

BUILDING POWER MONITORING SYSTEM

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**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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May 2014

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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I certify that this project report entitled “**BUILDING POWER MONITORING SYSTEM**” was prepared by **NICOLINE SAW YING JIE** and 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.

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ABSTRACT

The demand for energy is greatly increasing along with the growth of world population. Where commercial buildings are concerned, energy is consumed more than it is actually needed, causing a lot of wastage. The inefficient management of energy in buildings incurs high operational costs. Furthermore, high energy consumption of buildings causes environmental problems, not to mention the depletion of fossil fuels which are currently the main source of energy. Therefore, energy efficiency has become a well-known concern in the world nowadays. In this project, a power monitoring system which is capable of measuring and storing basic power consumption data is developed. The data measured includes frequency, voltage, current, active power, apparent power, reactive power, power factor and active energy. The user interface design and the functions that enable data to be stored and historical data to be viewed are developed using LabVIEW. The SBRIO platform is used for data acquisition and acts as the central unit for this system. The SBRIO is also programmed using LabVIEW. The measurements were performed in a switch room at one of the buildings in the university. Results show that the system is able to measure the parameters of a load (or loads) accurately and the data can be viewed real-time. The data can also be stored systematically in a file for further analysis and this historical data can be viewed on the user interface as well.

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LIST OF SYMBOLS / ABBREVIATIONS

NI	National Instruments
LabVIEW	Laboratory Virtual Instrument Engineering Workbench
VI	Virtual Instrument
DAQ	Data Acquisition
AMR	Automatic Meter Reading
AMI	Advanced Metering Infrastructure
RAM	Random Access Memory
ADC	Analogue to Digital Converter
DAC	Digital to Analogue Converter
TCP	Transmission Control Protocol
IP	Internet Protocol
GPS	Global Positioning System
PMU	Phasor Measurement Unit
FPGA	Field Programmable Gate Array
CT	Current Transformer
AC	Alternating Current
DC	Direct Current
RMS	Root Mean Square
BPMS	Building Power Monitoring System

CHAPTER 1

INTRODUCTION

1.1 Background

Commercial building proprietors generally spend about 30% of their operating budget on energy (M.Donnelly, 2012). According to the Commercial Building Energy Consumption Survey conducted in the US by the Energy Information Administration in 2008, every year 108 billion USD is spent on energy bills for commercial buildings (Environmental Defense Fund, 2012). In many commercial buildings, most of the operations are not energy efficient and energy usage is not managed well, incurring unnecessary waste. In addition, every year, 150 billion USD is lost to power outages and blackouts in the US (Environmental Defense Fund, 2012). Other reasons for high costs of energy bills include peak demand surcharge and power factor surcharge, just to name a few. Peak demand surcharge is the charge imposed on commercial or industrial buildings for their maximum energy demand, even though for a short period of time. Power factor surcharge is imposed on commercial and industrial buildings that have a low power factor of less than 0.85. Hence, we can see that costs of energy are not to be treated lightly and there must be means to reduce these costs.

Besides high costs due to the inefficient management of energy, extensive use of energy has contributed to environmental problems. Electricity accounts for more than half of the energy consumed by these commercial buildings. The burning of fuels such as coal and natural gas to supply commercial buildings with electricity causes a large amount of carbon dioxide emissions. Statistics show that 65% of

pollution causing global warming is likely to be caused by the production and use of energy (Environmental Defense Fund, 2012). Furthermore, the continuous burning of fuels will soon lead to the depletion of fossil fuels which are our main source of energy. There must be a control over energy consumption in buildings and this cannot be done without first monitoring and analysing energy data.

The increasing world population is driving a greater increase in demand for energy. The use of energy in buildings, in particular commercial and industrial ones, has called for more efforts in energy conservation. In light of this, the smart grid, said to be the future of energy efficiency, is developed to fulfil the growing global demand of electrical energy, provide high quality electrical energy, and increase the efficiency of power generation and at the same time reduce losses in transmission, distribution and consumption of electrical energy. The smart grid gathers and acts on information, such as information on how suppliers and consumers behave. All this is done in an automated way to improve the reliability, efficiency, sustainability, security and economics of the generation and distribution of electricity. However, to enable a smart grid to function, it needs the information obtained from measurement and monitoring of the electrical network. A smart grid cannot increase energy efficiency for the growing population of consumers unless it is systematically fed with energy consumption information to process. A power monitoring system is the core of the smart grid, as it provides information for the control to operate.

Moving towards an energy-efficient and energy-conscious society, renewable energy has become one of the solutions in overcoming environmental problems related to fossil fuel burning, and also as alternative sources of energy. Buildings have begun to use renewable energy to run their daily operations. However, there are problems arising due to implementation of renewable energy such as voltage unbalance and power quality issues. Solar power and wind power, as alternative energy sources, are highly variable, and so there is a need for more sophisticated control systems to facilitate the connection of sources to the main grid. All these require a power monitoring system so that the presence of renewable energy can be detected and energy flow can be monitored and hence controlled (US Department of Energy, 2012).

A recent study claims that 30% of energy used by commercial buildings could be reduced by focusing on energy efficiency (M.Donnelly, 2012). Investments such as improving building energy management practices are important for reducing energy costs, and this is where a power monitoring system is imperative. Using a power monitoring system, building performance can be optimized and this reduces energy demand from the main grid. This in turn lowers carbon emissions from the generation of electricity and the burning of fuels. With the help of power monitoring systems, the data collected in buildings have become increasingly useful to help property owners and managers make wise decisions.

In view of the problems faced by commercial buildings and electrical networks and the importance of collecting data on energy consumption, the present project sets out to develop and study a power monitoring system within a specific building in UTAR. The objectives are delineated in the following section.

1.2 Objectives

The first objective of this project is to develop a data acquisition system to collect data and monitor power usage by using Single Board Reconfigurable Input Output (SBRIO), an embedded control and acquisition device developed by National Instruments (NI). The system is able to calculate energy cost based on the different tariffs. The data acquisition system also consists of a graphical interface for real-time viewing and monitoring of energy use. This is to give users a comprehensive analysis on the data collected by the system. The second objective of this project is to develop a database management system which forms an archive of stored energy data. The data centre developed should be clearly structured and easily accessible for trend analysis or forecasting purposes.

1.3 Scope of project

This project aims to develop and study a power monitoring system. The power monitoring system consists of a data acquisition device, the user interfaces to be viewed on the computer, and a data centre. The power and energy consumption data will be collected from SE block in Universiti Tunku Abdul Rahman (UTAR), over a period of 1 week. NI SBRIO-9632XT, voltage measurement card and current measurement card are used as data acquisition hardware. This project requires LABVIEW graphical programming language skills for communication with the SBRIO, for designing comprehensive graphical user interfaces and for building an organised data centre. The scope of this project also covers wireless communication, as the data obtained from the SBRIO is to be transmitted wirelessly to a computer for viewing and also recording. Furthermore, this project requires planning, designing, troubleshooting and problem solving to achieve its objectives.

CHAPTER 2

LITERATURE REVIEW

2.1 General description of a Building Power Monitoring System

A building power monitoring system (BPMS) is a system that measures, monitors, records and analyses the power usage of a building, making it useful for energy consumption monitoring and management. The power monitoring system consists of software and hardware and this will be explained in detail in chapter 3. The power monitoring system can be incorporated with controlling and operating systems within a building to form an energy management system. The operating systems of buildings that can be managed and controlled include heating, cooling, lighting, ventilation, power and security systems, taking into account their different specific components.

Driven by technological advances, the market for building energy management systems continues to grow. These energy saving systems are critical in the light of a high energy demand society. Studies show that improperly configured energy management systems account for 20% of building energy usage. Therefore being one of the key components of an energy management system, it is vital that power monitoring systems are properly designed and installed to achieve their purpose.

2.2 Architecture of a Power Monitoring System

The design and architecture of a power monitoring system can be categorised into four levels. The system architecture is illustrated in Figure 2.1.

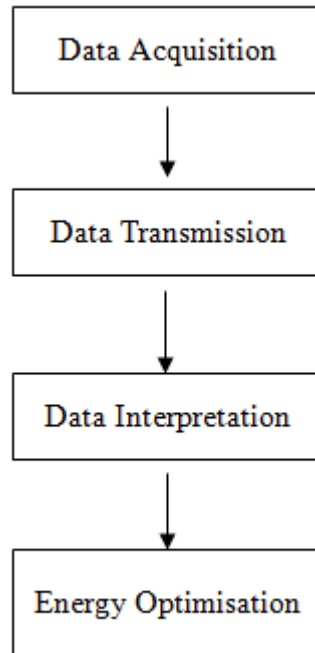


Figure 2.1: System architecture of power monitoring system

2.2.1 Data Acquisition (DAQ)

The first layer is the data acquisition layer. Data acquisition is the process of acquiring electrical data using a variety of intelligent energy measurement devices such as sensors and metering devices. The primary data that needs to be measured and recorded in a power monitoring system are frequency, voltage, current, single phase real and reactive power, 3 phase real and reactive power, apparent power, energy consumption and power quality. This data will enable building owners to know the operation of equipment in the building. Currently in the market, some of the devices that are used for data acquisition are such as smart meters, sensors and phasor measurement units.

Smart meters. Smart meters are useful for obtaining information from devices and controlling their behaviour. Basically, these meters perform the task of data acquisition. Traditionally, Automatic Meter Reading (AMR) systems were used. AMR is a technology that enables status, consumption and diagnostic data from energy meters to be collected automatically. It then transfers data to a central database so that analysis, adjustment, troubleshooting and billing can take place. There is only a one-way communication. Advanced metering infrastructure (AMI) systems (D. G. Hart, 2008) is an improved version of AMR systems (D. W. Rieken, 2011). AMI is an architecture that allows a smart utility meter with an IP address to communicate with a utility company in an automated fashion (M. Rouse, 2010). This two-way communication is the advantage of AMI over the traditional AMR. Thus, there is real-time acquisition of nearly all of the information, allowing better chances for an improved system operation.

Smart meters are also known as AMI meters. Being the updated versions of the traditional electrical meters, they collect energy consumption data periodically and then send the data back to the utility company for the purposes of monitoring and billing (Federal Energy Regulatory Commission, 2010). In addition smart meters can disconnect and reconnect remotely. This controls the electrical appliances in the building and manages loads and demands. Using smart meters, electricity bill costs can be estimated and thus energy consumptions can be managed to reduce costs. Real-time pricing can also be realised. This is important as it gives users a better oversight on their energy usage and encourages users to decrease their load demands during peak periods. These load reductions help utilities to cut down on the cost of providing electricity (GE Appliances, 2011).

Sensors. Sensors and their networks are employed as a monitoring and measurement approach for a range of purposes (I. F. Akyildiz, 2002). One of these purposes is to detect mechanical faults in power grids, for example, when the conductor fails, the tower collapses or the grid experiences extreme mechanical conditions. In the application of a sensor network for secure electric energy infrastructure, it was proposed by Leon *et al.* that sensor networks be installed into the power grid so that they can help in assessing the real-time electrical and mechanical conditions of transmission lines (R. Leon, 2007). Then, imminent and

permanent faults can be detected. This information will trigger off appropriate actions automatically or suggest control measures to the system operators.

One of the sensors used for data acquisition is a current transformer. It is used to measure alternating current (AC). By clipping the split core type of current transformer straight onto either the live wire or neutral wire coming into the whole building, the electricity consumption of the building can be measured (Open Energy Monitor, 2012). Other sensors used to measure current are Hall Effect IC sensor which can measure AC, DC or pulsating current, the Rogowski coil which is used to measure AC or high speed current pulses, and the fiber optic current sensor. Compared to traditional current sensing technologies, fiber optic current sensors have the advantage that the electrical interference caused on the signal line is minimal, and they respond quickly with high measurement accuracy. Also, these sensors have a reduced size and weight (Fibercore, 2014).

The sensor network can be designed such that a combination of different types of sensors can correctly acquire data. Munoz et al. designed and verified their design of a mixed electronic system to obtain data for energy management. The system was designed to perform measurement of active, apparent and reactive energies delivered to a load in a single-phase AC voltage line. The sensor network comprised a smart sensor which itself consisted of a temperature sensor and all the signal processing required to perform the energy measurements including line-voltage period and rms measurement, and also a magnetoresistance sensor which performed the same functions as a current transducer. The purpose of the magnetoresistance sensor was to provide direct isolation from the mains voltage. All the measurements obtained from the sensor network were transferred to the computer using a LabVIEW application, and after that the data will be processed and presented to the user (D.R.Munoz, 2008).

Phasor Measurement Unit (PMU). Considered as one of the most important measuring devices in power systems, a phasor measurement unit (PMU), also known as a synchophasor, measures the electrical waves on an electricity grid. Its time synchronization feature enables real-time measurements of several measurement points located far apart from each other on the grid. Normally, PMU readings are

collected from these dispersed points on the grid and synchronisation of the readings are performed with the help of a global positioning system (GPS) radio clock. The large number of PMUs everywhere on the grid as well as the capacity to compare AC shapes from the readings allows system operators to understand the state of the power system by using the sampled data and respond to system conditions rapidly and dynamically (US Department of Energy, 2012).

The data acquired by PMUs can be used for grid protection functions. These may include monitoring fault events, locating electrical and mechanical disturbance, estimating the state of the power grid and monitoring power quality (A. Carta, 2009). Thus, PMUs help in ensuring reliable power transmission and distribution.

Several countries have adopted PMUs for their power monitoring systems. For instance, South Korea, Brazil, Japan, Mexico, Norway, China and France and the U.S. have installed PMUs and are researching on them or developing prototypes (P. Zhang, 2010). The installation of PMUs for power monitoring and measurement on transmission lines and distribution grids has become an important movement.

Data acquisition board. DAQ hardware (board) is the interface between the computer and the signals from the sensors or meters that obtain data. The DAQ board converts the analogue signals from the sensors into digital signals that a computer can interpret. The key components of a DAQ board for a power measurement are analog-to-digital converter (ADC), signal conditioning circuitry, and a computer bus. The function of a signal conditioning circuitry is to modify a signal into an appropriate form for input into an ADC. Signals can be amplified, attenuated, filtered, and isolated. Built-in signal conditioning is included in some DAQ boards for measurement of specific types of sensors. Analogue signals produced by the sensors must be converted into digital signals and this is done by the ADC. Samples of the signals are taken periodically at a specific sampling rate and then transferred through the computer bus to the computer where the original signal is reconstructed (National Instruments, 2014).

A DAQ hardware or board could be in module form joined to the computer's ports (parallel, serial, USB, etc.) or cards slotted in the motherboard. For a power

monitoring system, according to EN standard 61000-4-30 and 61000-4-7, the data acquisition rate must be more than 18kHz in order to obtain accurate measurements. The requirement of a sample rate of 18kHz on each channel (voltage measurement channel and current measurement channel) needs a powerful hardware to support. According to Bartofi (R. Bátorfi, 2008), accurate measurements require stronger hardware devices and this can be achieved with a personal computer (PC) and a data acquisition board. Another advantage of a PC-based system for power monitoring as opposed to other measuring devices is a PC is much faster, powerful and flexible, and it can be enhanced with many other peripherals to suit many other required functions.

2.2.2 Data Transmission

Data transmission is the second level. It can be performed through different types of communication networks. Since the success of the power monitoring system depends on a reliable and effective data exchange, the communication system should ensure quality service of data. The reason being data obtained is critical and should be conveyed promptly. Besides this, the communication system must be reliable to support the connection of many devices and technologies used. In order for the power monitoring system to have a quick response to any event, the communication system must have a wide coverage of the whole network being monitored. Lastly, the communication system must be secure and private (X.Fang, 2012).

In a power monitoring system, data transformation must be realized between the field bus interface and Transmission Control Protocol /Internet Protocol (TCP/IP) network. This is so that data can be transmitted between a data collecting device and a computer that acts as a management centre. The data is transmitted by wired or wireless networks with TCP/IP communication protocol. Data transmission must follow specified encoding rules and the procedure should involve authorization, encryption and authentication. This is to ensure the stabilisation and reliability of data.

There are usually two ways to transmit data, namely, wired (cable) and wireless. The current state-of-art communication technologies are illustrated in Figure 2.2 and Figure 2.3. There are many ways to transmit data using wired cable. These are Ethernet, RS485/RS232, PCI/PCI Express, Fibre optic communication and power line communication as illustrated. For wireless communication, data transmission is enabled using cognitive radio, cellular communications, microwave communications, satellite communications and wireless mesh network.

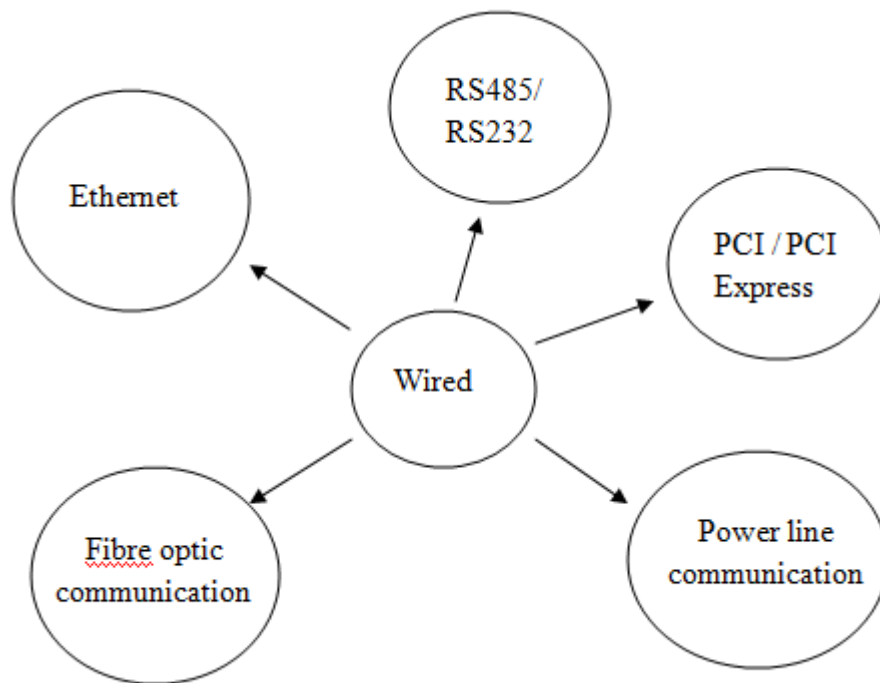


Figure 2.2 Wired communication technologies

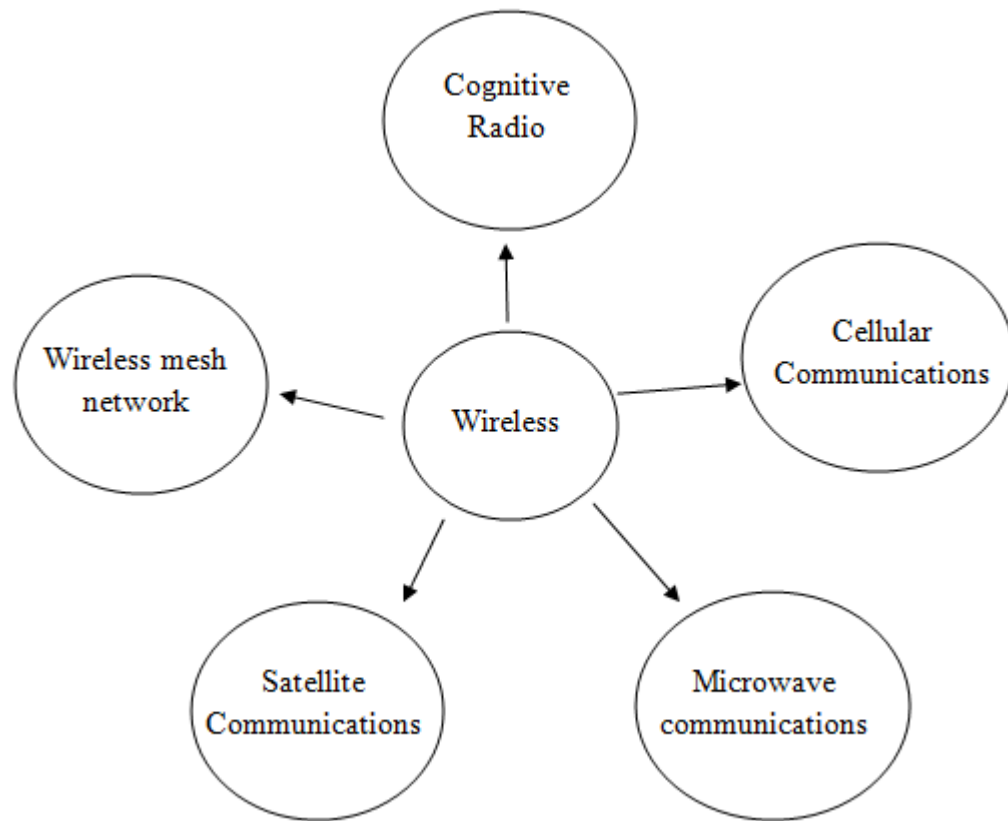


Figure 2.3 Wireless communication technologies

Wired Technologies. A computer bus functions as the communication interface between the DAQ device and computer. It is through the computer bus that instructions and measured data can be passed. DAQ devices are connected to a computer through a slot or port. The most common computer buses include Universal Serial Bus (USB), Recommended Standard-485/RS-232, Peripheral Component Interconnect (PCI), PCI Express, and Ethernet.

