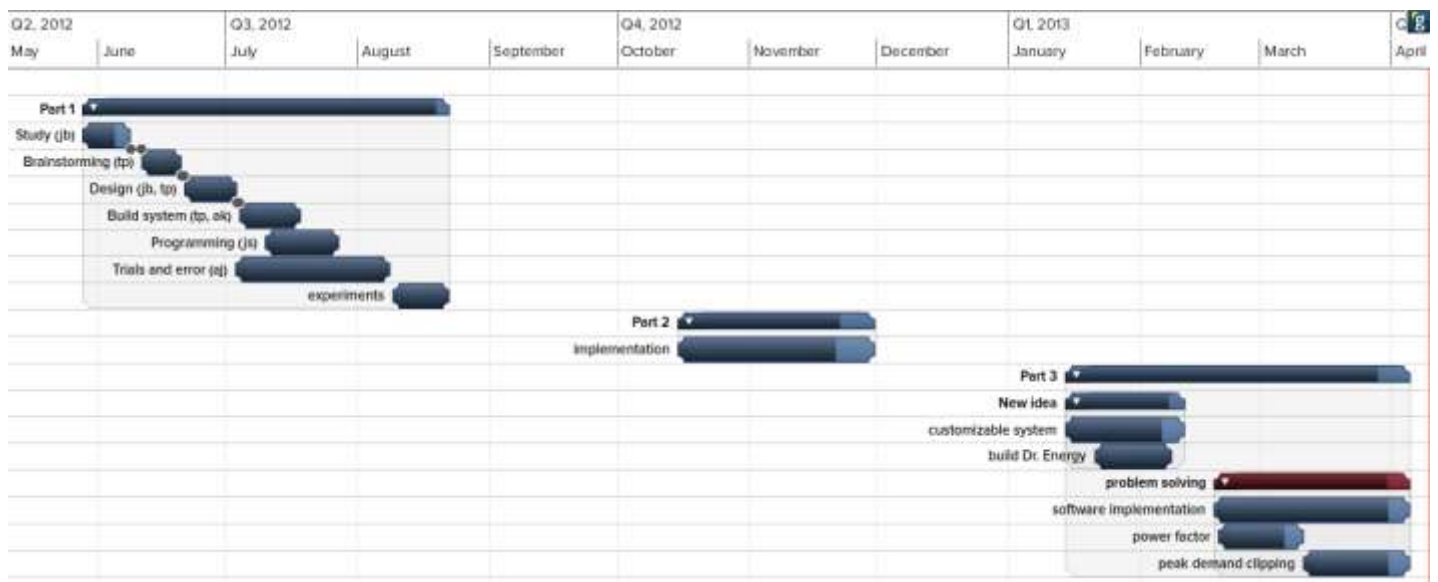
Figure 1.3: Gantt chart of this project

	Name	Durati...	Start Date	End Date	%
0	Milestone List				
1	▼ Part 1	63 days	Mon 05/28/12	Wed 08/22/12	99 %
2	Study	10 days	Mon 05/28/12	Fri 06/08/12	90 %
3	Brainstorming	8 days	Mon 06/11/12	Wed 06/20/12	100 %
4	Design	9 days	Thu 06/21/12	Tue 07/03/12	100 %
5	Build system	11 days	Wed 07/04/12	Wed 07/18/12	100 %
6	Programming	14 days	Tue 07/10/12	Fri 07/27/12	100 %
7	Trials and error	27 days	Tue 07/03/12	Wed 08/08/12	100 %
8	experiments	10 days	Thu 08/09/12	Wed 08/22/12	100 %
9	▼ Part 2	35 days	Mon 10/15/12	Fri 11/30/12	85 %
10	implementation	35 days	Mon 10/15/12	Fri 11/30/12	85 %
11	▼ Part 3	60 days	Mon 01/14/13	Fri 04/05/13	93 %
12	▼ New idea	21 days	Mon 01/14/13	Mon 02/11/13	94 %
13	customizable system	21 days	Mon 01/14/13	Mon 02/11/13	90 %
14	build Dr. Energy	15 days	Mon 01/21/13	Fri 02/08/13	100 %
15	▼ problem solving	35 days	Mon 02/18/13	Fri 04/05/13	92 %
16	software implementation	35 days	Mon 02/18/13	Fri 04/05/13	95 %
17	power factor	15 days	Tue 02/19/13	Mon 03/11/13	90 %
18	peak demand clipping	20 days	Mon 03/11/13	Fri 04/05/13	90 %

Table 1.2: Milestone of this project

CHAPTER 2

LITERATURE REVIEW

2.1   Microgrid

A microgrid is defined as a fusion of generation and electrical loads. The generators in the microgrid may be mutual engines, fuel cells, or any of the alternate power sources. A microgrid may be integrated in college campus, industrial park, or shopping center. A microgrid can be considered as an electrical load which can be inhibited its volume to the utility. The power consumption could be constant, or it could be increased during night time when electricity is cheaper, or else it could be zero during peak time.

The objective of the Energy Management System (EMS) is to judge based on the best use of the sources to produce electric power. These judgements are due with the power consumption of the equipment, temperature, cost of fuel and many other considerations. In the final system, the EMS will be responsible to make decisions on the period and timing to operate each of the generator, at what power level, when to store energy, and what is its priority.

Only EMS control signals will be the real power output of the generation when the microgrid is connected to the grid. Power delivered is expected to be at unity power factor. Interruptions to the normal distribution system voltage control measures such as shunt capacitors and voltage regulators are not allowed by any voltage control. However, voltage may rise if the distribution feeder is unloaded.

In grid-connected mode, a power sensor is used on the microgrid feeder where the microturbine is connected in order to set the power level used or to load a command. The interconnection bus voltage in the grid-connected mode is not allowed to be regulated by microturbine. However, this voltage regulation is implied when the microgrid is in standalone. The microturbine can regulate voltage on the microgrid's own buses. In addition, a set power level can also be provided and output power factor can be controlled within limits. Within the microgrid, voltage regulation will only be supported on the buses that are linked to microturbines.

In the grid connected mode, the microgrid can be treated as either a constant power consumed, or load peaks can be eliminated, or load can be varied purely as a purpose of totalled load within the microgrid. To dispatch signals from the EMS, the voltage on certain critical buses of the microgrid would be regulated. Other than that, EMS is also needed to perform rapid load shed within the microgrid so that generation and load can be balanced. A frequency droop characteristic would be operated by the microturbines in the grid independent mode. When a frequency droop is sensed, power output is increased, hence, frequency within the microgrid can be regulated. A voltage droop characteristic would be operated by the microturbines which reactive power output is increased when a voltage droop is sensed no matter in the grid independent mode or in grid connected mode. Therefore, the microgrid is controlling the reactive power.

When the feeder is unloaded, the voltage increased from the distribution system feeder to the microgrid. The feeder is unloaded either caused by dropping of load from the microgrid, or caused by the microgrid which feeding its own load. This kind of voltage rise is not considered as active voltage regulation of the feeder. It is a highly efficient way in improving distribution system performance by performing the voltage regulation which is a logical function and nature of the microgrid. In the future, voltage regulation will be provided by the microgrid for the distribution system.

2.2   Power Quality

Power quality is defined as "the availability of pure voltage sinusoidal waveform at delivery point". Ideally, the best electrical supply from the utility is a constant amplitude and frequency sinusoidal voltage waveform. However, because of the non-zero impedance of the feeder, the power quality of the supply may be degraded. Incompatibility between power supply and the industrial equipment may cause failure to the customer equipment or poverty in the quality of industrial equipment. Main power quality issues are related to voltage unbalance, harmonics, voltage flicker, voltage dips, voltage swell, and transients. These will cause a lot of problems such as unexpected power supply failures for example breakers tripping and fuses blowing. Moreover, there might be failure, overheating or malfunctioning of equipment that may lead to their lifetime reduction. Some more, it might causing damage to sensitive equipment and increasing system loss.

The quality of electricity can also defined as a set of values of parameters, such as deviation in transient voltages and currents, voltage magnitude, continuity of service, harmonics in the AC power and others. Many people think that power quality is a compatibility problem as people will question that whether the equipment attached to the grid compatible with the measures on the grid. Is the power sent by the grid compatible with the equipment that is attached? Normally, compatibility problems have two solutions, either transform the equipment to be stronger, or clean up the power. For IEEE Standard 1100-1999 Recommended Practice for Powering and Grounding Electronic Equipment, power quality is the idea of powering and grounding electronic equipment which is appropriate with the function of the equipment and compatible with the foundation wiring system and other linked equipment. A general categorization of power quality phenomena also provided by IEEE based on the duration, principal spectral content, and magnitude of the disturbance. Table 2.1 shows categories and characteristics of power system electromagnetic.

Table 2.1: Categories and Characteristics of Power System Electromagnetic Phenomena

Table 2.2   Categories and Characteristics of Power System Electromagnetic Phenomena [4].

No.	Categories	Typical spectral content	Typical duration	Typical voltage magnitude
1.0	Transients			
1.1	Impulsive			
1.1.1	Nanosecond	5-ns rise	< 50 ns	
1.1.2	Microsecond	1-μs rise	50 ns - 1 ms	
1.1.3	Millisecond	0.1-ms rise	> 1 ms	
1.2	Oscillatory			
1.2.1	Low Frequency	< 5 kHz	0.3 - 50 ms	0 - 4 pu (per unit)
1.2.2	Medium Frequency	5 - 500 kHz	20 μs	0 - 8 pu
1.2.3	High Frequency	0.5 - 5 MHz	5 μs	0 - 4 pu
2.0	Short-duration variations			
2.1	Instantaneous			
2.1.1	Interruption		0.5 - 30 cyc	< 0.1 pu
2.1.2	Sag (Dip)		0.5 - 30 cyc	0.1 - 0.9 pu
2.1.3	Swell		0.5 - 30 cyc	1.1 - 1.8 pu
2.2	Momentary			
2.2.1	Interruption		30 cy - 3 s	< 0.1 pu
2.2.2	Sag (Dip)		30 cy - 3 s	0.1 - 0.9 pu
2.2.3	Swell		30 cy - 3 s	1.1 - 1.4 pu
2.3	Temporary			
2.3.1	Interruption		3 sec - 1 min	< 0.1 pu
2.3.2	Sag (Dip)		3 sec - 1 min	0.1 - 0.9 pu
2.3.3	Swell		3 sec - 1 min	1.1 - 1.2 pu
3.0	Long Duration Variations			
3.1	Interruption, Sustained		> 1 minute	0.0 pu
3.2	Undervoltages		> 1 minute	0.8 - 0.9 pu
3.3	Overvoltages		> 1 minute	1.1 - 1.2 pu
4.0	Voltage Unbalance		steady state	0.5 - 2%
5.0	Waveform Distortion			
5.1	DC Offset		steady state	0 - 0.1%
5.2	Harmonics	0 - 100th harmonic	steady state	0 - 20%
5.3	Inter-harmonics	0 - 6 kHz	steady state	0 - 2%
5.4	Notching		steady state	
5.5	Noise	Broadband	steady state	0 - 1%
6.0	Voltage Fluctuations	< 25 Hz	intermittent	0.1 - 7%
				0.2 2 Pst
7.0	Power Frequency Variations		< 10 s	

Source: IEEE Std 1159-1995

The acceptance of data-processing equipment to voltage deviation is often described by the CBEMA curve, which can figure out the magnitude and duration of voltage fluctuation that can be accepted. But now, CBEMA has been renowned as the Information Technology Industry (ITI) Council. To replace the original CBEMA curve, a new curve has been developed. In an ideal world, AC voltage is supplied by a utility as sinusoidal with an impedance of zero ohms at all frequencies having an amplitude and frequency given by system specifications or national standards. Figure 2.1 shows the ITI (CBEMA) curve.
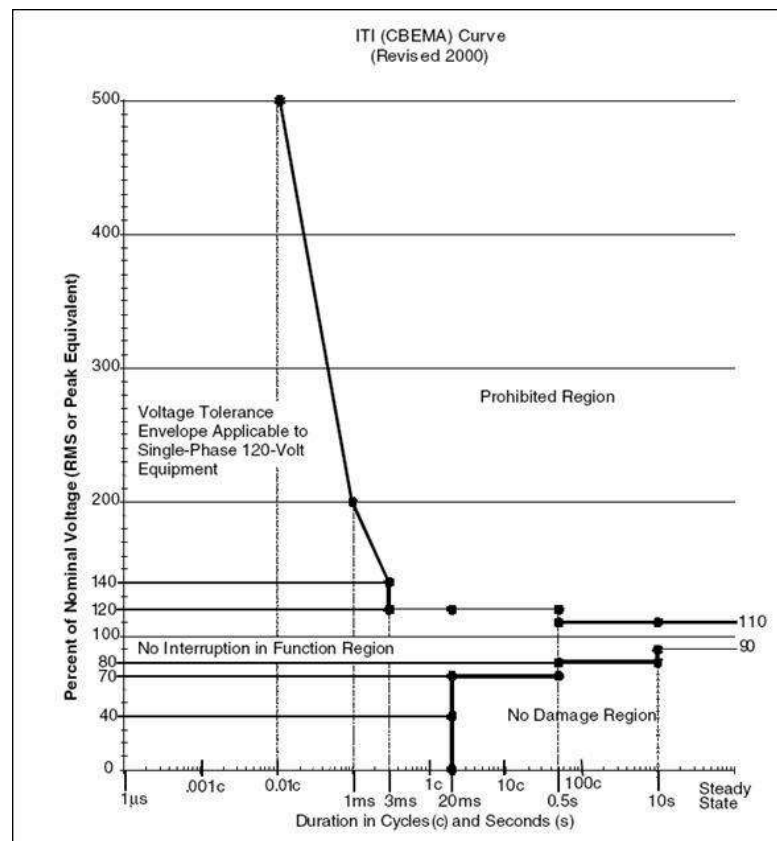
Figure 2.1: ITI (CBEMA) curve

Sensors used by modern systems called phasor measurement unit (PMU) scattered throughout the grid to observe power quality and respond automatically in some cases. Promises to bring better quality of power and fewer failures while concurrently supporting power from distributed generation, which would degrade power quality if it is unchecked can be achieved by using such smart grid features of fast sensing and self-healing of problems automatically in the network.

Various agencies from the world have collected some information on power quality to increase compatibility levels and to intensify the understanding of system performance. Power quality monitoring is still in the initial stage due to the reasons of cost. However, they are forced to compete due to the deregulation in the utility industry in many countries. The information needed to observe power quality is usually massed. Therefore, in order to characterize measures events and store the results in a database automatically, software must be utilised. It will be cost-effective to integrate the data collected from power quality and in-plant monitoring with electric power instrumentation, event information, and site descriptions (R.Sastry Vedam, 2009). A basis for developing equipment compatibility specifications and guiding principles for upcoming equipment enhancements can be provided by a power quality database. In addition, database of the causes recorded with disorders can be referenced to improve the system. Danger resulting from failure or equipment disoperation can be avoided by ensuring equipment compatibility.

