DEVELOPMENT OF SMART METER SYSTEM FOR LOW VOLTAGE RESIDENTIAL PREMISES IN MALAYSIA

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Bachelor of Electrical Engineering (Industrial Power)

June 2014

"I hereby declare that I have read through this report entitle '*Development of Smart Meter System for Low Voltage Residential Premises in Malaysia*' and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

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A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014

"I declare that this report entitle '*Development of Smart Meter System for Low Votlage Residential Premises in Malaysia*' is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree."

Signature : ....

Name : Muhd Khairi bin Abdul Arif

Date : ....

To my beloved mother and father

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ABSTRACT

Increasing energy demand encourages the utilities such as Tenaga Nasional Berhad (TNB) to improve the process of energy management and measuring energy consumption for billing purpose. The conventional meter reading is done manually whereby the utilities send human operator to every premise to take energy measurement. This requires huge number of labor work and long working hour to achieve a complete area measurement data collection. This process is not very effective when the meter is inaccessible. It is also constrained by bad weather condition. As energy demand rises due to the growing of population and industrial development, the process requires more human operators and longer working hours to complete. The problems are also arises during the event of disconnecting supply by utilities due to default bill payments since it is done manually. In order to improve overall efficiency in energy measurement process, a smart meter system is developed. The smart meter system acts as conventional energy meter but with additional features such as the system enables the utilities to retrieve the meter energy measurement data remotely via Global System for Mobile Communication (GSM). The smart meter system also allows the utilities to disconnect and reconnect supply to each and every energy meter in certain area remotely in order to save manpower consumption. The system also allows consumer to monitor their consumption by displaying voltage, current, and energy consumed in real-time. The system use Arduino Uno as a controlling unit to control contactor in disconnection and reconnection of supply and display standard electrical measurement such as voltage, current, and energy consumption using Liquid Crystal Display (LCD). The system is very suitable since GSM is widely used throughout the world. With this system, utilities can save cost in meter reading process and provide better service to their customer.

ABSTRAK

Peningkatan permintaan terhadap tenaga elektrik telah menggalakkan syarikat pembekal tenaga elektrik seperti Tenaga Nasional Berhad (TNB) mencari alternatif bagi meningkatkan tahap kecekapan proses pengurusan tenaga dan proses pengukuran penggunaan tenaga bagi kegunaan pengeluaran bil. Proses bacaan meter tenaga dari sistem meter konvensional dilakukan secara manual di mana TNB perlu menghantar pembaca meter ke setiap premis melakukan proses tersebut. Keadaan ini menggunakan ramai tenaga kerja dan juga masa yang lama untuk mengambil bacaan meter di sesebuah kawasan. Proses ini juga terdedah kepada ralat terutama bagi situasi di mana meter tersebut terletak di kawasan ceruk dan di pedalaman. Proses ini juga terpengaruh oleh faktor cuaca seperti keadaan cuaca hujan. Peningkatan terhadap permintaan tenaga elektrik yang seiring dengan perkembangan populasi penduduk dan pembangunan industri telah menyebabkan proses bacaan meter memerlukan lebih banyak tenaga kerja dan tempoh masa yang lebih panjang. Masalah yang sama juga timbul semasa proses pemotongan bekalan bil – bil tertunggak oleh TNB kerana proses ini juga dilakukan secara manual. Bagi meningkatkan kecekapan keseluruhan, sebuah sistem meter pintar dibangunkan. Sistem meter pintar ini membolehkan pihak pembekal tenaga elektrik mendapatkan bacaan meter secara automatik dengan menggunakan alat kawalan jauh yang dikawal oleh *Global System for Mobile Communication* (GSM). Sistem pintar ini juga membolehkan TNB untuk memutuskan dan menyambungkan semula bekalan kepada setiap meter di kawasan tertentu secara jarak jauh bagi menjimatkan tenaga kerja dan masa. Sistem meter pintar ini juga membolehkan pengguna memantau penggunaan tenaga yang telah mereka gunakan iaitu dengan memaparkan nilai voltan, arus, dan tenaga yang digunakan. Selain itu, sistem ini menggunakan Arduino Uno sebagai unit kawalan untuk mengawal sesentuh dalam proses pemotongan dan penyambungan semula bekalan. Sistem ini juga boleh memaparkan bacaan elektrik seperti voltan, arus dan penggunaan tenaga dengan menggunakan *Liquid Crystal Display* (LCD). Sistem ini sangat sesuai digunakan kerana GSM digunakan secara meluas di seluruh dunia. Melalui sistem ini, TNB dapat menjimatkan kos dalam proses bacaan meter selain dapat menyediakan perkhidmatan yang lebih baik kepada pelanggan mereka.

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CHAPTER 1

INTRODUCTION

1.1 ELECTRICAL ENERGY MEASUREMENT

Measurement is defined as the set of operations having the objective of determining the value of a quantity [1]. Usually measurements of a quantity are done using a certain device or system. In electrical power system, electrical energy is measured by the electric energy meter in order to determine the quantity of electrical energy that has been used by the consumers. Energy that has been measured is then used by the utilities for billing purpose. Measuring process is one of the elements that play an important role in the electrical power system.

Electrical energy meter uses the kilowatt hour (kWh) as it is the measurement of electrical energy. It is equals to the amount of energy used by a load of one kilowatt over a period of one hour [2]. Electrical meter uses the magnitude of current and voltage that flow through voltage and current coil and integrates them to produce energy consumed in real time. Energy consumed is then accumulated in certain period of time in order to calculate total energy consumption. Since its commercial use, electricity has been managed and monitored by utilities to ensure efficient electricity distribution to consumers as they need to pay the total electricity used.

1.2 PROBLEM STATEMENTS

Until today, conventional electromechanical energy meters are still being used. Those metering system is most likely utilities friendly but not very user friendly. The electric meter shows the accumulated energy measurement from the first time of its operation. So the meter’s measurement needs to be processed by a special device made by utilities in order to know how much energy being used when the bill is forwarded to consumer. The consumers have no idea on how much consumption are made during the whole month. They only know how much they have used at the end of the month without knowing other details such as time they consumed the most. Since they cannot monitor the consumption, it is difficult for them to control the consumption without knowing exactly how much consumption is made at certain time. So there is a great lack of real-time and evidence of demonstrative reading [3].

Utilities have tried to encourage consumers to utilize electrical wisely to avoid wastage by imposing tariffs rate that increase according to how much electricity consumed in one month. In Malaysia the tariffs rate that increased after consumers use more than 200kWh of energy in each month [4]. With the conventional metering systems this is hard to achieve since the information regarding the consumption is given in an unfamiliar form. The conventional meter displays numbers that represent entire energy consumption from the beginning of operation of the meter and this number keeps increasing whenever there is energy used by consumers. In order to get how much energy has been used in a month, operators will need to do some calculation from the number displays by the meter. So, consumers never know how much consumption has been made through in real time until the bills come to them at the end of the month.

The billing process also has become an issue to the utilities which the collection of data is still through site visit or manual reading, so still there are dependencies of manpower because electric consumption is still collected manually through site visit for billing purpose [5]. Usually the utilities sent their meter reader to each premise to take readings. The billing issue becomes worse when the premise is located in rural areas or meter position is in the hidden areas. A way to solve this inaccessible meters problem is by issuing estimation bills. Estimation bills are sometimes quite a burden to consumers since they are not really representing the accurate consumption. This will give impact to customer – utility relation. In the case of disconnection or reconnection supply also has the same issue whereby the process of disconnection or reconnection must be done manually. So this kind of practice is a manpower consuming and energy consuming with high cost and low efficiency [6].

As the electric demand is increasing as a result of population and industrial development, utilities need to provide more manpower and the consumers also need to be aware of their energy consumption in order to reduce waste [7]. Smart meter system helps increase awareness to consumers on how much electricity is consumed by giving information about the current electric consumption while the system contribute in minimizing manpower utilization in billing purposes by totally making the system automatic.

1.3 OBJECTIVES OF PROJECT

The objectives of this project are:

1. To develop a smart meter system that measure and display standard electrical measurement such as voltage, current, and energy.

2. To design a smart meter system that can send energy consumption data to utilities remotely via GSM.

3. To build a smart meter system with automatic disconnection and reconnection of electric supply through utilities command.

1.4 SCOPES OF PROJECT

The scopes of this project are:

1. To measure standard electrical measurement such as voltage, current and energy consumption of a single phase system of residential premises.

   The voltage and current of the power line to residential premises are measured and the energy consumption is calculated by the system using microcontroller. The value of single phase voltage is up to 240V with tolerance of +10% and -6% while the value of current used in the project ranging from 0 to 50A.

2. To utilize the GSM as the wireless communication structure for the system and Arduino as the control unit of the smart meter system.

   GSM is used for sending energy consumption data to utilities and receiving command from utilities to disconnect or reconnect power lines. Arduino used as a controlling unit, to operate LCD, GSM and contactor.

3. To display energy consumption through LCD.

   The LCD projects the measurements and energy consumption that calculated by microcontroller.

CHAPTER 2

LITERATURE REVIEW

2.1 THEORY AND BASIC PRINCIPLES

It is important to increase consumers' awareness on managing electrical energy consumption effectively. The increasing tariffs rate depending on how much consumption in a month is imposed by the utilities in order to encourage consumer to use electrical energy wisely and prevent electrical wastage. Smart meter system helps in delivering the information of consumption to the consumer as to give ability to estimate bills from the collected information and thus manage their energy consumptions to reduce their electric bills [8].

The smart meter system involves two way communications between the meter itself and both utilities and consumer. The system basically permits both parties to get energy consumption data from the meter through some kind of communication system. The communication system comprises of two types; wireless and wired communication network. Wired communication network apply the Power Line Carrier and Telephone Line Network while wireless communication network utilizes GSM, Bluetooth and ZigBee as the medium [9]. The measurement of current and voltage of residence system are made and calculated by the microcontroller to produce the value of power and energy that has been used. The values are displayed on display device. The values also can be sent to the utilities for billing purpose or to the consumers themselves as for energy remote monitoring.

Smart meter system also provides automatic disconnection or reconnection of supply to consumer in case of consumer wants to want to stop electricity supply services or in the event of default payment of electrical bills. There are special code sent to the smart meter and microcontroller will actuates the contactor that will disconnect or reconnect the connection of phase and neutral line of premise electrical system [10]. There are many researchers who have used different approach in developing smart meter system in order to display energy consumption more efficiently and try to integrate smart features that can improve performance of whole metering process.

2.2 REVIEW OF PREVIOUS RELATED WORKS

A lot of studies have been conducted by many researchers and the designed concepts are all more or less the same to each other in terms of metering system operation. Most of them using current and voltage transducer to measure data of voltage and current parameters and the data received are then be calculated to produce the power consumption. A development of current transducer and voltage transducer has been done by Y. Huayun et. al [10]. They proposed the application of adaptive optical current transducers and adaptive optical voltage transducers in digital meter. Adaptive optical current transducers are based on Faraday magneto-optic effect principle which has great measurement linearity and able to measure not only alternating current but also capable of measuring direct current. The Faraday magneto-optic effect principle that has been applied by the optical current transducer will never encounter frequency band problem while it has great harmonic measurement accuracy. The adaptive optical voltage transducer is based on Pockels effects. Both optical current and voltage transducer are made if optical sensor head and secondary converter. The secondary converter provides the optical source for optical sensor and receives the analog optical signal. Then the second converter collects the voltage or current signal and realizes the synchronization according to received synchronization signal of master clock.