For commercial buildings that are newly constructed, an Ethernet cable network is recommended so that pre-installation is easier and the communication is reliable. Ethernet is a physical and data link layer technology for local area networks (LANs). Protocol units called frames enable data travels over Ethernet (B.Mitchell, 2010). Having evolved over a significant time frame, the Ethernet physical layer includes the twisted pair, coaxial and fibre optic interface. The speeds of data transmission are from 10 Mbit/s to 100 Gbit/s. Three most common wiring standards for Ethernet technology used are listed below: 10BASE-T representing a speed of

10Mbit/s, 100BASE-TX representing a speed of 100Mbit/s, and 1000BASE-T representing a speed of 1Gbit/s. All these are designated by the Institute of Electrical and Electronic Engineers, IEEE802.3, which is the standard specified for Ethernet (IEEE Standards Association, 2014).

RS-485 is one of the serial interfaces for data communications. Published by the Telecommunications Industry Association/Electronic Industries Alliance (TIA/EIA), it defines the electrical characteristics of drivers and receivers in a digital communication system. Through this standard, configuration of inexpensive LANs as well as multipoint communications links are enabled. For cable length of 10m, the transmission of data is required to achieve speeds of 35 Mbit/s, and for cable length of 1200m, the speed is 100 kbit/s. The cable length can span a relatively large distance of up to 1200m because this standard uses twisted pair balanced lines (L.Frenzel, 2013).

RS-232 is one of the oldest serial interfaces. Originally it was established as a way to connect data terminal equipment (DTE) to data communications equipment (DCE). Now its uses have expanded to include connections to modems, computers, and video terminals. The cable medium can be simple parallel wires or twisted pair. The protocol used with the RS-232 interface defines the data rates which can reach up to 115.2 kbits/s (Sangoma, 2013). The RS-232 serial port on a PC can be exposed to a TCP/IP network using a small hardware device called a serial device server or TCP-Com software (Tal Technologies, 2014).

The PCI was developed by Intel and it is an interconnection system between a computer and attached devices. The PCI bus is a 32-bit computer bus that is also available as a 64-bit bus. The design of the PCI is such that it is synchronised with the clock speed of the microprocessor. The PCI Express is a high-speed serial computer expansion bus standard with reduced pin count and increased bandwidth. It was designed to substitute the older PCI versions (Intel, 2005).

Fiber-optic Communications have long been in use by large power companies for the connection of generation network with their control centre. Fibre optic communication suits an environment using high voltage because fibre optics are

immune to electromagnetic and radio interference, along with the fact that they have high bandwidth capacity (R.Paschotta, N.A). Although there are cost issues, use of a fibre optic network can be justified with the high speed of information obtained (X.Fang, 2012).

Powerline communications transmits data on a conductor that is also used for electrical power transmission. Since the power lines are already in place, the operation costs of powerline communications are comparable to the costs of using wireless technologies. While this is an advantage of using powerline communications, there are many security issues faced (X.Fang, 2012).

Wireless Technologies. The difficulty in installing new communication wires in different parts of a building causes attention to shift to wireless technologies (X.Ma, 2010). Hence, wireless transmission has to be considered for flexibility and connection. Wireless technologies also are significantly advantageous over wired technologies in their mobility and low installation cost, making them suitable for remote applications. This section will discuss wireless mesh networks (WMN).

A communication network comprising radio nodes which are organized in a mesh topology, WMN has surfaced as a key technology for wireless networking in future generations (I. F. Akyildiz, 2005). It is recommended that WMNs in a power monitoring system follow the standards IEEE 802.11 and 802.16. Based on IEEE 802.15.4 standards, there are three wireless communication technologies suitable to be used in a power monitoring system (B. Akyol, 2010), namely, Zigbee, WirelessHART, and International Society of Automation (ISA) 100.11a.

Zigbee is created for radio frequency applications requiring long battery life, low data rate and secure networking. Since a standardised platform is provided for the exchange of data between the measurement devices and appliances or equipment positioned in buildings, many electric utilities have selected Zigbee technology for smart metering devices. WirelessHART technology is based on the Highway Addressable Remote Transducer Protocol (HART). Catered specifically to fulfil the requirements of process field device networks, WirelessHART follows the international standards IEC 62591 and IEEE 802.15.4.

2.2.3 Data Interpretation

The third layer is the data interpretation stage and also includes performance evaluation. In this layer, the data is processed and displayed. It is also saved into an energy information database for use during building performance evaluation. During performance evaluation, the level of energy use is assessed and any defects or abnormalities of building equipment and operations are detected. The evaluation performed will ensure that the usage of energy and reliability of equipment is monitored (A.Stublen, 1997). The building manager may use the information collected for preventative maintenance, corrective maintenance and energy cost calculations.

Basically, a BPMS needs to establish a data centre for processing data in order to carry out the task of saving energy in the building. Data interpretation is central to the entire system because it gives meaning to the values obtained from the data acquisition device. This enables the diagnosis to save energy and building energy consumption analysis to be conducted smoothly. In addition, during this stage, a clear and comprehensive user interaction interface is necessary. This is because the ability to record data and present it in a user-friendly format is one of the key assets of a BPMS.

The data server is in charge of the data saving and management. The deployment of a data server makes it possible for data centralization and better maintenance of the data. Zhong bocheng *et al* report in their design that in a data server there are typically two types of energy consumption databases. The first type is an original database which does data-saving after obtaining the data through the many transmission methods. Software is used to analyse and model the energy data, so that it can produce current trends on energy consumption to predict future trends. The other type of database is a terminal database which saves the processed original data which has been automatically classified using a processing and classifying software. The data in the terminal database can be uploaded to the Internet in a graphical method by means of a web server (B. Zhong, 2012).

The data obtained from the data acquisition board must be presented in such a way that users can understand performance of the building and hence improve its performance through modifications. Some BPMS software have a trend logging facility whereby graphical trend logs can be produced and updated dynamically. Spreadsheets running in a graphical environment can be made used of, allowing users to perform data extraction from the BPMS. Spreadsheets that are tailored to specific information needs can then be created and users can use software such as Microsoft Excel to plot graphs, charts and histograms (C.A.Norburn, 2005).

The graphical display of the BPMS should give the building manager a very clear picture of the building performance and energy usage. There are four types of graphic interfaces, namely, dynamic graphics, active graphics, animated graphics, and bitmap support. Dynamic graphics provide a dynamically updating representation of the system that is graphically displayed on the screen. Active graphics enables the condition of the system to be adjusted by the user. Besides that, it is possible to prompt warning texts or items to be displayed under certain conditions such as a failure in ventilation. In animated graphics, movement can be added to the graphics to enhance the user interface. Bitmap support allows the display of scanned digital photographs (for example photographs of floor layouts) in the user interface (C.A.Norburn, 2005).

In a web-based real time industrial energy monitoring system designed by E.Irmak *et al*, the user interface was a web interface. The user has to key in username and password before the interface can establish a connection with the DAQ device. Then, energy parameters and operating status of the system can be viewed on the interface. The information was displayed in both graphical and digital form (E.Irmak, 2013).

Many BPMS can capture and store information on disturbances occurring in the plant or facility. This enables analyses of disturbances. Many BPMS also feature a waveform capture that can compute harmonic levels and total harmonic distortion automatically. Through this feature, operations in a facility can be improved when the harmonic problems are identified and corrected (A.Stublen, 1997).

Another example of how data is interpreted and managed can be observed in the energy monitoring and management system developed by K.Collins *et.al* for industrial applications. The data interpretation and management layer is represented by their modules: Disaggregation and Time-of-Use Calculator (DTOUC) and In-operation Machine Detection (IMD). Machines that are in use in the industrial building are identified by the IMD, and the time period when those machines are operating is determined as well. The DTOUC serves to disaggregate the energy consumption of these machines and performs calculations of the energy costs associated with their operations (K.Collins, 2012). All these modules provide valuable data for measures to improve energy usage, and this is further elaborated in the next section on energy optimisation.

2.2.4 Energy Optimisation

Energy optimization is implemented in the fourth layer of the system architecture. This is for power monitoring systems that are implemented together with energy management systems. In this level, the data obtained, interpreted and analysed is actually put to good use. There are measures taken to lower the energy consumption and costs and hence improve energy efficiency of the building. This can be done by optimising the operation of the equipments, repairing any faulty equipment. Other optimization measures include optimal start/stop management, peak demand control, installation of power factor correction devices, dynamic optimal settings of operation parameters, etc.

The information analysed can also be incorporated into a scheduled maintenance program suited to the individual building (K. Park, 2011). This can be seen in the energy monitoring and management system designed by K.Collins *et al*, where the Graphical User Interface and Operation Scheduler (GUIOS) module enables the operator to explore different machine operation schedules that will lead to significant electricity cost savings. Other modules developed in the system- the DTOUC and IMD also gives useful feedback to the operators so that they know how to better utilize the machines within the industrial facility and can follow a scheduled maintenance plan (K.Collins, 2012).

It is vital for the building to have accessible and up-to-date information for efficient control of energy. Energy optimisation requires decisions to be made at the right time. Hence, a BPMS should be designed to deliver these decisions with functional graphical user interfaces which have a clear display of building information. A BPMS is designed such that all authorised occupants will find it a simple and easy-to-use system for everyday use.

2.3 Further Uses of a Power Monitoring System in a Building

A power monitoring system is important for all levels of building data management. The data collected and analysed is potentially useful to improve energy performance in buildings and identify opportunities to use energy more efficiently. All these will contribute in reducing costs as well as carbon emissions, and improve occupant comfort. The building manager can focus on monitoring energy usage and cost data monthly. To develop a consistent process for energy tracking, comparisons with utility bill data are conducted. By investigating monthly electricity bills, along with weather data and basic information on building structure the building owner can understand the basic building performance. Energy usage data can also be manually keyed into a database or spreadsheets regularly to produce monthly trends or help identify changes in energy usage in certain buildings or areas. When weather data is correlated with consumption data, weather-sensitive electricity or fuel consumption patterns can emerge (M.Donnelly, 2012).

Similarly, a power monitoring system is a very effective tool for energy auditing companies that perform audits on commercial buildings. This is because auditors can easily obtain all the information they want on the electrical network of the building. The information obtained and analysis performed is useful to help the building to cut down on costs, improve the efficiency of production operations, detect faulty equipment and also to extend the service life of equipment.

Also, costs related problems mentioned earlier such as peak demand and power factor surcharges can be managed effectively with the implementation of a power monitoring system. Other than performing data measurement, power

monitoring systems can provide alarms to alert building owners when the energy consumption is going to reach the peak capacity. This will prevent the building owners from being severely penalised for peak energy consumption. In the same way, power factor surcharge could be prevented. Apart from this, power monitoring allows accurate cost allocation to the specific product being manufactured. The power monitoring data provides the necessary information to determine the profitability of a product or service.

With a power monitoring system, an unstable source such as wind or solar power can be harnessed and its supply sustained for use. For commercial buildings that rely mostly on alternative sources of energy, this is important to ensure that they receive maximum energy for their daily operations.

In summary, the presence of a real-time power monitoring system in buildings brings about numerous advantages. The overall management of the building is improved, where inefficient equipment and irregular energy consumption can be detected, and peak demand is reduced. Basically, the ultimate goal of BPMS is to help ensure that the buildings use energy optimally, practise energy conservation and enjoy a pleasant indoor environment and reduced operational costs.

CHAPTER 3

METHODOLOGY

3.1 Hardware Setup and Description

Basically, the power monitoring device is a diagnostic tool that is connected between the source and the load during measurement. This is illustrated in Figure 3.1.

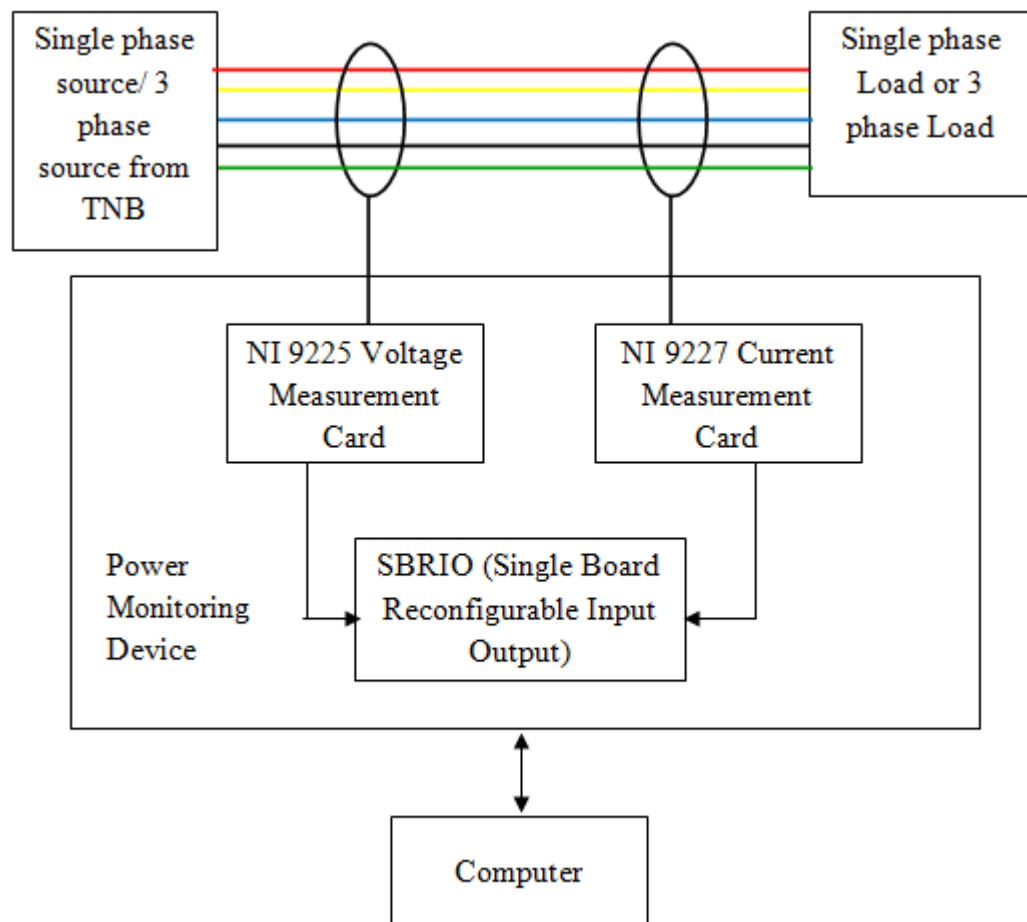


Figure 3.1: Setup of power monitoring system

This section briefly describes the technology used. This project selects NI Single-Board RIO 9632XT because it allows easy integration of commercial off-the-shelf hardware with the board for the design of control, monitoring and test systems. The advanced features of the device have enabled it to be used as the central processing unit in testing, controlling and monitoring in this project. The SBRIO features an industrial Freescale MPC5200 real-time processor with a processing speed of 400MHz. The processor is combined with an onboard reconfigurable Field Programmable Gate Array (FPGA), which is useful for applications that are deterministic. Other features include built-in analogue and digital Input/Output (I/O), 10/100BASE-TX Ethernet port for network communication and RS-232 serial port for connection of peripheral devices. The SBRIO 9632 model has 110 digital I/O channels, 32 analogue input channels and 4 analogue output channels.

Furthermore, the SBRIO has three connectors for adding custom C series I/O modules or third party modules. For this project, the Connector for C Series Module in the board is used with the NI 9227 3-Channel Current Measurement Card and NI 9225 3-Channel Voltage Measurement Card. Their functions are to measure and monitor the analogue voltage signal and output current signal for the single phase supply and also the three-phase supply. The measurement cards perform analogue to digital conversion of data for the SBRIO to use. The data acquisition rate for these measurement cards are both 50kS/s, allowing accurate measurement of data.

The switching power supply of model NES-100-24 is a separated power source to power up SBRIO-9632XT. The use of current transformers (CT) in our device is to measure line current and also to step down the current to a level suitable for the measurement cards. There are 2 types of CTs used. Fixed core CT is an internal CT for single and three phase line current measurement, and split core CT is an external CT for switch yard line current measurement.

The device for monitoring power is shown below in Figure 3.2 and Figure 3.3.

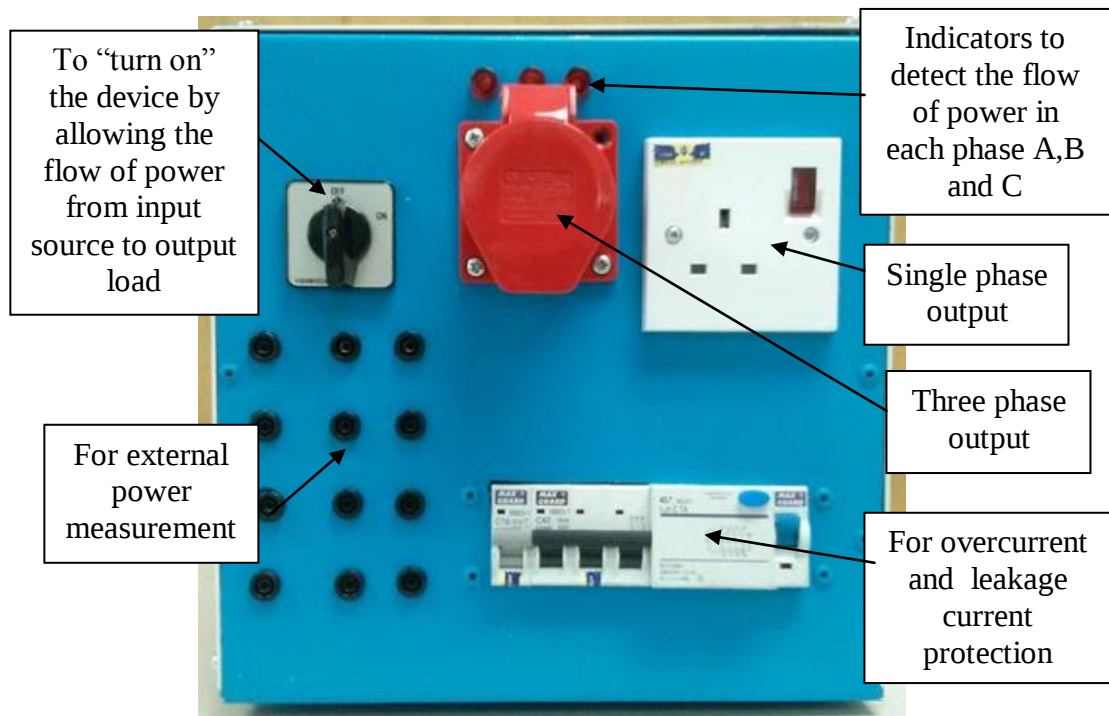


Figure 3.2: Front view of power monitoring device

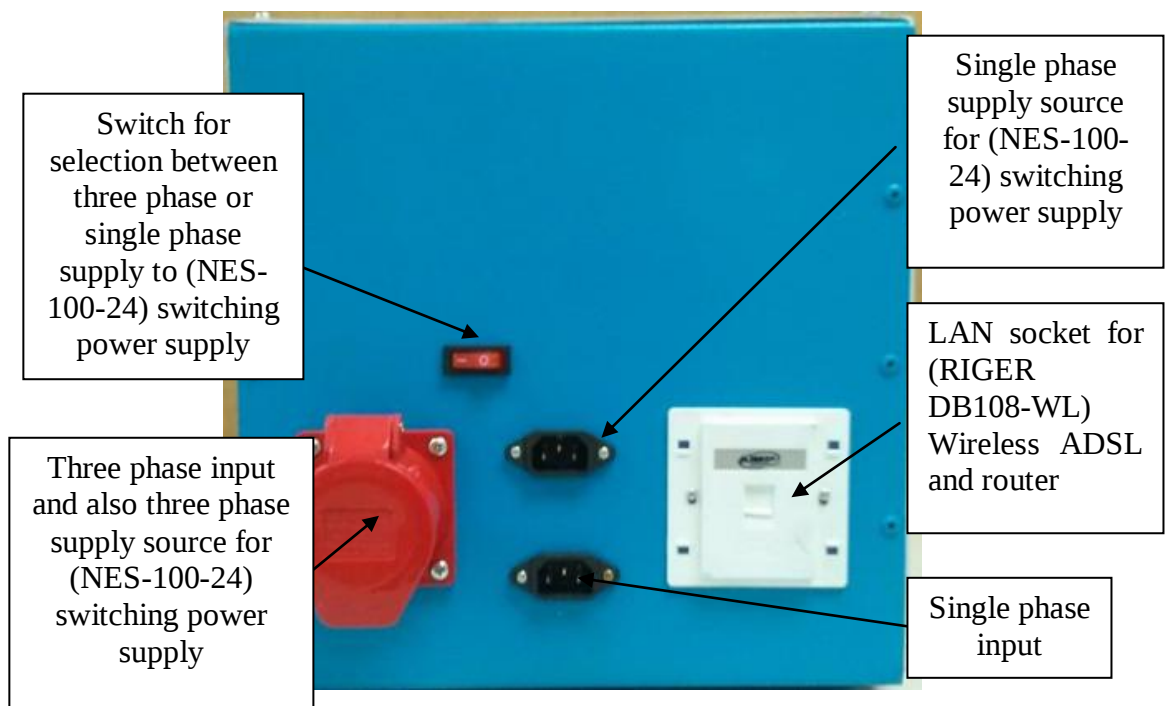


Figure 3.3: Back view of power monitoring device

Figure 3.4 shows the whole device from a 3-Dimensional view.