2.3   Voltage Unbalance Factor (VUF)

In a three phase balance power distribution system, the three line-neutral voltages are equal in magnitude and are 120 degrees phase displaced from each other in a balanced sinusoidal supply system. It is said to be unbalanced supply or known as Voltage Unbalance Factor (VUF) if there is any differences that present in the three voltage magnitudes and / or a shift in the phase separation from 120 degrees (Vic Gosbell, 2002). Figure 2.2(a) shows a balanced system whereas Figure 2.2(b) shows an unbalanced system.
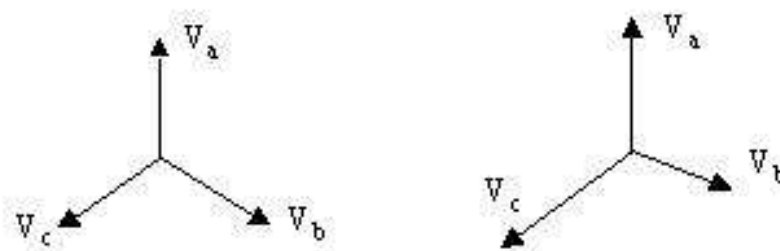

Figure 2.2: (a) A balanced system; (b) An unbalanced system

The voltage unbalance in the distribution networks may be due to several reasons such as (Von Jouane, 2001, Valios, 2001 and Yaw-Juen Wang, 2001):

1. Irregular distribution of single phase load across the three phase network
2. Variation of instantaneous demand continuously
3. Utility supply is unbalance

Voltage Unbalance Factor is defined as the fraction of negative sequence voltage (V⁻) to positive sequence voltage (V⁺) according to the European Standards, as expressed below (P. Trichakis, 2006 and C.-Y. Lee, 1999):

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

The negative and positive sequence of the system voltage can be calculated by the following expression:

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

where V_a, V_b and V_c are the three phase line voltages and V^0, V^+ and V^- are the zero, positive and negative sequence voltages components respectively. In Malaysia, the statutory limit of the voltage unbalance is 1% (Tenaga Nasional Berhad, 2006) which is much strict as compared to 1.3% in the UK and 2% in EU (P. Trichakis, 2008).

Voltage rise or voltage tolerance margin is also a problem to be concerned in the three phase power distribution system. It is defined as the nominal voltage rating for utilities to regulate the service delivery and operating tolerance. In Malaysia, the tolerance boundary is set at a range of +5% & -10% for primary distribution with voltage level of 240V. By having the tolerance limit, the equipment will perform satisfactorily in conformance with product standards throughout the voltage range provided from the utilities.

2.4   Demand Side Management

Network constraints become an issue in both developing countries and industrial where electricity requirement is growing and network infrastructure is fetching to insufficient. However, the necessity for network expansion can be delayed by network-driven DSM. "Demand-side management" or DSM, refers to "Actions taken on the consumer's side of the meter to change the amount of electricity usage. Electricity DSM strategies have the objective of increasing end-use effectiveness to prevent or delay the building of new generation plants." (USA Department of Energy) This has been conventionally used in electricity loads. But, it is also applied for changes that can be ready to demands for all kinds of energy.

Most of the case studies and papers describing about DSM that are correlated to electrical demand due to programs lay down by governments and utilities and not many of them focuses on electrical DSM programs. Nevertheless, it is also essential to think about DSM related to other energy resources on perhaps the local level in Africa, where a modest percentage of the population have right to use the generated electricity. Normally these would be environmental, economic, marketing or regulatory. The payback of DSM to customers, utilities, society and enterprises can be realized through:

- Cut down of energy bills;
- Decreased in the demand for new power plant, transmission and distribution networks;
- Encouragement of economic growth;
- Jobs opportunity caused of new technologies integrated;
- Competitiveness between local company raised;
- Decreased in air contamination;
- Cut down the reliance of energy sources from foreign countries;
- Cut down of peak demand surcharge for electricity.

Demand-side management has been conventionally understood as a meaning of reducing peak demand of electricity so that utilities can postpone the expansion. Actually, DSM has different advantageous effects by decreasing the general load on an electricity network, including minimizing electrical system emergencies, mitigating the number of breakdown and maximizing system trustworthiness. Other advantages can also consist of decreasing energy prices, decreasing reliance on costly fuel imported, and decreasing dangerous emissions to the surroundings. At last, DSM plays an important role in delaying huge amount of money invested in generation, transmission and distribution networks. Therefore, DSM used in electricity systems contributes major economic, reliability and environmental advantages.

The concept of Demand-Side Management (DSM) was summarized by Electric Power Research Institute (EPRI) which covers load management, energy efficiency and electrification for the purpose of changing the amount of power demand at particular timing for the collective benefit of utility and customers. Since the introduction of DSM over the last four decades in response to the oil crisis in 1970s, it has evolved from energy efficiency and conservation programs into price responsiveness in the DSM portfolio in response to the changing needs of restructured power markets. The price responsiveness DSM programs highlights different criteria and taxonomies for classification and evaluation of DSM programs to meet the objectives, expected needs and outcomes of DSM initiatives (Kenneth, G., G.N. Richard, and P. Karen, 2004). Demand-side Management (DSM) programs comprise of scheduling, planning, monitoring and executing activities of power demand for purposes of reducing energy infrastructure investments, reducing electricity prices, improving energy security and others ancillary benefits. There are four basic strategies of DSM as follow (Katherine J, 2007):

1. Energy Efficiency: reduce overall energy usage
2. Peak Demand Clipping: Decrease the peak demand
3. Load Shifting: Relocate demand to off-peak hours
4. Load Building: Maximize demand to off-peak hours

2.5   Peak Demand Clipping

During a time cycle, peak demand is the maximum energy consumption required. It is due to the total consumption of many correlated points across the whole network system. In Malaysia, peak demand typically occurs during 11 a.m. to 3 p.m. because at these time majority of the industries started to operate.

The power station must produce power when it is required to meet the demands of the customers as electrical power cannot be stored. To reach its maximum efficiency, the generators in the power station should run at their rated capacity although the demands of the customers have large variations. Hence, these results the design of a power station is very much difficult. The problems of high peak demand are:

- Need of standby power plants which are only operate 4 – 6 hours daily
- Increase in production cost because the generators in standby power plant are not operated at its maximal rating and hence resulting lower efficiency
- Need of additional equipments to adjust the rates of supply of raw materials in accordance with the power demand made on the plant.

Large users of electricity such as commercial building and industry factor regularly bear unreasonably high electricity bills as they are required to pay more for the electricity actually used, where paying more for the right to have energy capacity availability at specific time whether or not they are using that volume of energy. This is called a "maximum demand charge". Power consumption is the overall quantity of energy consumed over a period of time and is calculated in kilowatt hours (kWh) whereas maximum consumption is quantity of energy which is being used at any time and is normally calculated in kilowatts (kW). Typically the maximum demand charge can be as high as 40 % of the total power consumption. The following example shows an electricity cost for Universiti Tunku Abdul Rahman:

Power consumption: 208,501 kWh   x   RM 0.312   = RM 65,052

Maximum demand: 1,002   kW   x   RM 25.9   = RM 25,952

Percentage of maximum demand charge is 40 % !

2.6   Power Factor

Power factor is an indicator applied to work out the efficiency level of electricity usage, which is kind of measurement on how efficiently the current is being transformed into functional work output. More specifically, it is a good index of the outcome of the load current on the effectiveness of the utility. Higher value means efficient usage of electricity and vice versa. Low power factor will shorten the lifetime of equipments or appliances and causes power losses to Tenaga National Berhad. In carbonated drink analogy, large foam means low power factor resulted. A poor power factor can be the outcome of an inductive load such as an induction motor, power transformer, lighting ballasts, welder, or it can caused by a high harmonic content or deformed current waveform. This constitutes a loss to both the consumer as well as utility.

Low power factor will cause a power factor surcharge by Tenaga National Berhad (TNB). The TNB surcharge is as follow:

(a) Below 0.85 to 0.75   ➔ multiple of 1.5 per unit
(b) Below 0.75   ➔ multiple of 3.0 per unit

For example, if the total unit used for a company is 5000 kWh and the power factor is 0.5, at the rate of RM 0.323 per unit, the total bill is:

$$\text{Basic power cost: } 5000 \times RM\ 0.323 = RM\ 1615$$

$$(0.85 - 0.75) \times 1.5 + (0.75 - 0.5) \times 3 = 0.9$$

$$\text{Low power factor penalty} = 0.9 \times RM\ 1615 = RM\ 1453.5$$

$$\textbf{Total amount} = \textbf{RM 1615} + \textbf{RM 1453.5} = \textbf{RM 3068.5}$$

In this example, the low power factor causes the increment of bill to **90%** of its original bill.

In order to enhance the power factor, consumers are advised to install capacitors (KVAR Generators) which includes: capacitor, corrector, synchronous generators, and synchronous motors. Besides, customers can diminish operations of lightly loaded motors to prevent operating equipment above its rated voltage, change the standard motors as they will be damaged since energy efficient motors used and others.

The advantages of enhancing power factor are minimizing the kW billing demand, eliminating power factor surcharge, maximize system capacity and decrease system losses in the electrical system, and boost up voltage level in the electrical, hence, resulting in more efficient motors. Low Power Factor needs power supplied by TNB which having high reactive power **(KVAR)** and apparent power **(KVA)**. Hence, generation and transmission capacity was forced to be increased in order to handle this extra demand. Customers use less KVAR by increasing power factor. The consequence is less KW used, which equates to saving of money. Therefore, by increasing power factor, customer can avoid this additional surcharge. In Malaysia, TNB is allowable through the Malaysian Grid Code and the Malaysian Electricity Distribution Code to enforce a surcharge to the consumer if the power factor is <0.85 for consumers using less than 132kV as in above calculation (Tenaga National Berhad 2013).

Besides, power system loss is caused by low power factor in the customer's electrical system. These losses can be minimized by improving power factor. Increased facility efficiency is important when it comes to the current rise in the cost of energy. In addition, consumers can add extra load in their electrical system with lower system losses. Likewise, customer may experience a voltage drop as power losses increase. But, overheating and premature failure of motors and other inductive equipment can be caused by severe of voltage drops. Hence, consumers can diminish these voltage drops along feeder cables and keep away from related troubles by increasing the power factor. With a slightly increase in capacity and starting torque, motors will run more efficiently.

2.7   LABVIEW

LabVIEW (short for Laboratory Virtual Instrumentation Engineering Workbench) is a system design stage and growth environment for a visual programming language from National Instruments. LabVIEW is commonly applied to instrument control, data acquisition, and industrial automation in a range of platforms as well as Microsoft Windows, various versions of UNIX, Linux, and Mac OS X.

The programming language applied in LabVIEW, is a dataflow programming language. Execution is determined by the structure of a graphical block diagram on which the user connects different function-nodes by connecting wires. These wires propagate variables and any node can perform once all the input information is ready. It is capable to run in parallel execution since it might be multiple nodes simultaneously. Multiprocessing and multi-threading hardware is automatically broken by the built-in scheduler, which diverse numerous OS threads over the nodes ready to be performed.

LabVIEW ties the configuration of user interfaces into the development cycle which known as front panels. LabVIEW programs are known as virtual instruments (VIs). Each VI has three elements: a front panel, a block diagram, and a connector panel. Controls and indicators on the front panel enable the user to input data or export data from an executing VI. The front panel of VI can be used a subVI. Hence, a VI can either be run as a normal program with its front panel or dropped as a node onto the block diagram as subVI. Inputs and outputs node can be defined through the connector panel. This means that each VI can be easily tested or does some troubleshooting work before being embedded into a larger program.

Beside, the graphical approach enables users that not familiar with LabVIEW to construct programs by drag and drop the virtual representations of lab devices which they are familiar with. The LabVIEW programming, with the included examples and documentation, let the new user can simply create small applications to play with. This is one of the benefits, yet, there is also a certain probability where underestimating the expertise needed for high-quality programming. For difficult

algorithms or large-scale of coding, the user must possess extra understanding of the special LabVIEW syntax and the memory management. The most superior LabVIEW development systems present the possibility of constructing individual applications. Moreover, it is possible for the user to create diverse applications, which communicated by server scheme, hence easier to be implemented.
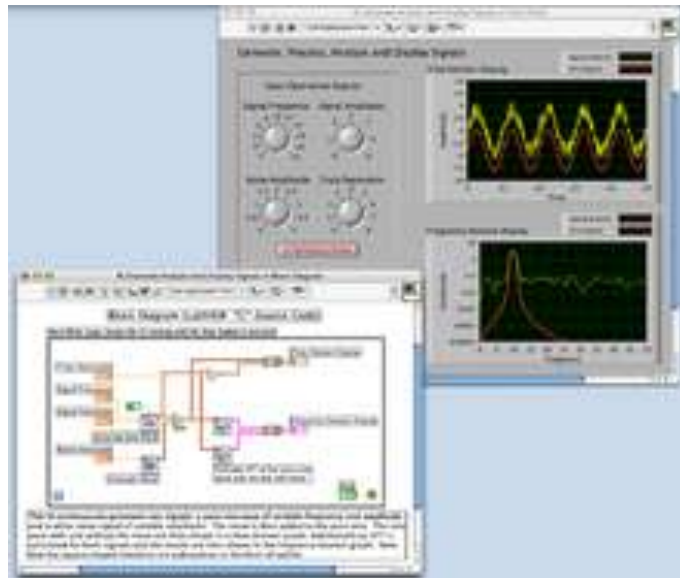

Figure 2.3: Screenshot of a simple LabVIEW program

Figure 2.4 is an illustration of a simple LabVIEW program showing the dataflow of block diagram in the lower left frame and the I/O variables in graphical objects in the upper right frame. These two are the necessary elements in LabVIEW programming.

The main benefit of LabVIEW compared to others is the extensive support for accessing instrumentation hardware. It also includes drivers and abstraction layers for many different kinds of instruments and buses. They are presented as graphical nodes. To communicate with hardware devices, the abstraction layers offer standard software interfaces. Program development time can be saved by the provided driver interfaces. The sales point of National Instruments is that, when compared to more traditional or competing systems, even people with limited coding experience can write programs and set up test solutions in a decreased time frame. Although not a .NET language, LabVIEW also provides an interface to .NET

Framework assemblies, which makes it feasible to use, for example, databases and XML files in automation projects.

For performance, LabVIEW includes a compiler that produces simple code for the CPU platform. By translating the syntax and by compilation, the graphical code is translated into executable machine code. The LabVIEW syntax is stringently imposed during the amending process and compiled into the executable machine code when requested to run or upon saving. In the later case, the executable and the source code are combined into a single file. The executable runs with the aid of the LabVIEW run-time engine, which comprises some precompiled code to perform ordinary works. The run-time engine decreased time of compiling and also provides a regular interface to various operating systems, graphic systems, hardware, etc. The run-time environment allows the code to be portable across platforms. Generally, LabVIEW coding might be slower than corresponding compiled C code, although the differences often rely more with program optimization than inbuilt performing speed.

Many libraries with a huge amount of functions for signal generation, data acquisition, mathematics, analysis, signal conditioning, statistics, etc., along with various graphical interface components are provided in several LabVIEW package options. The advanced mathematic blocks for functions such as filters, integration, and other specialized functions also coupled in the function. LabVIEW enables easy programming in different kind of tasks that are executed in parallel by means of multi-threading. This can be easily done by drawing two or more while loops. This is a good assistance for test system automation, as it is a general practice to run processes like data recording, test sequencing, and hardware interfacing in parallel.

There is a low-cost LabVIEW Student Edition for learning purposes. LabVIEW is an ownership product of National Instrument. Nothing like general programming languages such as C Programming, LabVIEW is not administered by a third party standards committee such as ANSI, IEEE, ISO, etc. Runtime library for any language is required to use the standard controls and the required libraries for common languages such as C are supplied by all major operating system suppliers. Nevertheless, the runtime essential for LabVIEW is not provided with any operating system and is needed to be purposely installed by the user. This requirement can cause troubles if an application is spreaded to a user who may be prepared to execute the application but does not have the authorization to install the supplementary files on the host system prior to running the executable. For an environment embattled for repetitive application, LabVIEW includes no built in functions for officially testing confines, reading a restrictions file, and conveniently tracking the passing or failing results.

