ENERGY USAGE MONITORING SYSTEM WITH AUTOMATIC TARIFF CALCULATION

by

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LIST OF SYMBOLS

V_p	Primary winding Voltage
V_s	Secondary winding Voltage
$I_{pk\ p}$	Primary peak current
$I_{pk\ s}$	Secondary peak current
$I_{mean,sq}$	Mean square current
I_{rms}	Root Mean Square current
V_{rms}	Root Mean Square Voltage
THD	Total harmonic distortion
S	Apparent Power
P	Real Power
Pf	Power Factor
P_i	Instantaneous Power
V_i	Instantaneous Voltage
I_i	Instantaneous Current
V_{sum^2}	Sum of squared voltage
I_{sum^2}	Sum of squared current

LIST OF ABBREVIATIONS

RMS	Root Mean Square
LCD	Liquid Crystal Display
AC	Alternating Current
DC	Direct Current
Vac	Alternating Voltage
CT	Current Transformer
IoT	Internet of Things
V	Voltage
I	Current
A	Ampere
W	Watt
VA	Volt Ampere
Hz	Hertz

ABSTRAK

Dalam projek ini, sistem pantauan pengunaan tenaga elektrik telah di bina. Projek ini memudah kan penguna untuk memantau pengunaan tenaga elektrik di dalam rumah mereka. Selain itu, projek ini juga memudah kan penguna untuk mengira tariff pengunaan tenaga elektrik. Projek ini mengunakan kotak kawalan untuk mengumpul dan memproces data untuk mengira nilai kuasa sebenar, kuasa elektrik dan kuasa tidak nyata. Selain itu, kesemua data ini akan di hantar ke laman sesawang melalui sambungan internet. Penguna lebih mudah memantau pengunaan tenaga elektrik melalui atas talian. Amaran akan di berikan jika pengunaan tenaga elektrik melebihi kadar yang telah di tetap kan. Twitter akan di gunakan sebagai platform untuk memberitahu penguna sekiranya pengunaan telah melebihi nilai yang di tetap kan.

ABSTRACT

The objective of this project is to design a system that will allow real-time electrical energy usage monitoring with automated tariff calculation and IoT capability. This project uses a microcontroller as the main processor to collect data and perform calculation to get real power (P), apparent power (S) and reactive power (Q) and others. Values of RMS current, RMS voltage, Real Power, Apparent Power, Power Factor and Tariff that have been calculated will be sent to the cloud or an internet server. Users will be able to monitor their real-time power usage online using any internet connected gadgets. A warning or alert message will be sent to the users if their power usage exceeded certain threshold that have been set. This notification message will be sent through the user's Twitter account to alert the user.

CHAPTER 1

INTRODUCTION

1.1 Background

In the era of rapid advancement of technologies, electricity has become the most important source of energy for mankind and undeniably the most important aspect in our lifestyle. Malaysia Energy Information Hub [MEIH] stated that the electrical energy consumption in Malaysia has been increasing yearly [1]. The electrical energy consumption in year 2000 was 5262 ktoe [61 Billion kWh] and rapidly increased to 11042 ktoe [128 Billion kWh] in year 2014 as shown in Table 1.1. The trend of increasing in the consumption of the electrical energy is shown in Figure 1.1. Electrical energy consumption for the industrial sector recorded the highest demand [1].

Table 1.1: Energy Consumption in Malaysia from 2000 to 2014 [1]

Year	Final Electricity Consumption (ktoe)					
	Agriculture	Commercial	Transport	Industrial	sident	Total
2000	0	1478	4	2805	975	5262
2001	0	1579	3	2930	1081	5593
2002	0	1698	4	3059	1161	5922
2003	0	1818	5	3242	1248	6313
2004	0	1979	5	3340	1319	6643
2005	0	2172	5	3371	1395	6943
2006	5	2272	5	3475	1514	7271
2007	16	2480	4	3587	1598	7685
2008	19	2598	15	3687	1668	7987
2009	21	2743	12	3719	1792	8287
2010	24	3020	18	3994	1937	8993
2011	26	3172	18	4045	1974	9235
2012	30	3325	21	4509	2126	10011
2013	32	3466	21	4809	2262	10590
2014	36	3566	22	5072	2346	11042