Another way to obtain the power consumption from existing power meter is by impulse counting system. P. Prudhi, et. al. has proposed the smart meter architecture [11]. The research was done at India so they focused on how to provide advance but low cost smart meter system and still conserving existing meter. Their research uses additional conversion module for detecting pulses from digital meter or detecting rotating disc on electromechanical meter. From that, they calculated how much energy consumed and provide the data to the utilities. The implementation of electric impulse counting can easily lead to the loss of counting impulses, or lead to multi-counting impulses due to the shaking impulse during switching event of digital data. So these can lead to wrong counting and influence the precision of automatic reading.

The other type of acquiring the meter’s measurement data is by capturing the image of the meter itself. S. Dongmei and co-workers have proposed the automatic meter reading using image processing technology [12]. They implemented the technology of digital image processing, intelligent recognition, image segmentation and character recognition to identify the measurement data. The system composition consists of three levels such as reading terminal at bottom level, area concentrators and main computer for control at the middle and at the top level is the main computer of electrical administrative department which governs by utilities. This automatic reading system was proposed because its ability to contribute to real time with high efficiency and small errors in recognition which highly overcome the shortage of impulse counting.

Smart meter also involve providing two way communications between consumer and utilities. ZigBee wireless communication network is used for communication network for smart meter system. Shang-Wen Luan et. al. has mentioned that ZigBee communication network have advantages of low cost and low power consumption [13]. The smart meter with ZigBee based consists of two parts; the ZigBee based power meter and the end processing system. At the power meter, voltage and Current waveform are sampled by a data acquisition module and then converted to digital signal via ADC module of Microchip dsPIC30F microcontroller series. The voltage and current measured is calculated by microcontroller to obtain power consumption data and be sent to end processing system via ZigBee device. The end processing system contains ZigBee coordinator and software that designed to establish a power consumption and outage event database as well as to offer the inquiries of power consumption data. Each ZigBee power based system is acts as a node that need to communicate with the ZigBee coordinator of end processing system. The connected power meter to ZigBee coordinator will allow the end system to send command to receive power consumption data from each power meter. The ZigBee wireless communication networks are limited to small area network for a few kilometers square.

Petri Oksa et. al. has present their research on consideration of automatic meter reading system using PLC [14]. It is stated that PLC is a convenient networking functions without additional cables. This type of communication system has an advantage where by the networking and digitalization of existing facilities can be organized and managed at low cost. The power lines are actually used to supply electrical energy to various types of electrical appliances and devices. The lines are specially designed with low levels of impedance. The abrupt changes arising from load characteristic due to irregularity in electrical appliances themselves, using power lines for any such other purposes as communication is commonly not very feasible. Additionally, PLC system data transfer speed is a bit slow which it was reduced nearly 50% in this research. PLC also limited to small area network since the larger system of PLC can reduce transfer speed over 65% [14]. These measures are considered as a major loss to data transmission which the reduction in data transmission speed will contribute to data loss or data corruption.

Furthermore, GSM also used to be the communication structure for the smart meter system. This system is presented by Anmar Arif et. al. and it is on the implementing the application of GSM to transmit energy consumption data to the utility [15]. The system contains of a digital energy meters that measures the consumption of electrical energy and provides other additional information as it provide an easy way both consumer and utilities to monitor the consumption. The measured energy consumption is sent to the utilities, which can store the data and notify the consumer thorugh Short Messaging System (SMS) or through the internet.

K. Ashna et. al. through their research has brought GSM based automatic energy meter reading system with instant billing [16]. They have proposed system that replaces traditional meter reading methods and enables remote access of existing energy meter by the utilities. Also they can monitor the meter readings regularly without the person visiting each house. The utilities will collect the data of energy consumption from each premise through their billing point stations. GSM has many advantages since its widespread use throughout the world and the use of Subscriber Identity Module (SIM) cards to send SMS messages. The wide area can be useful since large area consist of many smart meter can send data to one end processing center to collect all data.

There are a lot of designs has been shown in developing a smart meter system. The system design parameters such as the method of obtaining power measurement and communication structure have variety of options that can be used. The summary of the smart meter system design concept is in Table 2.1.

Table 2.1: Summary of the smart meter system design concept.

No.	Proposed Design	Descriptions
1	Application of optical current and voltage transducer in energy meter [10].	• Measuring element of the system based on pure optical voltage transducer and optical current transducer. • It has high accuracy and more immune to electromagnetic interference but it is expensive so it is not very practical to be used in low voltage energy meter.
2	Smart meter system using impulse counting system [11].	• The energy consumption is captured from the previous meter by using conversion module by counting the blinking of energy meter to represent consumption of energy. • Simple design and still use the existing meter but can lead to loss of counting pulses.
3	Smart meter system using image processing technology [12].	• Energy consumption is done by read the meter indirectly via digital image processing technology. • The image is captured by lens of video camera in the reading terminal that installed close to the energy meter. • This technology is not relevant to be used for large scale because of high cost of the lens of video camera.
4	Smart meter system using ZigBee Communication [13].	• Focused on the communication between energy meter and the data based of the billing station. • The current and voltage transducer used to measure current and voltage and it is calculated by microcontroller to producer energy consumption. • The consumption data is then transfered to billing station or data base via wireless

		network of ZigBee. • ZigBee communication has a stable communication structure but it covers a limited range of networks so it might need a type of repeater to send data over a long distance.
5	Smart meter system using power line communication system [14].	• Focused on the communication network between uitilities and consumer through power line communication system. • Not very suitable since the consumption data is in high frequency form which not very suitable for power line cable that operate at 50 to 60 Hz of frequency.
6	Smart meter system using the combination of GSM and ZigBee communication system [15].	• Uses GSM and ZigBee as communication network. • ZigBee used to provide small area communication network between energy meters. So there is a need of one station to collect data from the meter. The data is sent to utilities using GSM because GSM provide wide area communication network. • This uses high cost of installation because of the combination of two different communication systems.
7	Smart meter system using GSM communication system [16].	• Based on the utilization of GSM as communication network. • Covers small and wide area network of energy meters.

In this project, the criteria that need to be focused for the proposed system were to ensure low cost of development and good communication system between consumer and utilities. Finally, the proposed smart meter system also must make sure the utilities have the control ability in disconnecting or reconnecting supply to the consumer. In addition, the proposed design for smart meter system chooses GSM as its communication network. It is known that in this design, the smart meter focusing in the application of GSM and not other type of network because GSM covers the widest area of network. In order to get the low cost system, this project not considering any combination of communication structures and GSM alone could provide an adequate communication network for the smart meter system.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 RESEARCH WORK FLOW

The commencing of the project consists of two parts; hardware development and program sketching for microcontroller. This project starts with literature review that shows design concepts that has been done by other researchers in terms of things related. This process give better understanding about how the project should be done and gives other options on how to improve or how to choose better component of the project to make the project achieve its objectives. The process of literature review involves reviewing journals, articles, internet facts and books related to the project itself.

Then, the project proceeds with designing the circuit for the component of the system such as communication structure system, measurement system and main controlling system. This process involves choosing the right devices to be included in each component of the system. The circuit is tested to make sure it gives the desired output. The components that include are voltage and current transducer, GSM module, contactor, LCD, and Arduino Uno microcontroller. The problems arise in circuit are troubleshooted properly and several test is done again until circuit designed operate well.

The process is the same with program sketching where by the command for microcontroller is programmed through integrated development environment. The program is simulated to see the outputs. After both program and hardware works well, they both are combined together. The program is burn into microcontroller. The following process is essential to ensure the program works well with the hardware and they fulfill the specification and desired objective. The data or result also must be relevant with the system. At this stage, testing is still being carried out to make sure the system works perfectly.

After troubleshooting is done, the system is tested and went through some experiment in order to see its behaviour when apply to changes of parameters such as voltage and current value. It is to make sure that the tolerance of the system towards changes of parameter is in the acceptable range before proceeding to the building model phase. The model consists of casing that will hold all the circuits into it and also external circuit that is installed together with the model to make the system easily demonstrated for presentation. Figure 3.1 shows the flowchart of work plan of the project.

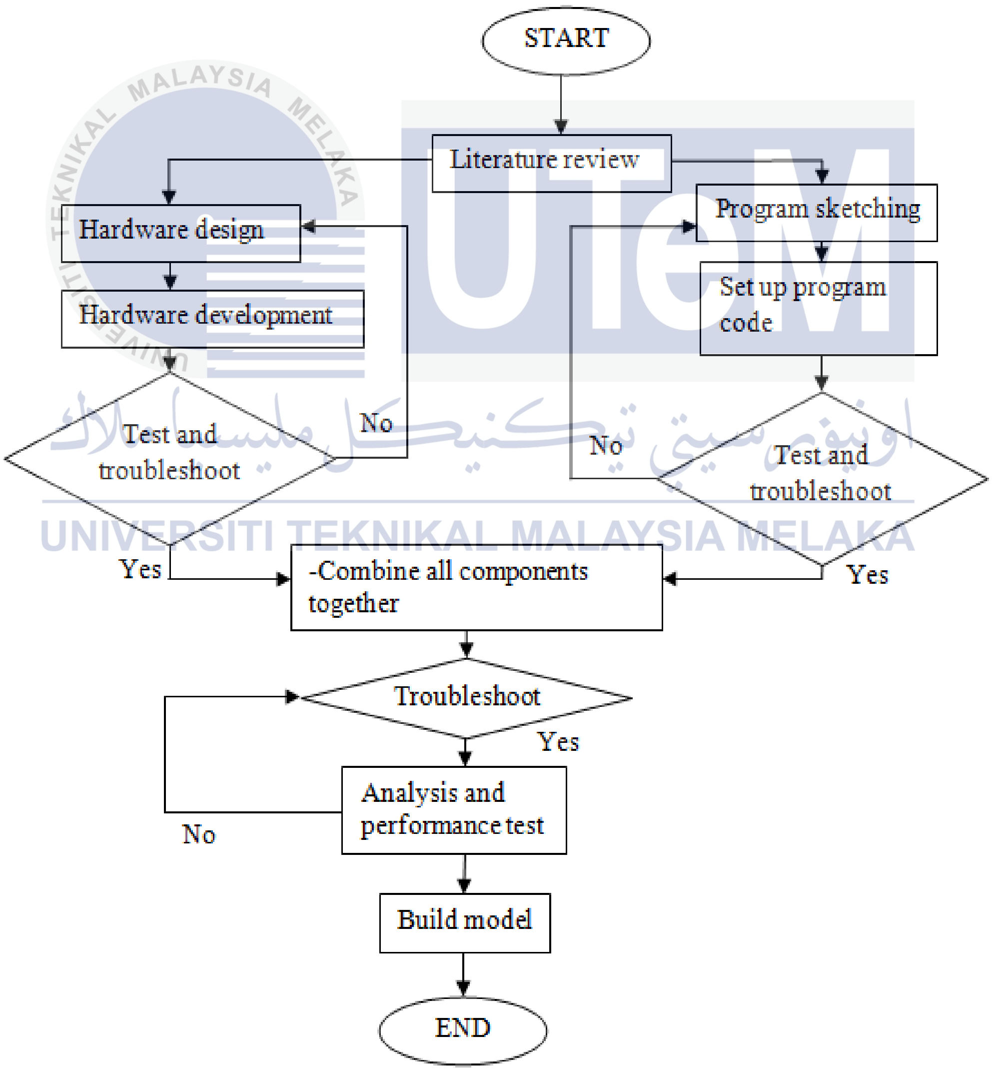

Figure 3.1: Flowchart of the work plan.

3.2 DESIGN AND DEVELOPMENT PHASE

3.2.1 Schematic Diagram of Smart Meter System

The smart meter system consists of LCD, GSM module with MAX232 level converter, voltage and current transducer circuit and also contactor. All components controlled by microcontroller. The command and instruction are programmed to the microcontroller using Arduino IDE software. Figure 3.2 shows the schematic diagram of smart meter system.