Figure 3.4: 3D view of power monitoring device

3.2 Software Application

3.2.1 LabVIEW

In this project, a graphical programming language LabVIEW is used to program the SBRIO and also used to design the interface for users to view the data measured. LabVIEW stands for Laboratory Virtual Instrumentation Engineering Workbench. Produced by NI, LabVIEW's applications cover industrial automation, data acquisition and instrument control. The platforms applicable are wide in range including Microsoft Windows, Mac OS X, Linux, and various versions of UNIX.

The structure of a graphical block diagram determines the execution of the program. Users can connect different function-nodes by connecting wires. The wires propagate variables and once all input information to the node is available, the node can perform. By means of multi-threading, different kinds of tasks that are parallel in execution can be easily programmed. Parallel execution is an essential feature as for a test system, hardware interfacing, data recording, and test sequencing are all processes that run in parallel.

The major benefit of LabVIEW is the wide-ranging support for working with instrumentation hardware. This type of support also includes drivers and abstraction layers that are presented as graphical nodes for many different kinds of instruments and buses. Standard software interfaces are offered by the abstraction layers to communicate with hardware devices. The provided driver interfaces have the potential to save program development time. Compared to other competing systems or traditional systems, LabVIEW has the upper hand as people with insufficient coding experience are able to write programs to perform system testing in a reduced period of time.

LabVIEW provides many libraries with a large number of functions. These functions are for signal conditioning, mathematics, analysis, signal generation, statistics, data acquisition and many more, along with a range of graphical interface components. LabVIEW programs are known as Virtual Instruments (VIs). Moreover, users can create flexible and scalable tests. All in all, the tools required to build and set up a measurement and control system are provided in this software.

Therefore, in view of the numerous advantages of LabVIEW, it is clear why LabVIEW is selected as the programming language for this project.

3.2.2 Configuration of SBRIO to computer

The SBRIO must be configured so that the computer can detect the device. Only then can the energy consumption data be collected, saved and viewed on the user interface on the computer. The following paragraphs explain how the configuration of SBRIO was performed.

Firstly, the SBRIO was powered up by turning on the power supply and connecting the SBRIO to the computer using LAN cable. Next in step two, the NI MAX application was opened. This is illustrated in Figure 3.5.

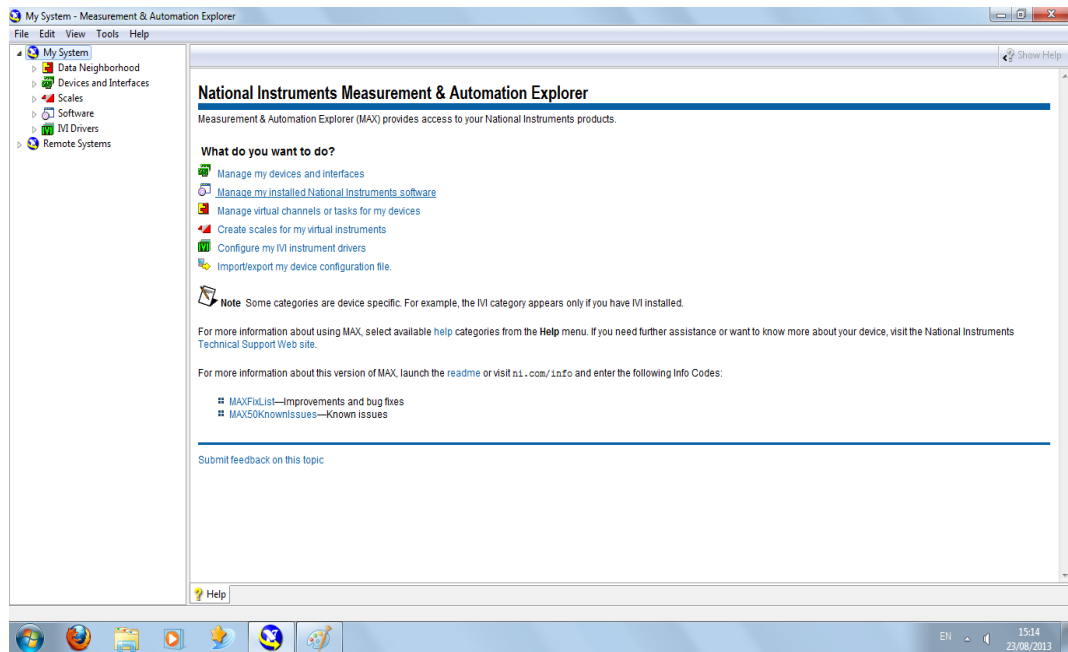


Figure 3.5: Opening NI MAX Application

In step three, the model of the board that the computer was connected to was found by clicking on ‘Remote Systems’. This is shown in Figure 3.6.

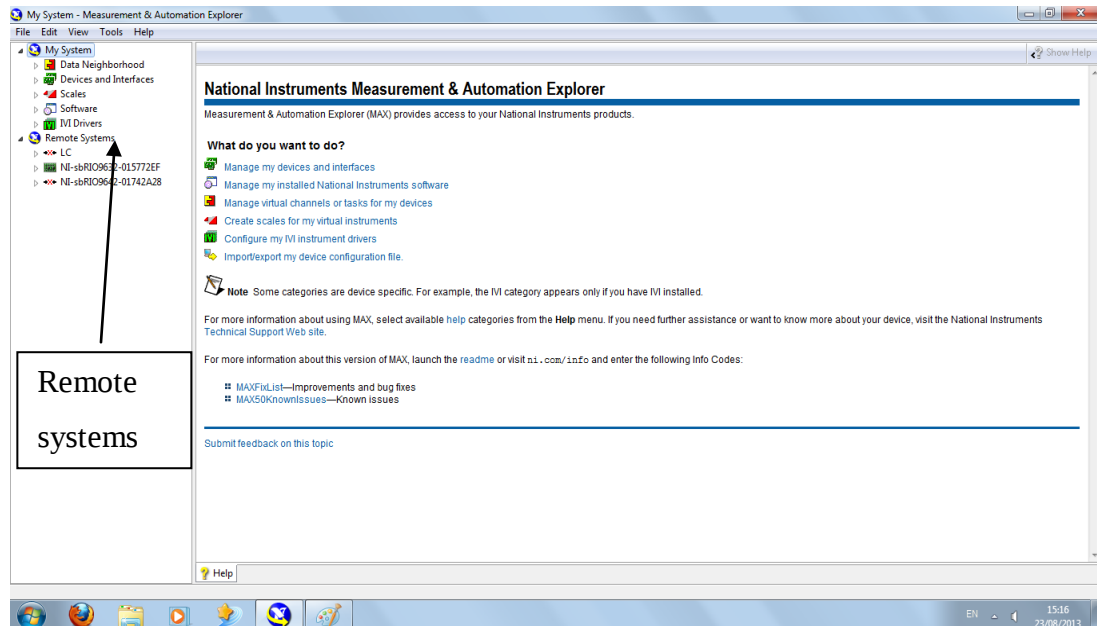


Figure 3.6: Finding Remote Systems

Next, the board model was selected, and in this case it is NI-SBRIO9632-015772EF. Then ‘network settings’ was clicked on. The IPv4 Address was then taken note of, which in this case it is 169.255.10.10 as shown in Figure 3.7.

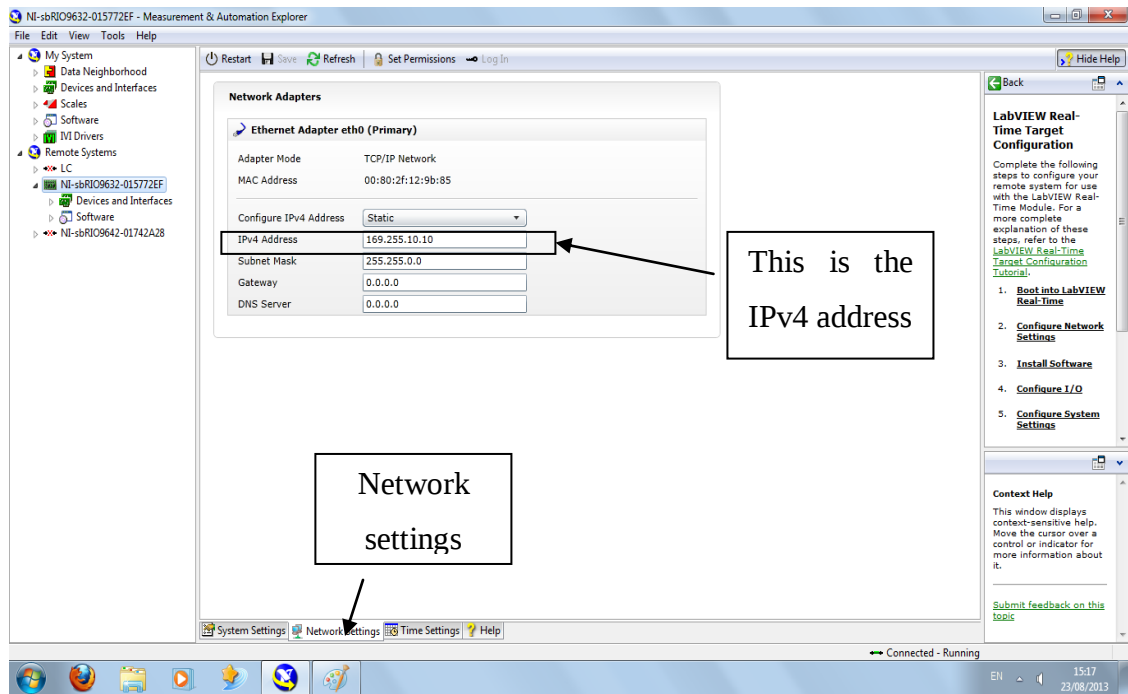


Figure 3.7: Network Settings

Then the following actions were taken: Control Panel → Networking and Sharing Centre → Change adapter settings. This is shown in Figure 3.8.

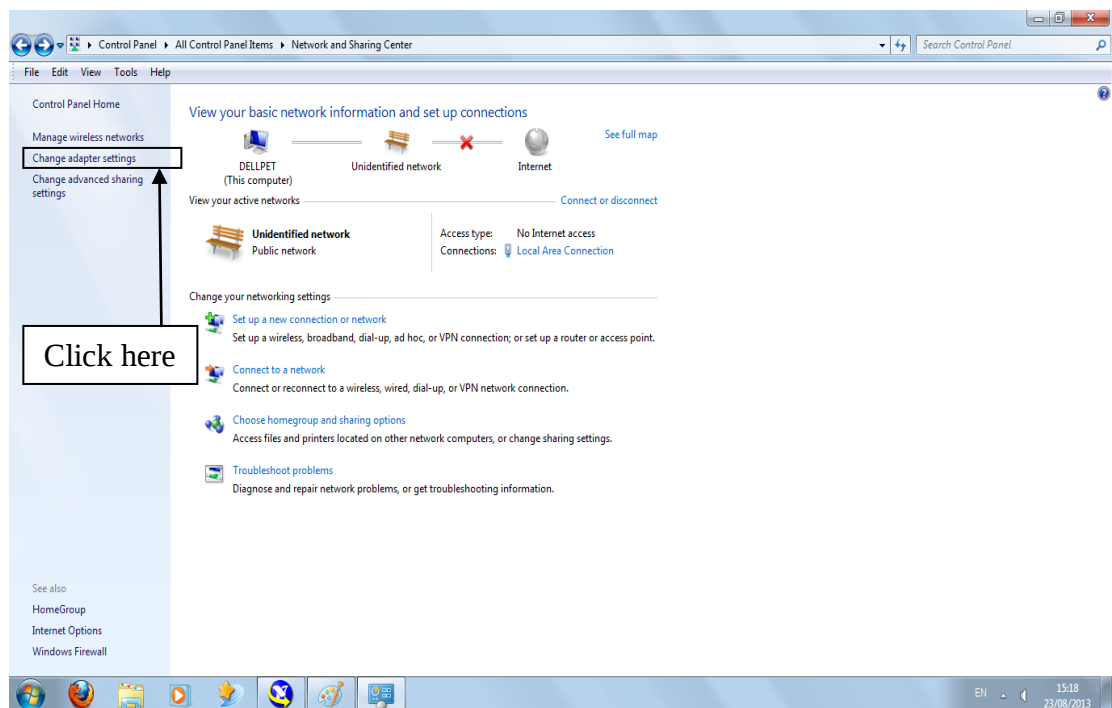


Figure 3.8: Network and Sharing Centre

The properties of the Local Area Connection were located by right clicking on Local Area Connection Atheros Fast Ethernet, and clicking 'Properties'. This is illustrated in Figure 3.9.

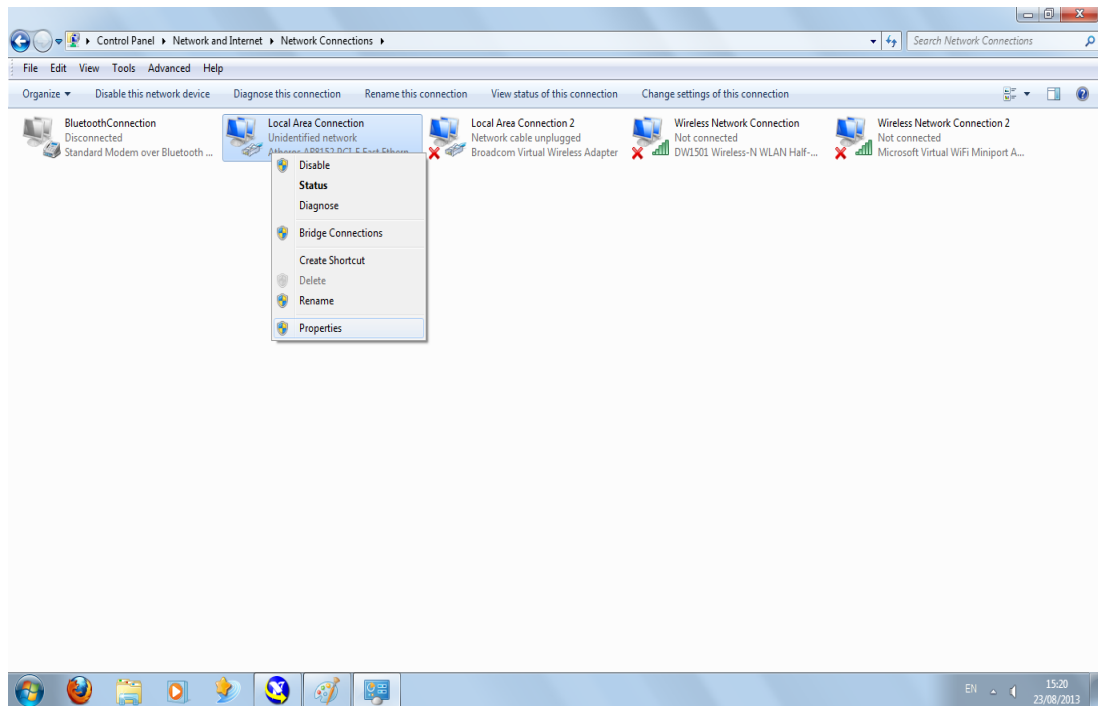


Figure 3.9: Change Adapter Settings

After that, the properties of Internet Protocol Version 4 (TCP/IPv4) were located by clicking on Properties as can be seen in Figure 3.10.

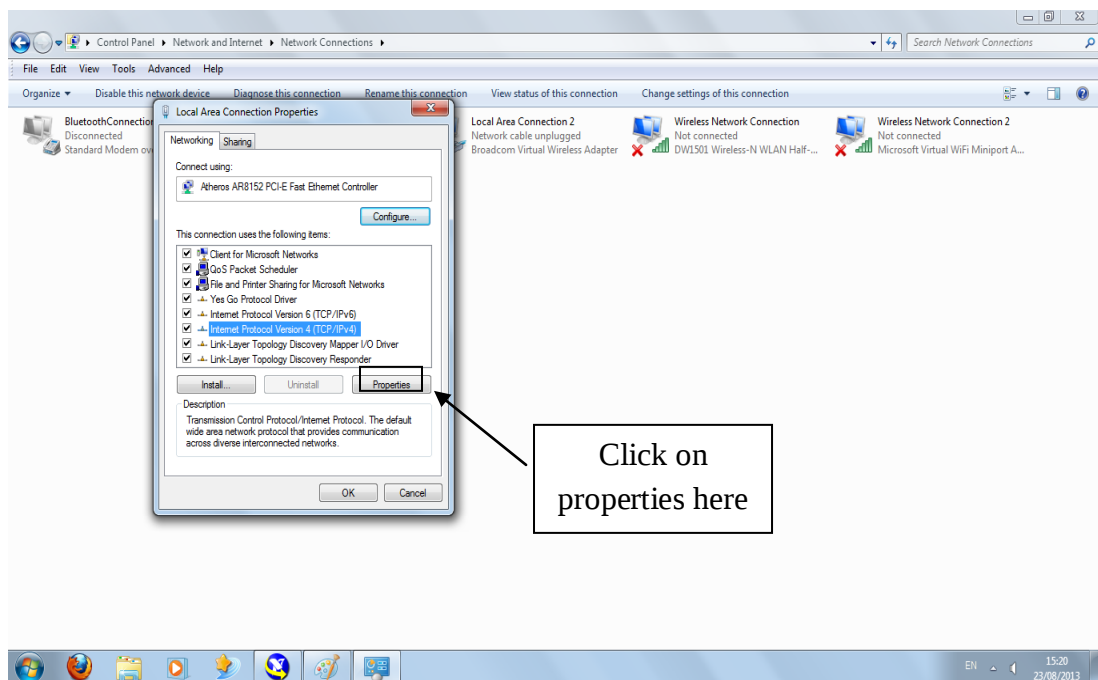


Figure 3.10: Local Area Connection Properties

Then, the option 'Use the following IP address automatically' was chosen and the IP address slot filled up. The IP address was the IP address of the SBRIO board taken earlier. However, the IP address filled in must be decremented or incremented by 1. Then, the subnet mask was automatically generated by clicking on the subnet mask row. Figure 3.11 gives a clearer picture of how this was done.

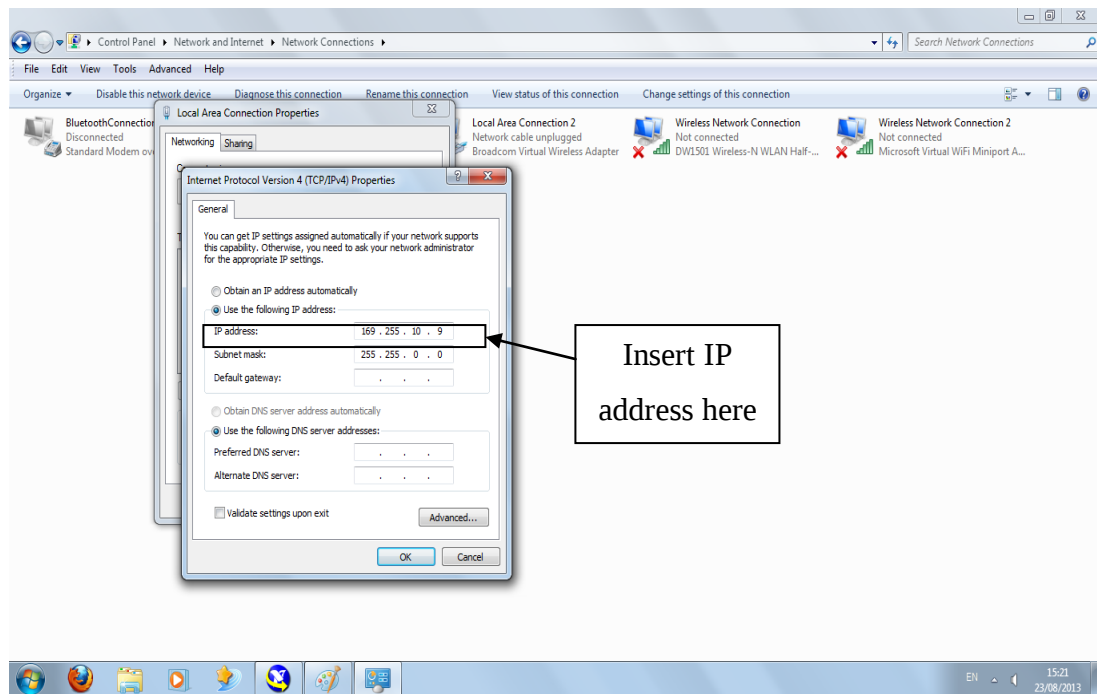


Figure 3.11: Internet Protocol Version 4 Properties

Finally, the configuration of SBRIO-9632XT to the computer was completed after the OK button was clicked and the control panel window was closed.