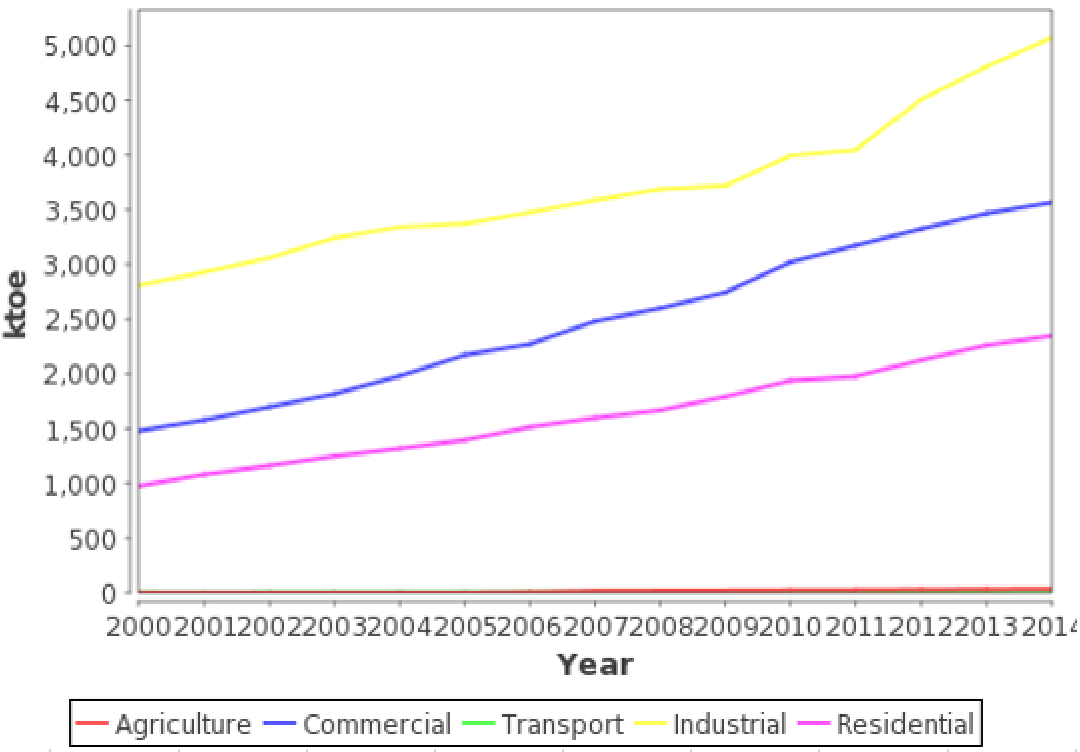

Figure 1.1 : Electrical energy consumption from year 2000 to year 2014[1]

Residential area in Malaysia is responsible for up to 21.25% of the nation's electrical energy consumption [1]. For this reason, cost of living is increasing yearly. Therefore, many people nowadays are looking into ways to reduce their bills and minimize every possible expenses. This situation is getting worse when the El-nino phenomenon engulfed Malaysia in early 2016. Usage of electrical energy was at its peak due to the usage of air-conditioner for a longer period of time [2]. People were clueless on how many unit of kWh they have used daily or weekly and that kept them on a comfort zone until the end of the month when they received their electrical bills. This may cause them to fall into financial problems if the bills exceeded their monthly budget.

The rapid advancement of technologies is growing and it will help people to have a better life. The smart rigid technology offers the vision of enhancing the efficiency of electricity utilization from the generation up to the end-user points. One of the most effective way to help reduce the electrical energy consumption is to allow consumer participation in the demand-side. An effective electrical energy monitoring system will help the consumer to monitor their usage and allow them to avoid overuse of electrical energy. An effective electrical energy monitoring system must be highly automated, intelligent, and able to support high level of information and communication technology (ICT).

The Internet of Things (IoT) has recently acquired considerable attention in the technology and electric monitoring system researches. It is a network consisting of objects having identities, virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate with the users in a social and environmental contexts. Therefore IoT will allow electrical energy monitoring system to monitor the usage of electrical energy in real-time. Therefore, the utility could be deployed for appropriate demand-side actions to the households to control their usage and lower their electricity bills.

For this project, collecting data such as magnitude of current and voltage using current transformer and potential transformer is essential. Arduino Uno will be the processor that will process this data into valuable information such as Power, Reactive Power, Apparent Power and Power Factor. All of these data will be sent to a server/cloud for graph plotting and presenting in understandable information for the customers to monitor via internet. Wi-Fi module ESP8266 Arduino Ethernet Shield will be used to give internet access to the Arduino Uno. Customers will be able to set their own threshold for their electrical energy usage at the website and if the threshold is exceeded, the system will send a notification alert to the customer's social media such as twitter.

The information that the users can obtain by using this device is:

I. Root Mean Square Voltage

II. Root Mean Square Current

III. Real Power

IV. Apparent Power

V. Power Factor

All the data that has been collected can be displayed on a Liquid Crystal Display (LCD) module or any internet accessible device such as smartphones and laptop because this project is developed with consideration of IoT. This will allow the users to keep monitoring their electrical energy usage wherever they are.

1.2 Problem Statement

Electrical energy is a very important source of energy as technologies are growing and abundance of new gadgets are produced to make life easier. All of these electrical appliances increase the power usage of a household. The uncontrolled daily electricity consumption causes the monthly electricity bill to escalate and in worst cases it exceeds the user's budget. The customers are unable to determine their electricity usage in real-time and not being able to estimate how much the cost of current usage they have been using for a certain electrical appliance. This kind of information can help the user to alter their lifestyle to control minimise electrical energy consumption. Therefore, the electrical energy monitoring device will be very helpful to the users to obtain the real-time information that they need to manage their electrical energy usage. They will be able to determine which appliances consume high electrical energy in standby mode that leads to high electricity bills. The users will be able to determine which electrical appliance that consumes the most power in their house and with all this information, the user can alter their lifestyle to reduce their electricity bills.

Moreover, there are a lot of users which do not receive their electricity bill at the end of the month. Sometimes the bills are not sent to the house or it might have been misplaced or swept away by the wind. In this scenario, this electrical energy monitoring project will help users to check their electricity bills and this will be more convenient for the utilities company rather than posting the bill to each house every month.

Therefore, it will be a huge change of game if there is an affordable device that will allow them to monitor their real-time electrical energy usage. Advanced real-time monitoring system of electrical energy usage in addition with automated tariff calculation will help people to monitor their usage and avoid them from exceeding their budget. This will bring a positive impact to our society as they can manage their monthly cash flow efficiently. Besides that, it also helps in reducing electrical energy overdue payment that is usually caused by over budget usage.