Therefore, LabVIEW is system design software that provides engineers and scientists with the tools needed to construct and set up measurement and control systems through unparalleled hardware integration. It also allows users to create flexible and scalable test, control and embedded design applications. LabVIEW can inspire the user to solve problems, accelerates productivity, and boost up the confidence to continually innovate.

CHAPTER 3

METHODOLOGY

3.1 Design Methodology

Figure 3.1: The experimental setup of the smart conditioning system

In this project, NI Single-Board RIO 9632XT is selected because it integrates commercial off-the-shelf hardware to simplify development when designing control, monitoring and test systems. Therefore, with the advance features of the device, it is use as the central control system in this project. From the 110 3.3 V (TTL/5 V tolerant) DIO lines embedded in the board, the I/O is sufficient enough to activate the routines of the load bank. Moreover, the Connector for C Series Module in the board are used with the NI 9225 3-Channel Voltage Measurement and NI 9227 3-Channel Current Measurement to measure and monitor the voltage level and output current in the three-phase supply respectively.

The NI Single-Board Rio9632XT is used to turn on/off of the load bank via the solid state relay. The load in each phase can be varied from 0 W to 1000 W in step of 200 W. The Sunny Island 5048 is a bidirectional inverter. It acts as an energy storage unit to absorb and deliver power to the electrical network. With the integration of bi-directional inverter, this system is used as a buffering agent to deliver power during peak periods and to absorb power during off-peak periods. So, this system is able to reduce the electricity bill of customers from high demand electricity surcharge and reduce the stress of utility companies during high peak demand power by clipping the power demand. In addition, it provides uninterruptible power supply (UPS) to customers during power outage and improve the network efficiency.

However, this energy storage system (ESS) is made up of bi-directional power flow inverter and battery bank which is bulky and not portable to be brought over. Therefore, we make it into modular, customizable system. "Dr.Energy" is one of the modules where it is highly portable to carry out energy services for commercial buildings. Having the feature of different types of plug point, the power quality for three-phase and single phase can be analyzed by connecting the loads to the module. All the information regarding the power quality can be viewed via the graphical user interface by LABVIEW. In electrical terms, load profiling is a graph of variation in electrical loads over time. In actual scenario, the load profile varies across different loads. With different kind of load profile available in the database, electrical equipment in laboratories can be identified and any abnormal power consumption can be detected as well. Figure 3.2 shows a picture of Dr Energy i.e. the power diagnostic tool

Transformed
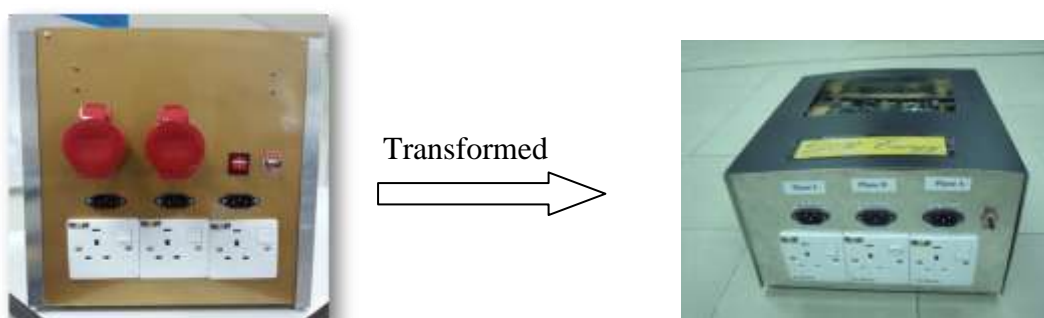
Figure 3.2: Dr Energy : The Power Diagnostic Tool

3.2 Design Architechure

A graphical user interface is developed in NI LabVIEW. NI LABVIEW can be easily integrated with NI devices for measurement and control purposes which could solve many problems related to the integration of hardware and software as well as the needs of code composer. The voltage unbalance factor (VUF) is calculated from the network three phase voltage. The technical requirement of VUF in distribution network is below 1 %. Hence, the system is designed to react such a way to limit the VUF from exceeding 1 %. The system will react when the VUF reach 0.8 %. If the VUF is greater than 0.8 %, the system will start to compare the voltage at each phase.

For example, if mode 1 is selected and phase A is having lowest voltage among the three phases, the PV inverter will be channelled to phase A via the phase selector or when the PV inverter is not connected to the network, Sunny Island will be connected to phase A and supply to load. If mode 0 is selected, and the demand of power decreased in phase A, the PV may cause unbalance if the load demand is less than the power generated by the PV. At this moment, the battery charger will be turned on to store the excess power into battery to maintain the balance of all three phases. As a result, the VUF of the network will be minimized. Figure 6 shows a flow chart of the energy conditioning system.
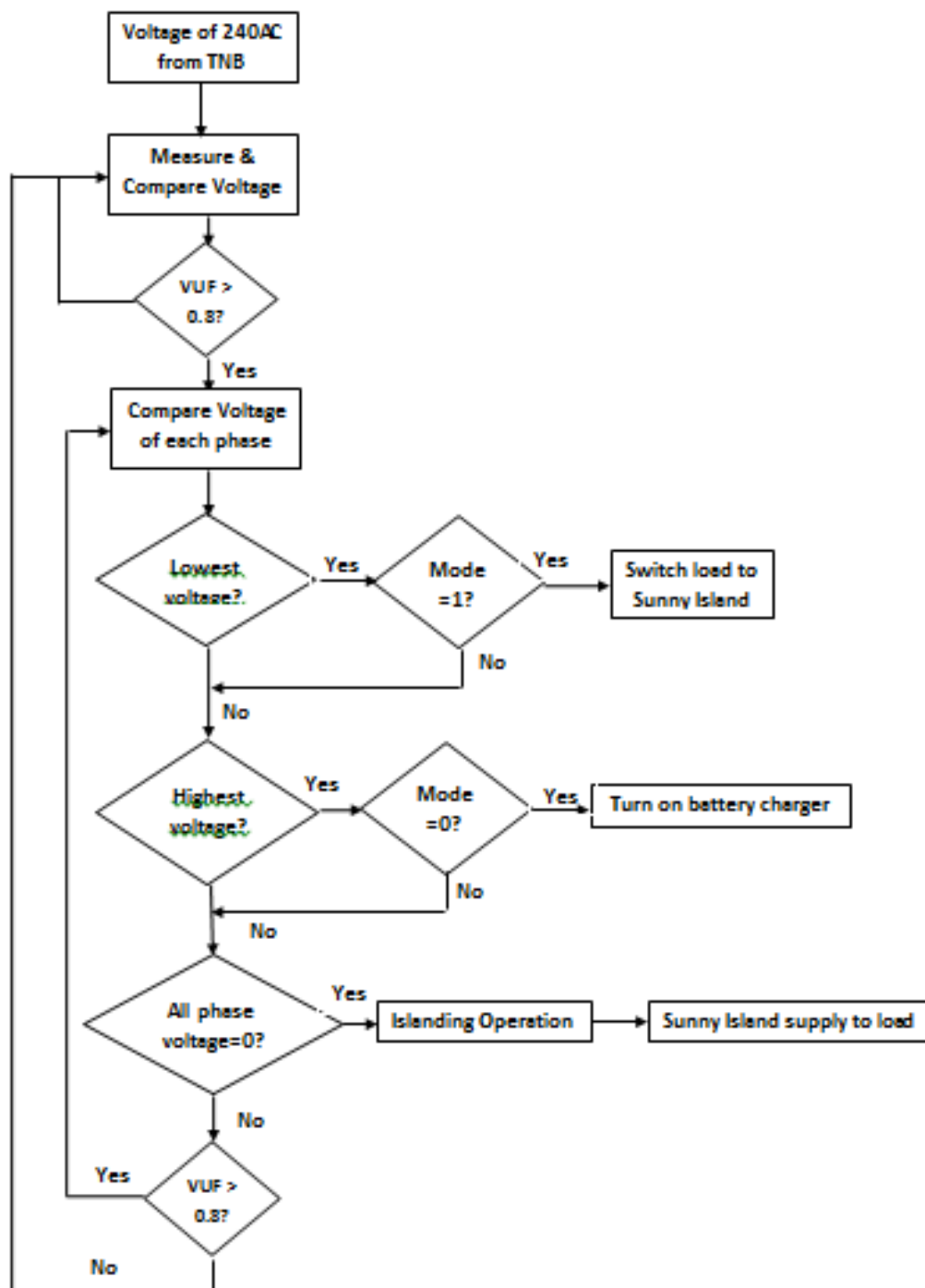
Figure 3.3: Flow chart of the energy conditioning system

Figure 7 shows first graphic user interface of the smart energy conditioning system developed in LabVIEW. Basic parameters consist of a load bank control, battery charger control, phase selector control, and the measurement of power, energy consumption, current, voltage and VUF. There are 3 indicators lights to indicate the voltage unbalance factor (VUF) level. Red indicator will blink when VUF exceed 1%. Besides that, there is also two method of operating the smart conditioning system namely the manual control and the automatic control.

The manual control allows the user manual control the Sunny Island to either supply power to load or absorb power to charge batteries via the "SI Manual Control" menu. Whenever the VUF is greater than 1 %, the energy storage system will be turned ON to either absorb or deliver power via the buttons shown under SI Manual Control. While in auto control, the smart conditioning system will operate the Sunny Island based on the control algorithm. The "Automated Indicators" shows the connection of Sunny Island for different scenario. There are two methods used for VUF mitigation. The first method is to channel the excess load that causes the VUF to exceed 1 % to the Sunny Island. The second method is to charge the battery bank which is connected to Sunny Island when one of the phases tends to have too high voltage due to low loading.
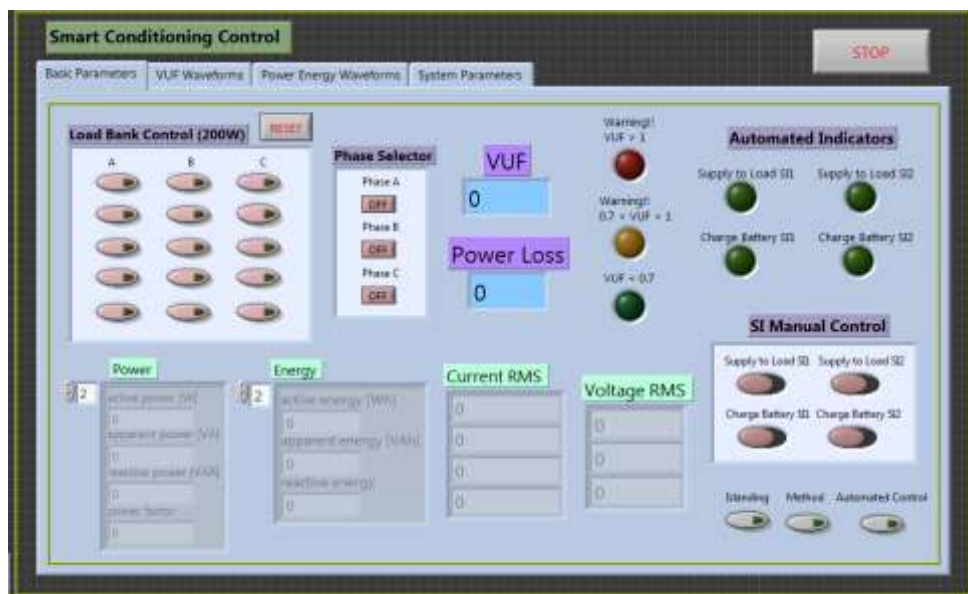
Figure 3.4: Energy Conditioning System

Figure 8 and Figure 9 show the VUF and power energy waveforms. These graphs provide a good view for users in the dynamical change of VUF and power energy.
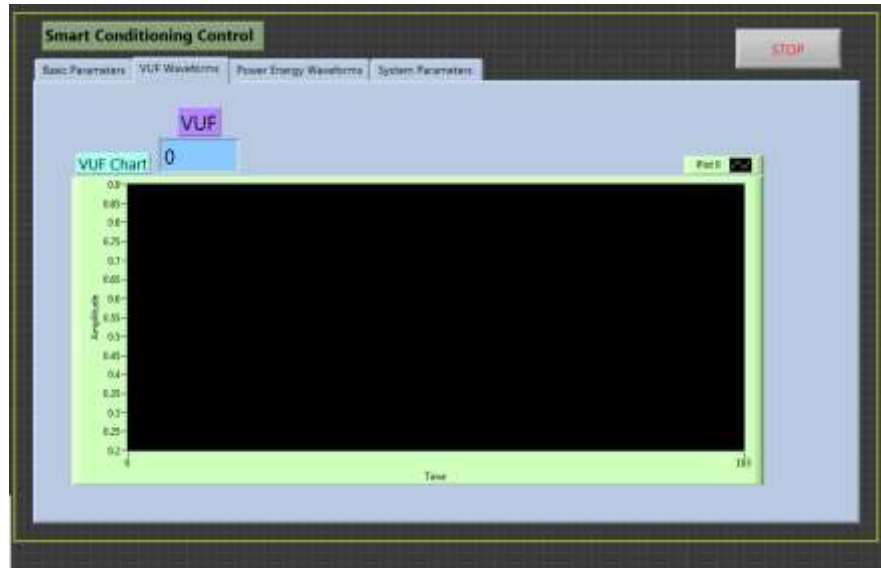
Figure 3.5: VUF waveforms and values

Figure 3.6: Power energy waveforms and values

After that, a new face was developed for our system, which compatible with the newly developed product called Dr. Energy. This user interface uses a tab control to make our interface compact and looks nicer with the icon added. Energy monitoring is an energy efficiency technique that helps users to manage energy usage wisely. So, the first tab is used for monitoring. It shows the power, energy, RMS voltage and RMS current values with graph plotted.
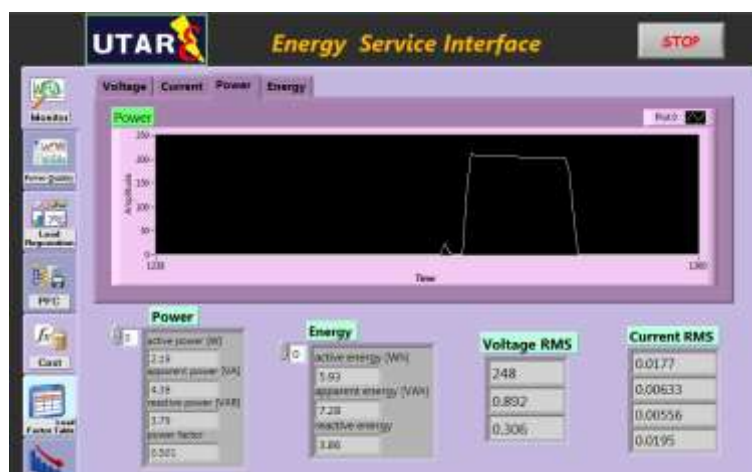
Figure 3.7: First page of user interface (monitoring)