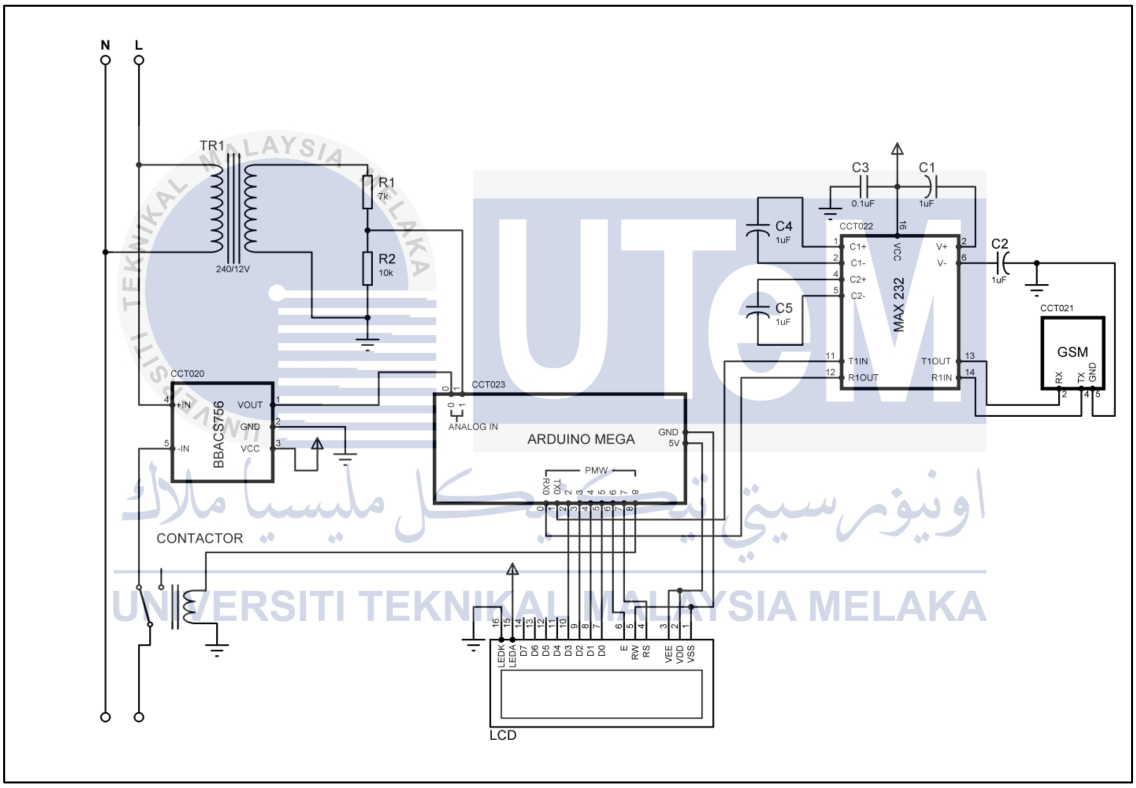

Figure 3.2: Schematic diagram of smart meter system.

3.2.2 Operation of Smart Meter System

Figure 3.3 and 3.4 shows the operation of the system. When the supply is injected to the system the microcontroller initialize all involved ports and initialize the LCD. The voltage transducer and current transducer measure the current and voltage. The value of current and voltage is sampled once in every one second and calculated by the microcontroller to find the value of power and energy consumed. The calculated power and energy consumed is then saved in microcontroller's memory. Before the power is display to LCD, the microcontroller checks for command signal from GSM to check inquiry from utilities and consumer. If there is no command signal received from GSM, system will check if the contactor is open or closed. This is to differentiate whether the supply is connected or not. The closed contactor means that the meter is normal operation and no disconnection supply are happen or the utilities has reconnected back the supply to consumer since the consumer already pay the overdue bill. The data is loaded to LCD to display the energy consumed. If the contactor is in open condition it means the consumer involved in default payment and the utilities have disconnect the power supply lines to the consumer. So LCD will display warning signal that tells the consumer to pay the overdue bill.

When signal is received at GSM, it checks what kind of command is there before proceed to next instruction. If the utilities send command to retrieve the consumption data, the microcontroller will send the data through GSM. If the command is to disconnect or reconnect supply lines to consumer, microcontroller will send signal to contactor and actuates it. Lastly if the command is from the consumer, microcontroller will send consumption data to consumer but the data in the memory is never cleared since only utilities can clear the data in memory.

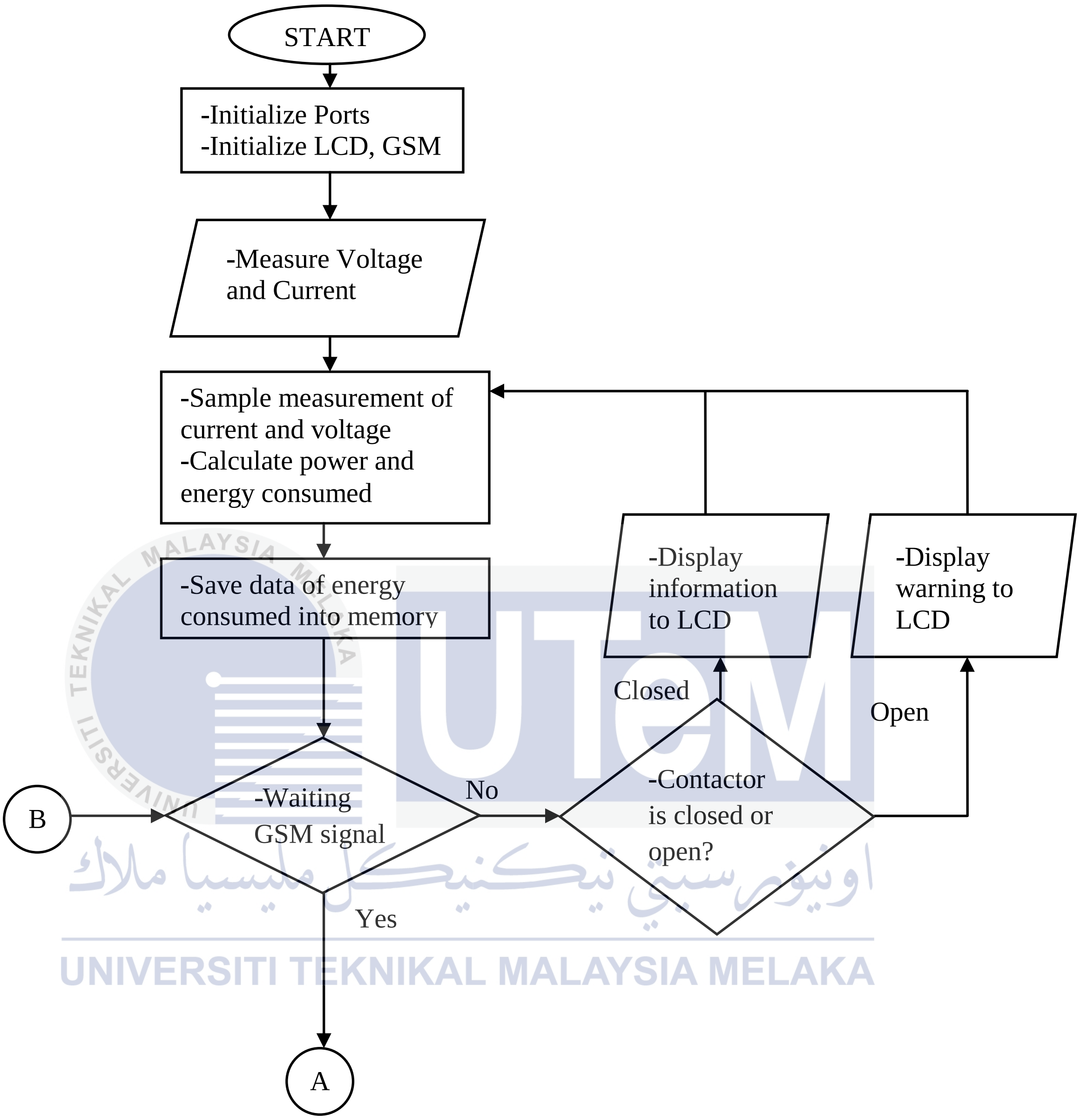

Figure 3.3: Flowchart of the smart meter system.

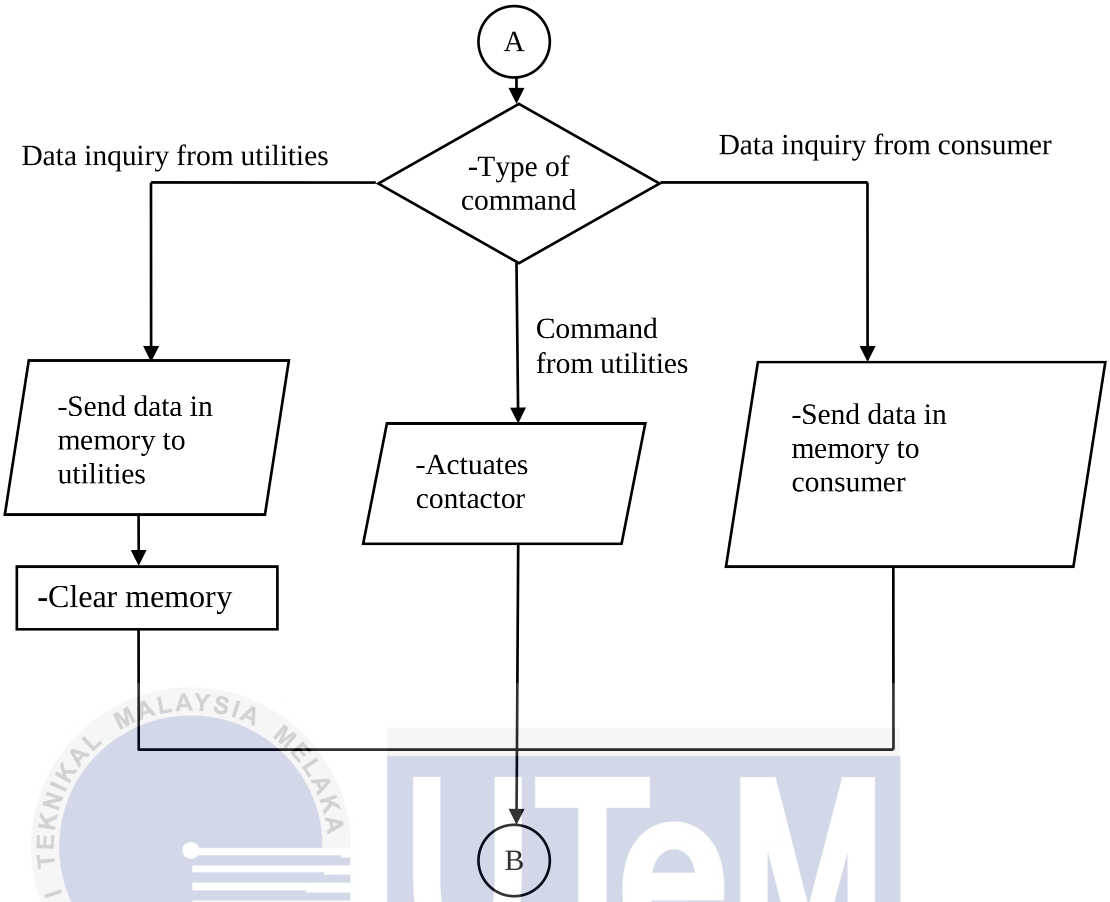

Figure 3.4: Flowchart of the smart meter system (continue).