This project uses affordable microcontroller as the processor of the monitoring device. All the data will be sent to cloud/server which will allow users to analyse and check their electrical energy usage. This process will be done by using Wi-Fi module ESP8266 Arduino Ethernet Shield that will give internet access to the processor. Besides that, the information can also be read at the Liquid Crystal Display module.

1.3 Research Objectives

The objectives of this research are:

1. To build an energy usage monitoring system that can give real-time information of power consumption on an LCD display as well as through the internet server.
2. To add function for real-time tariff calculation to the energy usage monitoring system.
3. To make the energy usage monitoring system able to alert the user when a certain usage threshold is exceeded.

1.4 Scope of the research

In this project, Arduino Uno microcontroller will be used as the processor. This processor will be used to read and process the data from the current transformer and voltage transformer. Current transformer SCT-013-000 is used to measure the magnitude of the current flow of the electrical appliance. This current transformer is able to operate up to 100A maximum current and have a turn ratio of 100:0.05. It is also very easy to use since it only requires users to clip the device over the current carrying wire that they want to measure.

Potential transformer is used to measure the magnitude of the voltage that flows into the electrical appliance. The voltage transformer that will be used in this project will be a step down transformer that will step down 240VAC to 9 VAC. Both the current and voltage transformer will require a voltage or potential divider before feeding the output to the Arduino. This potential divider is used to ensure a suitable voltage which is below 5V is fed into the Arduino. Wi-Fi module ESP8266 Arduino Ethernet Shield in plugged onto the Arduino UNO board to give the processor access to the internet in order to send all the data to the server/cloud. Users can monitor their power usage and other information of their electrical energy consumption at the webpage. All electronic gadgets that have access to the internet will able to view this webpage. Besides that, the information also can be read at the Liquid Crystal Display module.

1.5 Thesis Organisation

This thesis consists of five chapter which is the introduction of this project as the first chapter. The first chapter will describe the research background, problem statement, research objectives and scope of research.

The second chapter is the literature review of the past studies on smart monitoring system and also the real time monitoring system. This chapter will review all the past projects and research including the different methods that have been studied by different researchers.

Chapter three covers the methodology part of this project. This part will describe the design and concept of this project, hardware part, software and testing plan of the project. This chapter will consist of all the flow charts of the design and steps to accomplish this project.

Chapter 4 is the procedures of all the experiments carried out and results to put this project to test. All the result obtained will be analysed and discussion will be made and presented.

Lastly the fifth chapter will be the conclusion part. In this chapter, it will include the conclusion that we can make based on this project and suggestions for further improvement of this project in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

There are many types of e-monitoring device available in the market. This review will focus on 4 major aspect in electrical power monitoring device. Real-time electrical energy monitoring system and low cost power monitoring system are two types of e-monitoring device that will be focused in this review. Implementation of Internet of Things (IoT) system in electrical energy monitoring system and method identifying electrical appliances will also be included in this review.

2.2 REAL-TIME ELECTRICAL ENERGY MONITORING

Real-time energy monitoring is very important in this era. This technology can help in increasing the reliability and efficiency of a system. Besides, it also helps in collecting and grasping a real-time situation and problem. There are a few problems that will be faced in implementing real-time energy monitoring such as the data collection from homes may suffer from different types of faults which is data point missing, sensing error, communication loss [3].

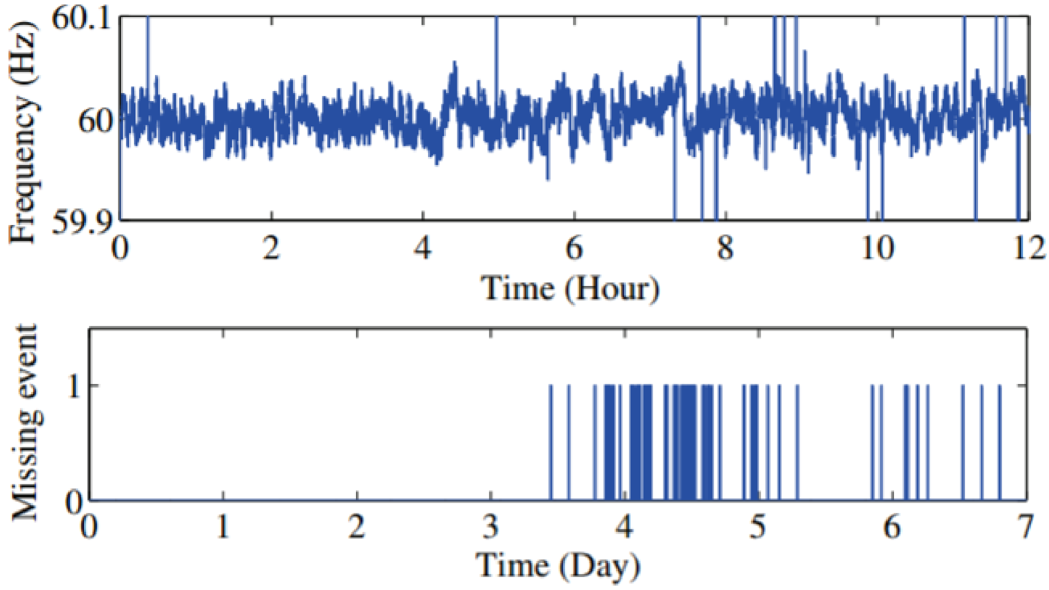

Figure 2.1: Examples of data faults in real-time energy monitoring [3]

Figure 2.1 above shows examples of faults obtained in real-time energy monitoring. The first graph is caused by the sensing error that came from the sensor used and the second graph shows the frequency of missing data received by the cloud.

