# BATTERY MANAGEMENT SYSTEM FOR WATER QUALITY MONITORING SYSTEM IN AQUACULTURE APPLICATION

**AZMAN AB MALIK**

**UNIVERSITY SAINS MALAYSIA**

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# BATTERY MANAGEMENT SYSTEM FOR WATER QUALITY MONITORING SYSTEM IN AQUACULTURE APPLICATION

**by**

**AZMAN AB MALIK**

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| Photovoltaic | PV |
| Lithium Ion | Li-ion |
| Constant Current | CC |
| Constant Voltage | CV |
| Power Management System | PMS |
| Constant Current-Constant Voltage | CC-CV |
| Intensive Care Unit | ICU |
| Deep of Discharge | DoD |
| Single-Ended Primary Inductive Converter | SEPIC |
| Direct Current | D.C |
| State of Charge | SoC |
| Alternating Current | A.C |
| Ante Meridian | A.M |
| Post Meridian | P.M |
| Minimum | Min |
| Maximum | Max |
| Average | Avg |
| Standard Deviation | STDEV |

## LIST OF SYMBOLS

| **List** | **Symbol** |
|---|---|
| Voltage | V |
| Ampere | A |
| Hertz | Hz |
| Kilo | K |
| Ampere hour | Ah |
| Degree | ° |
| Watt | W |
| Duty cycle | D |
| Watt Hour | Wh |
| Hour | h |
| Second | s |
| Mega | M |
| Micro | u |

# SISTEM PENGURUSAN KUASA UNTUK APLIKASI SISTEM PENGAWASAN KUALITI AIR DI DALAM APLIKASI AKUAKULTUR

## ABSTRAK

Projek ini mencadangkan sistem pengurusan kuasa untuk sistem pengawasan kualiti air dalam aplikasi akuakultur. Sistem kawalan kualiti air ini memerlukan bekalan kuasa 12V, 200mAh yang mengandungi 5 jenis penderia iaitu, penderia amonia, penderia suhu, penderia paras air, penderia kandungan oksigen dan penderia pH. Sistem yang diketengahkan ini menggunakan bateri jenis lithium ion batteri memandangkan saiznya yang lebih kecil, lebih ringan, jangka hayat yang lebih lama dan voltan keluaran yang lebih stabil. Pada masa kini pengecas bateri ini hanya terdapat untuk bateri yang disusun secara selari sahaja. Maka konfigurasi ini hanya sesuai untuk menyokong applikasi 3V. Walaubagaimanapun untuk sistem 12V, voltan haruslah ditingkatkan daripada 3V kepada 12V dan proses ini akan menyebabkan kehilangan kuasa. Justeru, pengecas untuk knfigurasi sesiri dikaji didalam projek ini.

Empat model dibina di dalam projek ini iaitu; 1) bateri yang disusun secara selari dan tenaga solar digunakan untuk mengecas bateri, 2) bateri yang disusun secara sesiri dan tenaga solar digunakan untuk mengecas bateri, 3) tenaga solar dan bateri yang disusun secara selari digunakan untuk membekalkan kuasa kepada sistem 4) tenaga solar dan bateri yang disusun secara sesiri digunakan untuk membekalkan kuasa kepada sistem. Ekperimen untuk mendapatkan kadar pengecasan dan kadar nyah cas telah dijalankan untuk setiap model dengan menggunakan beban yang sama.

Keputusan menunjukkan bahawa model kedua memberi penambah baikan sebanyak 173% tempoh nyah cas berbanding model 1. Berbanding model 1 dan model 2, keputusan menunjukan model ketiga meningkat sebanyak 193% dan 7% terhadap kadar nyah cas. Untuk model keempat kadar nyahcas meningkat sebanyak 406%, 85% dan 73% berbanding model 1, model 2 dan model 3. Keputusan juga menunjukkan dengan menggunakan pengecas LM2577 di dalam model 2 dan model 4 di dalam proses mengecas meningkat sebanyak 25% berbanding model 1 dan model 3 yang menggunakan pengecas MCP1630. Kesimpulannya, model 4, dengan menggunakan bateri lithium ion yang disusun secara sesiri dan pengecas LM2577 dicadangkan untuk projek sistem pengawasan kualiti air di dalam aplikasi akuakultur.

# POWER MANAGEMENT SYSTEM FOR WATER QUALITY MONITORING SYSTEM IN AQUACULTURE APPLICATION

## ABSTRACT

This project proposes a Power Management System (PMS) for water quality monitoring systems in aquaculture applications. The proposed system requires power supply 12V, 200mAh with five sensors, which are ammonium sensor, temperature sensor, water level sensor, dissolve oxygen sensor and pH sensor. The proposed system use lithium ion battery due to its smaller size, lighter, longer life span and stable output voltage. Nowadays battery charger is only available for batteries that are arranged in parallel. Hence it is suitable only for the 3V application. However for the 12 V system, the voltage have to step up from 3V to 12V, and it will cause power losses during the step up process. Therefore a charge in series configuration is studied in this project.