3.2.3 Performing Basic Measurement Using LabVIEW

The following flow chart in Figure 3.12 shows how LabVIEW was used to perform basic measurement of the electrical parameters in a power system.

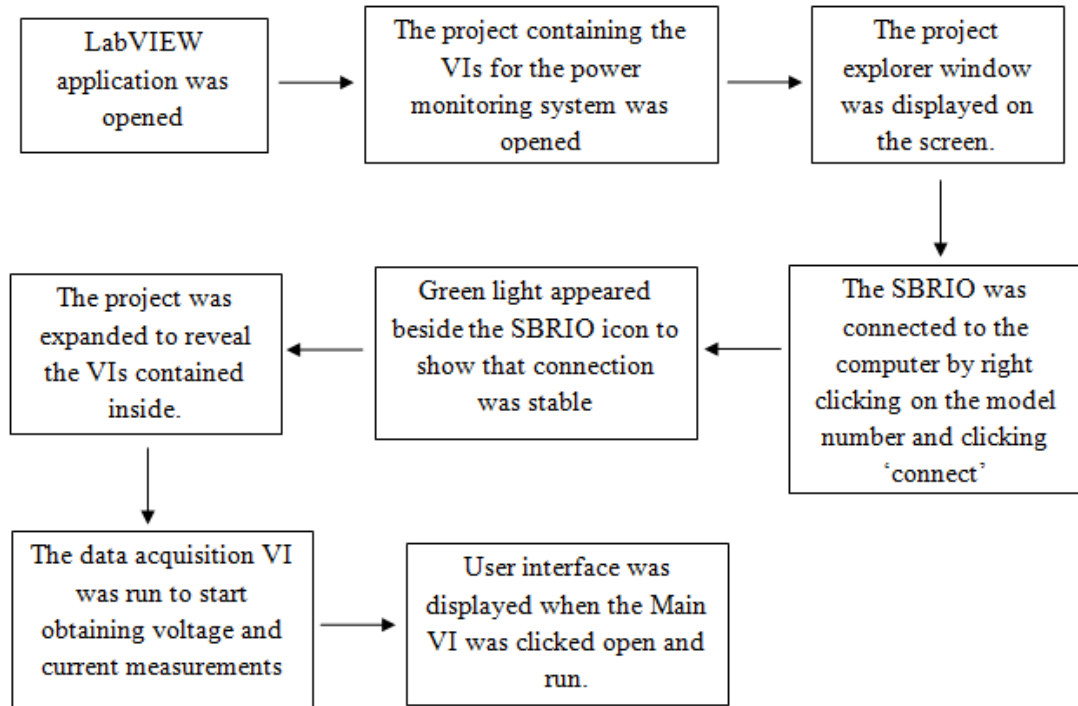


Figure 3.12: Performing Basic Measurement

3.3 Design Architecture

In designing this BPMS, a total of 4 main VIs were constructed and developed. All the VIs were saved into a project under LabVIEW. As explained in the flow chart earlier, to access all the VIs developed for this application, users must first open the relevant project. Data measurement, viewing and recording can then be conducted provided that the SBRIO is already connected to the computer and the power monitoring device is connected properly to the power source and load. The VIs also consist of sub-VIs to ensure that the block diagram looks neater and for easy troubleshooting. The four main VIs are named as Data Acquisition VI, TDMS Write VI, View Real-Time VI and Read from TDMS VI. In the following sections, each

main VI will be described and discussed in detail in terms of their front panel and block diagram (coding).

3.3.1 Data Acquisition VI

The function of the VI, as its name clearly states, is to acquire data from the SBRIO and interpret the data into values that can be further used by other VIs for other purposes. This VI is essential in converting the raw data into proper values of the correct format that are required by a power monitoring system. In this VI, a total of 15 elements are collected from the SBRIO. These 15 elements are categorised into 5 network shared variables. The purpose of the network shared variables is to allow other VIs in the same project to access these data values as well. The elements that are collected can be viewed in Table 3.1.

Network shared variable	Frequency	Current	Voltage	Power	Energy
Elements	Frequency	Phase A	Phase A	Active power	Active energy
		Phase B	Phase B	Reactive power	Reactive energy
		Phases C	Phase C	Apparent power	Apparent energy
		Neutral		Power factor	

Table 3.1 Data parameters collected from SBRIO

The sub-VIs (VIs inside another VI) of the Data Acquisition VI are built-in VIs of the Electrical Power Basic Measurement module in LabVIEW. The sub-VIs used are the AC DC coupling VI, Convert to Waveforms VI, Frequency VI, RMS VI, Power VI and Energy VI. Some snippets of the code are shown in Figure 3.13, figure 3.14 and figure 3.15 and explained.

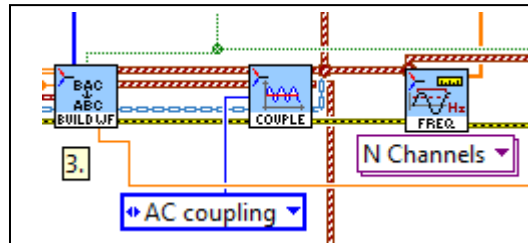


Figure 3.13 Convert to Waveforms, AC DC coupling, Frequency subVI

The convert to waveforms VI converts arrays of voltage and current data into voltage and current waveforms. The AC DC coupling VI eliminates the DC component of the voltage and current waveforms when AC type of coupling is selected. The voltage waveform is then passed through the frequency sub-VI, whereby the frequency of the voltage waveform is calculated. The output of the sub-VI is actually an array of frequencies that correspond to the 3 phases of voltage.

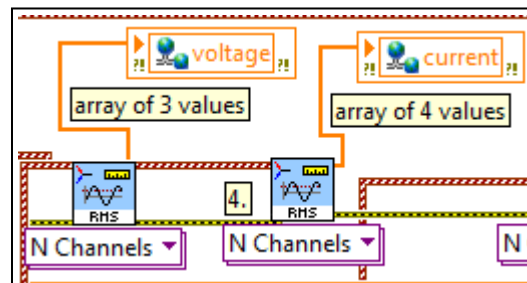


Figure 3.14 RMS sub-VI

Figure 3.14 shows how RMS sub-VI is used. The voltage waveforms are then passed through the RMS sub-VI which will calculate the Root Mean Square (RMS) values of the waveforms. An array of 3 values (phase A, phase B and phase C voltages) are obtained. The current waveforms are also passed through the RMS sub-VI to obtain the RMS values of the current. An array of 4 values (phase A, phase B, phase C and neutral current) are obtained. Similarly, in the power sub-VI, values of active power, apparent power, reactive power and power factor are obtained. In the energy sub-VI, values of active energy, apparent energy and reactive energy are obtained. Figure 3.15 shows how the power sub-VI and energy sub-VI are used.

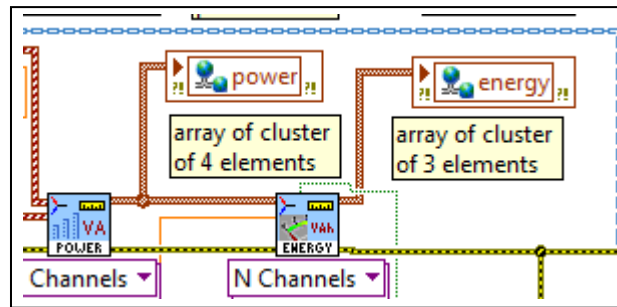


Figure 3.15 Power and Energy sub-VI

The power monitoring device designed has two options for the user to choose depending on the type of measurement performed, internal or external. Internal measurement is for measuring the power of one load, whereby the CT used is located inside the device. External measurement is for measuring the power of many loads by clamping a CT to the supply cable. Before the current waveform is passed through the RMS sub-VI, it is multiplied according to the CT ratio to get the actual value of current before it was stepped down earlier. The figures 3.16 and 3.17 show the coding for cases of internal measurement and external measurement.

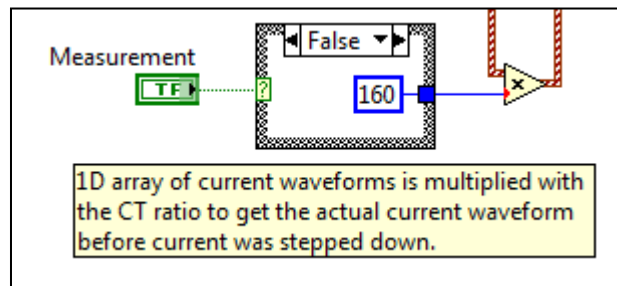


Figure 3.16 External measurement CT ratio

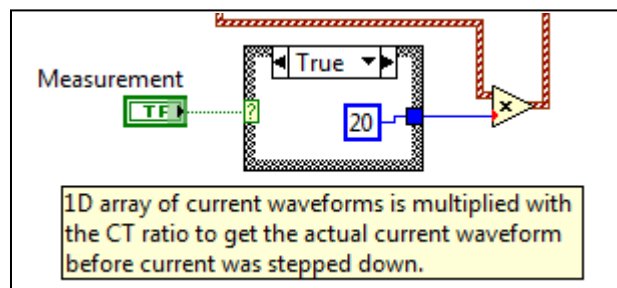


Figure 3.17 Internal measurement CT ratio

Figure 3.18 shows the overall block diagram for the Data acquisition VI.

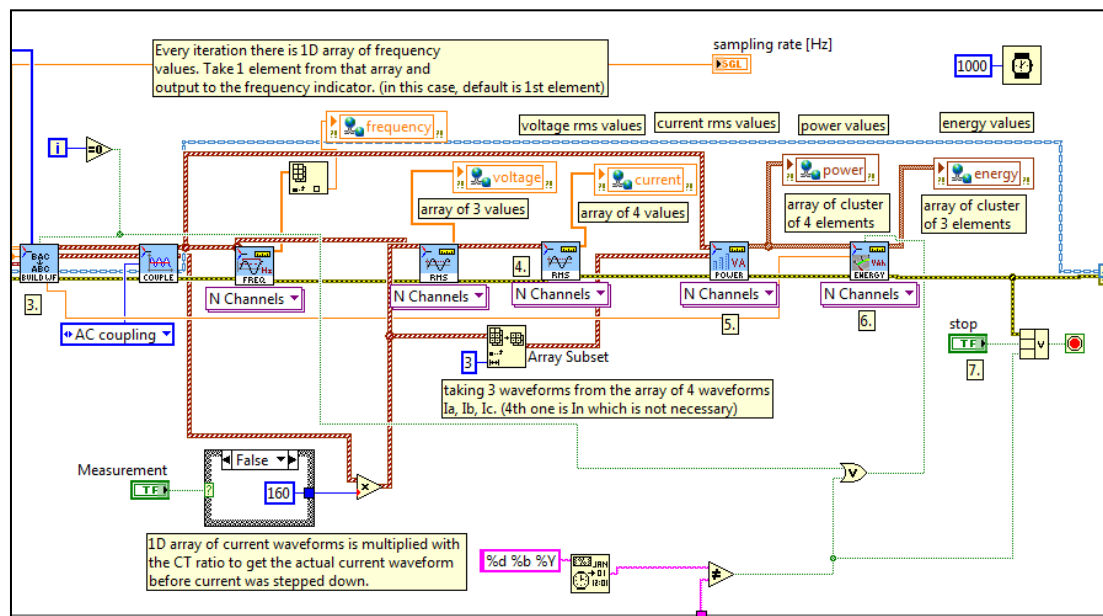


Figure 3.18 Block diagram of Data acquisition VI.

3.3.2 TDMS Write VI

Technical Data Management Streaming (TDMS) is a file format developed by NI for saving well-documented measurement data to disk. This file format ensures that data is stored in an efficient, organised and scalable method. As mentioned earlier, one of the objectives of this project is to create a database management system for the BPMS. To create a database, the measurement values obtained from the SBRIO need to be written and saved to the computer. The coding is designed such that the database created consists of many TDMS files containing the energy data, which is properly sorted according to month, date, time and parameter.

Using the TDM Excel Add-in Tool also developed by NI, the TDMS files can be loaded into Microsoft Excel and the once the TDMS file is imported, it can be opened using Microsoft Excel application. Each TDMS file loaded into Excel creates a new workbook. The data can then be viewed on spreadsheets and analysis can be performed easily.

The values from the network shared variables (frequency, voltage, current, power, energy) are written to the TDMS file using the TDMS Write function provided in LabVIEW (note that VI and function are not equivalent to each other). There are three levels of hierarchy, namely, file, groups and channels in a TDMS file structure. A group can have an unlimited number of channels. In this project, the groups refer to the dates that data acquisition is performed. The channels refer to the parameters of the data collected eg. Voltage phase A, current phase A etc. When the TDMS file is opened in Microsoft Excel, the group name corresponds to the worksheet name, and the channel name corresponds to the column heading in the worksheet.

To write data to a TDMS file, the file must be opened or created first. In the BPMS designed, the folder that contains all the TDMS data files is named 'Database' and the names of the TDMS files are the month names that signifies the date that data is acquired. The 'Application directory' function is used to produce the file path that holds the path of the VI, and when used with 'Build Path' function, will combine folder and file name, creating a file path for the 'TDMS open' function to run. Figure 3.19 shows how the file path was created.

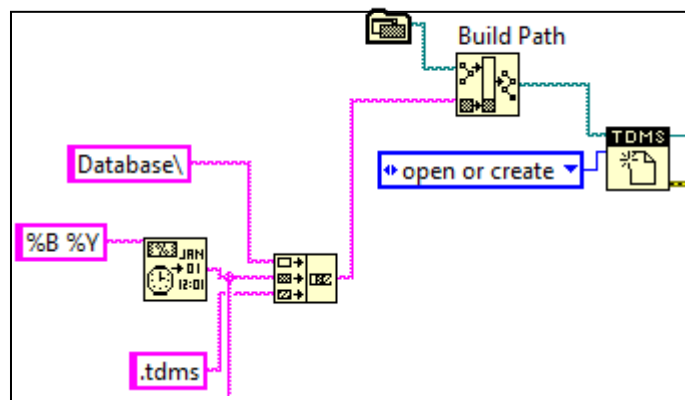


Figure 3.19 Creating a File path

The sub-VIs in the TDMS Write VI are Write to TDMS VI, Voltage Write to TDMS VI, Current Write to TDMS VI, Power Write to TDMS VI and Energy Write to TDMS VI as can be seen in the code illustrated in Figure 3.20. The time (in hour, minutes and seconds) corresponding to the data acquired is also recorded into the file using the 'Format date/time string' function and 'TDMS Write' function. The TDMS

Set properties function is used to change the main properties of the TDMS file. In this case, it is the name of the author of the file. The frequency is also written into the TDMS file after it is obtained from the network published variable.

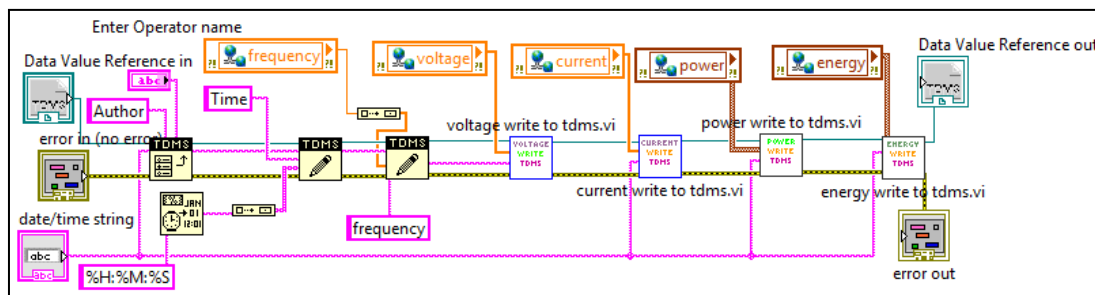


Figure 3.20 Arrangement of sub-VIs.

The Voltage Write to TDMS VI serves the purpose of writing the voltage data into the TDMS file. Similarly, the Current Write to TDMS VI, Power Write to TDMS VI and Energy Write to TDMS VI function to write the current, power and energy parameters respectively. All these VIs are arranged so that they do not perform at the same time, but one after another. This is done by using an error cluster which will give an error code or value if there is an error in any of these functions or sub-VIs. When error clusters are connected from function to function, the code will execute sequentially.

The array of RMS voltage values consists of three values each time the while loop iterates. These three values correspond to voltage phase A, B and C respectively. So the code must be written such that the elements can be extracted from the array and this is done using the Index Array function. Then, each data value is sent to a separate TDMS Write function, where the data will be assigned to a column that corresponds to the channel name. The data/time string function will generate the date eg. 14 Mar 2014, and when connected to the TDMS Write function, it will become the group name. All these data are written into the same TDMS file. The coding for the Voltage Write to TDMS VI is shown in Figure 3.21.

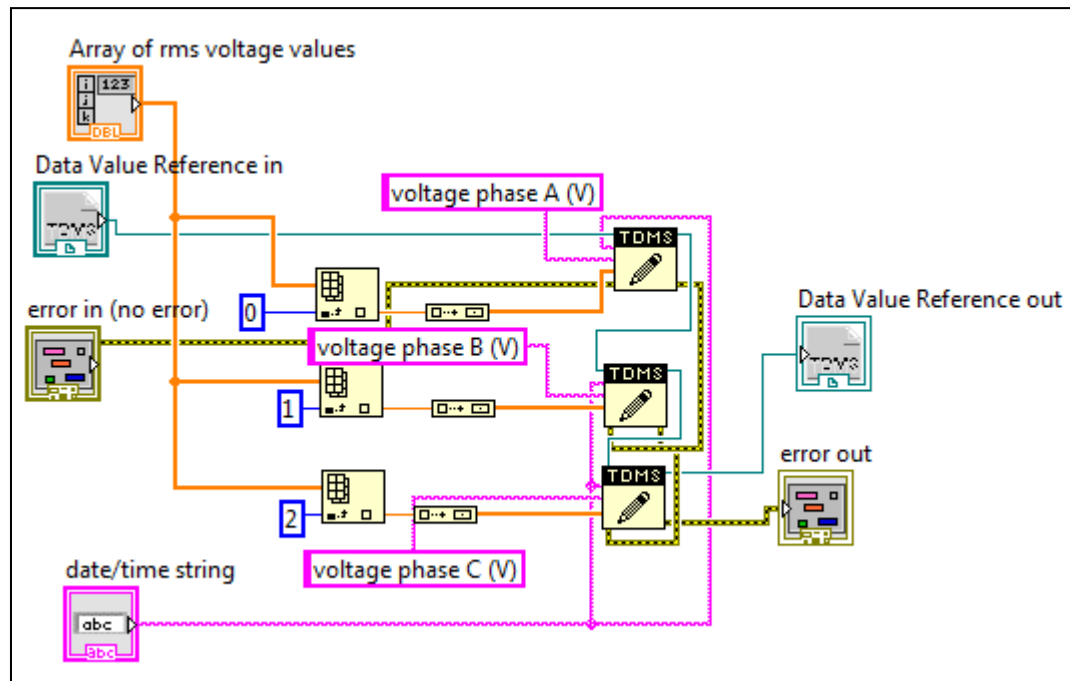


Figure 3.21 Voltage Write to TDMS VI block diagram

Figure 3.22 illustrates part of the TDMS Write VI. As can be seen on the block diagram, the data is written to the file every minute as the timing of the while loop is set to 60000ms which equals to one minute. Recording of data into the file can be performed continuously over a period of a few days, even up to months. The code written enables a new worksheet to be used every time the date changes. This is achieved by using the Format Date/Time String function and the Comparison function to observe any change in date. Any change in date will stop the while loop, following that a new date will be obtained and the data will be written into a new group in the TDMS file.