It is crucial to manage the data that we received effectively. In addition, it is more effective if there is a system to reconstruct the missing data. This missing data can be reconstructed by using the trend of the data that has been collected from past. The limited number of electrical appliances in one home results in a limited energy consumption pattern that will make the reconstruction of the missing data and prediction of electrical energy consumption of one home possible [3].

Therefore, data management and analysis are very crucial for real-time monitoring system to be more effective. All this data needs to be analysed and processed so that it can be presented in a form that is easier to understand by the household. This will increase the effectiveness and alertness of energy saving.

Availability of electrical energy monitoring system with real-time consumption data presented effectively in a household results in average of 12% decrease in electrical energy consumption in a short period of time [4]. Users are prone to check their electrical energy consumption each time they switch on an electrical appliance. Therefore, electrical energy monitoring will be more effective if it has real-time monitoring.

This shows that if the users have information on the consumption of each of their electrical appliances, it can help them to reduce their electrical consumption. Therefore showing electrical energy consumption of parts of house is very helpful because the users can identify which part of their house consumes more electricity [5]. Besides that, this will help them to identify which electrical appliances consumes more electricity.

The main requirement for a real-time electrical energy monitoring would be the feedback that must happen in real time to allow the users to associate their actions with patterns in energy usage. The system must be able to give the users the ability to compare their current consumption to their own historical data for estimation and the users must have the choice to set their own targets in energy consumption. The data needs to be presented in a form easily understandable by the users [6].

2.3 METHODS OF ELECTRICAL APPLIANCES IDENTIFICATION

Every electrical appliance has its own effect towards the current and power consumption. Based on the method in [7] Non-Invasive Load Monitoring Systems (NIALMS) identifying electrical appliances based on aggregated data from single energy meter, this will reduce the hardware part of an electrical energy monitoring system and also will help reducing the cost. Therefore it will make electrical energy monitoring system to be more affordable.

Every electrical appliance has their own active power measurements. Having measurement of active power from single meter is necessary to compute hidden variables defining states of appliance and the Additive Factorial Approximate MAP algorithm that allows to designate each electrical appliances [7].

Basically there are two types of energy consumption monitoring systems, invasive and non-invasive. For invasive system, additional meter is required whereas the non-invasive system only needs a single meter. Figure 2.2 shows the classification of methods for monitoring electrical energy consumption.

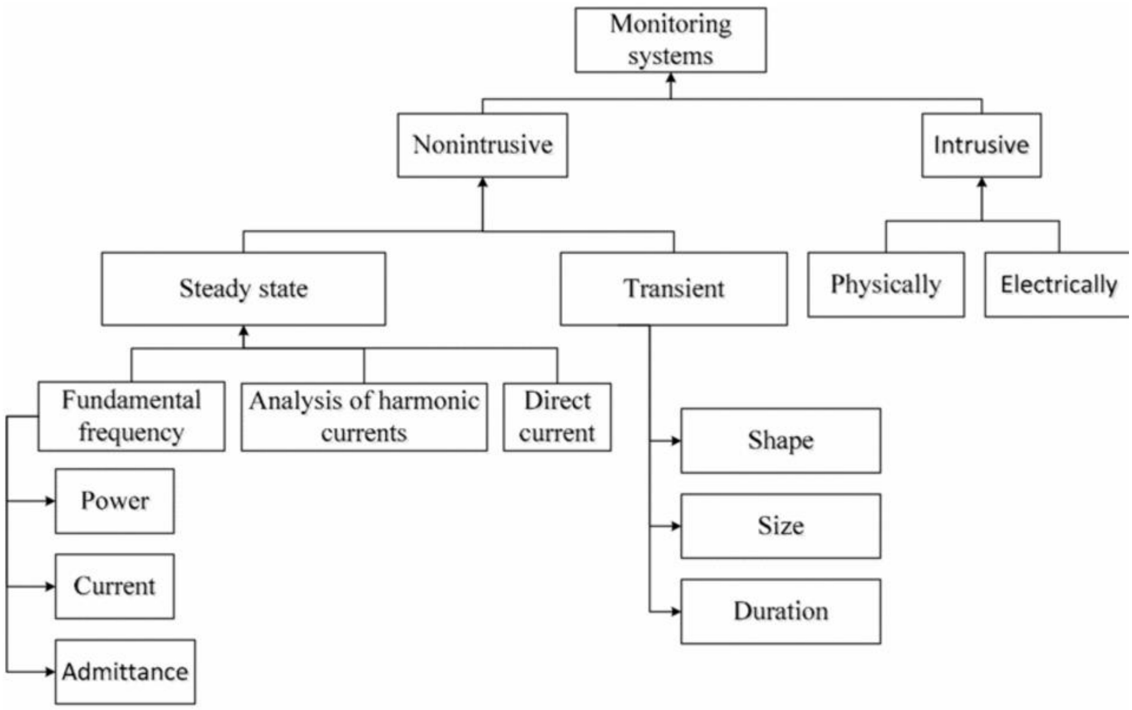

Figure 2.2: Classification of system for monitoring electrical energy [7]

The value of active power, current or admittance, and steady states can be used to identify the appliances. The measurement of frequency of electrical parameter higher than 100Hz makes it possible to analyse variability of the parameters in time and frequency domain. Below are the steps suggested in [7] to analyse the change in active and reactive power:-

- Identification of changes in active power during changes of appliances states
- Power change in Real power and Reactive power
- Grouping of clusters with opposite sign change
- Assigning of ungrouped clusters to new appliances
- Assigning of the grouped cluster to appliances