If there is command from utilities, GSM will send data consumption to utilities for billing purposes. After that the memory is cleared to start calculating new power consumption. The situation differs when consumer inquires for power consumption from the system, the microcontroller will send the data to consumer but the memory will never be cleared. In the event of disconnecting electrical supply from utilities, the command is send to microcontroller via GSM and actuates the contactor. This will eventually disconnects the main supply to the premises. The microcontroller also will send warning data to LCD to warn the consumer that they need to settle the payment. If the utilities want to reconnect the supply to consumer's premise, the command is sent to microcontroller and actuates the contactor so that the main line connects to consumer's premise. The simple visualization is shown in Figure 3.5 for better undestanding of the smart meter system operation.

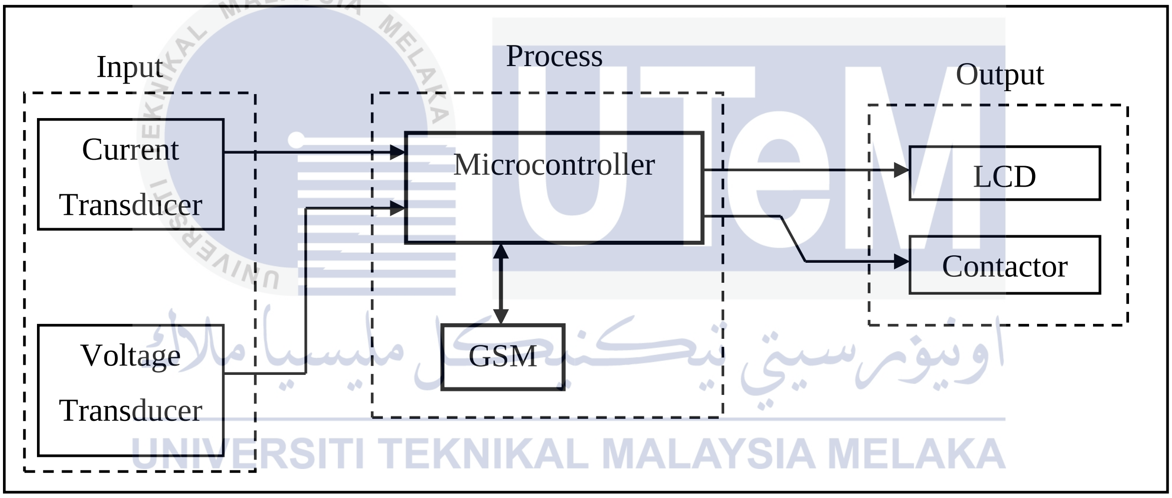

Figure 3.5: Operating flow diagram of the smart meter system.

3.2.3 Development of the Communication Structure for the System

GSM system is a standard set to describe protocol for digital cellular networks which is apply in all mobile phones as shown in Figure 3.6. This mobile phone technology is applied in the smart meter system. One of the special features of GSM is SIM card. The detachable SIM contains user’s information. This information can be used as the security code for the smart meter. When sending data, security code from the SIM is detected by receiver GSM system so it lets the utilities to know the data is sent from which meter.

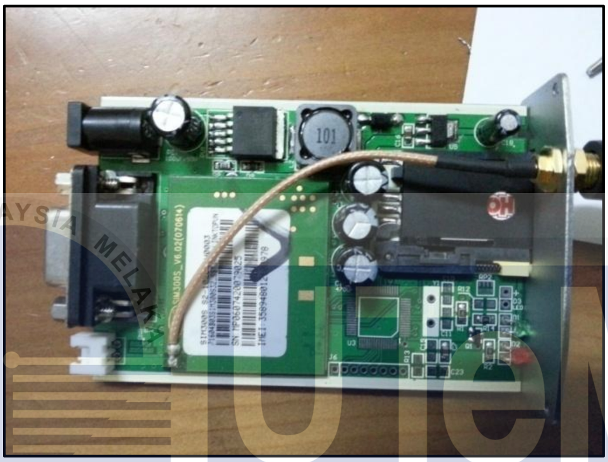

Figure 3.6: GSM system device.

3.2.4 Development of Data Extraction System

The voltage and current is measured by measurement circuits consists of potential transducer and current transducer. Current transducer is sensors that used to measure alternating current. Current transformer used in the system is the BBACS756. The device is very practical to use since it can be clipped direct on to either live or neutral wire coming into the building without having direct contact to any high voltage electrical work. Typical applications include motor control, load detection and management, power supplies and communications systems.

The current sensor is based on Hall-effect based linear current sensor integrated circuit as in Figure 3.7. The device consists of a precision, low-offset linear hall circuit with a copper conduction path located near the die. Applied flow of current through this copper conduction path generates a magnetic field which Hall integrated circuit converts into a proportional voltage. Voltage measurement is done by simple circuit consists of transformer, and divider resistor. The transformer is function to step down the voltage to a lower value. The detection of voltage is done by voltage divider where by the lower value at the secondary terminal of the transformer is fed to the voltage divider circuit to produce acceptable voltage that suitable to microcontroller.

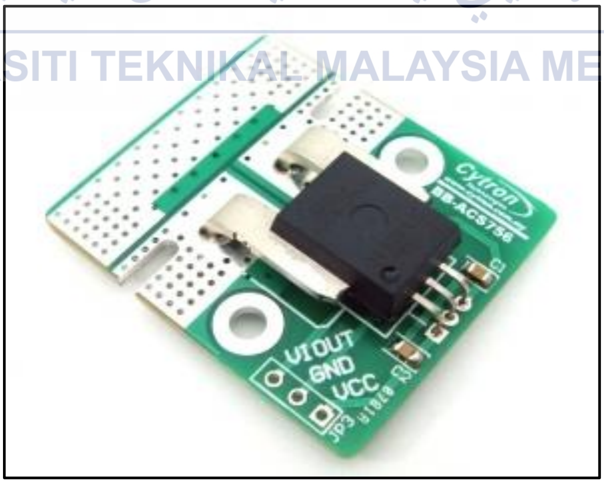

Figure 3.7: Hall-effect linear current sensor.

3.2.5 Development of Main Processing Unit.

The main processing unit as shown in Figure 3.8 is the device that receives current and voltage measurement data and calculates the value of measurement in order to find the energy consumed. The values of current and voltage is sampled by the current measurement and voltage measurement elements. The values are processed by microcontroller to calculate the power and energy consumed. The calculations of power and energy consumption are as equation (3.1).

$$\text{Average Power, P (W)} = \frac{\sum_{k=1}^{N} V_k I_k}{N} \tag{3.1}$$

As mentioned in the equation above, N is the number of sample taken and by multiplying the average power by time, t in terms of hour gives the total energy consumed[6]. The calculation is done by using equation (2).

$$\text{Energy Consumed, E (kWh)} = \frac{\text{P x t x 3600}}{1000} \tag{3.2}$$

The device also displays the power to the LCD and also have to send signal to control contactor in disconnection or reconnection power lines event. The signal from GSM will also processed by microcontroller and the next decision is determined from the command that has been programmed to it using Arduino Integrated Development Environment (IDE). The device use as main processing unit is an Arduino Uno microcontroller. It has different type of input/output that can be used like digital type, analog type and serial type for communications. Adruino Uno has a 256KB of flash memory of storing code of which 8KB is used for the boot loader, the 8KB of SRAM and 4KB of EEPROM which can read and written with its special library. The memory space included with this microcontroller is enough to support data of energy consumption.

Figure 3.8: Arduino Uno with variety of input and output pins.

3.3 PERFORMANCE TESTING

Experiment was set in order to seek out the performance of the system. There are four types of performance testing conducted. They are Current Measurement Experiment, Voltage Measurement Experiment, Power Testing Experiment and Time Response Experiment. These tests are carried out at laboratory and the results of the tests are analysed in terms of accuracy. The apparatus that are used in these tests other than the smart meter system are Lab-Volt 8821 Power Supply, Simplex Watt Muncher 5kW Resistive Load Bank, Sanwa CD800a Digital Multimeter and Fluke 43B Series Power Quality Analyzer.

Current and power measuring experiment comprised of an experiment with smart meter system is subjected with variety of loads ranging from 0 to 5000W by the load bank. Theoretically the changing of load is lead to changing of current and power consumed by the load since the voltage is kept constant at utilities standart voltage level which is 240V with tolerance of +10% and -6%. The measurement done by smart meter is collected and compared to digital multimeter.

Voltage measuring experiment comprised the voltage parameter is varies from 0 Volts to 240 Volts. The voltage is supplied from power supply to the smart meter and the output is measured from the meter. It is compared to the digital multimeter. At each level of changes, the measurement is kept monitored for 10 second to see the reaction of smart meter system towards the changes of paramater. The comparison is proceed with the calculation of error percentage for current, voltage and power. The error calculation is as equation (3.3). The Mean Absolute Percentage Error (MAPE) is calculated using equation (3.4) to find the average of errors produced by the smart meter system.

$$\text{Error percentage (\%)} = \frac{|\text{Actual value} - \text{Measured value}|}{\text{Actual value}} \times 100\% \tag{3.3}$$

$$\text{MAPE percentage (\%)} = \frac{1}{n}\sum_{t=1}^{n}\frac{|\text{Actual value} - \text{Measured value}|}{\text{Actual value}} \times 100\% \tag{3.4}$$

The time reponse experiment is done by counting the time taken for the smart meter to give feedback from the SMS command that has been send to it. The test is done repeatedly and the average of reponse time is taken as the result. Set of SMS commands sent to the smart meter and the behaviour of the meter is observed in terms of the availablity of supply lines and the display of the LCD.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 OPERATION OF SMART METER SYSTEM

The smart meter system is as shown in Figure 4.1. The circuit of the system is located inside the enclosure box. The GSM antenna is located at the right top of the enclosure box in order to send or receive message command from utilities or consumer. Other than that are the load sockets and the protection system for load socket such as Miniature Circuit Breaker (MCB) and Earth Leakage Circuit Breaker (ELCB). As shown in Figure 4.2 the smart meter system is subjected to a 100W light bulb in order to monitor the operation of the system. After the bulb was installed to the smart meter, the meter measured voltage and current of the load and then calculated the energy being used in real time. The measurement is displayed by the LCD as shown in Figure 4.3. The energy measurement is calculated and accumulated by microcontroller inside the smart meter.

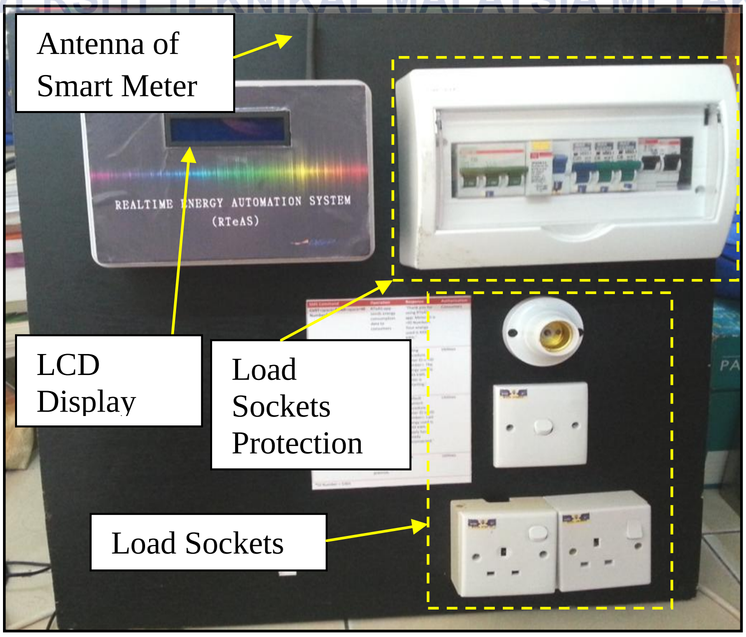

Figure 4.1: Smart Meter System.