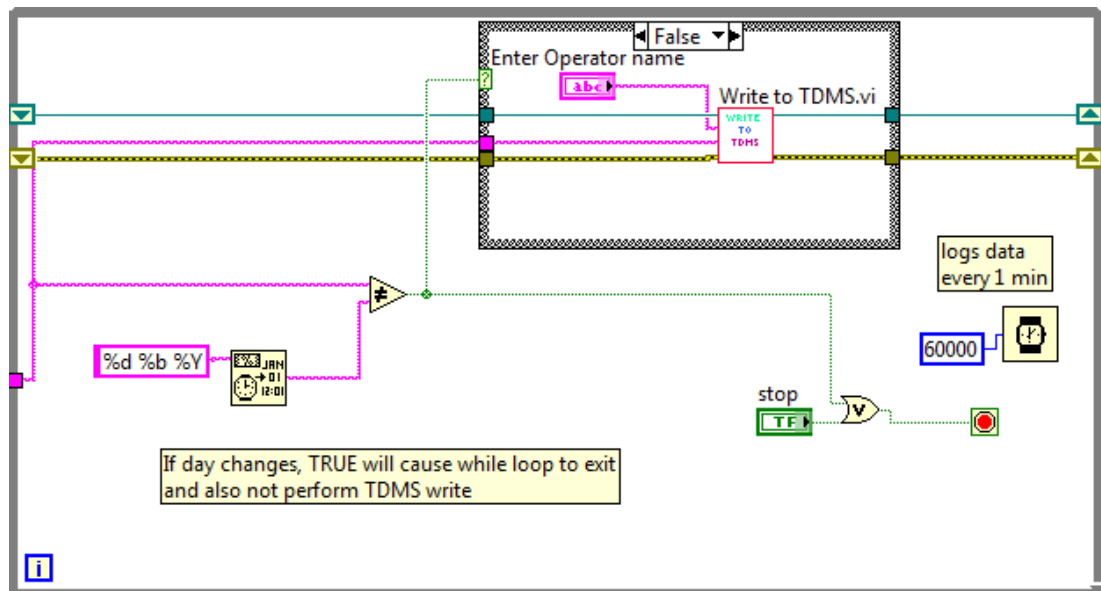


Figure 3.22 TDMS Write VI block diagram

3.3.3 View Real-Time VI

The Real-time VI displays the data obtained from the SBRIO in real time. The front panel of this VI is part of the user interface of the power monitoring system. In order to display the real-time data, the code must generate a waveform chart using the data values obtained. There are a total of 4 charts to display. They are voltage, current, energy and power charts.

Figure 3.23 shows the code for generating the energy chart. The 1D array of energy values are converted into cluster form before unbundling the cluster to obtain the elements from all 3 phases such as active energy, reactive energy and apparent energy. The purpose of unbundling the cluster is to extract the active energy of all the 3 phases, and also to change the unit of active energy from Wh to kWh. Then the active energy from these 3 phases are bundled together and fed into the waveform chart indicator, which will display the active energy waveform.

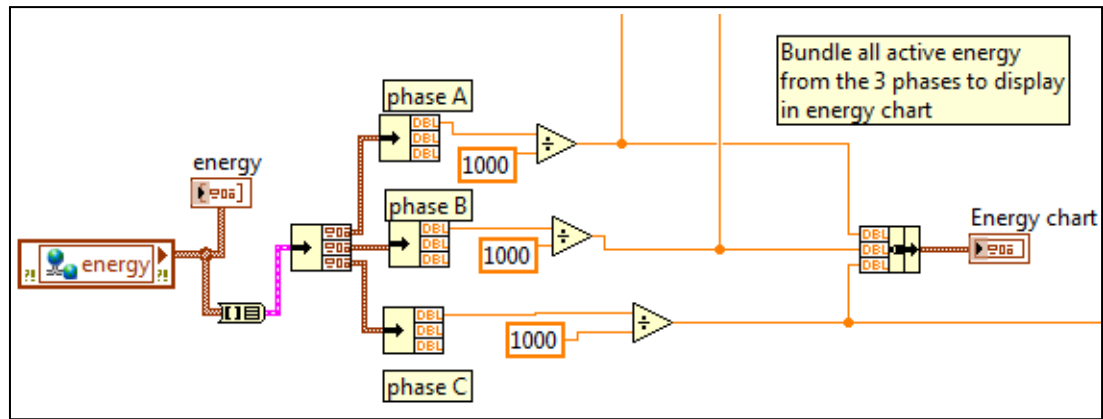


Figure 3.23 Displaying active energy in chart

Figure 3.24 shows the code for generating the current waveform chart. The code is simpler compared to the code for generating the energy chart. In this code, the data from the current variable is in the form of an array of double (floating point). So the array is passed to the Index Array function to get the elements of the array, which in this case is current phase A, current phase B and current phase C. These values are then bundled into a cluster and passed to the waveform chart indicator. The code for generating a voltage chart is also similar to this code.

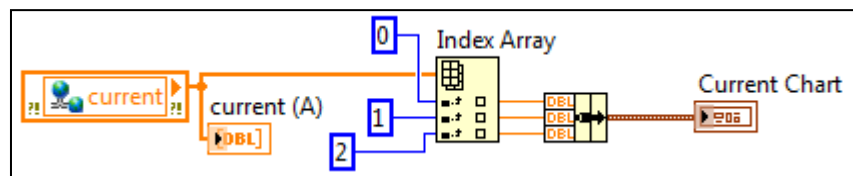


Figure 3.24 Displaying current in chart

Since the data is supposed to be viewed in real-time, the charts must be displayed according to the time that their values correspond to. To ensure accurate timing and display of time on the X-axis of the charts, the Get Date/Time function in LabVIEW is used along with the LV70TimeStampToDateRec VI and the property nodes of the waveform charts. The Get Date/Time function and the LV70TimeStampToDateRec VI output the total number of seconds elapsed since midnight, and this value is passed to the X scale offset, a property node of the waveform chart. This means that the starting value of the X scale will be the exact time as displayed on the computer clock. The X scale maximum is set to 60 (1 minute) so that time display on the X axis has a time span of 1 minute. The

waveform chart is also initialised to zero so that the chart is cleared every time the VI is run. Part of the code is shown in the Figure 3.25.

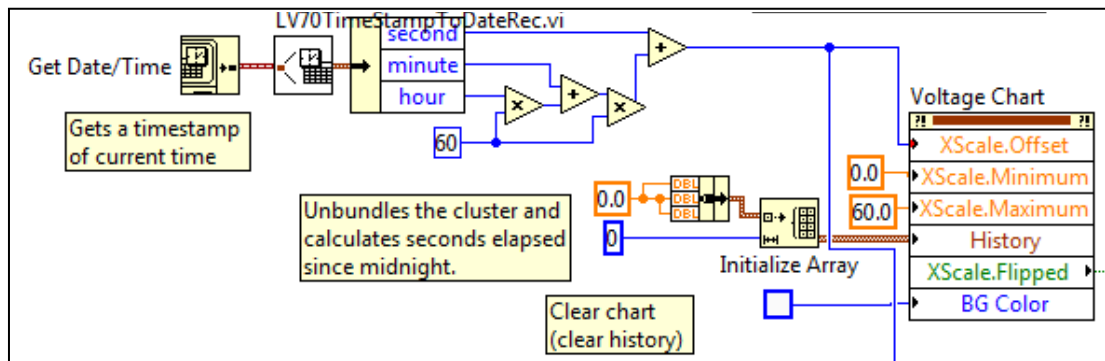


Figure 3.25 Setting time display on charts

The X scale spacing is set to 500ms which is equal to 0.5s. This means that the data will be taken every 0.5s and plotted on the chart. This is done by connecting the constant 0.5 to the X scale multiplier property node of the charts. The constant 500 is also connected to the 'Wait until Next ms Multiple' function, which will cause the while loop to iterate every 500ms. Since each iteration will generate one set of data, the data is acquired from the network published variables every 0.5 seconds. Figure 3.26 shows the code for setting the X scale multiplier of all the waveform charts to 0.5 seconds.

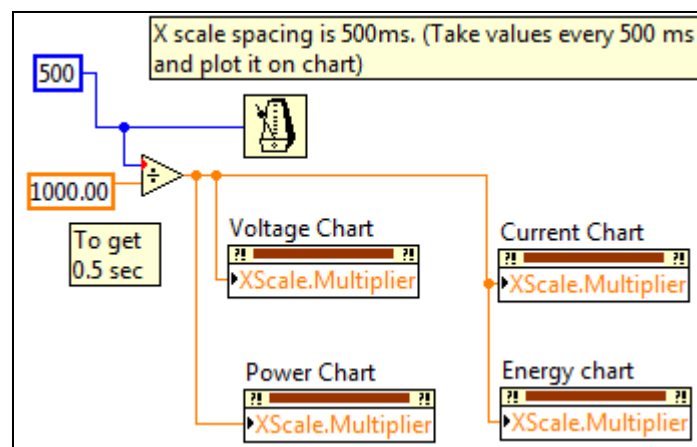


Figure 3.26 Setting X scale multiplier

3.3.4 Read from TDMS VI

The power monitoring system developed also allows users to view historical data. The data stored in the files must be able to be read on the user interface when the user chooses to do so. The system designed enables the historical data to be viewed per day and over a range of days. Hence, the coding for this function is divided into 2 sections: per day and range of days.

For the ‘per day’ section, users are required to choose the date and parameter that they want to view. An event structure is used to detect any change in value of the boolean ‘display’ button which the user will click to view the data. Clicking the ‘display’ button will change the boolean value from False to True. The event structure also has ‘Timeout’ event and ‘Stop’ event. If the user does not click on the display button, the event structure will go into the ‘Timeout’ event and continue to wait for the next action. The ‘Stop’ event will execute when the user presses the Stop button. During the Display event, the data will be read from the TDMS files and plotted on a graph. TDMS Read function is used and case structures are used for choice of parameter. The scan from string function is used to convert the ‘Time’ string obtained from the TDMS file into a timestamp because the XYgraph in LabVIEW cannot read string data type. Figure 3.27 shows part of the code for reading the data from the TDMS file and converting the string of time values into timestamps. This part of the code is for the case of active power.

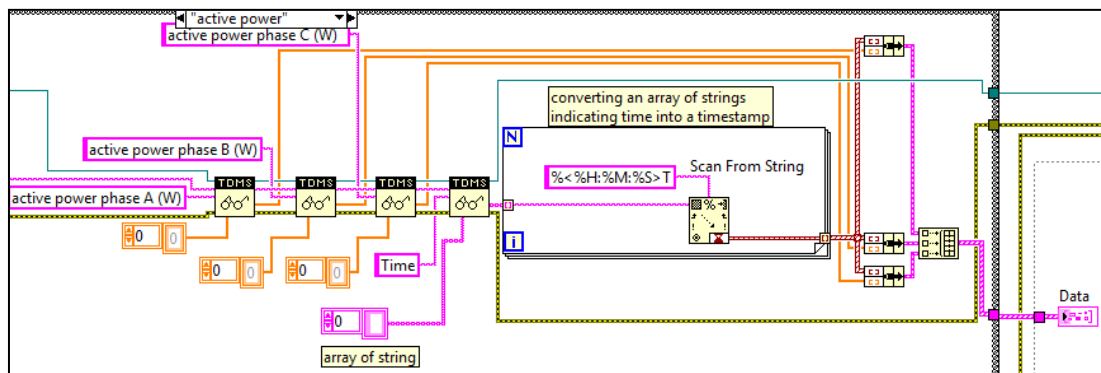


Figure 3.27 TDMS Read and Convert to timestamp

Other than displaying the historical data in the graph, some important data such as total active energy, electrical cost, average power factor and maximum

demand charge of the whole day are calculated as well. The total active energy is obtained by reading the array of active energy data from the TDMS file, and then taking the value of the last element of the array. This is because energy is accumulated, so the last value is the maximum value and represents the total energy consumed on that day. The electrical cost is calculated according to the tariff that the user chooses. A case structure is used to allow users to choose between the four tariffs: C1, C2, E1 and E2. The values of the tariff and the maximum demand unit price are then saved into the local variables as shown in the Figures 3.28 and 3.29.

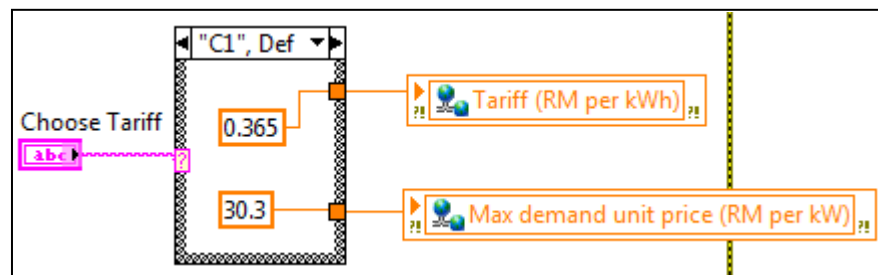


Figure 3.28 Case for C1 Tariff

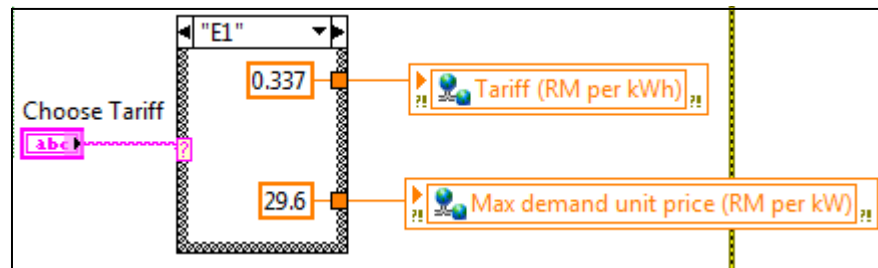


Figure 3.29 Case for E1 Tariff

Figure 3.30 shows part of the code for obtaining total active energy and calculating the electricity cost for the entire day. The tariff value is read from the local variable and multiplied with the total active energy to get the electricity cost.

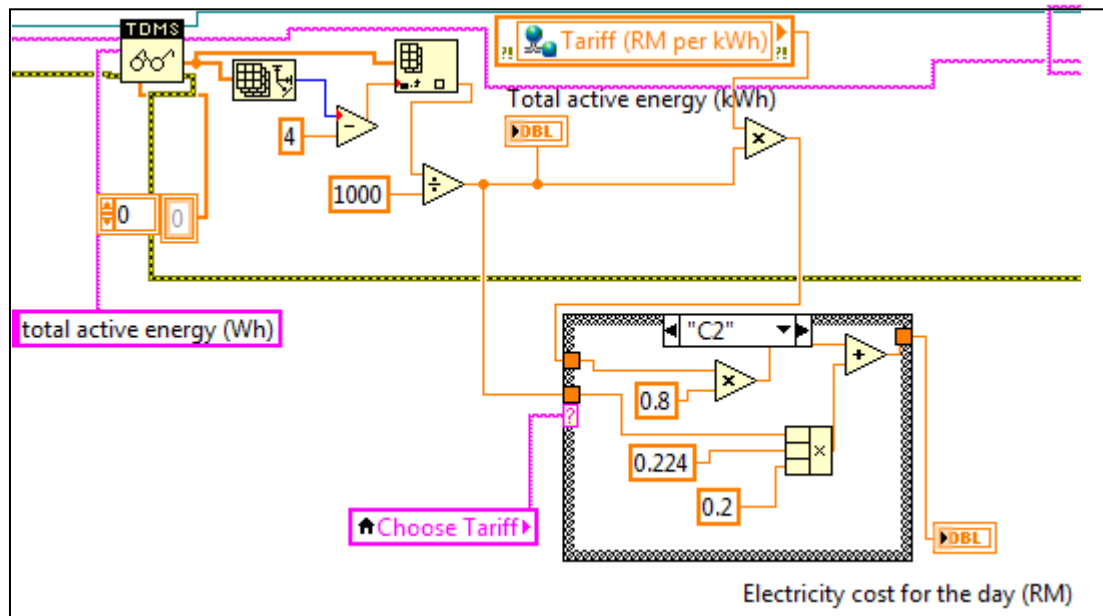


Figure 3.30 Total active energy and electricity cost per day

The maximum demand charge for the day is calculated by reading the values of active power from the TDMS file and averaging every 15 values. The maximum power all the averages is determined by the Array Max and Min function. Then the value of maximum power is multiplied with the maximum demand unit price to get the maximum demand charge for the day. Figure 3.31 shows how the calculation is performed.

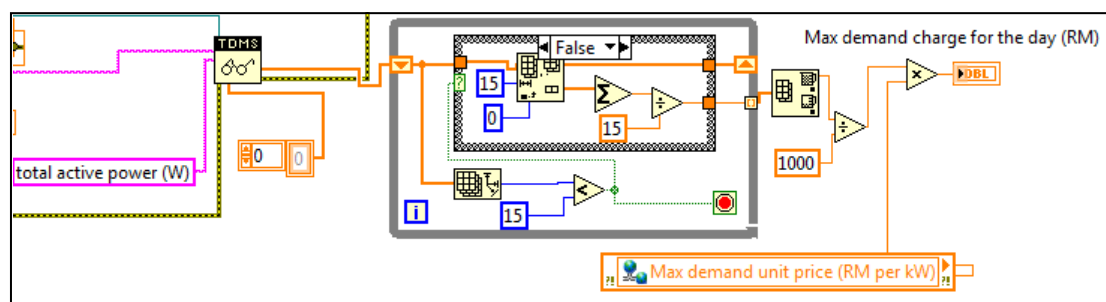


Figure 3.31 Maximum demand charge per day

The average power factor for the day is calculated by obtaining the array of power factors of each of the phases and taking the average. The 'Add Array Elements' function is used to sum up all the elements in the array. The 'Array size' function gives the total number of elements in the array. Using both of these functions in the code, the average value was calculated. Figure 3.32 shows the code for calculation of average power factor.

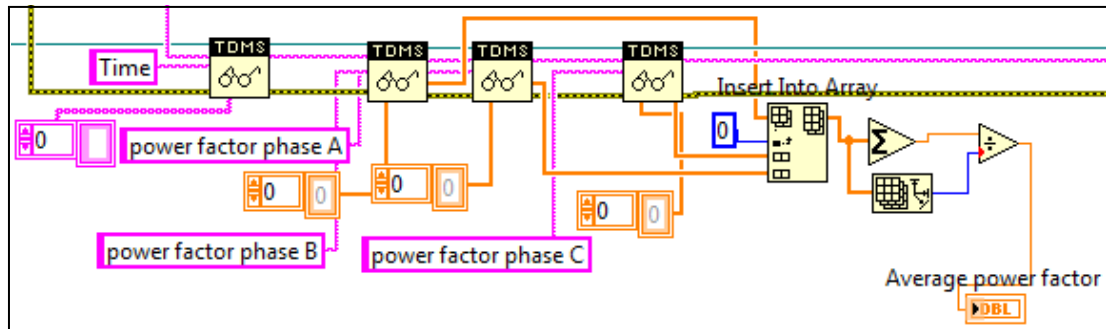


Figure 3.32 Average power factor per day

For the ‘range of days’ section, users can choose the range of days that they want for viewing the historical data on the user interface. Similar to the ‘per day’ section, an event structure is also used to trigger an event when the user clicks on the display button. In addition to the event structure, the code utilises a Listbox which allows users to select multiple days altogether. The selection mode of the Listbox is set to ‘0 or more items’ so that users can choose more than 1 day.

The Listbox lists all the dates that are stored in the database folder and TDMS files. The ‘List folder’ function is used to obtain all the file names. The ‘TDMS List contents’ will generate the group names (dates) in each TDMS file. The data output from the For loop is a 2D array of dates. This array is then converted to a 1D array and any empty array elements are deleted. The Search 1D array function searches the 1D array for any empty string constants and takes away the empty array elements. An example of the one of the elements of the array from the final data output is ‘24 March 2014’. The code for listing all the file names and file contents is illustrated in Figure 3.33.