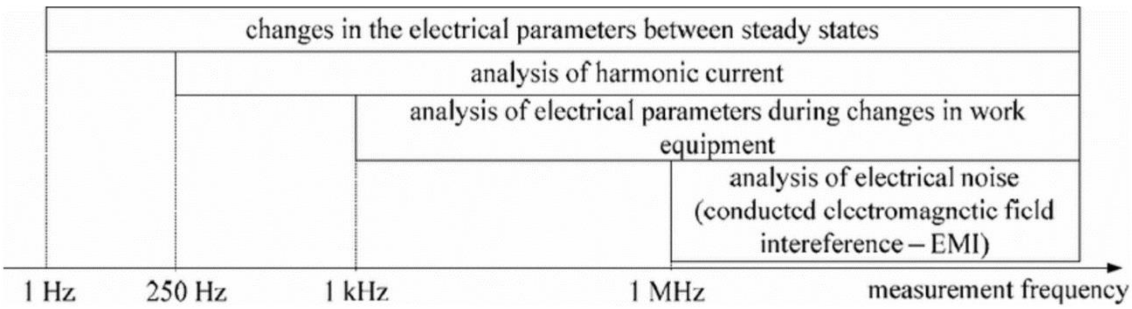

Figure 2.3: Identification using measurement frequency criterion [7]

There are quite a few electrical appliance in our household that has standby power mode or low level power state and high level power state such as the refrigerator and the water heater that only functions when there is insufficient hot water level in tank. Electrical noise will occur when there is a switching from low power level to high power. Therefore an electrical appliance with this kind of switching mode power supply can easily be identified using high frequency noise occurrence [7].

The value of voltage and current signal also helps in identification of electrical appliances as shown in Figure 2.4. The voltage-current signal pattern can be analysed and few features can be extracted such as the harmonic, active and reactive power and the shape or geometry of the voltage-current curve. Non-linear load will cause a harmonic power or distortion in current waveform. The percentage of total harmonic components to fundamental component will yield total harmonic distortion THD.

Leading current or lagging current vector also can be obtained from the voltage-current graph. This will help to obtain the power factor of the electrical load. This data will help in grouping the type of load nature which is resistive, capacitive and inductive. Leading current for capacitive load whereas lagging current for inductive load. [8] have discussed the method to analyse the electrical load based on the vector analysis of the voltage-current curve.

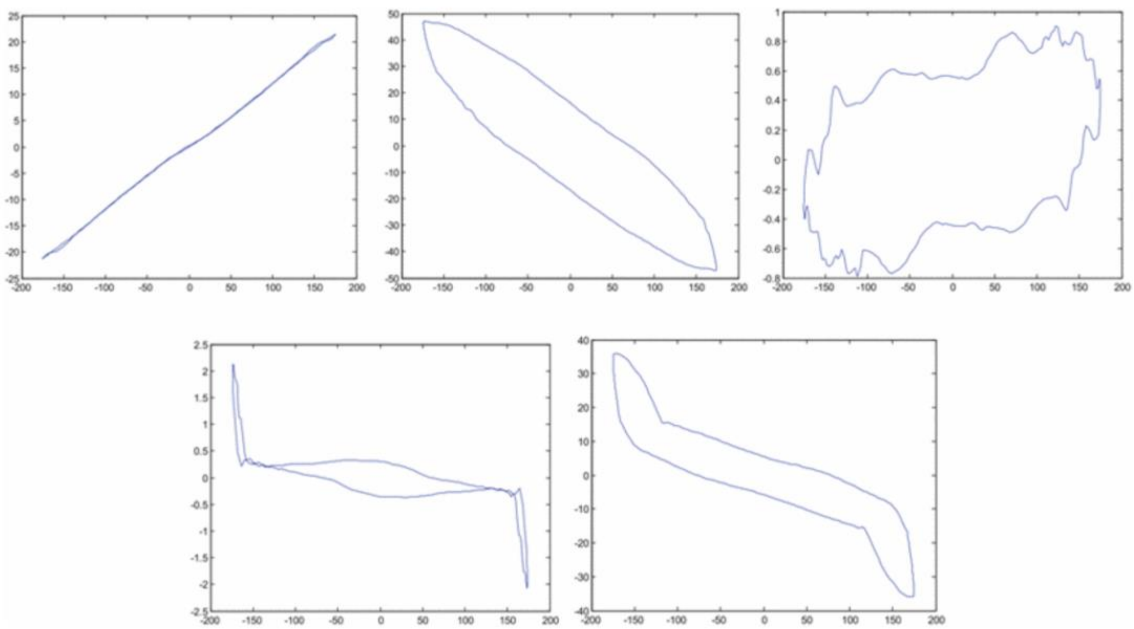

Figure 2.4: Voltage- current curve for different electrical appliance [8]

The shape of the voltage-current curve asymmetry, looping direction, area, curvature of mean line, self-intersection, slope of middle segment, area of segment will show characteristics of load and type of electrical appliances [8].

2.4 LOW COST POWER MONITORING SYSTEM

Every year, cost of living is increasing and therefore people are focusing more on reducing their bills and cutting short every expenses. Installing power monitoring system is one of the way in helping reducing the electrical energy consumption. However, power monitoring instruments are well known for its complexity and its expensive cost. Therefore, people will be reluctant on spending huge portion of their monthly budget to install this power monitoring system in their house even though it will help in reducing electrical energy consumption. There are a few factor that cause this power monitoring system to be expensive which is [9]:

1. The cost of developing the instruments
2. The quantity of instruments produced
3. The cost of manufacturing the instruments
4. The cost of installation
5. The cost of supporting the instruments, especially the cost of supporting special purpose software, throughout the life of the instruments.