For the second tab, it is about the power quality. Inside this page, there are three pages which includes harmonics, voltage unbalance factor, and voltage flicker. It can show the variation of harmonics through the graph and reading. These harmonics values follow the IEC Standard 61000-4-7 and 61000-4-30. It might be slightly different with the Europe Standard as EN50160 defines the calculation as "including all the harmonics up to the order 40" and we know that IEC standard covers up to 50 order.
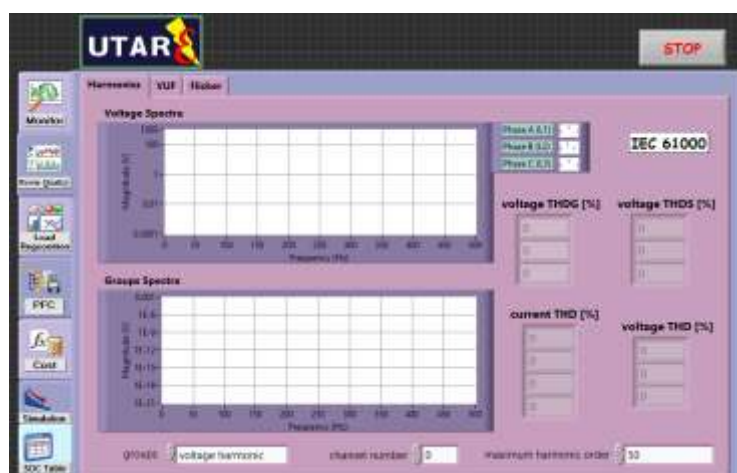
Figure 3.8: Second page of user interface (harmonics)

Voltage unbalance is one of the important issues risen in this high technology era. Hence, voltage unbalance factor (VUF) is calculated and it is much more advanced compared to previous interface. As you can see in Figure 3.9, besides showing the VUF, we can find out the occurrence of the VUF, where start time and stop time of the latest occurrence recorded with the duration. Besides, a table is created to record the occur time and duration of each VUF occurrence. However, this page is only used when dealing with three phase power.
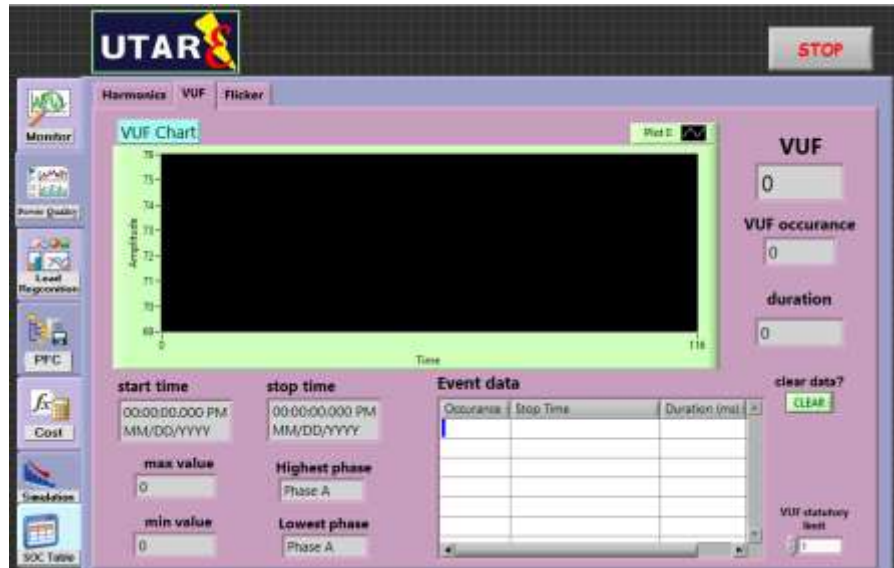
Figure 3.9: Second page of user interface (VUF)

There is only the interface where the user can view and observe. Besides designing this attracting interface, we make sure it is functioning together with its coding. Here I show some of the block diagram and explain how it works!
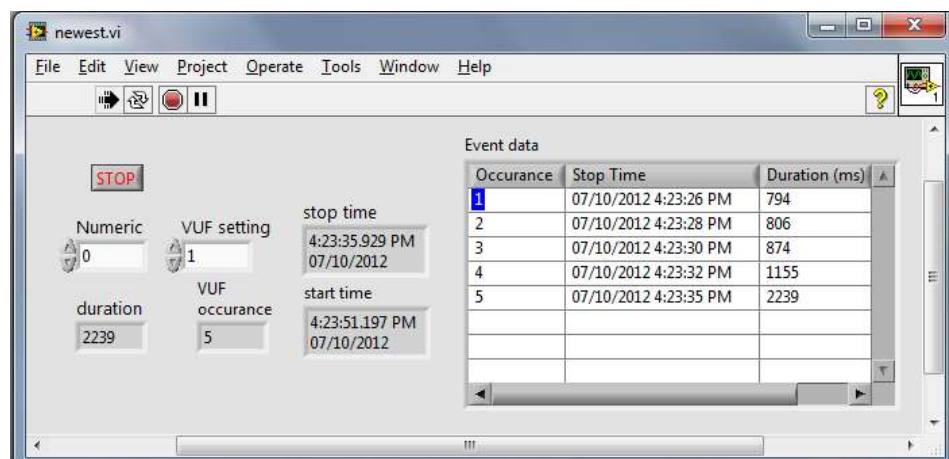
Figure 3.10: Functioning model of VUF used to record needed values

There are 3 cases in order to make this functions work. Firstly, when the VUF is larger than the VUF statutory limit, it fulfils the condition and go to case "true". In this case, time is obtained as stop time and timer 1 is started. Timer 2 (initially 0) is subtracted by timer 1 to obtain the duration. Then, it will compare the VUF with the VUF statutory limit. If VUF is larger, go to case "true"; if smaller, go to case "add".
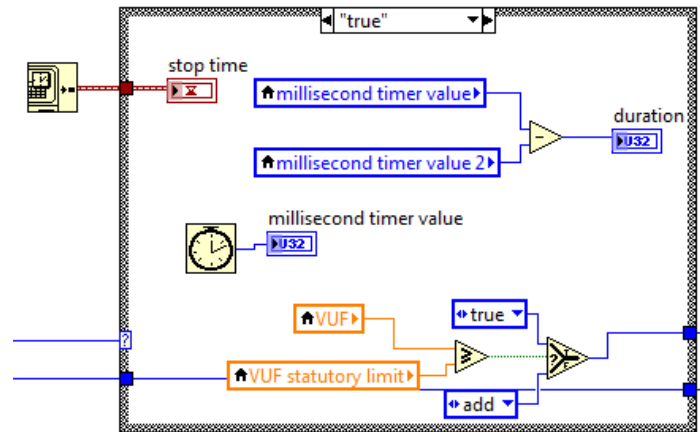
Figure 3.11: Case "true" of VUF occurrence

Let say the VUF now is under safe mode which is smaller than the VUF statutory limit, it goes to case "add". In case "add", one is added to occurrence. Then, it saves times of occurrence, duration, and time of occurrence to the memory of Single Board RIO through the stated file path in three columns. In addition, a button is created to clear the memory of the saved data to prevent congested. Again, it will compare. "true" if larger while "false" if smaller.
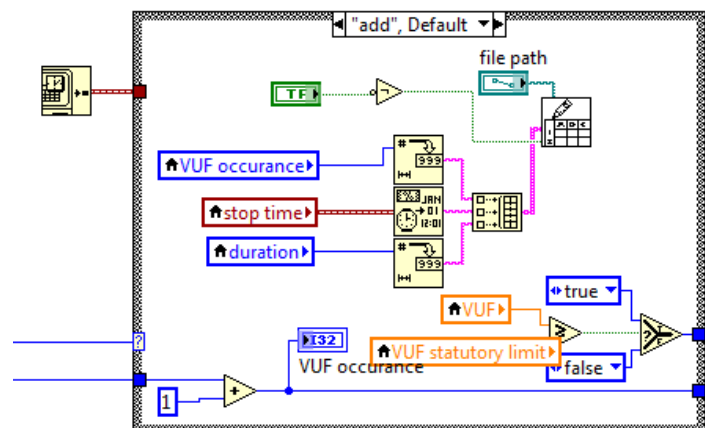
Figure 3.12: Case "add" of VUF occurrence

For the "false" case, time is obtained as start time and timer 2 is started. Comparison of VUF and VUF statutory also done to decide which case to go.
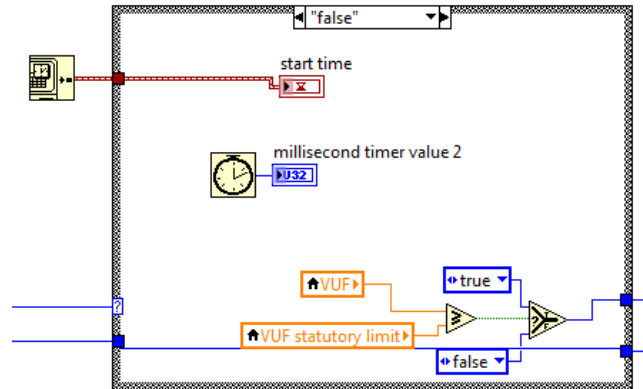
Figure 3.13: Case "false" of VUF occurrence

After data was saved in the memory, how can I read it and show it in the table? I send back the file path stated to the board and display the data saved in tabular form as shown in the diagram.
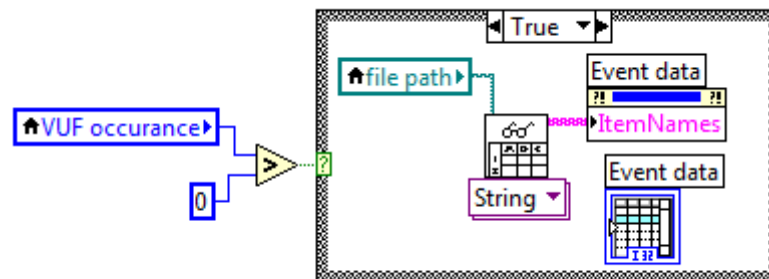
Figure 3.14: Case "false" of VUF occurrence

For voltage flickering, instantaneous graph is shown in order to let the user view the dynamic fluctuation of the three phase power. There are two types of flicker defined here. Pst is the short term flicker severity while Plt is long term flicker severity. Both of them are defined from the IEC 61000-4-15. For short term flicker, the interval is 10 minutes; for long term flicker, the interval is about 2 hours. When flickers occur and fulfil the condition of short term limit, the indicator will light up and flicker time will be shown as well.
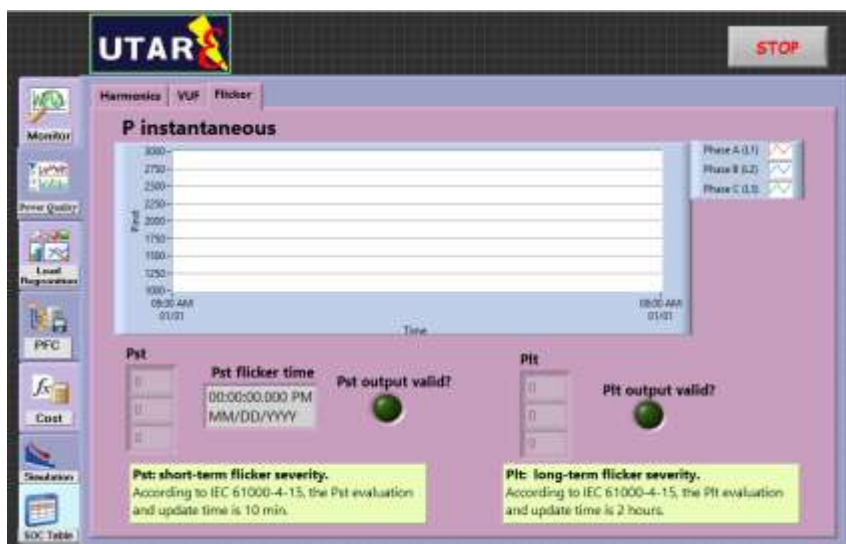
Figure 3.15: Second page of user interface (Flicker)

For the third page, it is about the load regconition. When we press the button, it can determine which equipment is plugged in and displayed at the output. Besides, amplitude of current, lowest current value, highest current value also shown as the load regconised due to the specified current of different equipment. For example, a handphone charger can be detected and a slogan "This is a charger" will be displayed. However, data have to be saved in the library for the first time. If not, a slogan "nothing is plugged" will be shown.
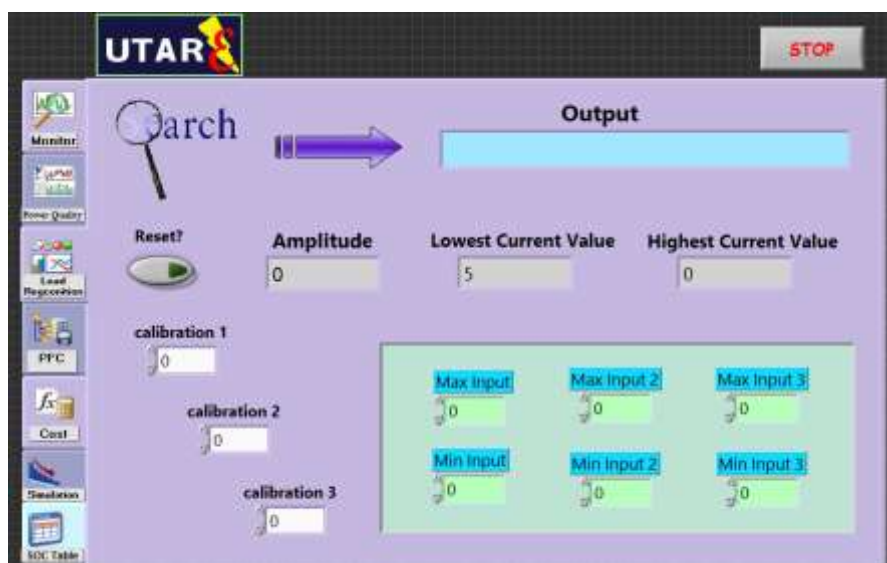
Figure 3.16: Third page of user interface (load recognition)
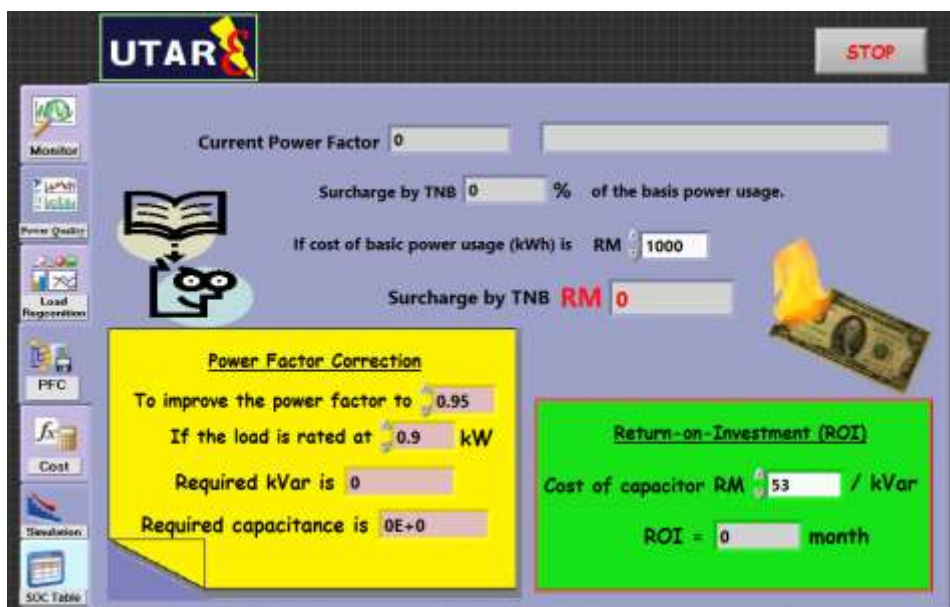
Figure 3.17: Fourth page of user interface (power factor corrector)

Power factor surcharge is one of the headache problem among businessman. Therefore, power factor corrector is an important issue and it is also considered in our system. Fourth page is about the power factor corrector. As shown in the diagram above, it shows the current power factor and advise is given just beside. It will show "Power factor is good!!!" when the power factor is more than the power factor target set by the user. However, it will show "Power factor needed to be improved!!!" when it is under target.
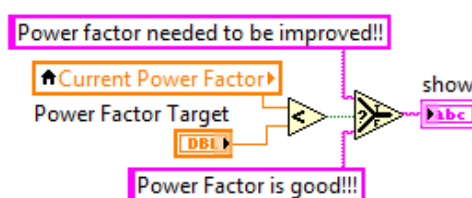
Figure 3.18: Block diagram of selector

The reason we need to correct the power factor is because there is a surcharge for power factor when exceeding the limit of 0.85. Hence, this system will act as a calculator to help the user to calculate the percentage charged by TNB and the extra amount of money needed to pay due to the power usage basis. However, there are different way to calculate the surcharge with different range of power factor.