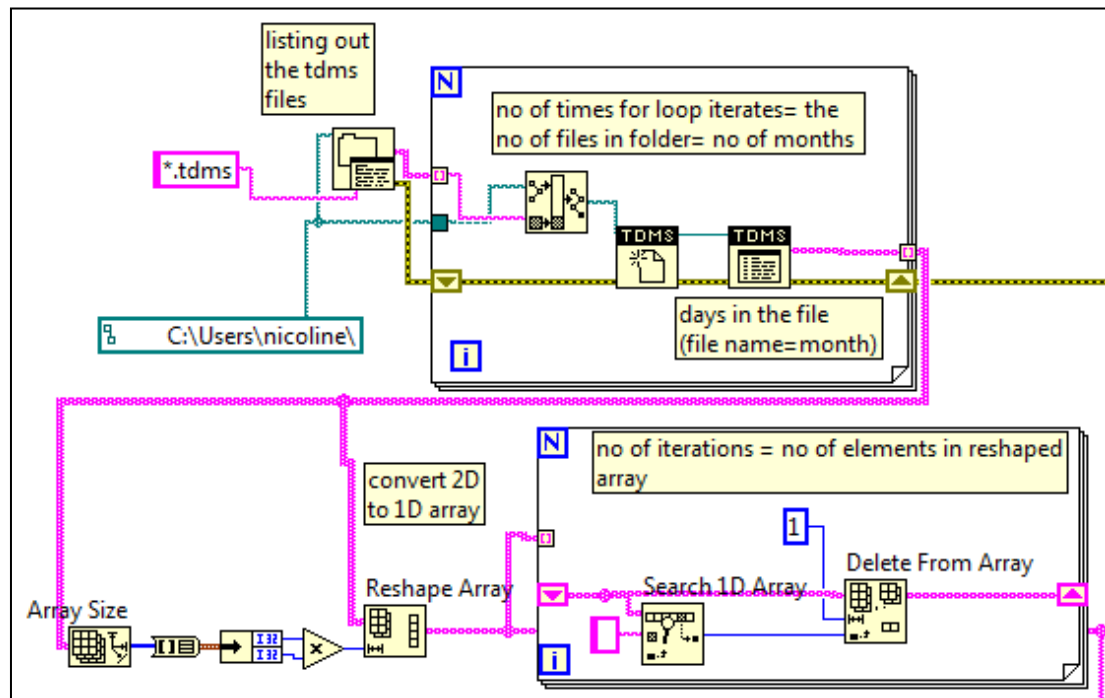


Figure 3.33 Listing TDMS file contents

The array of string elements are then passed through another section of the code to be sorted according to ascending days and months. This is important to ensure that the Listbox will show the dates in proper order for the users to select easily. The output is then fed into the Item names property node of Listbox, enabling the dates to be displayed on the Listbox on the user interface. The code is shown in Figure 3.34.

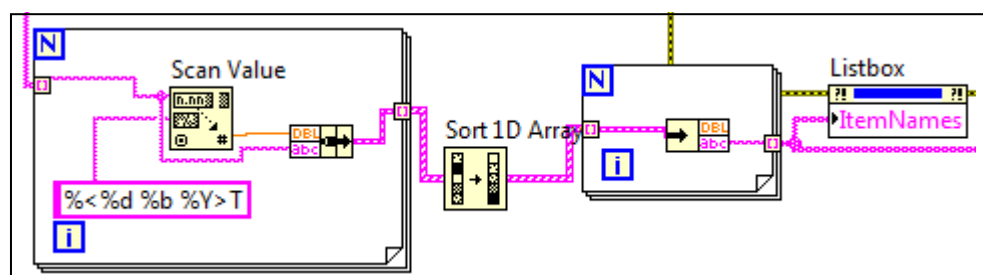


Figure 3.34 Sorting array elements

The event structure responds to any change in the Listbox value property node. The Listbox value is the row number of the selected item. To read the value of the Listbox is to read the index of the date selected. The code shown below enables the users to perform multiple selection of dates. The output of the Listbox control is an array of elements that represent the index of the date selected. For example, if the

user selected the first three dates that appeared in the Listbox, the array would have the elements 0, 1 and 2. The functions ‘Delete from array’ and ‘Insert into array’ are used with a Case structure to ensure that an item is selected when the user clicks on that item, and the same item is deselected when the user clicks on it again. Part of the code is shown in Figure 3.35.

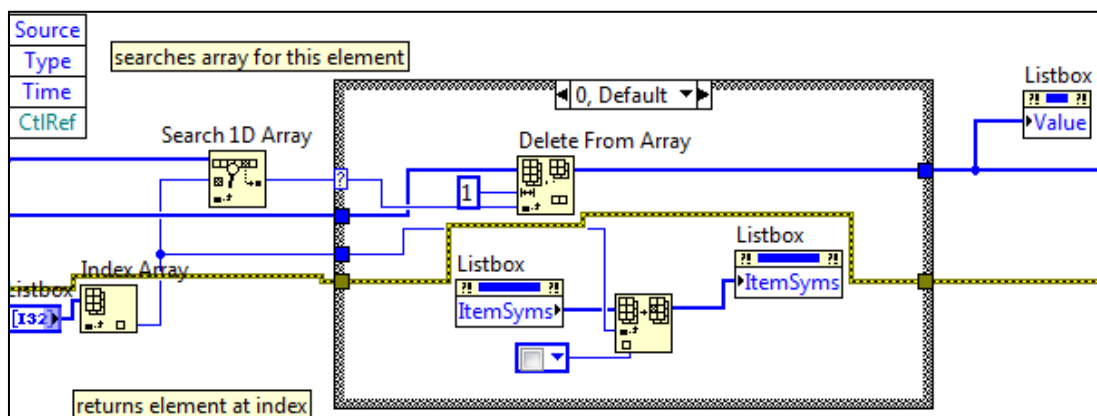


Figure 3.35 Multiple selection in Listbox

The event structure is also triggered by clicking the Display button. During the Display event, the historical data needs to be read from the TDMS file and plotted on the graph. A case structure is also used to house the code written for different parameters where each case represents each parameter such as voltage, apparent power etc. Figures 3.36 and 3.37 below shows the code for constructing the right file path based on the dates that the user selects and reading from the correct TDMS file for the case of ‘Total active power’ and ‘Reactive energy’.

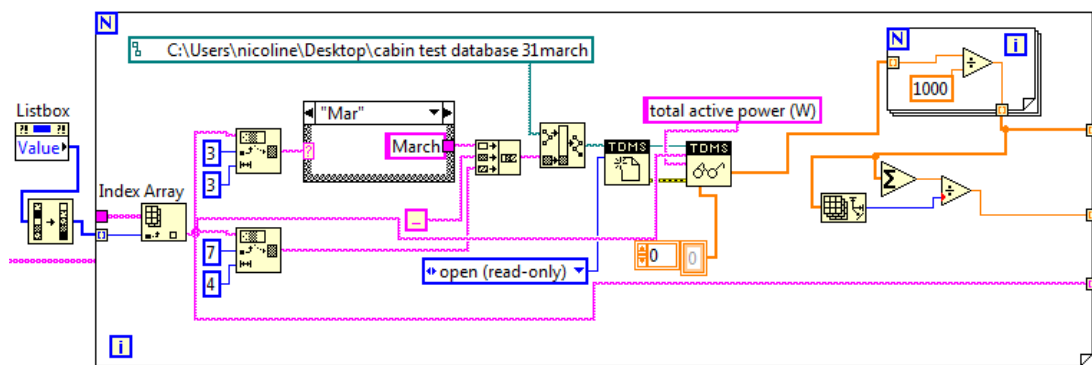


Figure 3.36 Read Total active power data

The array of Listbox values is passed to the Sort 1D array function to sort the elements in ascending order. This is important to ensure that the dates are in proper order and the graph is plotted with the earlier dates plotted first. The ‘String Subset’ function is used to extract a substring from the string input which is the date that the user chooses. Then ‘Build path’ function is used to build the correct file path using the substrings which represent the date and year, and the folder path. Similar to the ‘per day’ code, the code uses the TDMS read function to read the data from the TDMS file. The channel names vary according to the parameters.

The diagram illustrates a PLC program for a traffic light. It features a start button (N) connected to a timer (T) and a set coil (S) for a variable. The timer is set to 10 seconds. The variable is used in a logic block that controls the traffic light's state.

Figure 3.38 Convert date string to timestamp

3.4 Wireless Connection

In this project, the RIGER DB108-WL Wireless ADSL and Router is used for wireless connection. The router serves as a device to enable the computer to receive data wirelessly from the SBRIO. It also acts as an access point for other verified devices to receive data from the power monitoring device. The router is connected to the SBRIO via Ethernet cable. The Internet Protocol Version 4 properties must be set by the user first on the computer (or other devices) in order for the computer to gain access to the router. The procedure for configuration of SBRIO to the computer is similar to that of the configuration when using LAN connection explained in section 3.2.2.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

An experiment was conducted whereby the power system data was collected and recorded using the power monitoring system developed in this project. The power measuring device was put in the switch room located at SE block in UTAR, and an ethernet cable was used to connect the SBRIO in the device to the computer. The device was left in the switch room to collect data for a few days (18 March until 21 March, then 24 March until 28 March). In the following sections, the results obtained will be shown and explained.

4.2 Real-time power monitoring

The data that was obtained from the power measuring device in the switch room could be viewed real-time on the user interface. Figure 4.1 shows the voltage waveforms in the graph. The voltage values of phase A, phase B and phase C are also displayed next to the graph. The frequency of the waveform is also displayed clearly. The displayed values will change every 0.5 seconds as data is acquired every 0.5 seconds. It can be seen on the x-axis of the graph that the duration between the first point of data and the last point of data is 1 minute as programmed in the LabVIEW code.

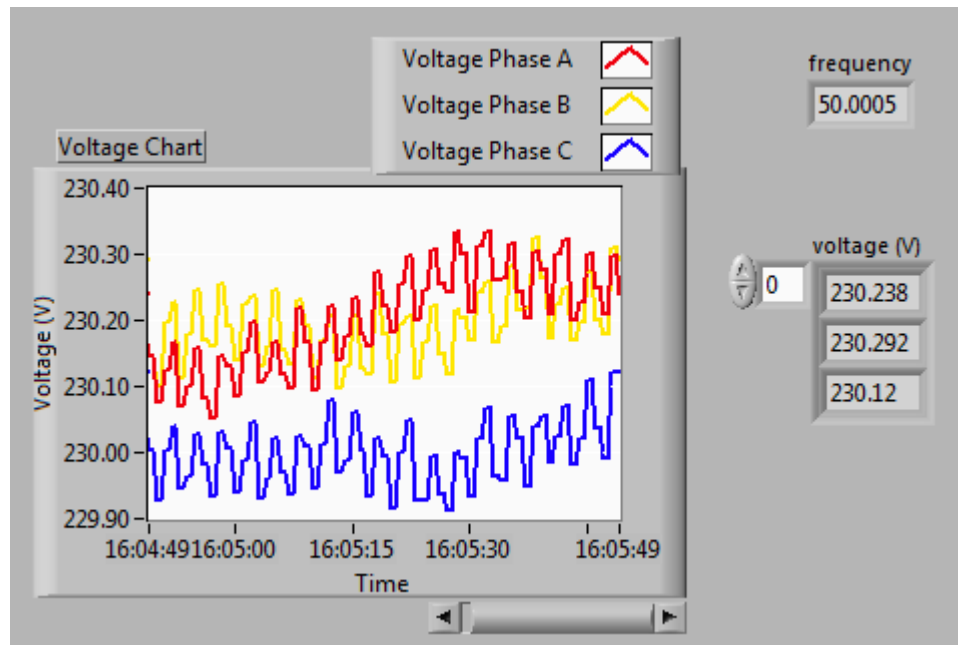


Figure 4.1 Real-time voltage chart

Figure 4.2 shows the current values obtained in real-time. The current values of phase A, phase B and phase C and neutral current are also displayed next to the graph.

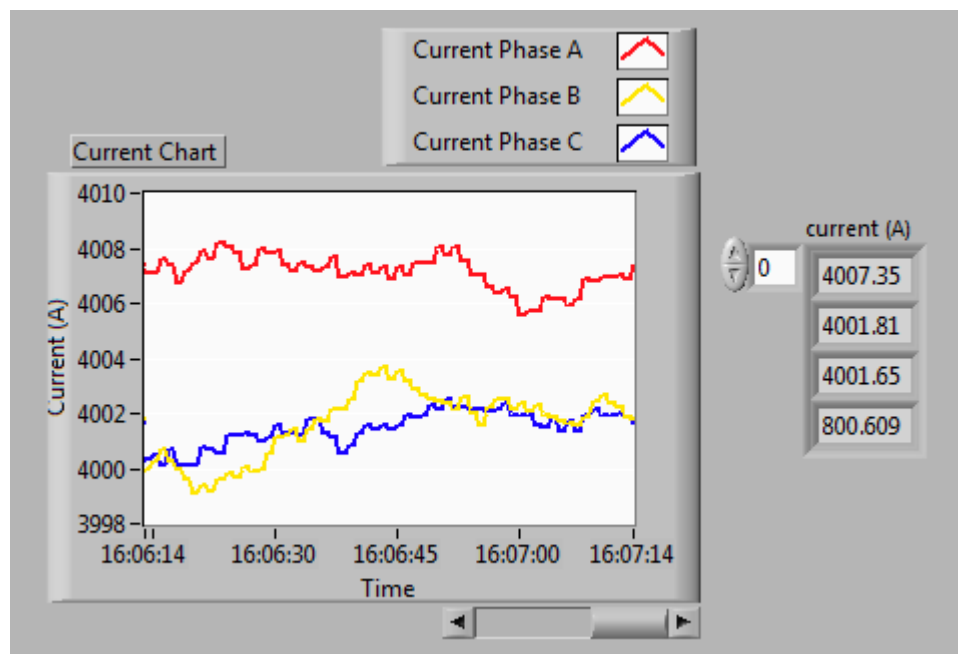


Figure 4.2 Real-time current chart

Figure 4.3 shows the active power values obtained in real-time. The graph displays the waveforms of active power of the 3 phases. The values that are displayed next to the graph are active power, apparent power, reactive power and power factor of each phase.

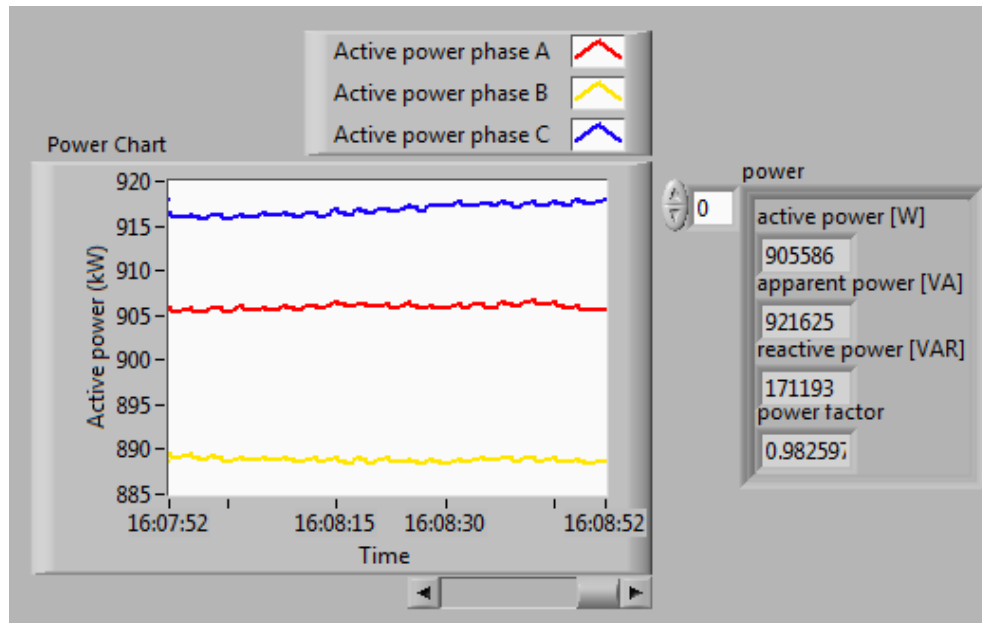


Figure 4.3 Real-time power chart

Figure 4.4 shows the active energy values obtained in real-time. The graph displays the waveforms of active energy of the 3 phases. The values that are displayed next to the graph are active energy, apparent energy and reactive energy of each phase.

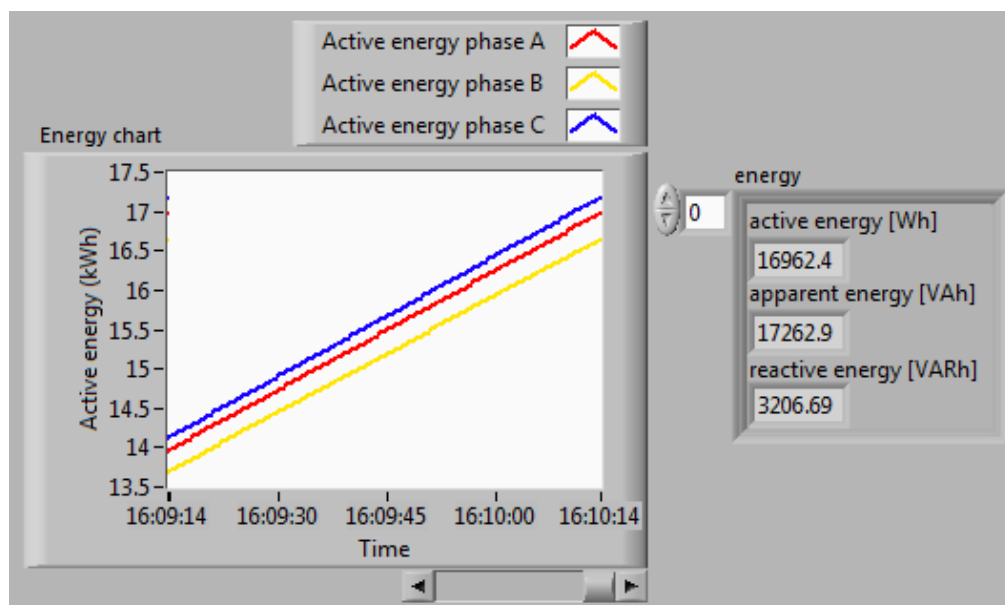


Figure 4.4 Real-time energy chart

4.3 Historical data recording

Data that is acquired from the power monitoring system is stored into TDMS files. The TDMS files, when opened with the NI TDM-Excel Add in Tool, will display data in Microsoft Excel format. Figures 4.5 and 4.6 show some of the data obtained on 25 March that is displayed in Microsoft Excel. It can be seen that the data is sorted systematically with each column representing a different parameter. Also, the 'Time' column has an increment of 1 minute for each set of data, which is correct according to the code developed.

Time	frequency	voltage phase A (V)	voltage phase B (V)	voltage phase C (V)	current phase A (A)
00:00:43	49.96034241	248.8055878	248.5809631	251.0260162	37.86884308
00:01:43	50.00629807	248.7151337	248.8229218	250.8298798	40.96302795
00:02:43	50.00048065	248.7270355	248.7668152	250.8413849	40.98553085
00:03:43	50.20330811	249.2745209	248.696228	251.0001221	41.27627563
00:04:43	50.03722382	248.9471283	249.0039978	251.1489868	42.41021347
00:05:43	50.02707672	249.2037354	249.0943298	251.2914581	39.10231018
00:06:43	50.18597794	248.7626801	249.268219	251.0719299	39.03336334
00:07:43	49.9303894	248.8405609	249.0233459	250.8514252	37.21669388
00:08:43	50.0619545	248.9835815	249.1508331	250.503067	39.99023056
00:09:43	50.24090195	249.3938904	249.2964783	251.2354126	25.19894981
00:10:43	49.99657059	249.3616791	249.306488	250.9003448	25.49449921
00:11:43	55.13892365	249.6920166	248.9643707	251.0229797	25.73907471
00:12:43	41.35580826	249.9057922	249.286377	251.0799408	22.29969597
00:13:43	50.28892899	250.1395111	249.3852386	250.9869385	22.32739258

Figure 4.5 Stored data in Excel

active power phase A (W)	apparent power phase A (VA)	reactive power phase A (VAR)	power factor phase A
9080.989258	9421.979492	2511.839844	0.963809013
9751.658203	10188.125	2950.092773	0.957159281
9897.582031	10194.20996	2441.268311	0.970902264
9999.318359	10289.12402	2424.811523	0.971833766
10238.08496	10557.90137	2578.933838	0.969708323
9355.368164	9744.441406	2726.025391	0.960072339
9319.226563	9710.043945	2727.080566	0.959751248
8947.87793	9261.023438	2387.892578	0.966186762
9674.942383	9956.911133	2352.779053	0.971681118
6023.327637	6284.464355	1792.7677	0.958447278
6116.688965	6357.351074	1732.636597	0.962144256
6189.623047	6426.841309	1729.986572	0.963089466
5256.550293	5572.823242	1850.685303	0.943247318
5269.077148	5584.962891	1851.658936	0.943439901

Figure 4.6 Stored power data in Excel

The Excel worksheet names are the dates on which the data recording was performed. The code in the TDMS Write VI has enabled the worksheet names to be labelled according to the correct date. Figure 4.7 shows how the dates are arranged.