Figure 4.2: Smart Meter System with 100W light bulb.

Figure 4.3: LCD display of Smart Meter System.

In order to receive energy measurement data remotely by consumers, a SMS command is sent to the smart meter. The SMS command is as shown in Figure 4.4. The SMS command contains the identification number which is unique to each meter. This number can act as the security for the meter where because this identification number is limited to the consumer and utilities only. In other word, there is no one other than the consumers and the utilities can read the energy measurement of the meter. After the meter received SMS command, it will reply to the consumer with the reading of energy measurement as shown in Figure 4.5. The SMS description of SMS command is in the Table 4.1 below.

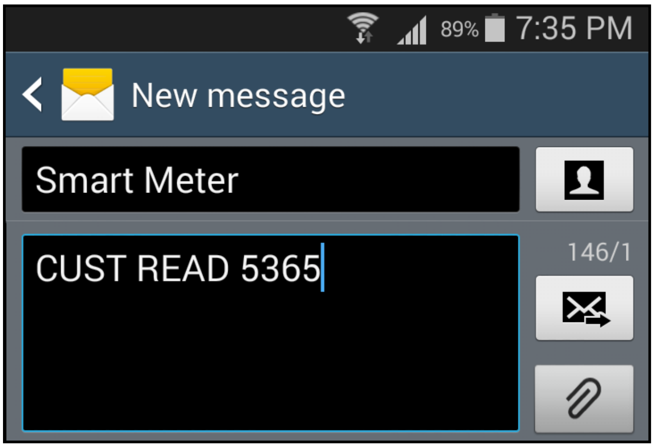

Figure 4.4: SMS command sent by consumer.

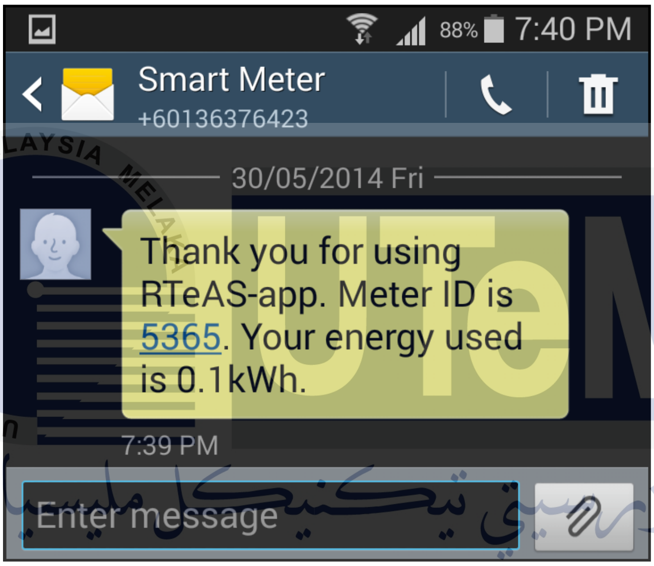

Figure 4.5: SMS replied by Smart Meter System to consumer.

Table 4.1: SMS command description for reading energy measurement by consumer.

SMS Command	Description	Response of Smart Meter
CUST<space>READ<space>5365	CUST - the message was sent by consumer READ - the command was to read the energy measurement 5365 - the identification of smart meter system.	'Thank you for using RTeAS-app. Meter ID is 5365. Your energy used is 0.1kWh.'

For energy measurement from the utilities, the meter will send the same energy measurement data to utilites, but the difference is the meter will reset the accumulation of energy usage as shown in Figure 4.6. The SMS command of utilities is as shown in Figure 4.7. The meter replied back with the energy measurement data to utilities for billing purposes. The SMS replied by smart meter system is as shown in Figure 4.8. The description of the SMS command is shown in Table 4.2.

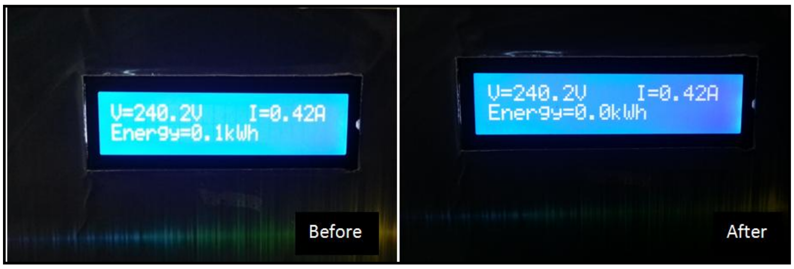

Figure 4.6: The display of LCD before and after utilities sends SMS command.

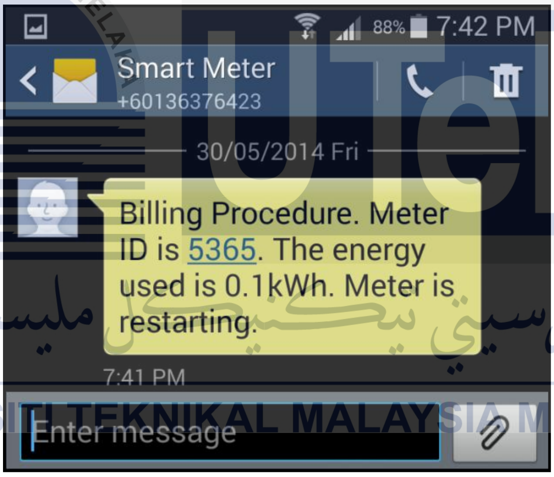

Figure 4.7: SMS command sent by utilities.

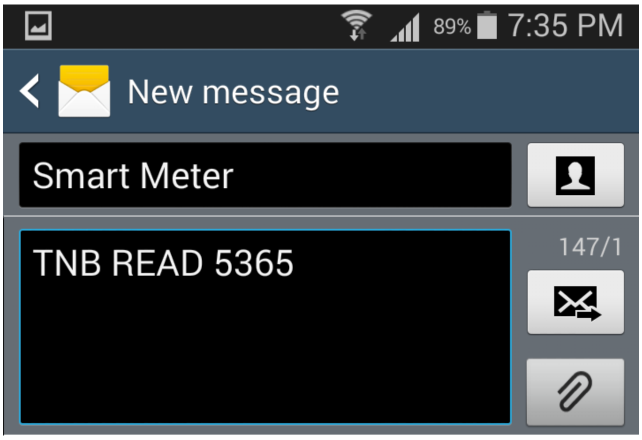

Figure 4.8: SMS replied by Smart Meter System to utilities.

Table 4.2: SMS command description for reading energy measurement by utilities.

SMS Command	Description	Response of Smart Meter
TNB<space>READ<space>5365	TNB - the message was sent by utilities READ - the command was to read the energy measurement 5365 - the identification of smart meter system.	'Billing Procedure. Meter ID is 5365. The energy used is 0.1kWh. Meter is restarting'

In the case of default payment which is the consumer doest not pay the electric bills for a certain period consecutively, the utilities can disconnect and reconnect the meter remotely. The SMS command sent by the utilities associated with this is as shown in Figure 4.9. Consequently, the meter receives the command and activates the relay of contactor located inside the meter. The contactor changed from Normally Closed (NC) to Normally Open (NO) and the supply to customer is diconnected as shown in Figure 4.10 and Figure 4.11. Then, the meter will reply with the confirmation of the disconnection process as shown in Figure 4.12. For the reconnection of supply from utilities, the process is just the same as disconnection process where by the SMS command is as shown in Figure 4.13. This will reconnect the supply back to the consumers through the control of contactor by the microcontroller. After the reconnection of supply the energy measurement is continue to be accumulated from the previous value as shown in Figure 4.14 and 4.15. The description of disconnect and reconnection of supply SMS commands are in Table 4.3.

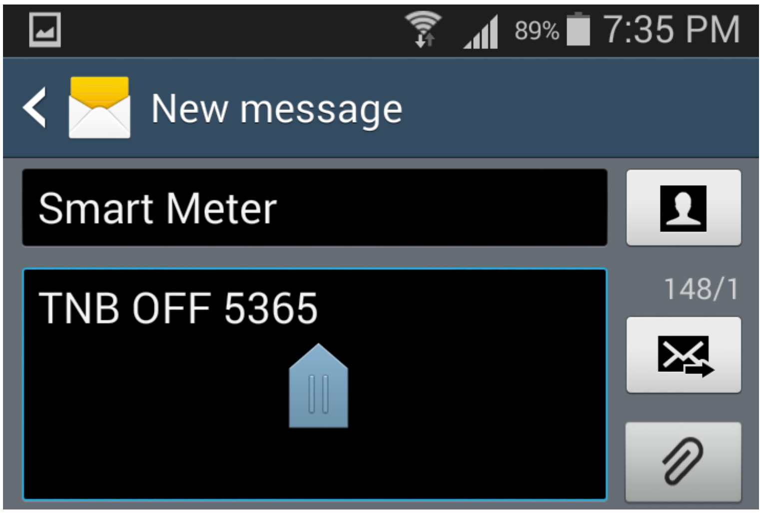

Figure 4.9: SMS command sent by utilities for disconnection of supply.

Figure 4.10: Smart Meter System disconnected the supply to consumer

Figure 4.11: System warns the consumer that supply is already disconnected.

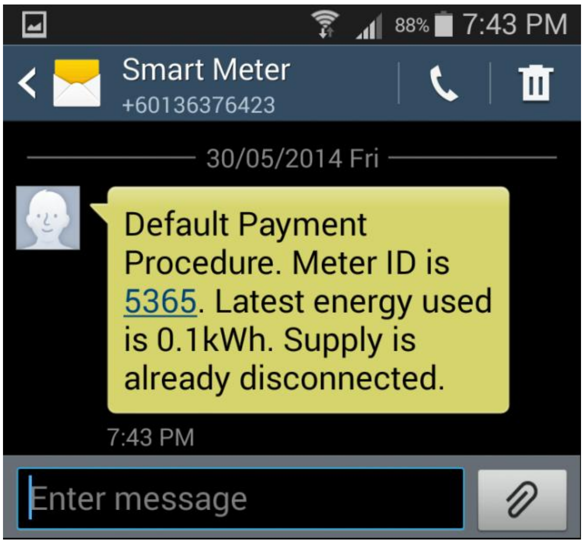

Figure 4.12: System confirmed that the supply is already disconnected.

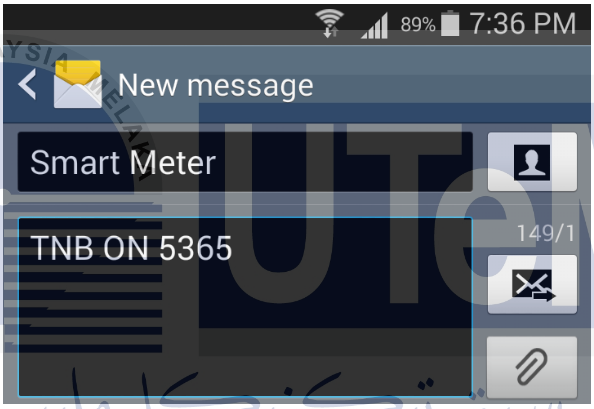

Figure 4.13: SMS command sent by utilities for reconnection of supply.

Figure 4.14: System reconnected the supply to consumer.

Figure 4.15: System continued to accumulate the energy used by consumer.

Table 4.3: SMS command description to the disconnection and reconnection of supply.