If the power factor is smaller than 0.75:

surcharge by TNB (%) = [(0.75 - power factor) x 3 + 0.15] x 100%

If the power factor is in range of 0.75 and 0.85:

surcharge by TNB (%) = [(0.85 - power factor) x 1.5] x 100%

(a)

(b)
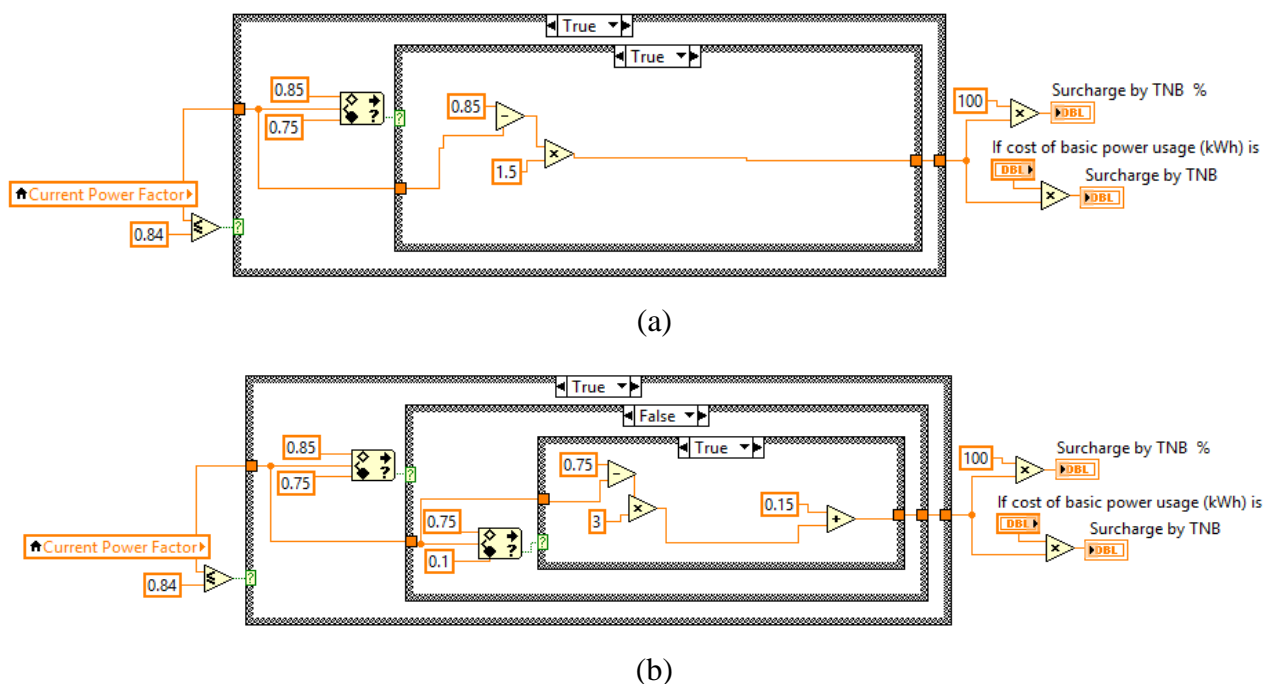
Figure 3.19: (a) Power factor in range of 0.75 &0.85

(b) Power factor less than 0.75

For example, if power factor is 0.8 which is in between 0.75 and 0.85, the surcharge by TNB is 7.5%. If cost of basic power usage (kWh) is RM1000, surcharge by TNB will be RM75. If the power factor is now 0.7 which is smaller than 0.75, 30% extra charge and hence, extra RM300 needed to pay just because of the surcharge. This is just a minute amount for a business man. However, it would be crucial when the cost of basic power usage is huge.

In addition, power factor correction and return on investment (ROI) also calculated in order to let the user know how much capacitance needed in order to increase the power factor to the safe condition. Here, the user have to set the desired power factor to be improved, and the rated load in kW. Then, the system will help to calculate the required kVar and the corresponding capacitance. The algorithm is as shown in diagram below.
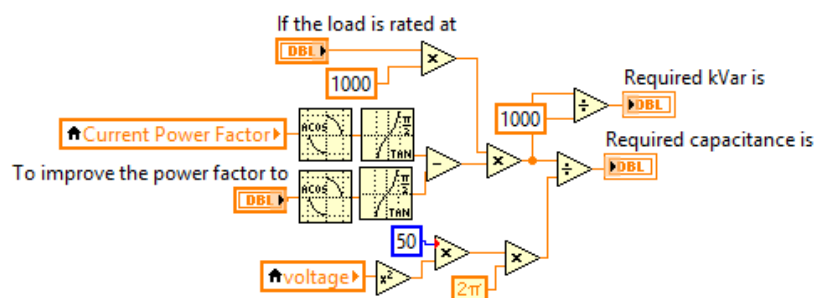
Figure 3.20: Calculation for required kVar and capacitance

Besides, many business man interested to know how long they need to recover from the extra money invested in order to escape from the surcharge. By knowing the cost of capacitor, ROI can be calculated.
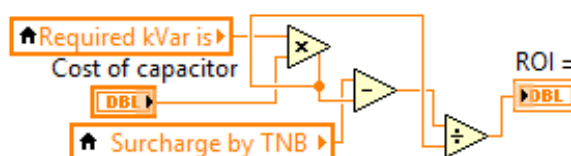
Figure 3.21: Calculation for ROI

Every day, we are using electricity no matter home appliances or machine in factory. Money is what we care the most nowadays but we are burning our money every second!! Hence, we also create another calculator to figure out the estimation cost. Steps are given: Firstly, tariff is set. Then, select the preset days you want to accumulate the cost. Finally, the user can view the cost estimation with the real time power. It will calculate the total energy consumption in Wh and hence calculate the cost of electricity when you switch on your electronic appliances. Amount of each phase usage also stated. For example, if hair dryer is used, how much you paid for it? The calculator can help you out on this.
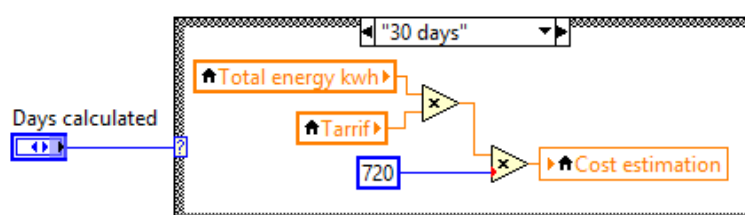
Figure 3.22: Calculation for estimated cost
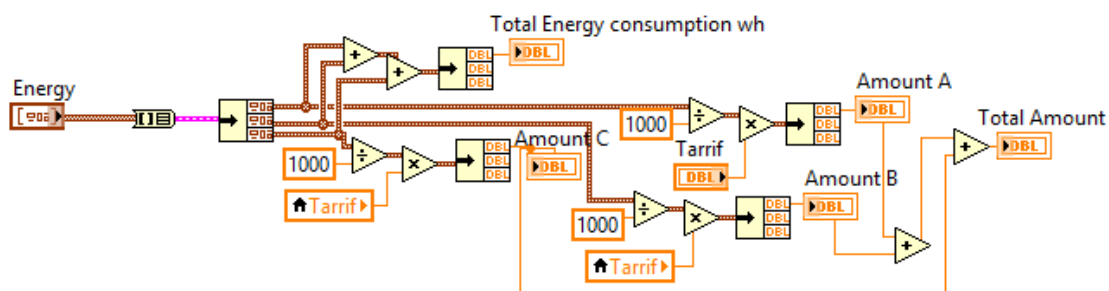
Figure 3.23: Calculation for cost of electricity

Due to the complexity of the coding, I also try to make the coding part by part into the sub VI. As shown below, a subVI is used to replace the coding of calculation for cost of electricity. While the diagram beneath that is the fifth page of our attractive interface.
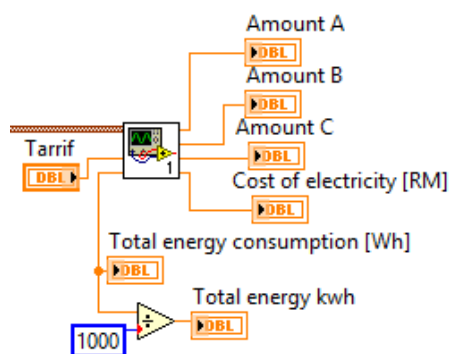

Figure 3.24: SubVI used to reduce coding complexity

Figure 3.25: Fifth page of user interface (cost)

Peak demand clipping strategy can effectively reduce the cost of electricity for consumer. The strategy used is to store energy in storage device during the off-peak period and to deliver energy back to the grid during peak period. A case study is carried out at Universiti Tunku Abdul Rahman. A power consumption of one of the building in Universiti Tunku Abdul Rahman is recorded. The building comprises of 10 tutorial rooms and 10 laboratories. Figure below shows a power consumption of the building on Sunday and Monday. This graph shows a typical power demand characteristic for college and university in tropical country where the power demand has correlation with its weather. The power consumption on weekend is low because there is no ongoing activity in the building. During weekday, the power demand start rises at around 7.30 a.m. because classrooms started to be occupied. It reaches maximum demand at 1.45 p.m. when weather is hot and air conditioning system is working at high power. The power demand drops significantly after 5.30 p.m. when students started to leave the building.
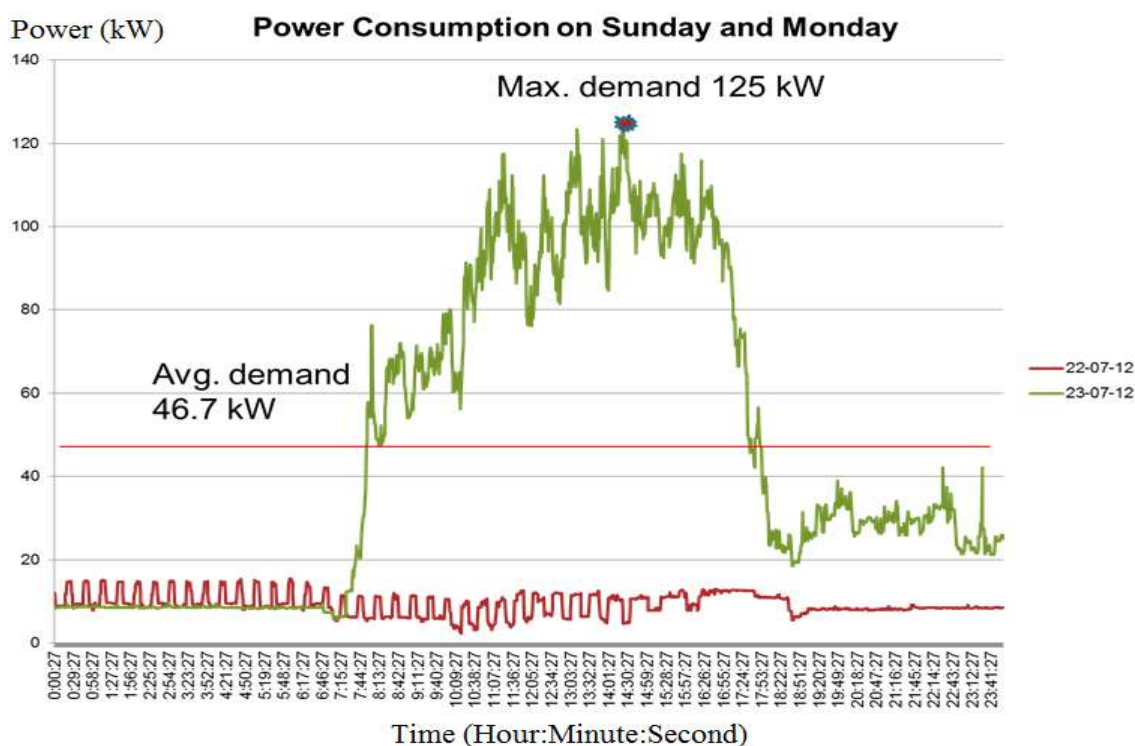
Figure 3.26: Power consumption of SE block on 22 and 23 July 2012

Hence, we create a bell-shaped graph and control loads due to the graph simulated to emulate the real power demand. However, it would not be only one type of load. So, three kinds of loads are simulated. They are representing as air conditioner, thermos, and heater. I will briefly explain on how to create graphs with different pattern., but I will explain on the thermos and heater graph first where they are only ON and OFF signal. There are five cases created for each types of load. When simulator is turned ON, it will go to the case "start". In this case, 0 is sent, it can be known as waiting to start as period can be set by the user. Let say 10, it means that it have to wait for 10 loops before it goes to the case "true". Different starting time is defined.
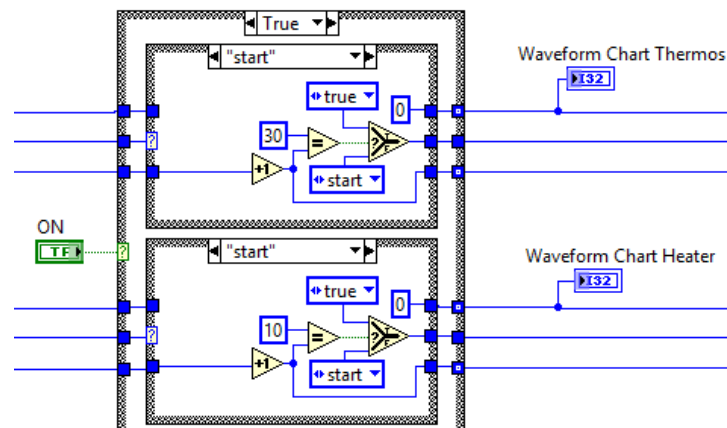
Figure 3.27: Case "start"