251.0760803	22.32733727	0.02065446	0.024550423
250.8633881	25.16054153	0.016797137	0.019588565
251.1048279	25.3138485	0.021316564	0.023733851
24 Mar 2014	25 Mar 2014	26 Mar 2014	27 Mar 2014
			28 Mar 2014

Figure 4.7 Worksheet names

The data recorded is also stored by month. Data of different months are stored in different Excel Workbooks and the dates in that month are represented by the worksheets in that particular workbook. Figure 4.8 shows the TDMS files in the Database folder. The file 'March 2014' contains all the data recorded in the month of March.

February 2014	28/02/2014 17:24	TDMS File	958 KB
February 2014.tdms_index	28/02/2014 17:24	TDMS_INDEX File	874 KB
January 2014	18/01/2014 15:37	TDMS File	96 KB
January 2014.tdms_index	18/01/2014 15:37	TDMS_INDEX File	88 KB
March 2014	07/04/2014 09:34	TDMS File	1,531 KB
March 2014.tdms_index	07/04/2014 09:34	TDMS_INDEX File	60 KB

Figure 4.8 TDMS file names

The data that is recorded in Excel can then be analysed. Some of the historical data obtained are plotted on graphs. Figure 4.9, Figure 4.10 and Figure 4.11 show the total active power consumption of the building on 20 March, 26 March and 27 March 2014. The total active power includes the power consumption of all the 3 phases (phase A, B and C).

From the graph plotted for 20 March, it can be observed that the total active power was very minimal before 7:30 in the morning. The amount of power used was below 10kW. Then, the power slowly rose to the range of 40-50kW from 7:30 in the morning to 3:00 in the afternoon. After 3:00pm, the power slowly decreased until it reached a value of less than 10kW at around 8:00 at night. The period of time when the power consumption was more than 30kW is 5 hours, that is, from 10am to 3pm.

The power consumption trend was similar to the graphs plotted for 26 March and 27 March on Figure 4.10 and Figure 4.11. The interval where the amount of power consumed on 26 March was more than 30kW was from 10am to 3pm. For 27 March, the period of time where the power consumption was more than 30kW is from 10am to 5pm. Since 20 March, 26 March and 27 March are all weekdays, it is natural that the power consumption was high from 10am to 5pm because this range of time was office hours. During this time, all classrooms were fully occupied by students attending tutorials or lectures. After that, only a few classrooms were occupied as there were fewer classes and this reduced the power consumed by that building. At night, all labs and classrooms were closed and so the power consumption was very minimal.

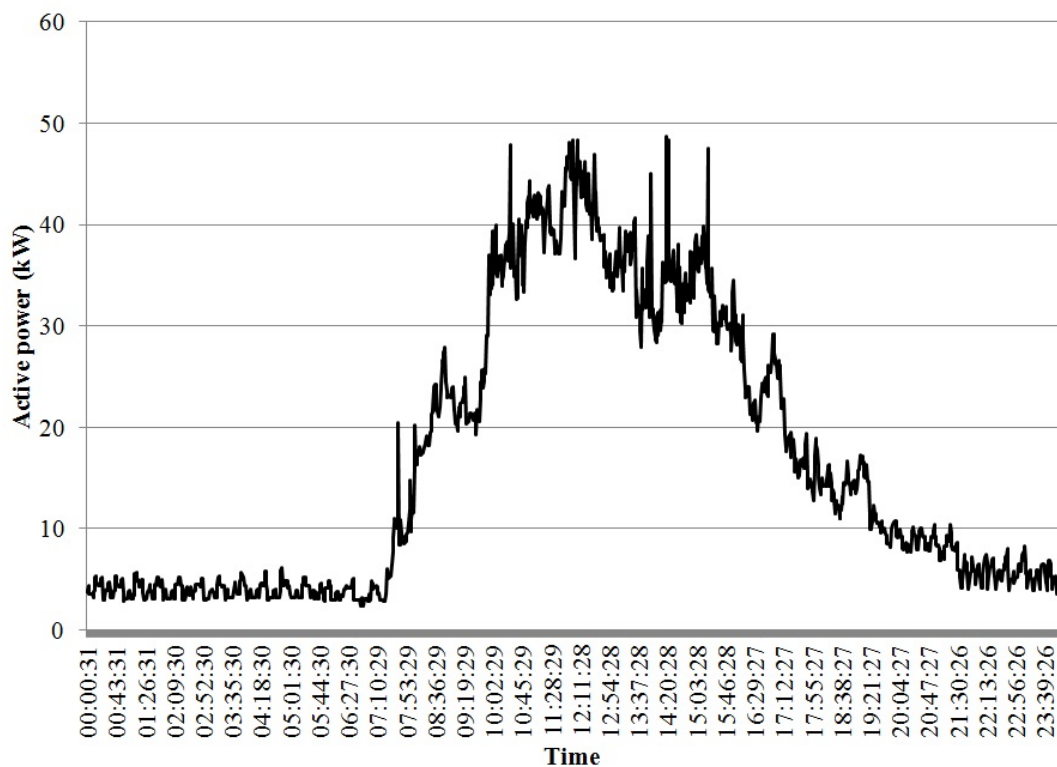


Figure 4.9 Total active power on 20 March

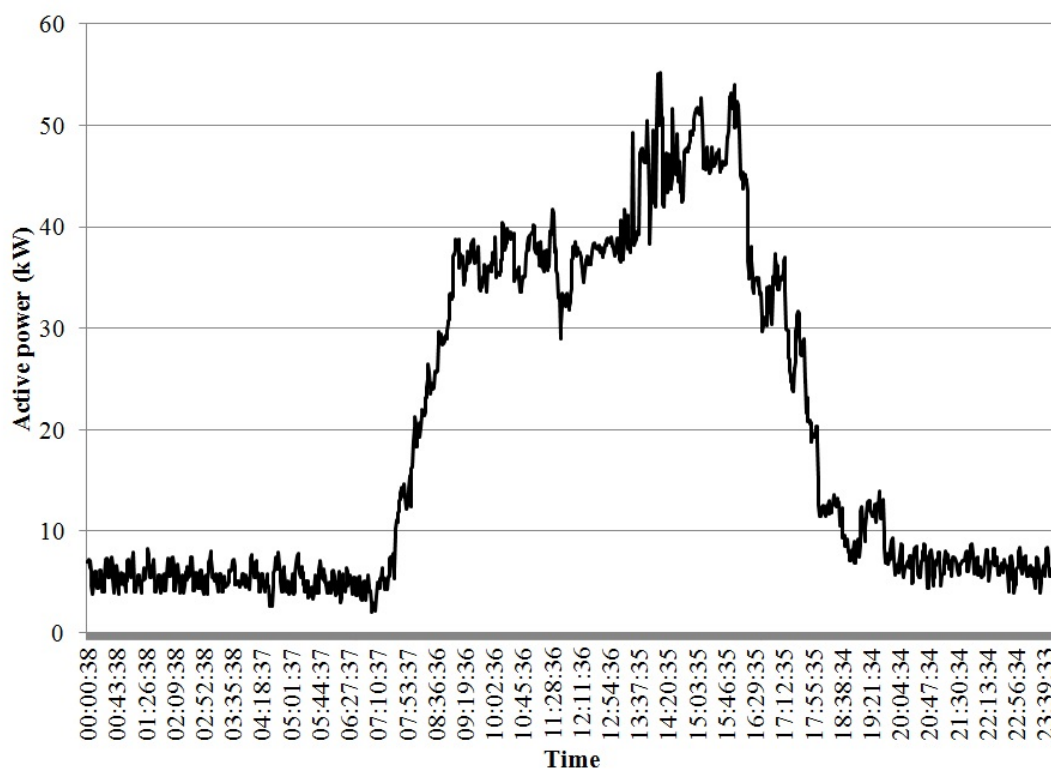


Figure 4.10 Total active power on 26 March

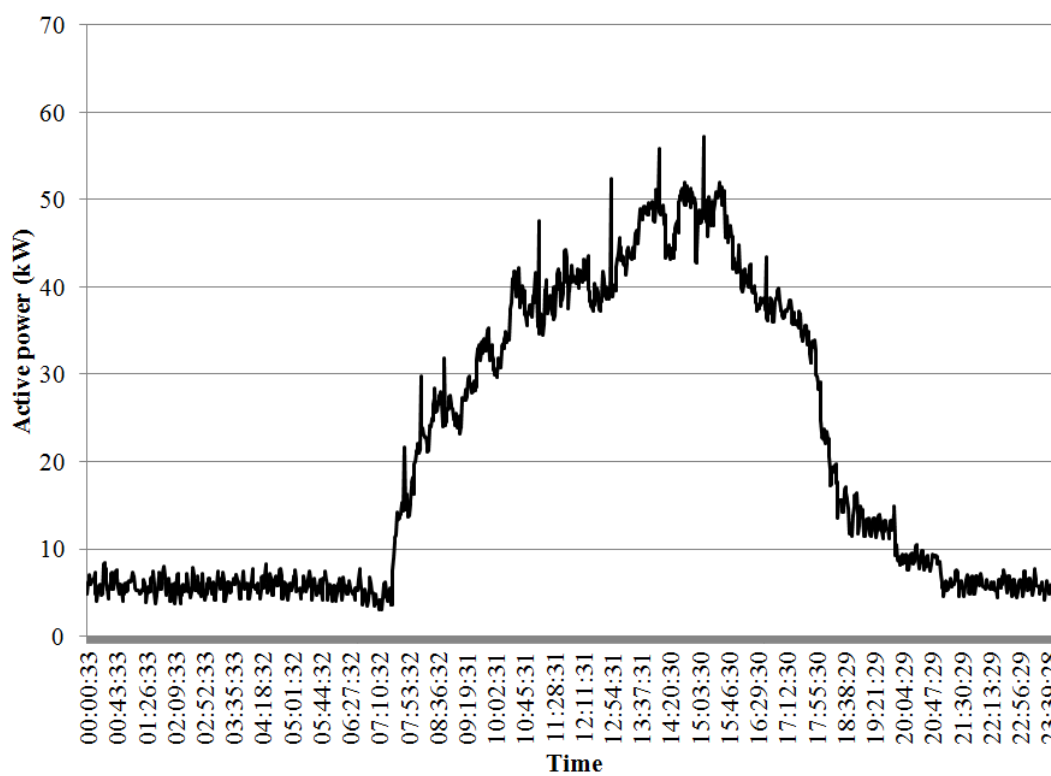


Figure 4.11 Total active power on 27 March

Figure 4.12 shows the phase A voltage measured from the SE building on 27 March. It can be observed that the highest voltage was 250V when the power consumption was very low. The lowest voltage was 237V when the power consumption was very high. An increase in load (load consumes more power) caused the voltage across the load to drop. This is because the load draws more current, increasing the internal voltage drop of the supply and thus reducing the terminal voltage supplied to the load. The voltage started from a high value and slowly decreased until it reached the lowest point at 11am, then after 3pm it slowly increased again. The range of fluctuation of the voltage was between 237 to 250V.

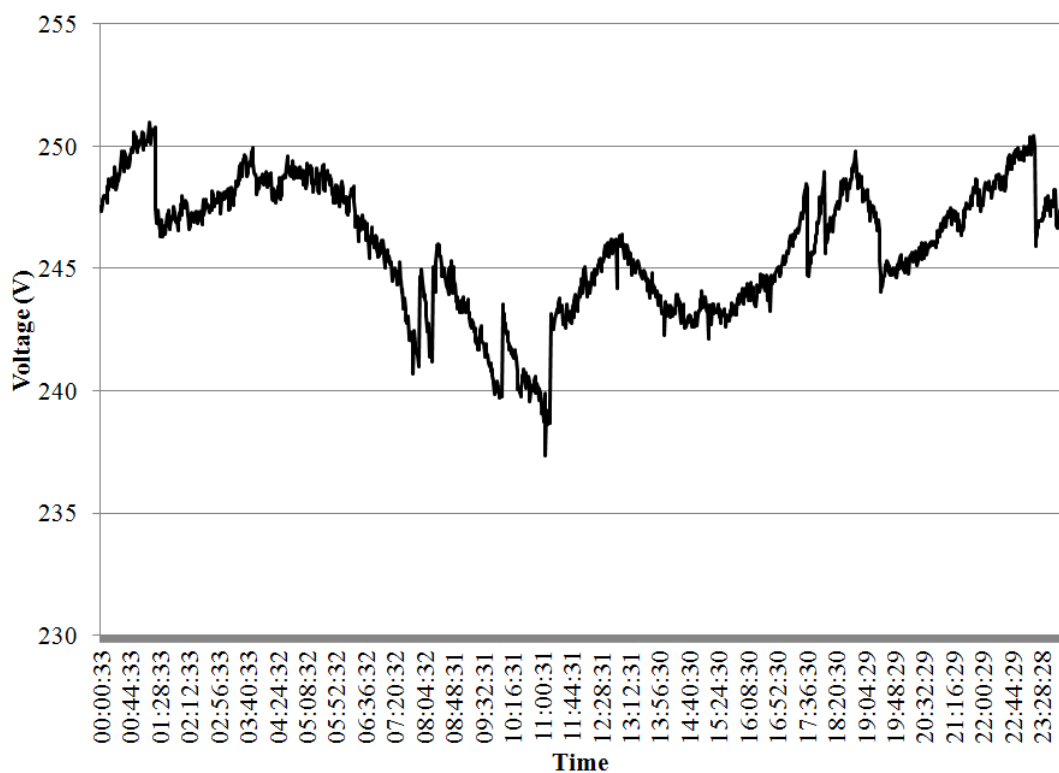


Figure 4.12 Voltage (phase A) on 27 March

Figure 4.13 and Figure 4.14 show measured values of phase B and phase C voltages. The voltages started to drop at 8am and reached their lowest point at around 11am. Then the voltages slowly increased again until the next day, where the cycle will repeat itself. The range of fluctuation of voltage for phase B was between 240 to 250V, whereas for phase C the range of fluctuation was 242 to 250V. All 3 graphs plotted for voltage measurement on 27 March were similar in that they had low voltage drops during office hours.

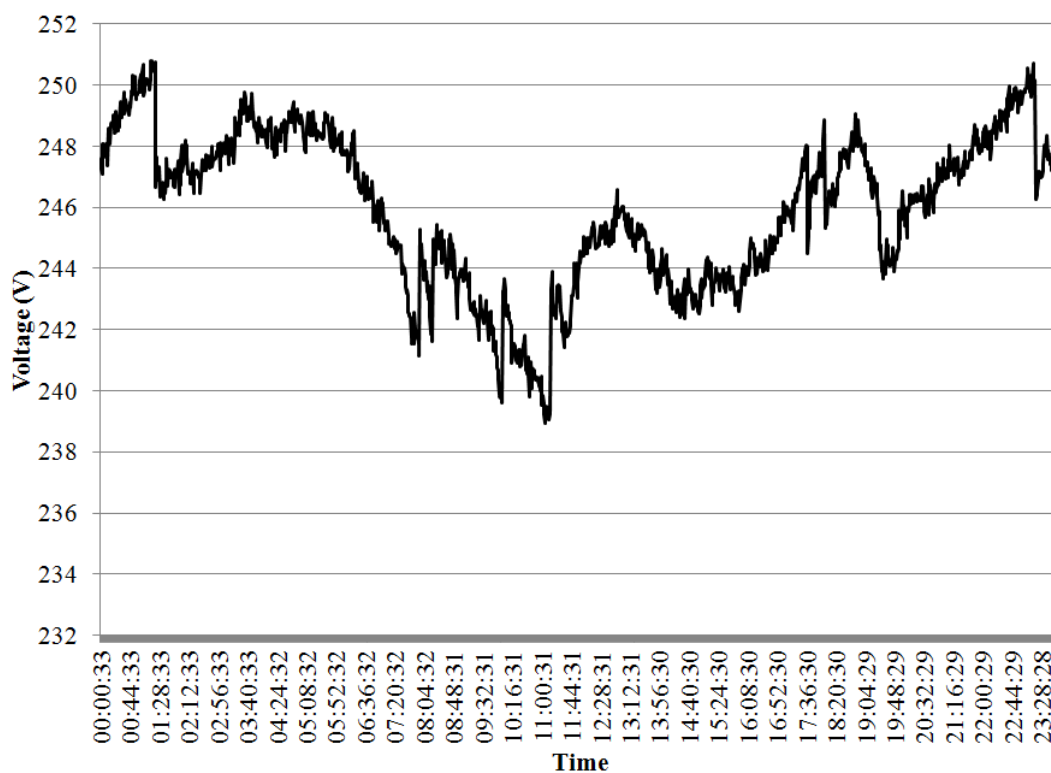


Figure 4.13 Voltage (phase B) on 27 March

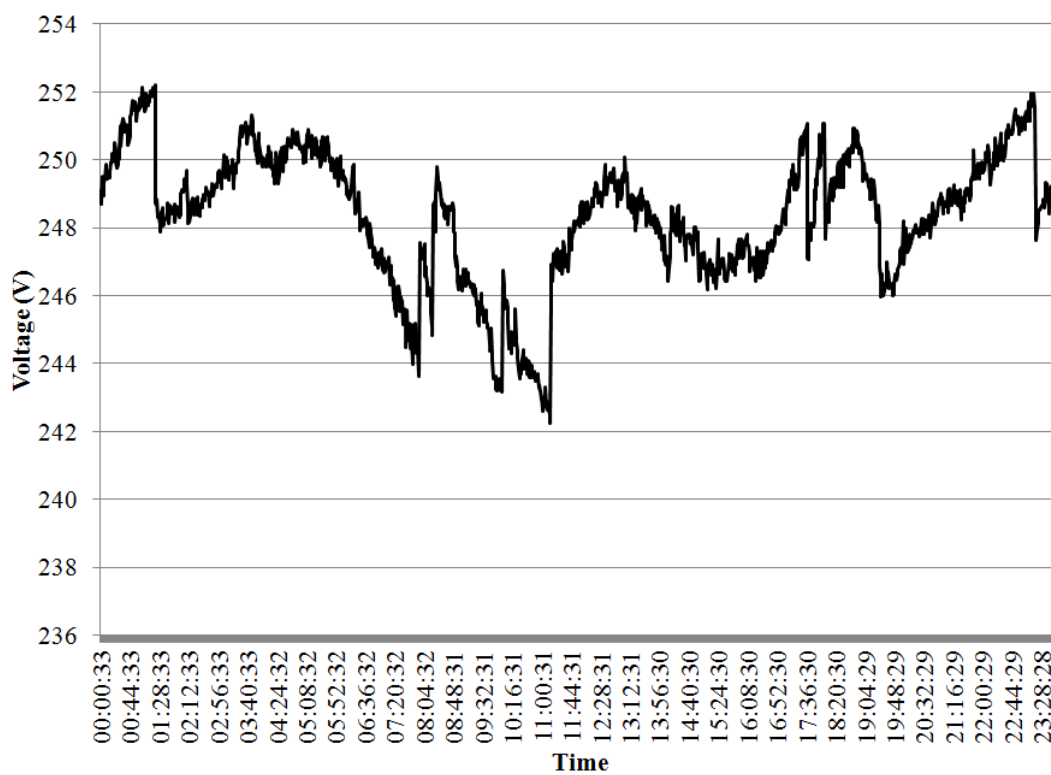


Figure 4.14 Voltage (phase C) on 27 March

Figure 4.15 shows the phase C voltage that was measured on another day (19 March). It can be observed that the voltage also dropped during office hours where the power consumption was high. However, from 12 noon to 1pm there was a slight increase in voltage. This could be due to students and lecturers leaving the labs and classrooms for lunch.