SMS Command	Description	Response of Smart Meter
TNB<space>OFF<space>5365	TNB - the message was sent by utilities READ - the command was to disconnect the supply 5365 - the identification of smart meter system.	‘Default Payment Procedure. Meter ID is 5365. Latest energy used is 0.1kWh. Supply has already disconnected.’
TNB<space>ON<space>5365	TNB - the message was sent by utilities READ - the command was to reconnect the supply 5365 - the identification of smart meter system.	Not available

4.2 CURRENT MEASUREMENT EXPERIMENT

The experiment was conducted at the Solar Laboratory in UTeM, Melaka. The load bank was varied and increased slowly and the data was collected. The magnitude of current was increased from 0A to 20A at an increment rate of 0.02A/s. Digital multimeter was used to measure the current drawn by the load bank. The connection of digital multimeter to the load is in series connection. After measuring the current by multimeter, the current measured by smart meter is collected to compare it with the multimeter readings.

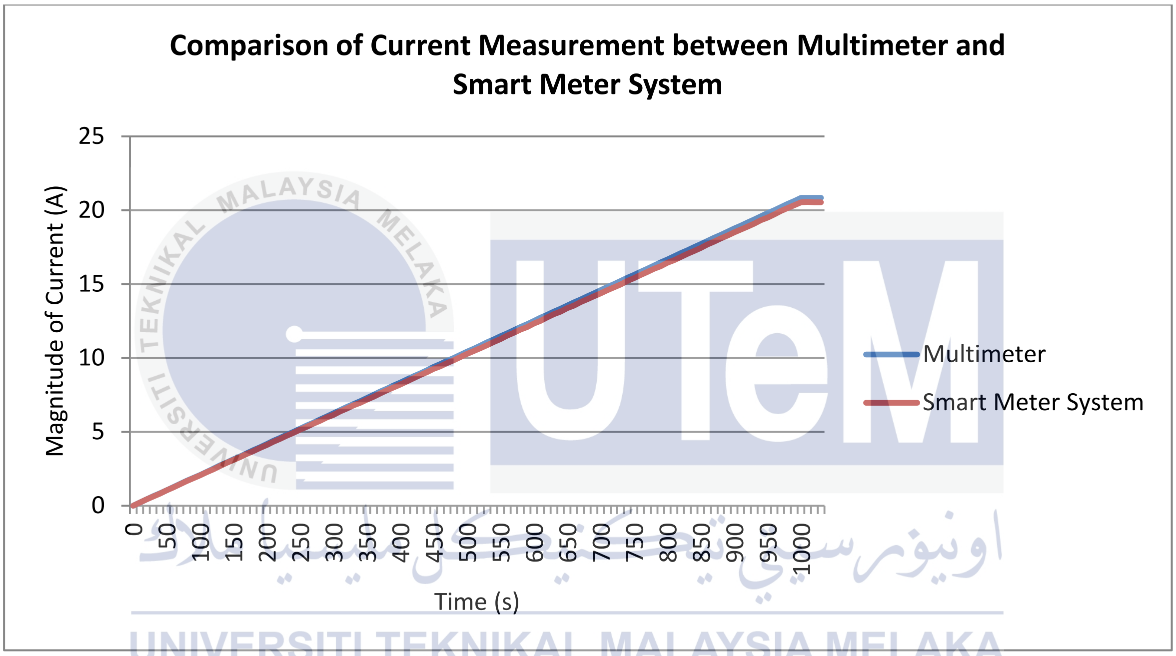

Figure 4.16: Current measurement comparison.

As shown in Figure 4.16, the current magnitude of smart meter system is slightly different from the current measured by the multimeter. The difference in readings between smart meter and the multimeter are more apparent as the value of current is increased. Eventhough the difference is larger but the error percentage is still in small value. The error percentage pattern can be seen in Figure 4.17 which consists of percentage of error from the beginning of the experiment to the end of the experiment. As shown in the Figure 4.17, the percentage of current is ranging from 1.2% to 1.8%. It is also shown that the maximum error percentage is happened around 320 to 360 seconds of the experiment. The maximum value is 1.8% but since this value is very small, the difference between smart meter and the multimeter measurement is not very obvious since the difference between multimeter and smart meter system is around 0.1A. It is can be estimated that the error percentage will stay in the same range if it is operated under normal operating condition. Normal operating condtion is the condition where by the voltage is around 240V with the tolerance of +10% and -6% while the current in the range of 0 to 50A. The mean absolute percentage error of the current measurement is 1.42%.

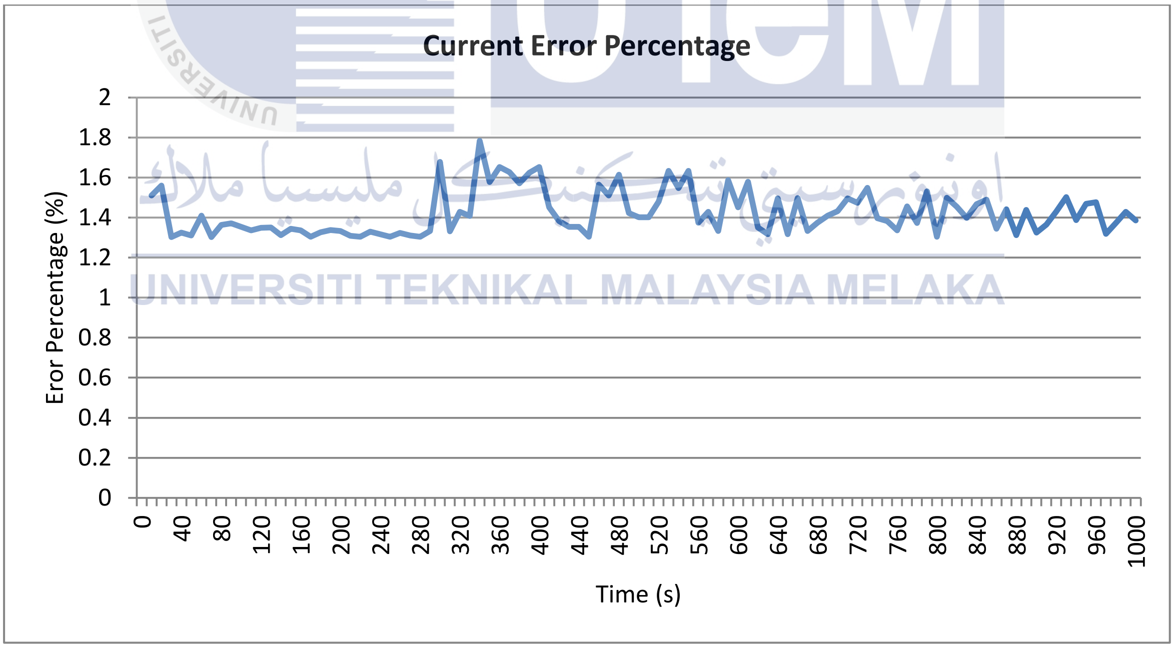

Figure 4.17: Current Error Percentage.

4.3 POWER MEASURING EXPERIMENT

This experiment was also conducted at the Solar Laboratory, UTeM. This experiment has the same procedure with the current measuring experiment where by the load was increased slowly at an increment rate of 5W/s and the measurement was taken by Fluke Meter and Smart Meter System. The results are shown in Figure 4.18. The comparison shows a little bit differences between Fluke Meter and Smart Meter System as the load increases to the maximum. The errors calculated for each load and it was visualized in a grapical manner as shown in Figure 4.19. Figure 4.19 shows that the percentage of error is in a small range of 1.5% to 2.5%. The mean absolute percentage error is 1.85%. The smart meter also did not take much longer time to response to each load changes in the 10 seconds of interval.

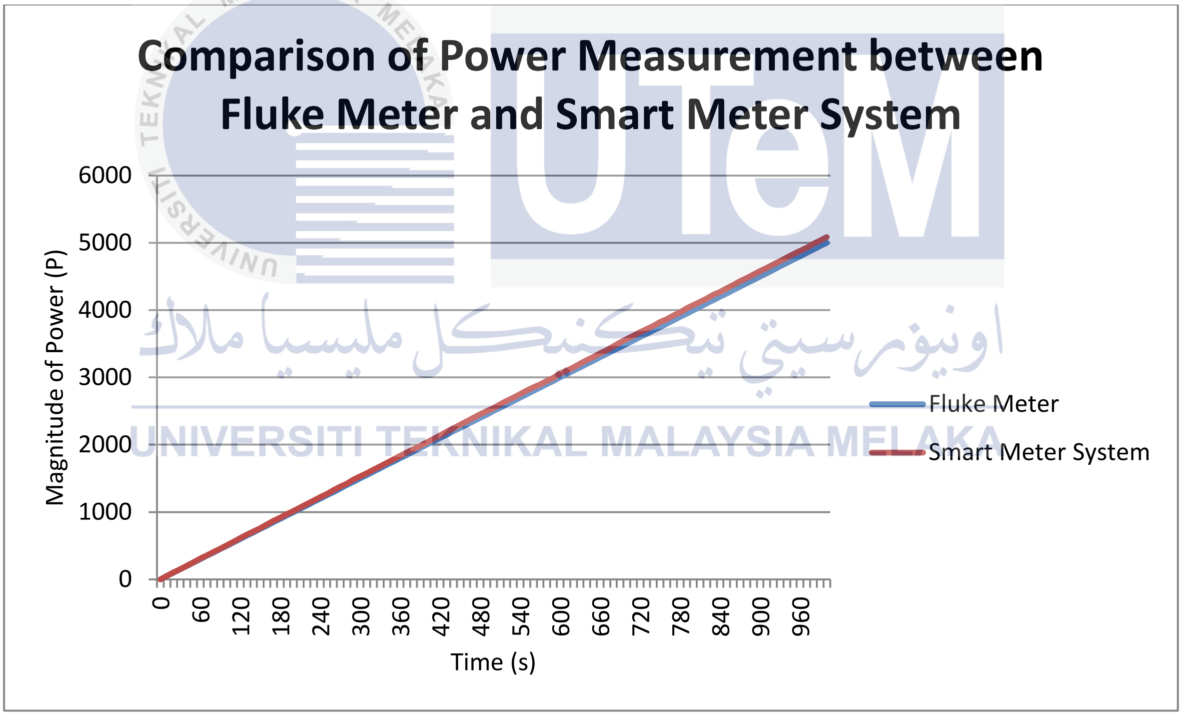

Figure 4.18: Power measurement comparison

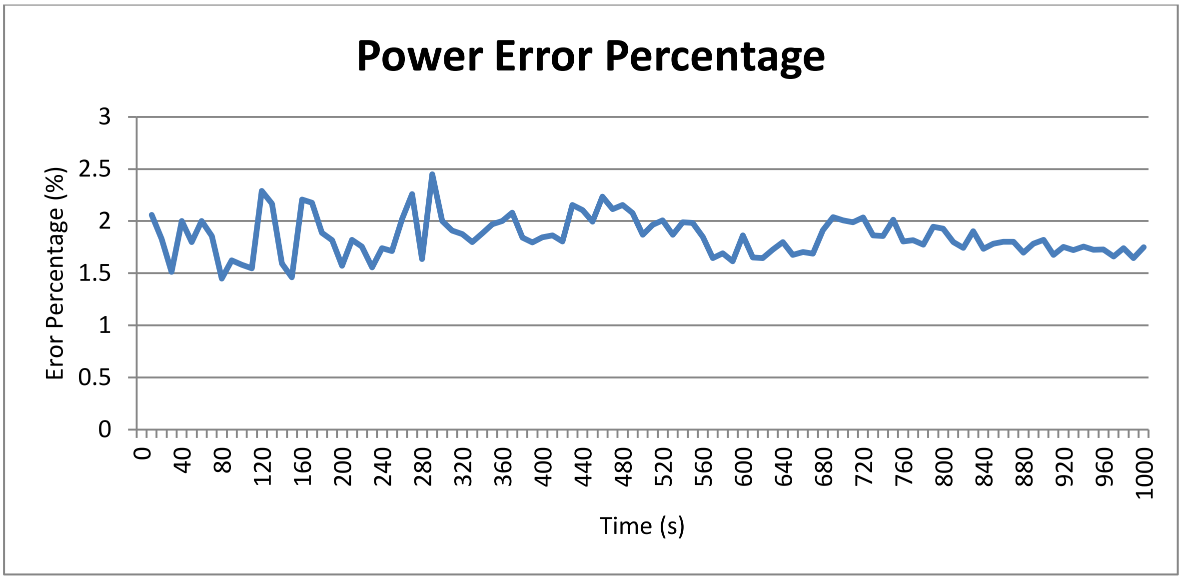

Figure 4.19: Power Error Percentage.