In the last few years, most of the cost listed above have been driven down simultaneously. This is because the traditional power monitoring instrument is built as a special purpose instruments. All its hardware, firmware and software have been developed specifically for this instrument. Currently, rapid development of digital signal processor have caused the price to drop far from usual. New digital signal processors are inexpensive and have built-in analog-to-digital and digital-to-analog conversion. Besides that, it also operate in minimal power [9]. This low cost processor greatly helps in reducing the cost of developing an electrical energy monitoring instrument. ATmega8 microcontroller is commonly use in developing a low cost project. This ATmega8 microcontroller is also commonly known as Arduino microcontroller. Many papers have been published with a design of low cost electrical energy monitoring system built using Atmega8 microcontroller such as in [10] and [11]. Below in figure 2.5 shows one of the design of electrical energy monitoring system that have been proposed in [11].

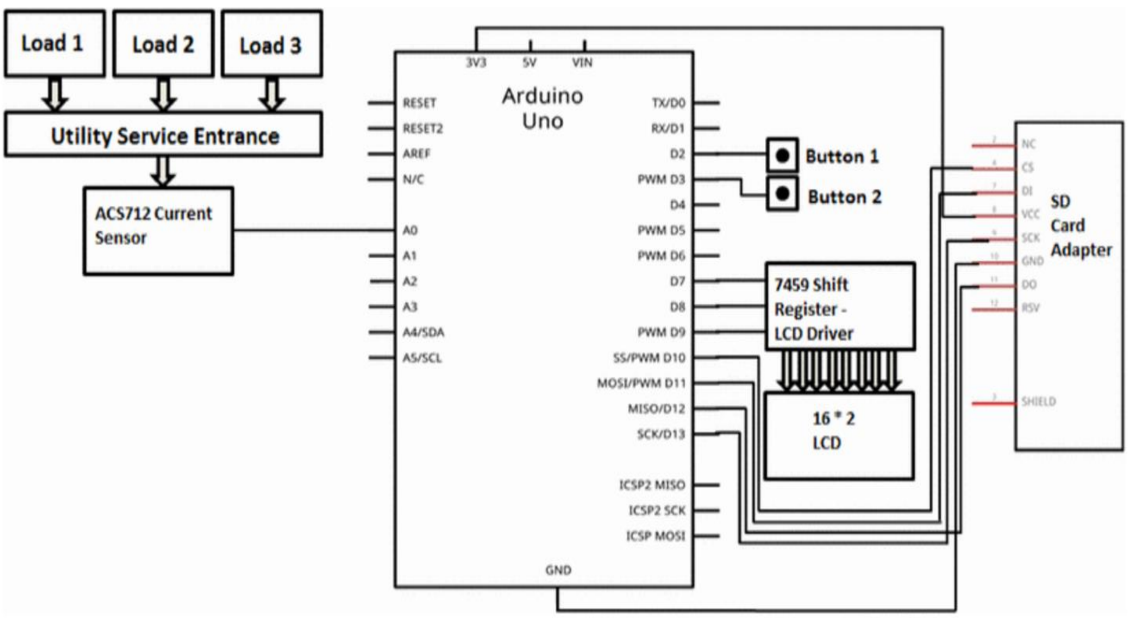

Figure 2.5: Electrical energy monitoring system schematic [11]

Microcontroller that is used in this project is Arduino UNO. This microcontroller is small in size but yet it is a powerful processor. In this project, it is used as a processor and data acquisition device. The system that is developed will be able to obtain the following data:

- RMS Voltage
- RMS Current
- Apparent power
- Real power
- Reactive power
- Power factor

All this data is used to monitor the electrical power consumption of a residence. This data is displayed on an LCD and can also be displayed on a laptop via cable. Short range application which transmits data to smartphones using Bluetooth is also a convenient way for users to monitor their power consumption.

2.5 Internet of Things (IoT) and ThingSpeak™

Internet of Things (IoT) is a major focus in development scope in this era. Explosion of data and connection is occurring in this era of digital economy. IoT is defined as a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual things have identities, physical attributes and virtual personalities, use intelligent interfaces and are seamlessly integrated into the information network [12].

However, in this era, the definition of IoT has been changed in parallel with the evolution of technology. The definition of IoT is implied as the use of computers to detect information without the use of human beings, not only focusing on sensing information from the environment but also using the internet as standard service for transferring information, analysing information, application and communications [12]. Development of IoT leads to advancement of cloud computing, robotics and increasing the capabilities of the internet.

ThingsSpeak™ is a free web service that offers free platform to gather and store data in the cloud. This cloud is the instrument used for interconnection of physical electronic devices such as sensors, and microcontrollers to the Internet. Registration as a user is required in order to use this cloud service. The user will be given a channel to display and monitor the data they harvest from the sensor. This is a public access channel which allows other users to read the data that we have obtained. Figure 2.6 shows the implementation of the PC application and figure 2.7 shows the IoT system module of ThingSpeak™ application [12].