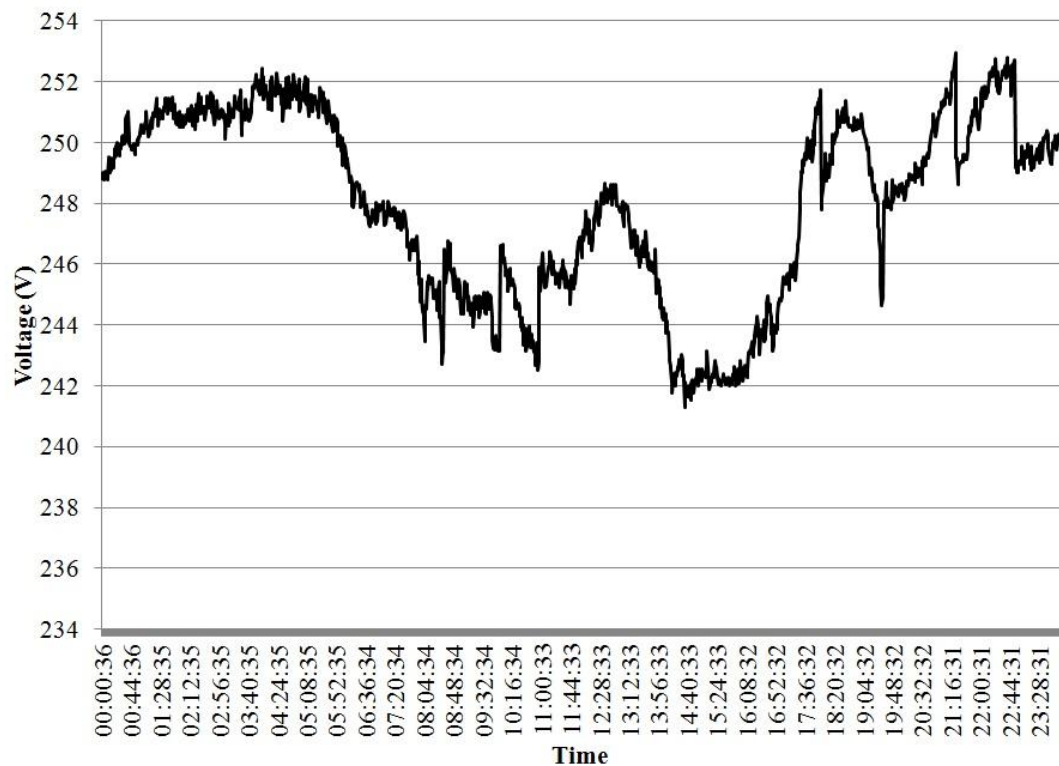


Figure 4.15 Voltage (phase C) on 19 March

Figure 4.16 shows the power factor of phase A for 18 March. The lowest value of power factor was 0.934 while the highest value was 0.999. The average power factor for that day was 0.98. The statutory limit for power factor should be less than 0.85. From the graph the power factor did not exceed the statutory limit.

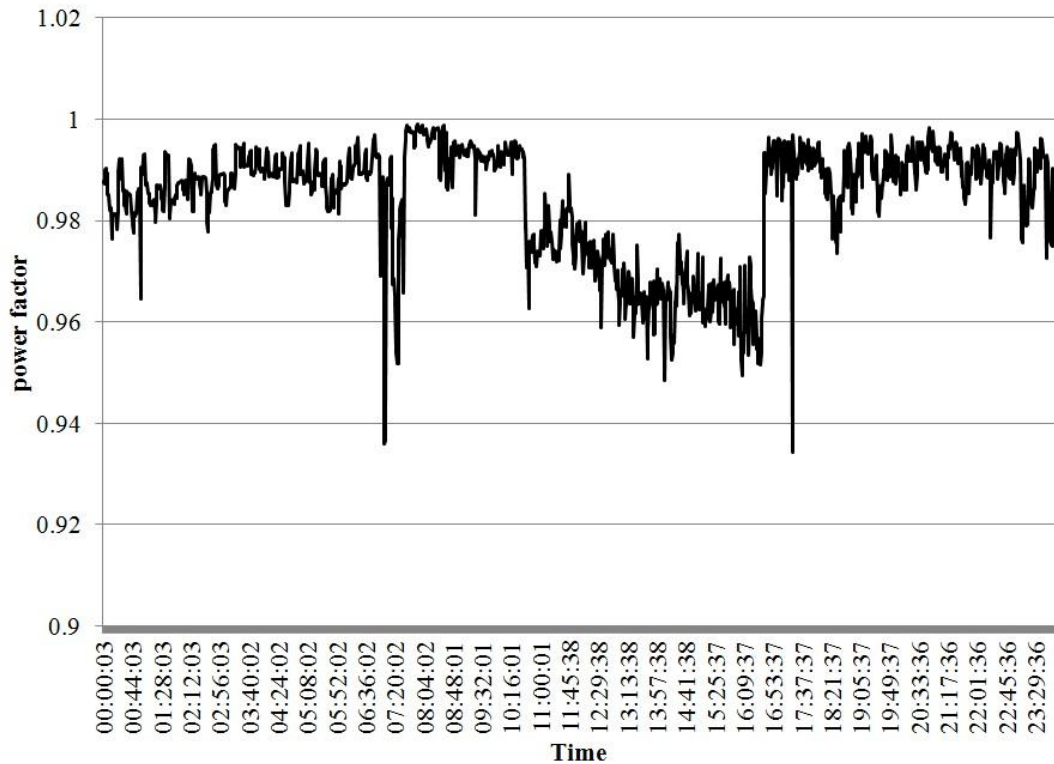


Figure 4.16 Power factor on 18 march

Other than storing the data in Excel, the historical data can be viewed on the user interface using LabVIEW when the users select the day of their choice. Users can choose the file they want to view by clicking on the browse button. The file path will then appear on the screen. Each time users want to view data from a different file, they have to click on the 'Read new file' button after they have selected the new file. Then the dates available in the file will be displayed on the screen for users to select. For this section, users can only select one day. After that, users choose the parameter of the data they want to view, for example current, voltage etc. Finally, when the user clicks on the 'Display' button, the data will appear on the screen. Figure 4.17 shows part of the user interface for viewing historical data where user has to select the file name, the date and parameter of the data.

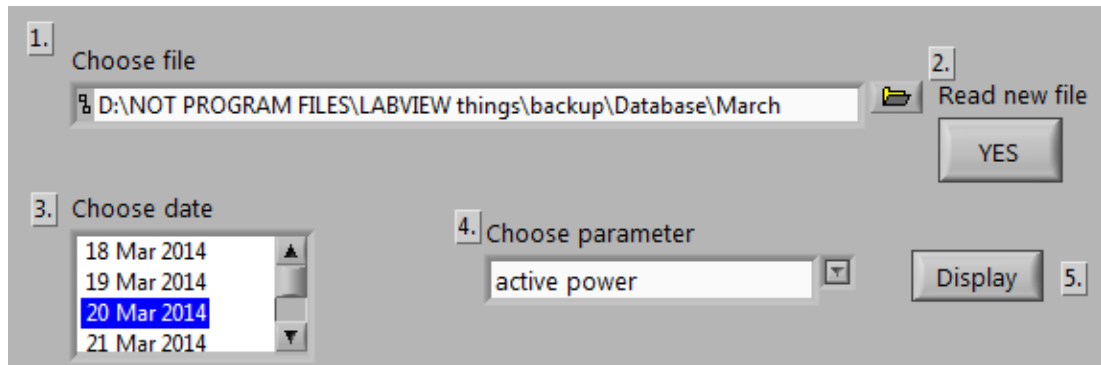


Figure 4.17 Selecting file, date and parameter

Figure 4.18 shows the data that appears on the screen once the ‘Display’ button is clicked. The graph shows the active power for the day where the red plot represents the power consumed (in watts) by phase A. The power consumed by phase B and C is zero because for the experiment performed, only phase A current was measured. The historical data displayed is that of 20 March as selected in Figure 4.17 earlier.

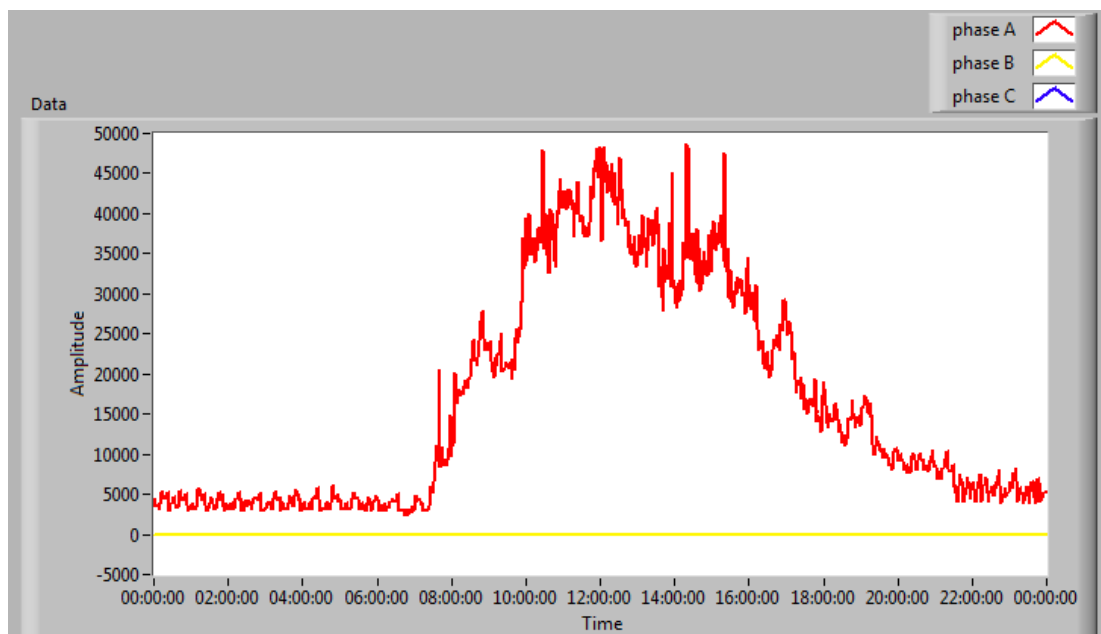


Figure 4.18 Active power on 20 March (historical data)

Figure 4.19 shows the voltages measured on 20 March. The red plot represents phase A, the yellow plot represents phase B, and the blue plot represents phase C.

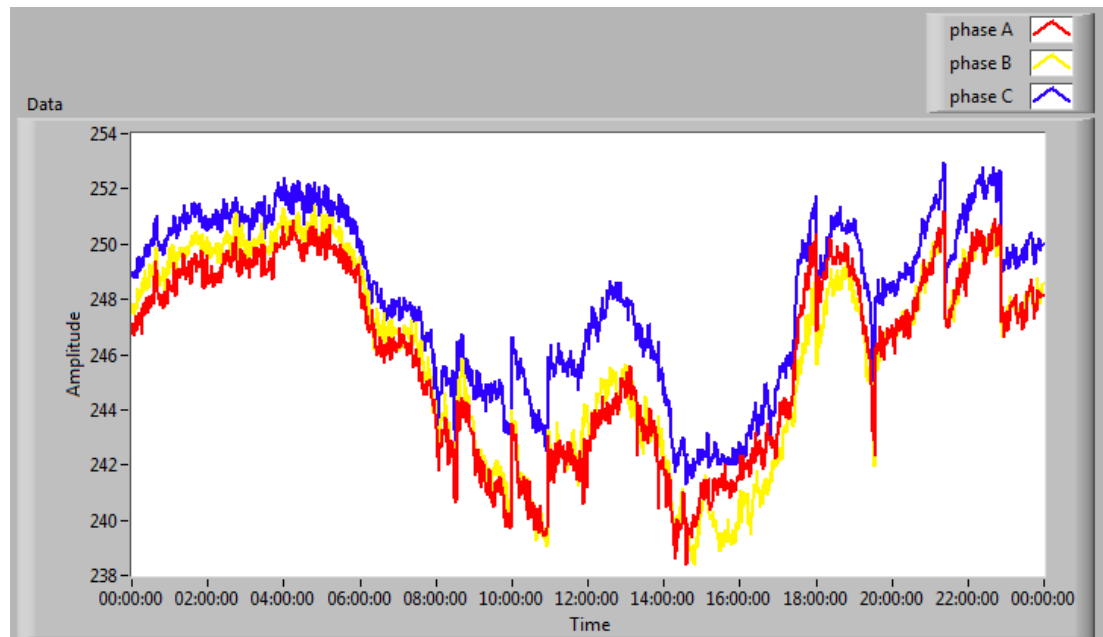


Figure 4.19 Voltage on 20 March (historical data)

In addition to the graph displayed, users are supposed to choose a tariff for which all the electricity cost calculations will be based on. There are 4 tariffs to choose from, namely, C1, C2, E1 and E2. C1 is a Medium Voltage General Commercial Tariff. C2 is a Medium Voltage Peak/Off Peak Commercial Tariff. E1 is a Medium Voltage General Industrial Tariff and E2 is a Medium Voltage Peak/Off Peak Industrial Tariff.

After the tariff is chosen, the average power factor, total active energy in kWh, electricity cost for the day and maximum demand charge for the day is displayed as shown in Figure 4.20.

Choose Tariff

C1

Average power factor

-0.0682

Total active energy (kWh)

79.3868

Electricity cost for the day (RM)

28.9762

Max demand charge for the day (RM)

1363.24

Figure 4.20 Costs and power factor for 20 March

If users want to choose multiple days to view the historical data of those days, they can select the 'Historical data (range of days)' tab as shown in Figure 4.21.

Real time Data Historical Data (per day) Historical Data (range of days)

Figure 4.21 Selecting Historical Data function

The user interface of the 'Historical data (range of days)' shows the dates available for selection. After selecting the date and choosing the parameter, users have to click on the 'Display' button. Figure 4.22 shows the user interface for viewing historical data of multiple days.

Please choose range of days to view historical data

☒	25 Feb 2014
☐	26 Feb 2014
☐	28 Feb 2014
☐	18 Mar 2014
☐	19 Mar 2014
☐	20 Mar 2014
☐	21 Mar 2014
☐	24 Mar 2014
☐	25 Mar 2014
☐	26 Mar 2014
☐	27 Mar 2014
☐	28 Mar 2014

Choose parameter

Display

Figure 4.22 Selecting range of days and data parameter

Figure 4.23 shows the data displayed on the graph when the multiple days of 24 Mar 2014, 25 Mar 2014, 26 Mar 2014, 27 Mar 2014 and 28 Mar 2014 were selected. The parameter selected was total active power. It can be observed on the graph that the 5 points represent the 5 values of average active power of each day.

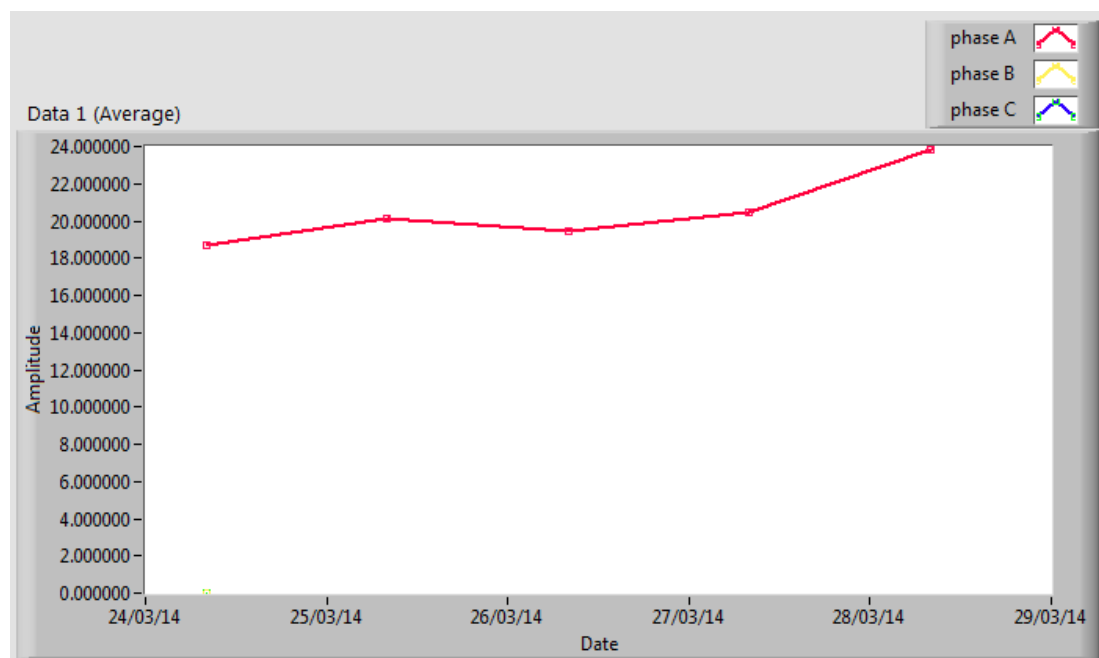


Figure 4.23 Average power (historical data)

Figure 4.24 shows the total active power plotted against the dates that the user has chosen. All the values are plotted and the averages of the values are not calculated in this case.

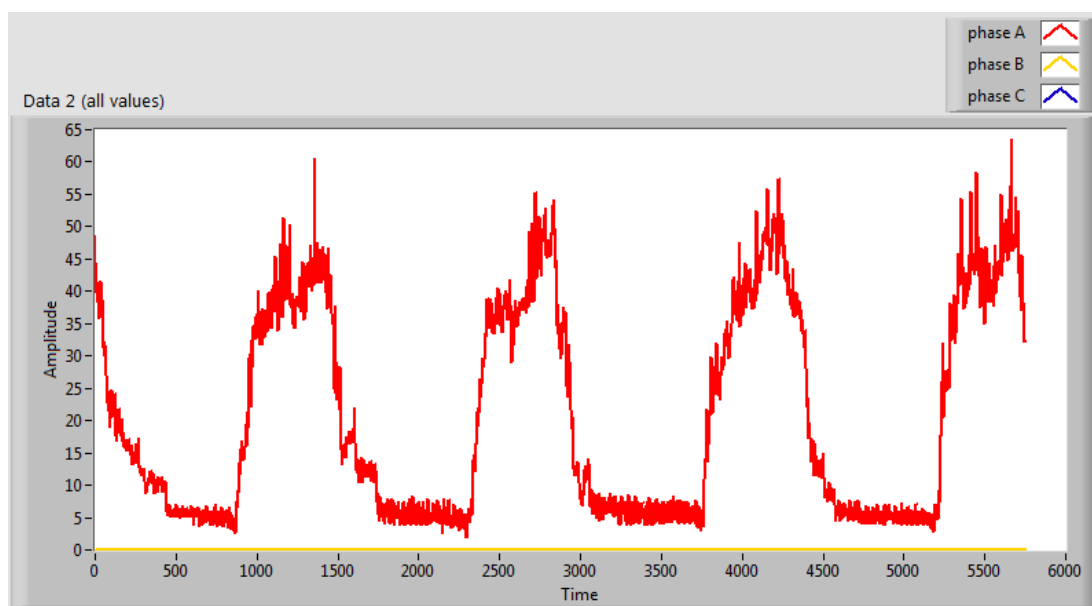


Figure 4.24 Active power for range of days (historical data)

Figure 4.25 shows the average power factor, the total active energy, the electricity cost and maximum demand charge for the chosen period that are also displayed next to the graphs.

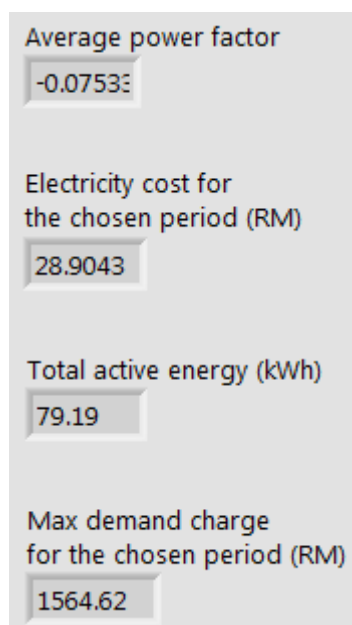


Figure 4.25 Cost and power factor (historical data)

CHAPTER 5

CONCLUSION

5.1 Conclusion

With the demand for energy increasing greatly, energy efficiency has become a growing concern of this world. The high operational costs incurred in industrial and commercial buildings and the environmental problems caused by excessive use of energy have further stressed the need for energy efficiency. Since energy management is known to be one of effective measures for improving energy efficiency, more efforts need to be put into energy management so that energy can be conserved. A worthwhile effort is to invest in a power monitoring system because such a system allows power consumption data to be measured and tracked, giving industrial and commercial building owners an opportunity to analyse their building energy data and invest in energy efficiency measures. This data is also extremely valuable to energy auditors who work at helping the building to cut down on costs.

In this project, a data acquisition system has been successfully developed using SBRIO. The system acquires data such as active power and active energy consumption, reactive power and reactive energy, voltage, current and frequency. The graphical interface designed enables users to view the data in real-time and monitor power usage. In addition, a database management system has been successfully developed in which the database contains all the data recorded. The data is stored systematically according to the months and days. This data is easily accessible as it can be opened with Microsoft Excel. The recorded data can be used for further analysis such as locating anomalies and predicting trends. Furthermore, the data that is stored in the archive can be viewed on the user interface. The

developed system can also calculate the total accumulated active energy used and total electricity cost based on the electricity tariffs that users select.

Future improvements to the power monitoring system developed include analysis of power quality and displaying the power quality data on the user interface as good power quality is vital to prevent the malfunction of sensitive equipment and instruments. Besides that, the power and energy data obtained could be compared with benchmarks for the earlier performance of the building or for the same type of building. This will show the ranking of the building regarding energy efficiency and also allows users to see the progress achieved so far. Another area of improvement is the communication methods. Currently, the building power monitoring system designed can communicate to the computer via Ethernet cable and through wireless connection. It would be more effective if the user interface can be viewed on smart phones, tablets or even uploaded to a web page on the internet so that the information can be easily accessible and viewed by more people, provided that these people are authorised to view the data.

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