4.4 VOLTAGE MEASUREMENT EXPERIMENT

The experiment was conducted at the Electric Machine Labortory in UTeM, Melaka. The power supply used was the variable 240VAC. The voltage was increased slowly from 0V to 240V at an increment rate of 2.4V/s and the value is kept constant for a while when the voltage reach 240V to observe the changes of smart meter system measurement when it is subjected to constant magnitude at that level. Digital multimeter was used to measure the voltage supplied by the power supply. The connection of digital multimeter to the load is in parallel connection. After measuring the voltage by multimeter, the voltage measured by smart meter sytem is collected to compare it with the multimeter readings. The comparison is shown in Figure 4.20.

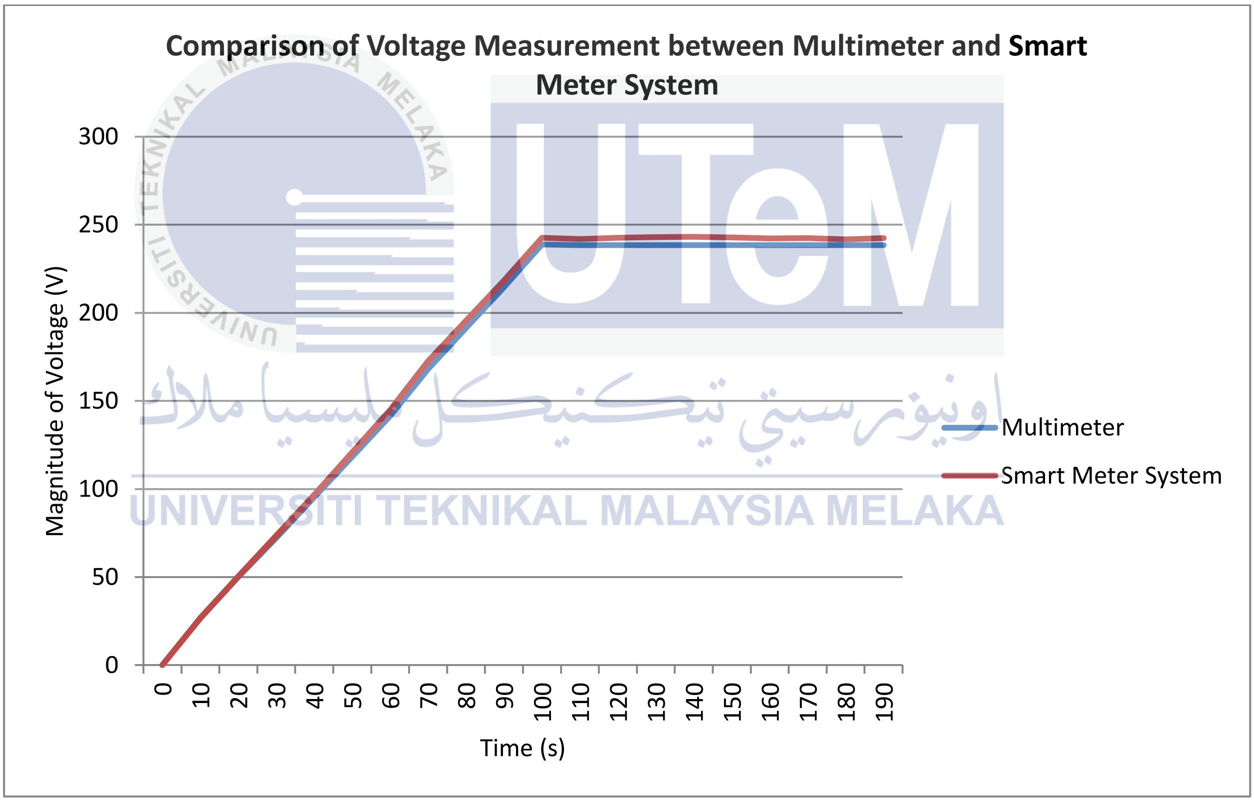

Figure 4.20: Voltage measurement comparison.

The comparison in Figure 4.20 shown the magnitude of voltage of the smart meter system is slightly different from the magnitude of voltage that has been measured from the multimeter.The difference from the beginning of the experiment to the end of experiment is very small compared to current measurement. As in Figure 4.21, the error percentage shows small value of error percentage ranging from 2.6% to 0.5%. The error range is very small compared to current measurement comparison. The pattern of error percentage also seems to be constant in the range of 2.6% to 0.5% and it can be estimated that the percentage will never be out of range. The mean absolute percentage error for voltage measurement is at 1.74%.

Eventhough the current and voltage measurement of the smart meter has differences with the multimeter and not showing the accurate value of current and voltage measurement, it can be considered true and acceptable since the error percentage is still in a small value. In the case of current measurement, the main component of the measuring element is the Hall-Effect Current Sensor which converts the value of current to small value of voltage to be passed to microcontroller. This device also has it own percentage of error in certain condition. It goes the same with the transformer in the voltage measurement element which is not producing the true value of secondary voltage. So when combining with other circuit component such as capacitors and resistors that built with their own tolerance value, it contributes to the differences of measurement from the actual values. The error can be kept at low percentage by calibrating the zero measurement of both current and voltage readings in certain period.

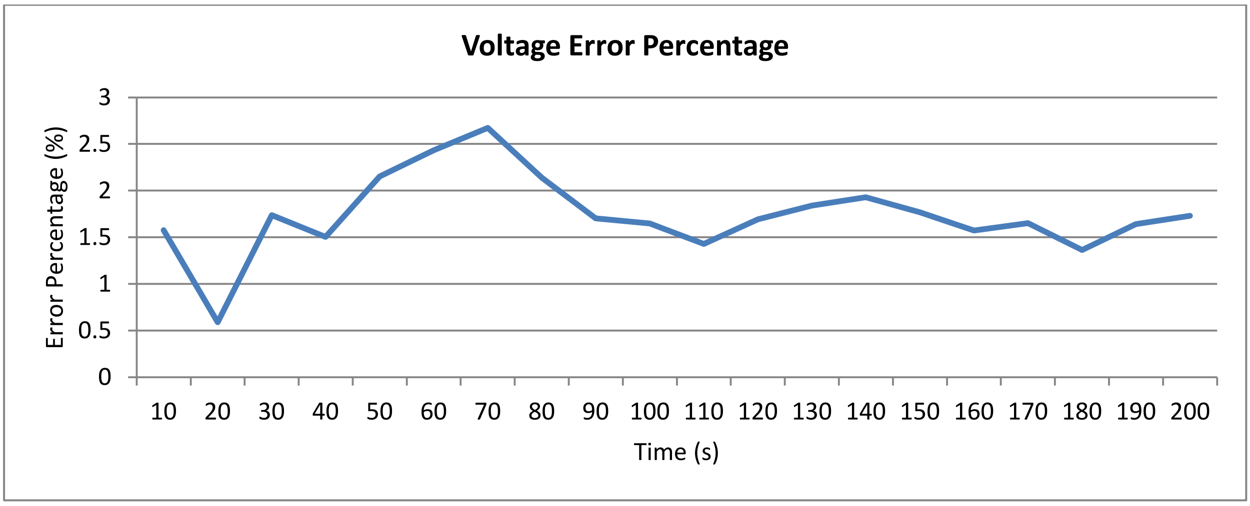

Figure 4.21: Voltage Error Percentage.

4.5 TIME RESPONSE EXPERIMENT

In this experiment, the smart meter system is operated under normal operating condtion of single phase power system. The normal condition is set up at 240V of voltage and a 7W light emitting diode (LED) type light bulb that draw small current. This condition imitates the common application of energy meter that has been used at residential premises. Various SMS commands are sent to the smart meter system to measure how long will it take for the system to response to the command. The experiment is done for 20 times for each command and the average time is taken as the results. The results are as shown in the Table 4.4. The response in terms of availability of supply lines and changes in the LCD display also being monitored as shown in Table 4.5. It is known that under normal operating condition the LCD displays current, voltage and energy consumption measurement. The connection of supply line to the load is determined by the status of light bulb whereby the bulb is turned off whenever the supply is disconnected.

Table 4.4: Average time taken for smart meter system to response to the commands.

SMS Command	Average Time Taken (s)
'TNB OFF 5365'	4.34
'TNB ON 5365'	4.28
'TNB READ 5365'	6.15
'CUST READ 5365'	6.09

Table 4.5: Response from smart meter system.

SMS Command	Display of LCD	Availability of Supply Lines	SMS Replied by Smart Meter System
'TNB OFF 5365'	'Supply Disconnected! Please contact TNB!'	Supply line is disconnected. Light bulb cannot be turned on.	'Default Payment Procedure. Meter ID is 5365. Latest energy used is XXXkWh. Supply has already disconnected.'
'TNB ON 5365'	'Supply is connecting' After a few seconds, LCD displays the measurement of current, voltage and energy consumption	Supply line is connected. Light bulb is turned on.	Not available
'TNB READ 5365'	LCD displays the measurement of current, voltage and energy consumption	Supply line remains connected.	'Billing Procedure. Meter ID is 5365. The energy used is XXXkWh. Meter is restarting'
'CUST READ 5365'	LCD displays the measurement of current, voltage and energy consumption	Supply line remains connected but the measurement of energy consumption is restarting.	'Thank you for using RTeAS-app. Meter ID is 5365. Your energy used is XXXkWh.'

As shown in Table 4.5, the first row shows that the smart meter system disconnect the supply lines after SMS command is sent to it. This command is allowed only for the utilities whenever the consumers do not settle the energy bill for a certain period. After the consumers settles the default payment, utilities can reconnect supply line back to the consumers’ premises at the same time the payment has settled without the need to send their operators to come to the location to reconnect the supply. The meter measurement can also be done by sending command as in the third row of Table 4.5. The smart meter system will send the energy measurement information to the utilities for billing purpose. The energy measurement restarts itself after utilities got the information of the energy consumption. Consumers also can get the information of energy consumption in case they are out of their premise’s location by sending SMS command shown in the table. The smart meter will send the energy consumption information to consumer.

4.6 PROJECT'S ACHIEVEMENTS

This project has been brought with the name of 'Real Time Energy Automation System –RTeAS' to International Engineering Invention and Innovation Exhibitions (i-ENVEX) on 11th of April 2014 to 13th of April 2014 which held at Universiti Malysia Perlis, UNIMAP and has been awarded with silver award medal. Figure 4.22 and Figure 4.23 shows the certification of participation and silver medal received. On May 18th, 2014, this project received gold medal during International Innovation Festival (INNOFEST) at Universiti Teknikal Malaysia Melaka, UTeM. Figure 4.24 shows the certification of participation.