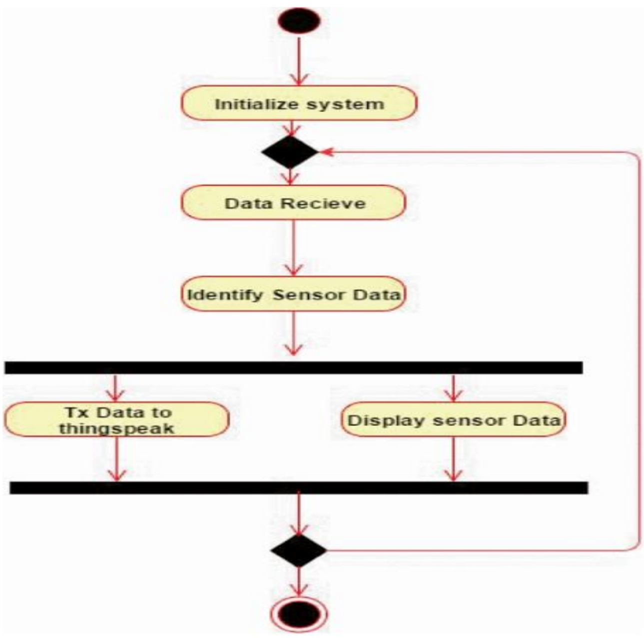

Figure 2.6: PC application module of IoT system

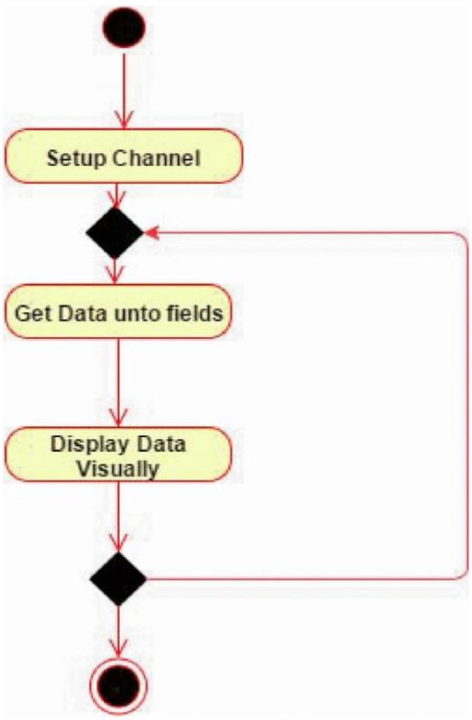

Figure 2.7: ThingSpeak™ module of IoT system

2.6 Summary

Chapter 2 provides information and background on electrical energy monitoring or power monitoring system. It also covers discussion on real-time electrical energy monitoring system and low cost power monitoring system. Method for electrical appliances identification were discussed in this chapter. Finally, the Internet of Things and ThingSpeak™ were also reviewed.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Chapter three will cover the methodology part of this project. This part will describe the design and concept of this project. The overall flow of this project and its explanation is shown in the form of a flow chart. The component required for this project would be the Arduino UNO as the processor, current transformer, potential transformer, Liquid Crystal Display (LCD) module and Wi-Fi module ESP8266 Arduino Ethernet Shield to give the processor access to the internet. All these component's functionality and operating principle in building the proposed electrical energy monitoring system to provide real-time monitoring of power consumption through internet server will be described.

3.2 Project Methodology

Arduino Uno microcontroller will be used as the processor for this project. This processor will be used to read and process the data from the current transformer and voltage transformer. Current transformer SCT-013-000 is used to measure the magnitude of the current flow of the electrical appliance. This current transformer is able to operate up to 100A maximum current and have a turn ratio of 100:0.05. It is also very user-friendly as users only have to clip over the current carrying wire that they want to measure. Potential transformer is used to measure the magnitude of the voltage that flows into the electrical appliance. The voltage transformer that will be used in this project will be a step down transformer that will step down 240VAC to 9 VAC. Both the current and voltage transformer will require a voltage or potential divider before feeding the output to the Arduino. This potential divider is used to ensure a suitable voltage which is below 5V is fed into the Arduino. Wi-Fi module ESP8266 Arduino Ethernet Shield in plugged onto the Arduino UNO board to give the processor access to the internet in order to send all the data to the server/cloud. Users can monitor their power usage and other information of their electrical energy consumption at the webpage. All electronic gadgets that have access to the internet will be able to view this webpage as well. Besides that, the information also can be read at the Liquid Crystal Display module.

Figure 3.1 is the flow chart of stage of work for this project. This flow chart includes every step that are required to accomplish this project. This flow chart can be used as a complete guideline to carry out this project.