When it goes to case "true", a value, let say 5, is sent and then go to case "wait true". As what case name is, it is used to decide the period of the signal. When it fulfils the condition, it will go to the case "false" where 0 is sent. After that, it will go to the case "wait false" which having the same function as "wait true". This is the general algorithm for ON and OFF graph which period can be decided by the user.
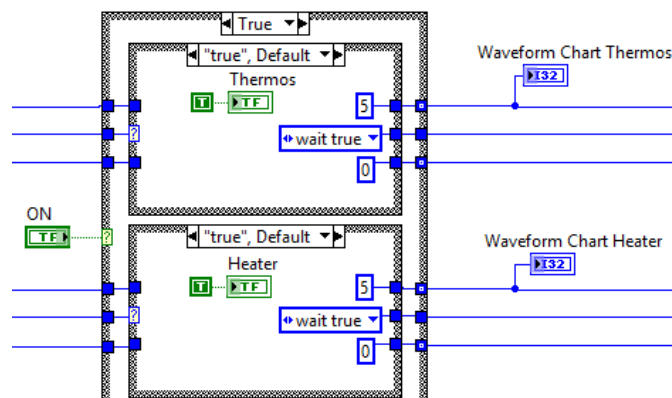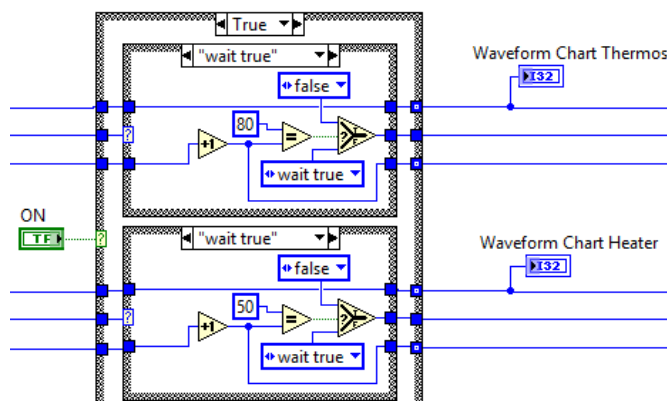

Figure 3.28: Case "true"
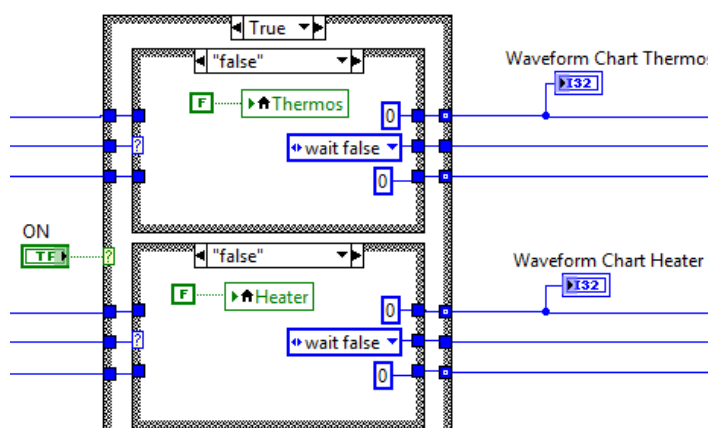
Figure 3.29: Case "wait true"
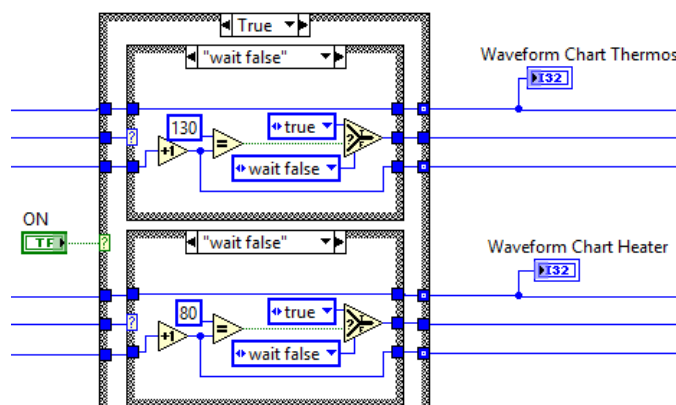

Figure 3.30: Case "false"

Figure 3.31: Case "wait false"

While for the bell-shaped graph, it is likely the same as what explained just now, but it is different as steps are needed. For case "start", it is same as others. But, for case "true", signal of " add 1" is sent. When comes to the case "wait true", another algorithm is needed to justify the steps of the staircase. For example, 5 steps for this graph. So, when it fulfils the condition of the period, another condition where 5 steps is needed to go to the case "false". Hence, it will go back to the case "true" to

add 1 to the signal and loop until 5, which is the steps needed. After that, signal of 5 will be minus by 1 in the case "false". Then go to the case "wait false" where having the same function as "wait true" but the condition to be fulfilled is 0 for this case. Hence, a bell-shaped graph is produced. Figures 3.32 shows varieties of cases for bell shaped graph.
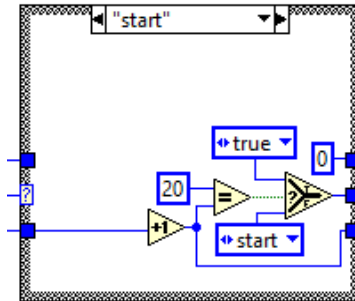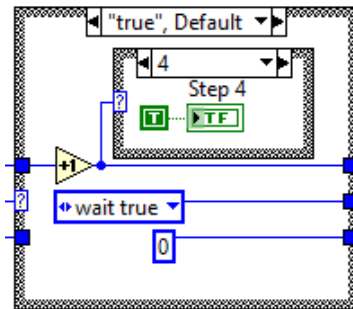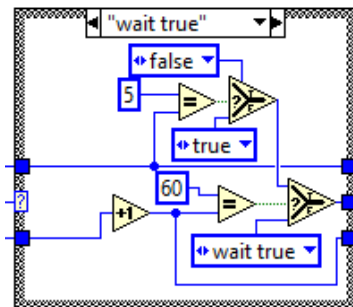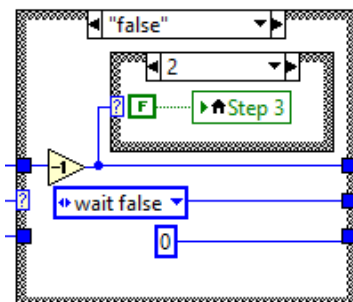

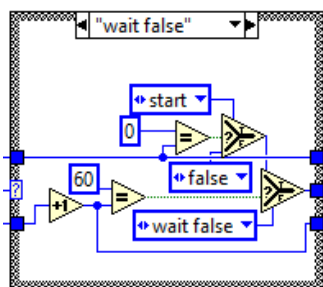**Figure 3.32: (a) Case "start" for bell-shaped graph**

(b) Case "true" for bell-shaped graph

(c) Case "wait true" for bell-shaped graph

(d) Case "false" for bell-shaped graph

(e) Case "wait false" for bell-shaped graph

For this three graphs, we will combine it and show them in the sixth page of our interface. Instead of that, we also link it to control the load bank. Each step for the bell shaped graph will be controlling load of 200W. However, once ON the thermos and heater, each of them will turn on 1000W of the load bank. Hence, real power graph is also shown in the page. Besides, indicator of each load will be displayed in order to make sure the load is on when it has to be. In addition, we also add in the Sunny Island 5048 which used in other module. We make use of this bi-directional inverter to store and deliver power. Therefore, peak demand clipping can be done when Sunny Island (SI) is integrated into the system. In the same way, we make it either in auto mode or manual mode. When auto mode is turned on, if power is larger than 1800, SI will be triggered to supply power to the load by battery. However, it will stop from supplying the load if and only if it is smaller than 1000. On the other hand, when active power is smaller than 500, SI will be triggered to charge the battery from the network and stop charging when power is more than 1000.
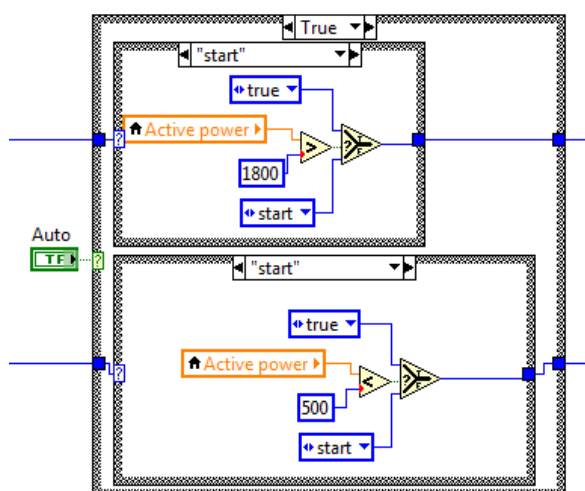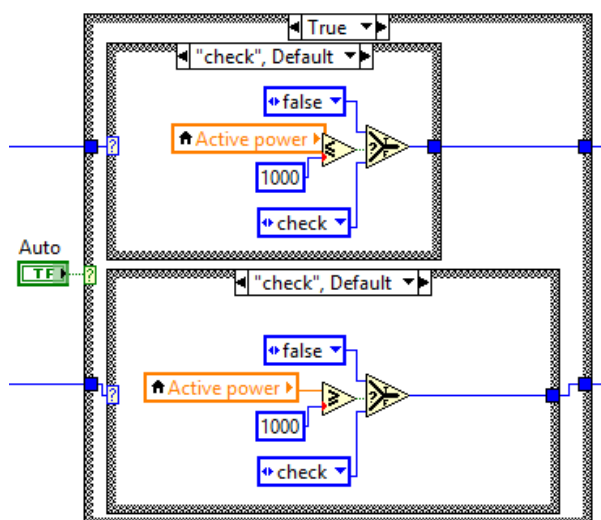

Figure 3.33: Case "start" for SI control

Figure 3.34: Case "start" for SI control

Graphs that are generated will be remain and graphs have to be cleared one by one every time they are generated. Hence, due to the user friendly designed, we also create a clear button for the user to clear all previous graphs generated. Besides, a reset button is also created in order to reset all the controls to be inactivated. This is because sometimes the user stop the program when the program is still running. So, it can be seen that some of the indicators are still ON although the program has been stopped. Therefore, this reset button can be pressed before the user stop the program. Mechanical action that used by this switch is "latch when pressed", hence, the action happens once only when the switch is pressed. Finally, here we form the sixth page of our interface.
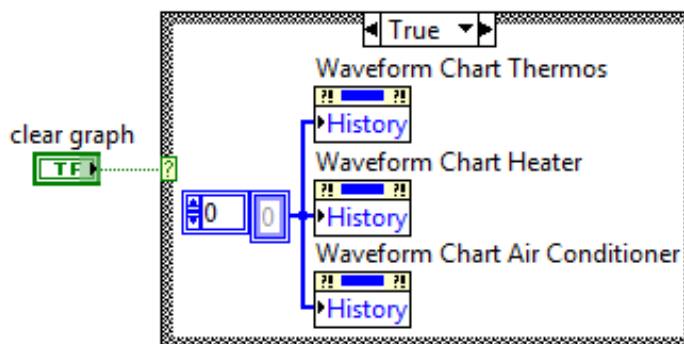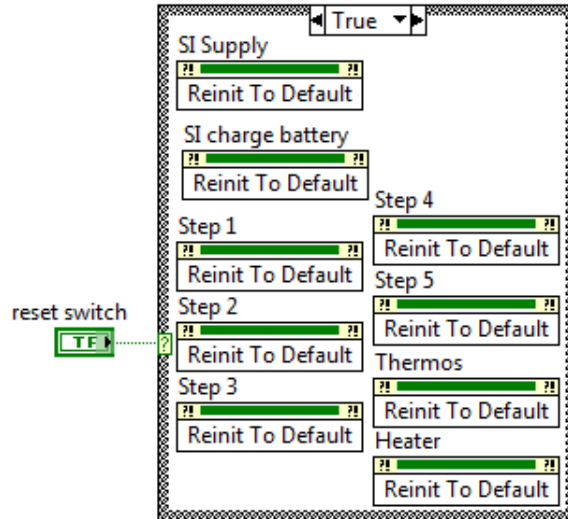

Figure 3.35: Clear graph

Figure 3.36: Reset graph

Figure 3.37: Sixth page of user interface (simulation)

Now, we come to the last page of our interface. It is about the battery state of charge table. In this system, we integrate the Sunny Island 5048 to absorb and deliver power no matter in mitigating the VUF, uninterruptible power supply or in peak demand clipping. However, questions floated where how long can the batteries supply to the load? This is the interest of many customers. Therefore, we make it into a table. For this system, 8 batteries are used. Each of the batteries is having 120Ah and 12V. Hence, this system is having 960Ah and 96V. If the batteries are supplying 100%, 92.16kWh can be supplied. By applying all of these information, we calculated the possibilities and form a table due to the state of charge of the batteries and amount of load supplied.

Figure 3.38: Last page of user interface (SOC table)

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1   Experiments

For the first module developed to conquer with the problem of VUF, we have done some experiments to show that the system and program are working well. The renewable energy used in this system is the PV panels. When the PV is connected to the network, it causes transients and rises of the VUF. The statutory limit of VUF set by Malaysian Grid Code is 1 %. Hence, the smart system is designed to react in such a way to avoid the network VUF from exceeding 1 %. The system will react when the VUF reach 1 %. Several case studies are conducted to represent the different scenarios faced by actual networks.

4.1.1   Experiment of balanced load condition

The experimental setup was enhanced with 2 units of Sunny Island 5048 as an energy storage device. Instead of human control, the energy conditioning system developed in this stage is capable of monitor and control itself automatically. Figure 4.1 shows the VUF chart from the conditioning system with balance load condition. The increment of balance load among three phases did not rise the VUF beyond the statutory limit which is at 1%.
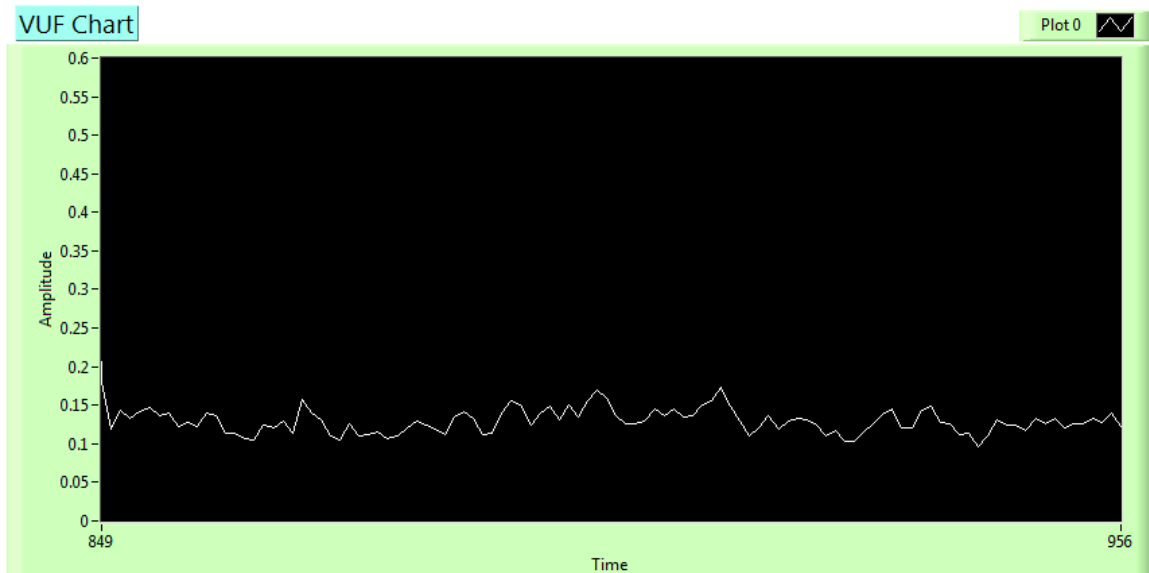
Figure 4.1: VUF waveform chart with balance load condition