Figure 4.22: i-ENVEX 2014 certification of participation.

Figure 4.23: Silver medal award.

KEMENTERIAN PENDIDIKAN MALAYSIA

UTeM
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MOSTI

CERTIFICATE OF PARTICIPATION

is here by granted to:

Muhd Khairi Bin Abdul Arif

as a presenter of

REAL TIME ENERGY AUTOMATION SYSTEM APPLICATION (RTEAS)

INTERNATIONAL INNOVATION AND DESIGN EXPO

in conjunction with

INTERNATIONAL INNOVATION FESTIVAL 2014

[18TH MAY 2014]

at

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

organized by :

ASSOCIATION OF INVENTIVE, INNOVATIVE AND CREATIVE THINKER UTeM (ASIIC)

in collaboration with :

MINISTRY OF EDUCATION MALAYSIA (KPM)
MINISTRY OF SCIENCE, TECHNOLOGY AND INNOVATION MALAYSIA (MOSTI)
STATE GOVERNMENT OF MALACCA
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Y.BHG. PROF MADYA DR. IZAIDIN BIN ABDUL MAJID
DEPUTY VICE CHANCELLOR (STUDENT AFFAIRS AND ALUMNI)
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 4.24: INNOFEST 2014 certification of participation.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Smart meter system is important as it has huge contribution to utilities and also to consumers. The system will provide the new alternative to an interactive relationship between utilities and consumer in order to save cost, save power and save energy.

The smart meter system has achieved its objectives as it can display energy consumption and communicate with both utilities and consumers successfully. The smart meter system able to disconnect and reconnect the supply line of the consumers' premises whenever it received commands from utilities. The system always standby for commands from utilities or consumers while constantly measures and displays the energy consumption. The errors from current, voltage and power measurement show that there is differences between measured and actual value of measurement but it still in small range of error since there is a tolerance in any system that have been developed. This error should be kept as minimum as possible in order to maintain its reliability to the consumers and utilities. There is an issue need to be highlighted such as the security of the meter system. There is a possibility that another party try to bypass the SMS command for unresponsible purposes. For example, someone who knows the secret SMS command tries to disconnect the supply in one of residential premises. The SMS command should be confidential and cannot be used by parties other than utilities and consumers. The SMS command procedure should be more advance in order to make sure it is not easily bypassed.

As for the recommendation, the smart meter system needs extra protection against electricity theft. There should be mechanical protection combine with the electrical circuit that can detect if there is any attempt to tamper the smart meter in order to use energy illegaly. Last but not least, the development of smart meter system managed to show its potential in contributing towards a smart electrical power system by improving overall efficiency in energy measurement process.

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APPENDICES

APPENDIX A

Turnitin Match Overview

APPENDIX B

Allegro MicroSystems, LLC

ACS756

Fully Integrated, Hall Effect-Based Linear Current Sensor IC with 3 kVRMS Voltage Isolation and a Low-Resistance Current Conductor

Features and Benefits

- Industry-leading noise performance through proprietary amplifier and filter design techniques
- Total output error 0.8% at $T_A = 25°C$
- Small package size, with easy mounting capability
- Monolithic Hall IC for high reliability
- Ultra-low power loss: 130 µΩ internal conductor resistance
- 3 kV_{RMS} minimum isolation voltage from pins 1-3 to pins 4-5
- 3.0 to 5.0 V, single supply operation
- 3 µs output rise time in response to step input current
- 20 or 40 mV/A output sensitivity
- Output voltage proportional to AC or DC currents
- Factory-trimmed for accuracy
- Extremely stable output offset voltage
- Nearly zero magnetic hysteresis

TÜV America
Certificate Number:
U8V 09 05 54214 021

Package: 5 pin package (suffix PFF)

Additional leadforms available for qualifying volumes

Description

The Allegro ACS756 family of current sensor ICs provides economical and precise solutions for AC or DC current sensing in industrial, automotive, commercial, and communications systems. The device package allows for easy implementation by the customer. Typical applications include motor control, load detection and management, power supplies, and overcurrent fault protection.

The device consists of a precision, low-offset linear Hall circuit with a copper conduction path located near the die. Applied current flowing through this copper conduction path generates a magnetic field which the Hall IC converts into a proportional voltage. Device accuracy is optimized through the close proximity of the magnetic signal to the Hall transducer. A precise, proportional voltage is provided by the low-offset, chopper-stabilized BiCMOS Hall IC, which is programmed for accuracy at the factory.

The output of the device has a positive slope (>V_{CC} / 2) when an increasing current flows through the primary copper conduction path (from terminal 4 to terminal 5), which is the path used for current sampling. The internal resistance of this conductive path is 130 µΩ typical, providing low power loss.

The thickness of the copper conductor allows survival of the device at up to 5× overcurrent conditions. The terminals of the

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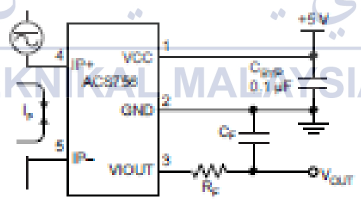
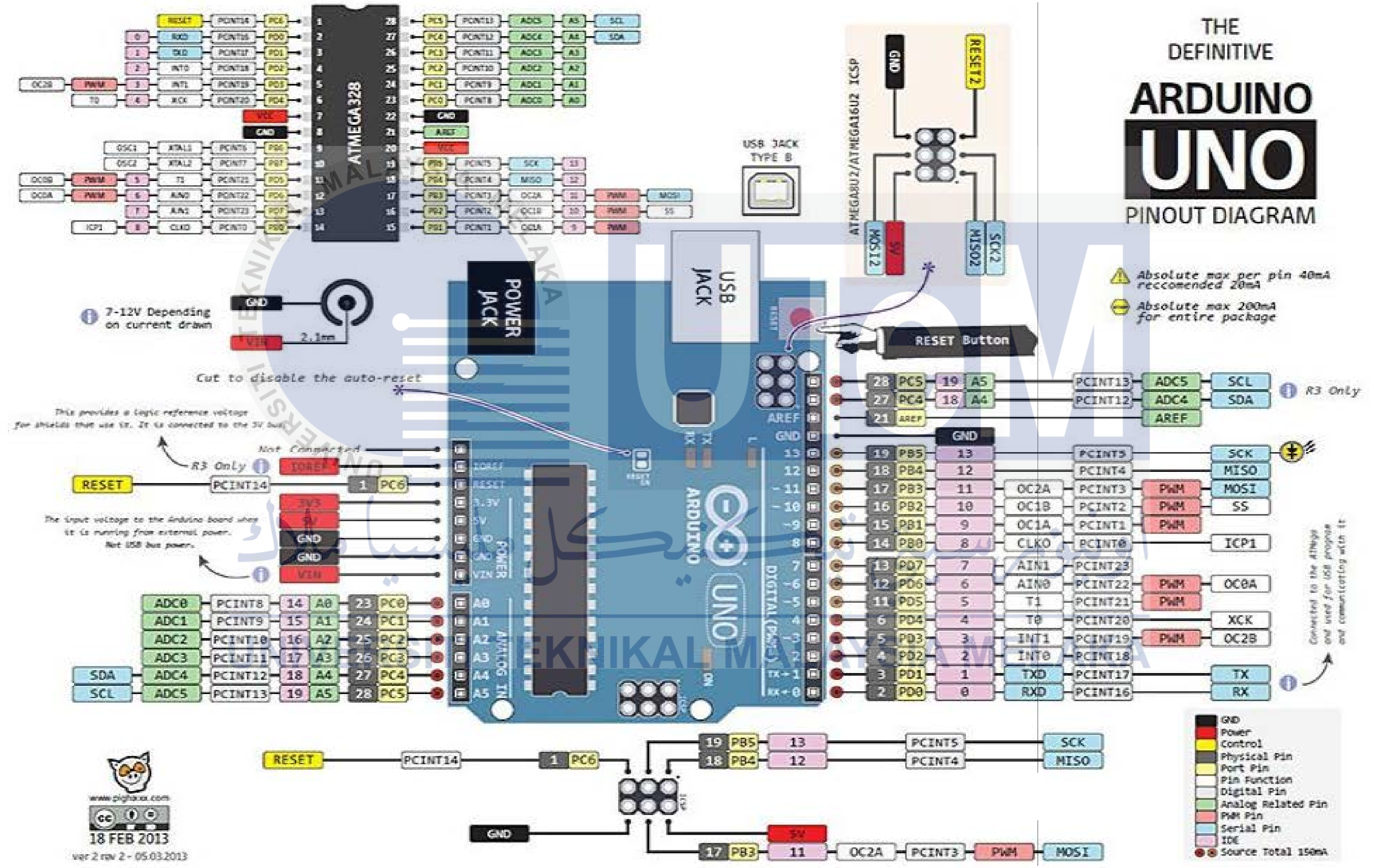
Typical Application



Application 1. The ACS756 outputs an analog signal, V_{OUT}, that varies linearly with the uni- or bi-directional AC or DC primary sampled current, I_P, within the range specified. C_F is for optimal noise management, with values that depend on the application.

APPENDIX C


THE DEFINITIVE
ARDUINO
UNO
PINOUT DIAGRAM
ATMEGA328
ATMEGA8U2/ATMEGA16U2 ICSP
GND
RESET2
MOSI2
5V
MISO2
SCK2
USB JACK TYPE B
USB JACK
POWER JACK
Absolute max per pin 40mA reccomended 20mA
Absolute max 200mA for entire package
7-12V Depending on current drawn
GND
VIN
2.1mm
RESET Button
Cut to disable the auto-reset
This provides a logic reference voltage for shields that use it. It is connected to the 5V bus.
Not Connected
R3 Only
IOREF
RESET
PCINT14
3V3
5V
GND
GND
VIN
The input voltage to the Arduino board when it is running from external power. Not USB bus power.
ADC0 PCINT8 14 A0 23 PC0
ADC1 PCINT9 15 A1 24 PC1
ADC2 PCINT10 16 A2 25 PC2
ADC3 PCINT11 17 A3 26 PC3
SDA ADC4 PCINT12 18 A4 27 PC4
SCL ADC5 PCINT13 19 A5 28 PC5
28 PC5 19 A5 PCINT13 ADC5 SCL
27 PC4 18 A4 PCINT12 ADC4 SDA
21 AREF AREF
GND
19 PB5 13 PCINT5 SCK
18 PB4 12 PCINT4 MISO
17 PB3 11 OC2A PCINT3 PWM MOSI
16 PB2 10 OC1B PCINT2 PWM SS
15 PB1 9 OC1A PCINT1 PWM
14 PB0 8 CLKO PCINT0 ICP1
13 PD7 7 AIN1 PCINT23
12 PD6 6 AIN0 PCINT22 PWM OC0A
11 PD5 5 T1 PCINT21 PWM
6 PD4 4 T0 PCINT20 XCK
5 PD3 3 INT1 PCINT19 PWM OC2B
4 PD2 2 INT0 PCINT18
3 PD1 1 TXD PCINT17 TX
2 PD0 0 RXD PCINT16 RX
Connected to the ATMega used for USB programming and communicating with it
AREF
GND
DIGITAL (PWM~)
ARDUINO
UNO
POWER
ANALOG IN
ON
ICSP
RESET 1 PC6 PCINT14
19 PB5 13 PCINT5 SCK
18 PB4 12 PCINT4 MISO
GND
5V
17 PB3 11 OC2A PCINT3 PWM MOSI
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18 FEB 2013
ver 2 rev 2 - 05.03.2013
GND
Power
Control
Physical Pin
Port Pin
Pin Function
Digital Pin
Analog Related Pin
PWM Pin
Serial Pin
IDE
Source Total 150mA