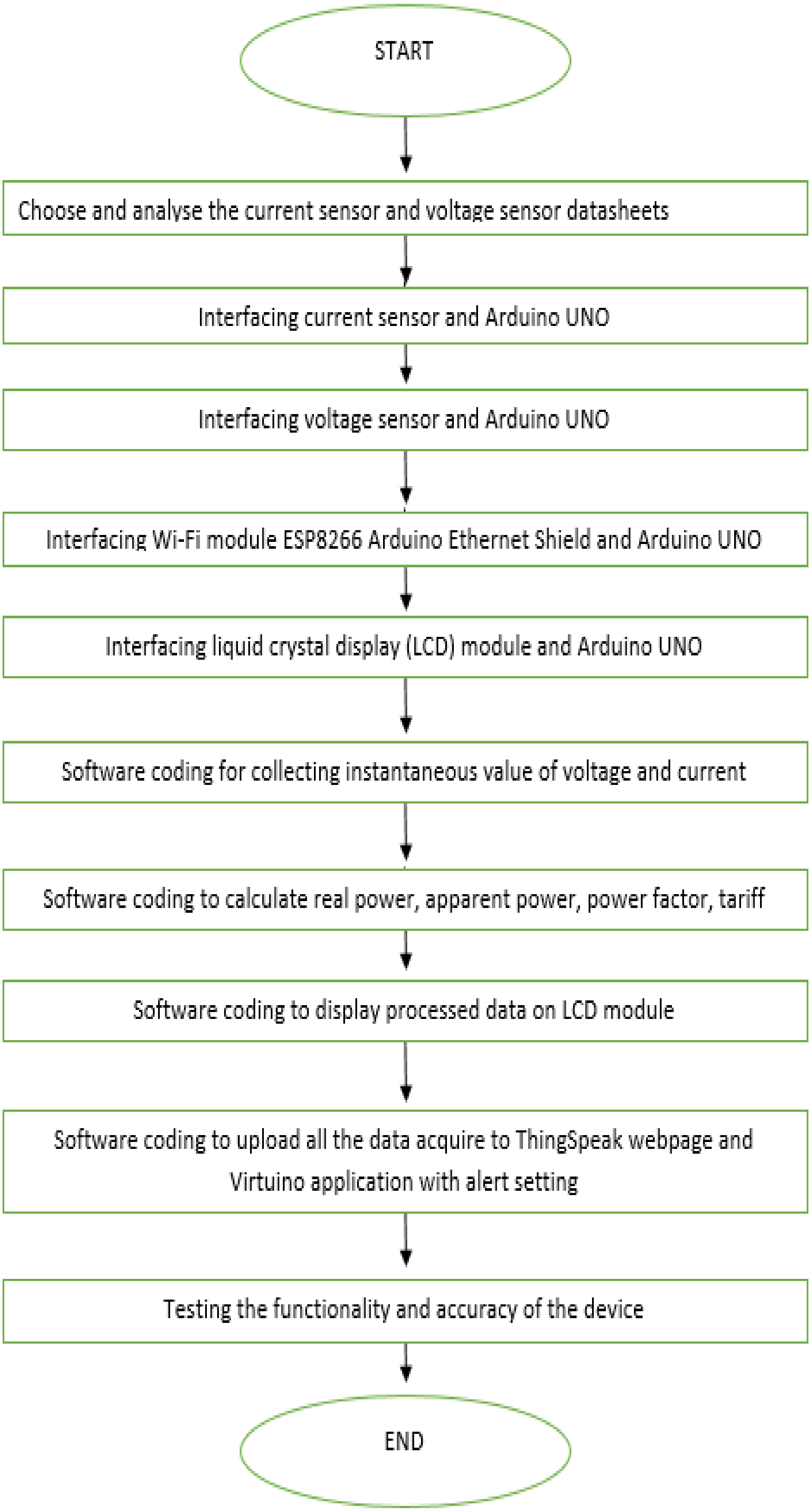

Figure 3.1: Flow chart of the project methodology

3.3 Project requirement

3.3.1 Hardware

3.3.1.1 Split-Core Current Transformer

In this electrical energy monitoring project, SCT-013-000 split core current transformer by YHDC Electronics is used as a current sensor. This current sensor is used to measure the alternating current flowing into the electrical appliance. The current transformer is able to operate up to 100A maximum current and have a turn ratio of 100:0.05. Current transformers are more convenient for this project as it can be easily used by just clipping it over any current-carrying wire of the electrical appliance to measure the magnitude of the current flowing. The current transformer needs to pass through the signal conditioning circuit before connecting it to the Arduino UNO. Signal conditioning circuit is crucial to ensure the voltage is scaled down to the same range of the accepted voltage range in analog input of the Arduino. As a precaution for this current transformer, only one wire carrying current is clipped by the current transformer at a time.

Figure 3.2: Current Transformer SCT-013-000

3.3.1.2 Voltage transformer (AC-AC Adapter)

Voltage transformer is a device used to change the voltage level by either stepping up or stepping down, depending on the ratio of the number of turn of coils in the primary winding to the number of coils in the secondary winding. Step down voltage transformer which is the AC-AC power adapter is used in this project that will convert 240Vac to 9Vac. This AC-AC power adapter is used to measure the alternating voltage input to the electrical appliance. This data is needed to calculate the value of real power, apparent power and power factor. Same as the current transformer, this voltage transformer is also required to do signal conditioning before feeding input to the analog input of Arduino UNO. The signal conditioning is required to scale down the voltage to the range of acceptance of the analog input of the Arduino UNO which ranges from 0V to 5V.

Figure 3.3: Voltage Transformer (AC-AC power adapter)

3.3.1.3 Signal Conditioning Circuit for Current Transformer

The current transformer used for this project has a ratio of 100: 0.05. Therefore it'll have 2000 winding at the secondary coil. A burden resistor is required to provide a voltage proportional to the secondary current. This burden resistor value needs to be low enough to avoid current transformer core saturation. There are a few calculations needed to obtain the value of the burden resistor. First we need to calculate the peak current flows in the primary winding using this formula below.

Peak to Peak primary current ($I_{pk\ p}$) = $Irms \times \sqrt{2}$ ……....(Equation 3.1)

Since the current transformer that we use in this project has a current range of 100A. Therefore the value of the I_{rms} will be 100 A.

Peak to Peak secondary current ($I_{pk\ s}$) = $\frac{Ipk\ p}{no\ of\ turns}$ ……....(Equation 3.2)

The secondary peak current can be calculated by using the above formula which the no. of turns of this current transformer is 2000 and to calculate the value of resistance need to be used to get an ideal voltage 2.5 V is using the Ohm's law which is

Burden Resistor (R_{burden}) = $\frac{Videal}{Ipk\ s}$ ……....(Equation 3.3)

With this formula, the ideal value of burden resistance calculated is 35.4 Ω. Therefore the value of resistance that will be used is 33 Ω.