4.1.2 Experiment of supplying power

The second case study is that when the PV inverter does not produce any output power and the network has the load profile of [1000 1000 0], which means that the phase C is at no-load condition while each of phase A and phase B are connected to 1000 W of load. In this case, the VUF is at around 1.5 %. In order to make the load to be balanced in all phases, the Sunny Island will draw power of 1000 W from phase C and store it into the battery. Hence, the load profile becomes [1000 1000 1000] and the voltage unbalance has been mitigated to 0.05% and the network becomes stable.
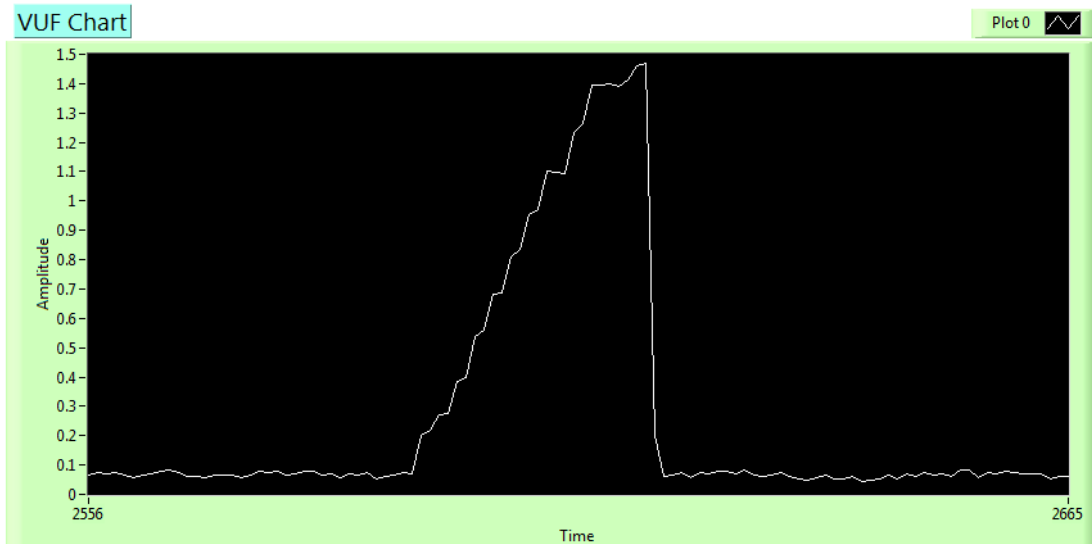
Figure 4.2: VUF waveform chart of the system with loading condition of [Load Load 0] and Sunny Island is connected to Phase C

4.1.3 Experiment of absorbing power

In the third case study, the PV inverter is not connected to the network and the load profile of the network is [1000 0 0], which means that phase A is loaded with load while phase B and phase C is in no-load condition. So, phase A having the lowest voltage and the VUF at this moment is around 1.4 %. The Sunny Island will be connected to the phase A and supply 1000 W to the load. Again, the load profile becomes [0 0 0] and the VUF has been mitigated to 0.3 %.
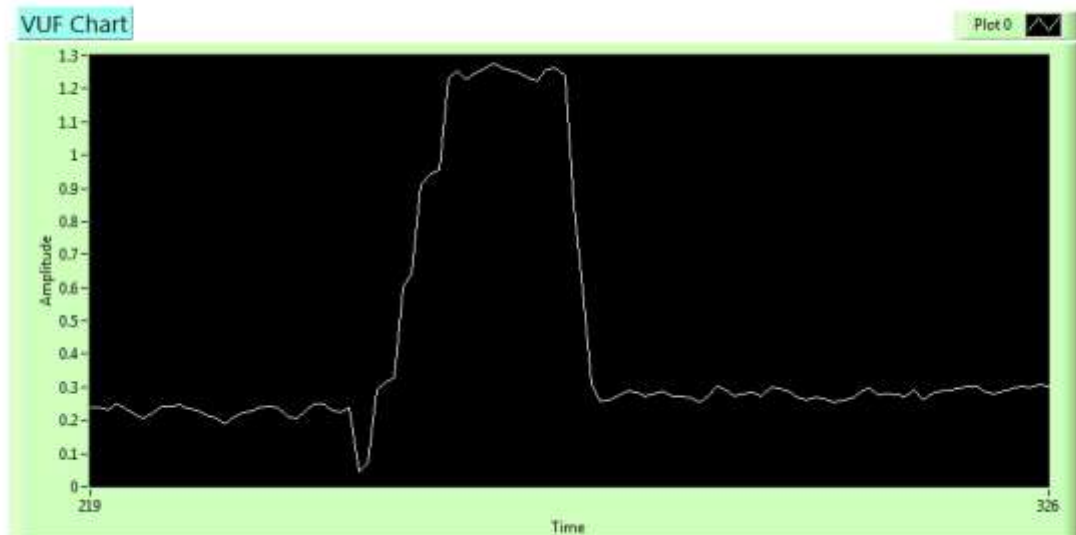
**Figure 4.3: VUF waveform chart with loading condition of [Load 0 0] and
Sunny Island connected to phase A**

4.1.4 Experiment when integration of PV

The forth case study is that the network is connected to PV of 1000 W. The voltage
of the three-phases are measured and compared. Now, the PV is channelled to phase
A via the phase selector. From figure 4.4, it was found that the VUF behaves in U-
shaped with the increment of load at phase A. It is due to the fact that the PV power
has compensated the load from 200 W to 1000 W; hence the VUF is reducing in this
region. When the PV power is equal to the load, the VUF reach its minimal value.
The further increment of load after 1000 W will cause the increment of VUF because
the PV power has no longer sufficient to compensate the load. After the correction of
energy conditioning system, in fact, the energy conditioning system has channelled
the excess power from PV to the battery from 0 W to 1000 W as shown in the graph
in order to maintain the balance of all three phases. This action has successfully kept
the VUF to be a minimal value. However, due to the fact that the maximum power
that can be provided by PV system is 1000 W. Hence, after 1000 W, the VUF will
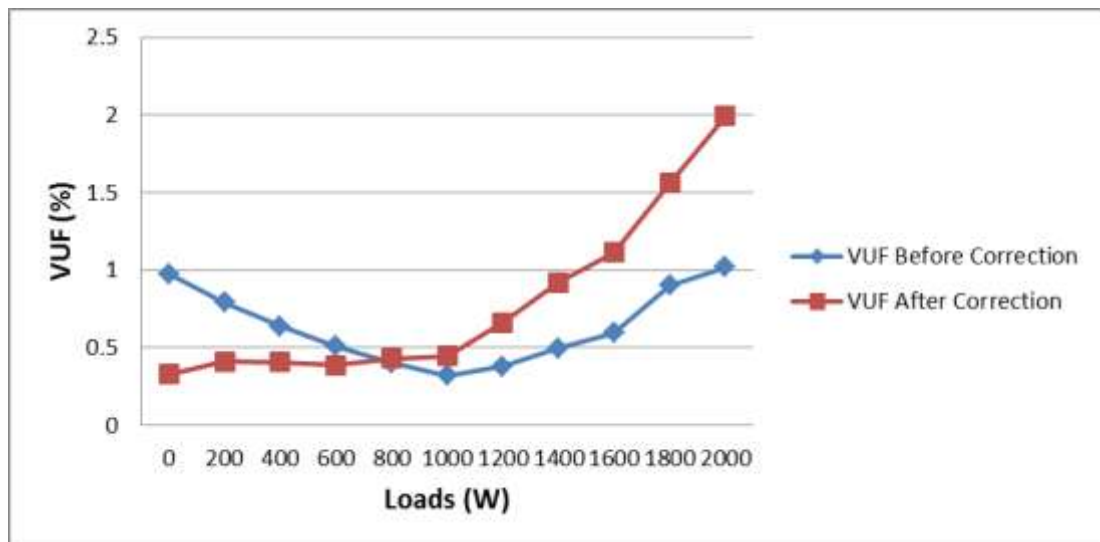rise as shown in the graph.

Figure 4.4: VUF with loading condition of [Load 0 0], PV system connected to the phase A, before and after the correction of energy conditioning system

4.2 Results

After the first module, we have developed another module which is called Dr. Energy. Dr. Energy is an electric power diagnostic tool for electrical network in a building. It is capable to monitor, record, and diagnose the electrical data in the electrical network. The main features of the system are:

    (a) Monitor the power usage of a building,

    (b) Provide tool for user to estimate the cost of electricity for specific appliances or activities,

    (c) Analyze the load profile for enhancing the demand response strategies to reduce the maximum demand,

    (d) Diagnose the power quality of the network,

    (e) Provide an Uninterruptible Power Supply to the network during power outage,

    (f) Provide peak demand shaving using Energy Storage System.

Here are some of the diagrams show the working Dr. Energy with its attractive interface. For this monitoring page, only phase A is plugged in.

Figure 4.5: Monitoring page

It can be seen in the graph of harmonics in figure 4.7 where 1st harmonics, 3rd harmonics, 5th harmonics and so on were plotted out. For cost, estimated cost of 30 days is also calculated as what you can see in figure 4.8.
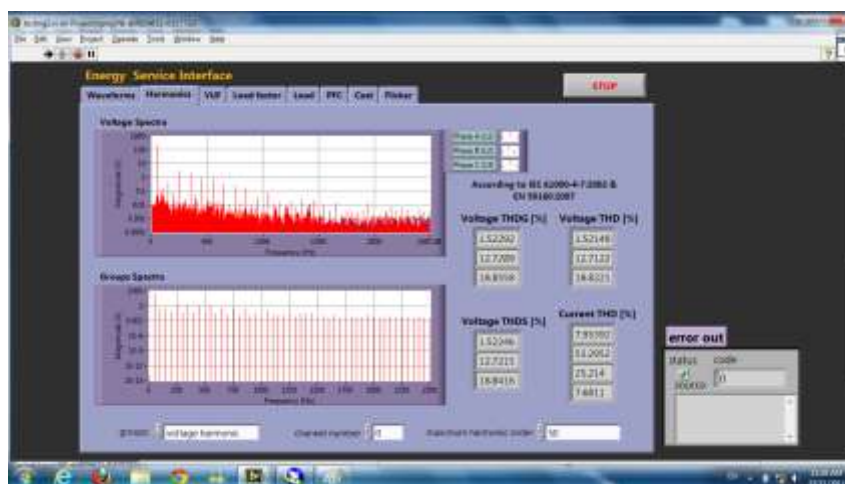

Figure 4.6: Harmonics
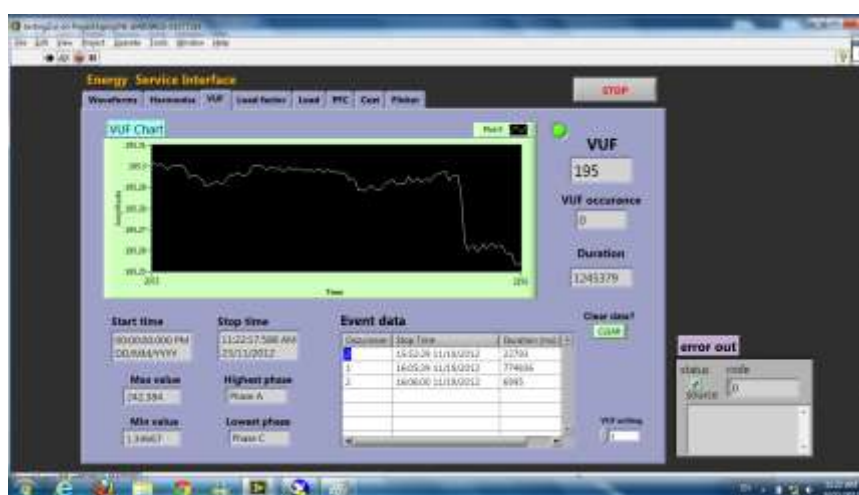
Figure 4.7: Cost

Figure 4.8: VUF

A poor PF due to an inductive load can be improved by the addition of power factor correction. Dr. Energy provides a service to help customer to monitor the power factor of their electric network. Once the electric network has power factor lower than 0.85, Dr. Energy will alert users so that they can cross check with the connected load and hence identify the equipment that cause the low power factor. It can provide a calculation on the surcharge that will be introduced to electric bill so that users can know the contribution of low power factor surcharge to the total bill and also provide an estimation of capacitor bank required to correct the power factor to above 0.85. As you can see in figure 4.10 and figure 4.11, power factor before correction is around 0.819. After turn on the corrector, power factor become 0.938 which is satisfied and surcharge by TNB can be avoided. As shown in the diagram, surcharge by TNB is 0 after power factor was corrected and the monthly payment also reduced accordingly.

Figure 4.9: Power factor before correction

Figure 4.10: Corrected power factor

Before plugged in any component and the switch is not ON, the VI shows no data. However, when the button is ON, figure 4.12(b) shows that it can justify what is the component was plugged in. As shown in figure 4.12(b), it is a blower!!!
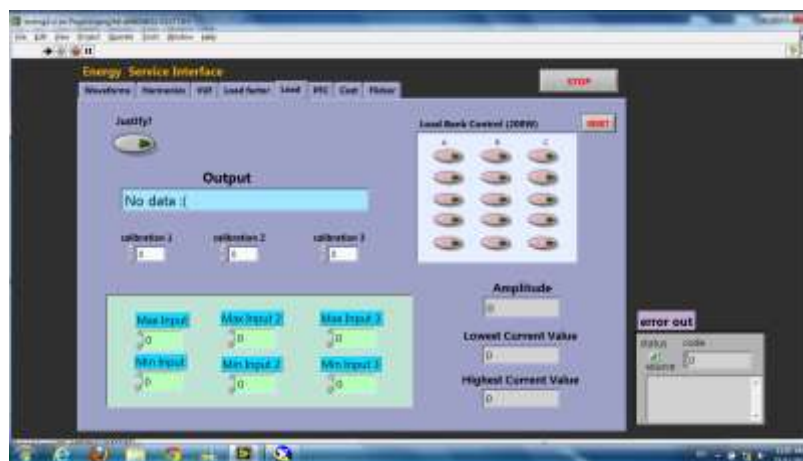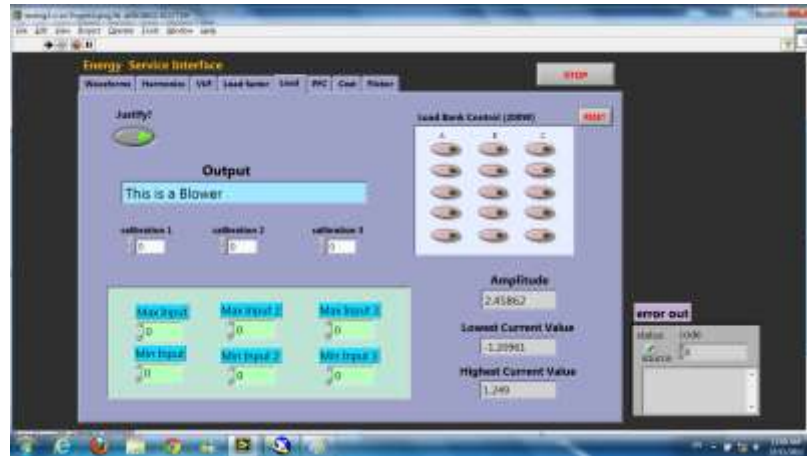

Figure 4.11: (a) Load recognition before plugged in

(b) Load recognition after plugged in

4.3 Simulation Results

Besides doing experiments tested with the real power, some simulation also done only by the software. For the peak demand clipping, normal demand is shaped like a bell. Hence, figure 4.14 is a bell-shaped simulated by coding with the period desired. While figure 4.15 is the loads simulated with different ON and OFF period where total power can be plotted out due to the graph simulated.
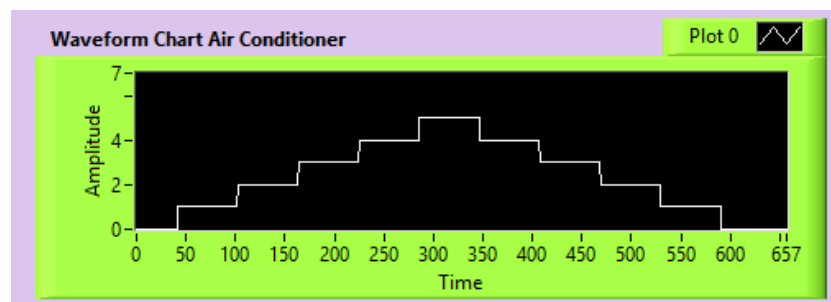
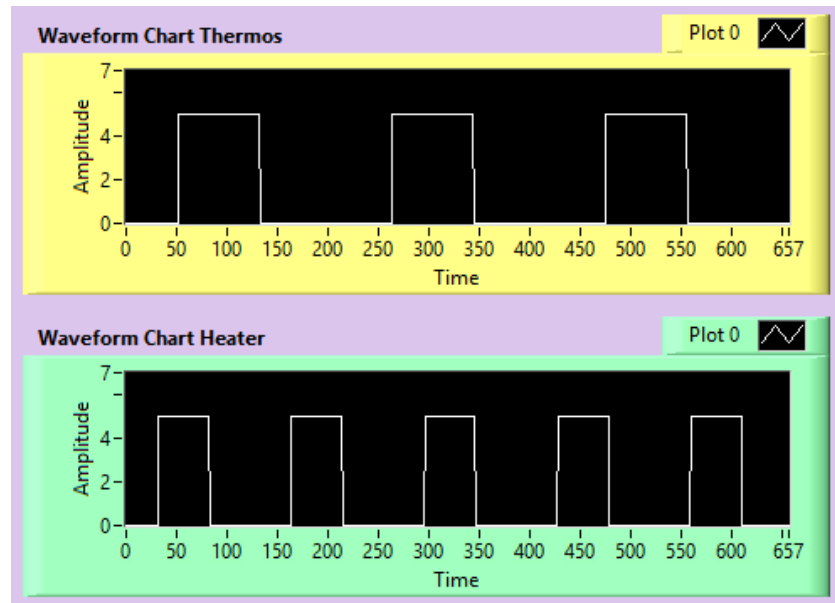

Figure 4.12: Bell shaped graph simulated

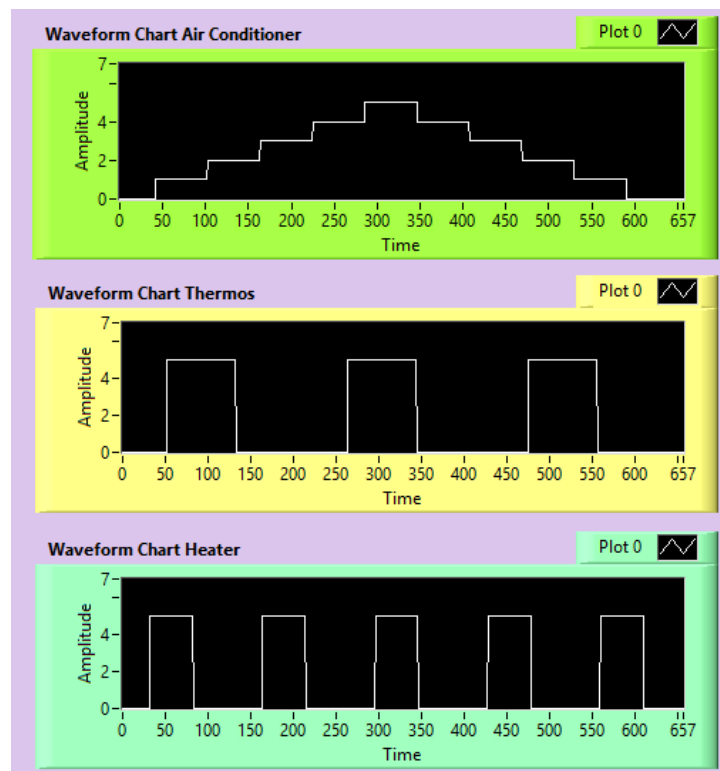**Figure 4.13: Load simulated with different ON and OFF period**

Figure 4.14: Combined graph simulated

For figure 4.16, it is the combined graphs that are simulated simultaneously. Hence, we can see that there will be overlapping where both of the components ON together or OFF together at the same time. And this combined pattern was recorded as total power in figure 4.17. It shows the pattern of the real power be where it can be high or it can be low due to the pattern of the components set.
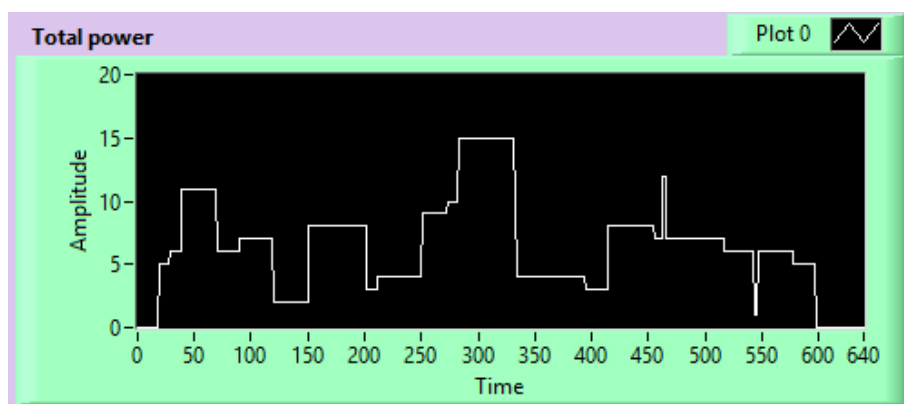
Figure 4.15: Pattern of power simulated

Besides that, figure 4.18 shows a 10 steps bell shaped graph was simulated. A high limit of 6 was set in this case. Hence, peak demand clipping can be done by the simulation in order to cut down the extra charges by the TNB. In figure 4.19, it can be observed that, surges happen for each of the further increases. It is the transient time when power is cut down in order to stay within the limit. This is for the ideal case. If in real case, it might not as nice as this. It might be having a curve like the charging discharging curve of capacitor.

Figure 4.16: 10 steps bell shaped graph simulated
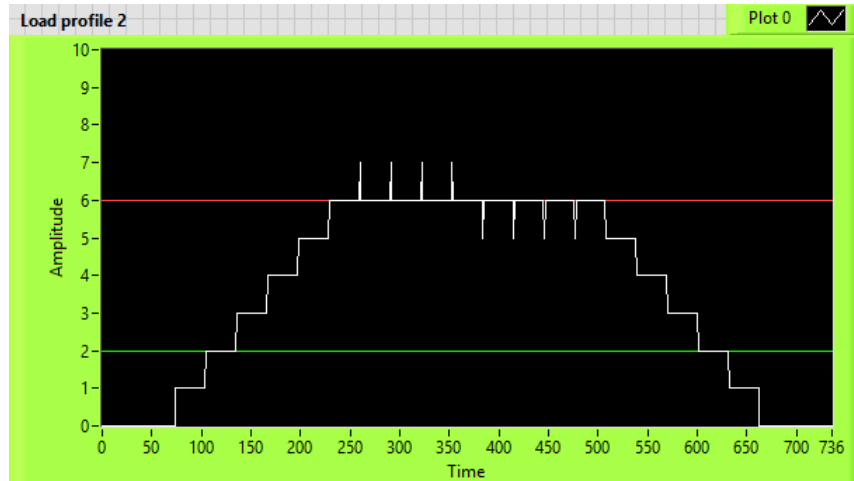
Figure 4.17: Peak clipped and power stay within limit
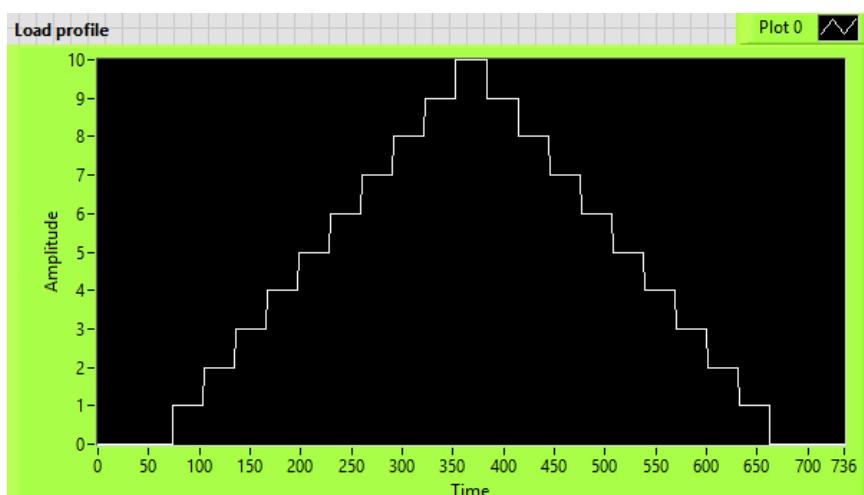
In the real application, we also charge the battery when the demand is low. Hence, low limit of 2 also set for the case above and the graph was plotted in figure 4.20. As you can see, when the power is lower than 2, the power will be used up to charge the batteries; when it is higher than 6, which is the high limit, it will be cut and remain at 6 as the loads are supplied by the batteries. Hence, peak clipping can be done and surcharge of peak demand can be avoided. Instead of demand side, TNB which burdened by the peak demand also can relieve as they no need to start up the backup generators due to the overloaded problem.
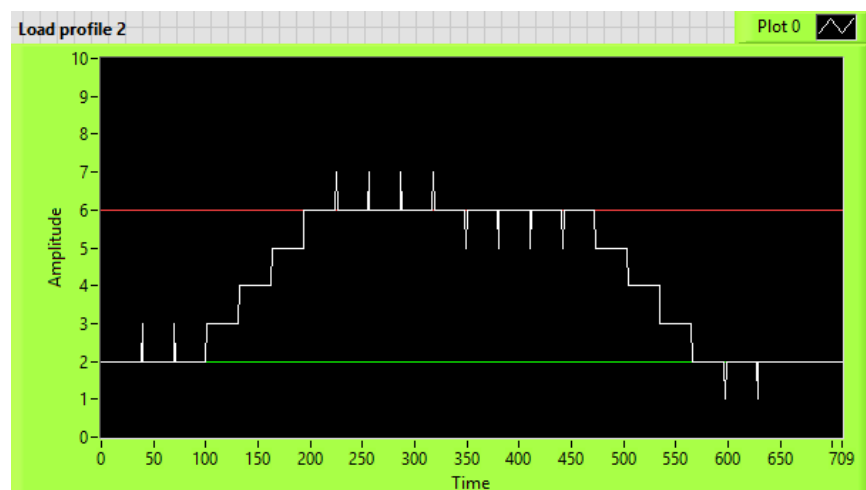
Figure 4.18: Power used when low usage

This method is integrated in the program generated before. When it is used in the graph of total power. The high limit set is 12 while the low limit set is 4. After simulated as what in figure 4.21, the signal which is higher than 12 will be clipped while smaller than 4 will be boosted and this graph pattern will most likely be the case happened in real power and surges occurs too.

Figure 4.19: Power clipped when high and used when low

Figure 4.5 shows our system's functionalities and features which having friendly user interface, modular, customizable, portable, scalable, expandable, compatible to IEC Standard, and reliability with experiment proved.

Figure 4.20: Functionalities and features of this system

CHAPTER 5

CONCLUSION

5.1   Conclusion

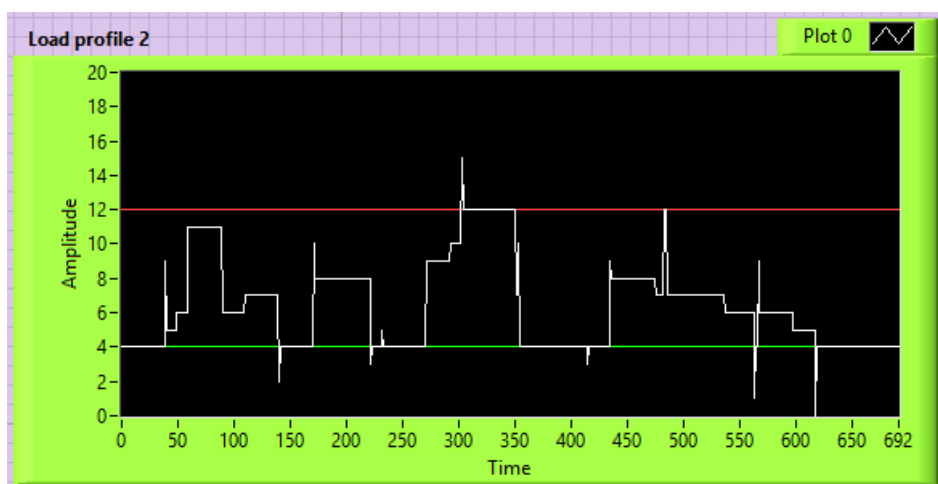Energy management has generally been accepted as an effective way for reducing operational costs in industry and commerce, and the utilities have come to accept the concept as a "win-win" measure, both for the consumer and the utilities. Utilities of the world are taking solid steps towards incorporating new technologies to evolve the traditional grid systems into smart grids. In line with this, a Smart Energy Conditioning System has been developed using NI LabVIEW and NI sb-RIO. This system can mitigate the voltage unbalance in the network with PV system. The installation of PV system without the energy conditioning system may cause the violation of voltage unbalance statutory limit. With the energy conditioning system, the excess power from PV system can be channelled to the energy storage system for future use at the same time the voltage unbalance can be kept at minimal value.

Besides, the energy conditioning system provides an uninterruptible power supply (UPS) to the network during power outage. This enhanced the reliability of the power supply and prevents economic losses due to the power outage. In fact, the energy conditioning system can also be utilized as standby peak load power station for utility company to supply power during the peak load duration. This can reduce the pressure of the high demand period as well as reduce the cost of operation for utility.

While the Dr. Energy module is mostly designed on the plug and play basis. The intuitive graphical user interface allow instantaneous readings of each parameter and also the control simultaneously. The whole process is less hassle as each module is able to provide automated analysis and correction after the measurement process without extra configuration. Uneven load distribution within the grid incurs great power losses and high monthly surcharges. Our modules focus on learning the existing load profile to improve the network quality through a sequence of corrections and adjustments. Load demands are manipulated to achieve the best possible efficiency and energy saving scheme. The portability and flexibility of the module provides an easy and simple approach to energy assessment. Each module serves a significant feature yet independent from one another. Working all the modules together helps deliver a near complete and powerful energy analysis. It reduces the lengthy processes and allows immediate solutions on the spot for each parameter. However, this system is not fully completed as there are still a lot of improvements needed.

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