Four models are developed and studied in this project which are; 1) batteries are arranged in parallel and solar energy is used to charge the battery. 2) batteries are arranged in series and solar energy is used to charged the battery, 3) solar power and batteries that are arranged in parallel are used to supply power for the system, 4) solar power and batteries that are arranged in series are used to supply power for the system. Experiments to get the charging rate and discharging rate to supply power for the system are carried out by using the same load.

Results show that the second model improves by 173% of discharging rate compared to model 1. Compared with model 1 and model 2, results show that the model 3 improves by

193% and 7% respectively for the total discharging rate. For the model 4, the discharging rate is better 406%, 85% and 73% compared to model 1, model 2 and model 3 respectively. Results also shows that by using LM2577 in model 2 and model 4 as a charger will increase the charging process by 25% compared to the model 1 and model 3 that use MCP1630 as a charger. As a conclusion, the model 4 with lithium ion battery with series configuration and LM2577 as a charger is proposed for the water quality monitoring system for aquaculture application.

# CHAPTER 1

# INTRODUCTION

## 1.1 Research Background

Water Quality Monitoring System (WQMS) is widely used to identify the performance of certain activities such as condition of water (Chapman, 1996) and quality of water(Ward et al., 1986). A few parameters have been set such as water level, pH, temperature, ammonia and dissolve oxygen in order to identify the condition of water. This system is not limited to measure the water quality in aquaculture but also implemented in other sectors such as in chemical industry(Chung, 2007, Jeong et al., 2006, Zhang et al., 2006) and sewage power plant(Baronti et al., 2000, Vanrolleghem and Lee, 2003, Bester, 2003).

Basically WQMS have a combination of equipment to develop a complete system. For example, it will use a sensor to get a data from water, microcontroller to process a data, communication medium and computer to analyze the data. There are two type of WQMS, which are indoor applications(Chung and Oh, 2006) and outdoor applications(Bulusu et al., 2000). The system for indoor application normally is set with good facilities such as electricity and internet infrastructure.For outdoor applicationsnormally itrequires additional devices such as microcontrollerto process a data from sensor and to perform data transfer from node to control room. All of the devices should use low power consumption (Chung, 2007).For indoor applications cable and computer are used to monitor all the activities and to analyze data. In outdoor applications microcontroller and transmitter are used to perform the data transfer. However the system cannot perform properly without a good or stable power supply. Hence a power supply with enough capacity is required to ensure that the system can perform properly(Koenck, 1984). Since this system is implemented at a place without electricity, a potential renewal energyshould be exploredto supply energy continuously (Sulaiman and Zain, 1996, Fornasiero and Graziani, 2006, Darus et al., 2009).

One of the renewable energy sources is solar energy. It is derived from sun and the energy is converted from light into electricity(Parida et al., 2011, Branker et al., 2011, Shah et al., 1999). The usage of solar energy is not only in a specific place, but people started to use solar energy in their home until today. According to (Bader et al., 2003), the use of solar energy has been widely used and could help reduce electricity consumption (on-grid system).

Solar energy requires storage to store the electrical energy and generally, the technology uses lead acid batteries as the electrical storage(Casacca et al., 1996, Hua et al., 2006, Divya and Ã˜stergaard, 2009). Lead acid battery is available, affordableand its role as the custodian of a consistent and efficient energy has make this type of battery monopolize the solar technology(Manwell and McGowan, 1993). However the usage of lead acid batteries requires space and its particular lifespan depends on consumption and the external factor such as temperature(Nakamura et al., 1996). Hence, lithium ion battery becomes a new alternative, which is able to become a source of energy savings. Lithium ion batteries are widely used in low voltage applications(van Schalkwijk and Scrosati, 2002, Moore and Schneider, 2001).. One of the advantages using lithium ion battery as an electrical storage is the size and make the space will take less compare to lead acid battery. Besides that, the lithium ion battery type has the capability of delivering high power and high energy compared to lead acid battery, energy delivering and power are lower (Zhang et al., 2004, Chan et al., 2007, Wakihara, 2001). In this project, lithium ion battery is investigated either it can bean electrical storage and solar energy as main source to supply energy continuously to WQMS.

Since the application of WQMS is used at certain area with no electricity provided, the power supply should have the ability to support without any disturbances during data collection. According to Song, (1999), lithium ion provides a good energy based on the number of charge and discharge compared to another type of rechargeable battery such as NiCad and Silver zinc.  The small size of the battery allows it to be fixed in the same casing, the price is also reasonable and this will make the system more portable and user friendly. Lithium ion battery is available in a small size capacity such as 3.75V. A certain number of cells have to be assembled in series or parallel configuration to achieve the desired battery size. In this project, WQMS requires 12V voltage to power up the system. If the cell of battery is less than 12V, it will requires a booster and if exceed 12V it's requires a step down to achieve a requirement.

In 12V D.C power supply, normally lead acid battery is used to store electrical energy from solar panel. In this project a Power Management System (PMS) using lithium ion battery as storage to store electrical energy from the solarpanel is explored. Figure 1.1 shows a block diagram of the current technology using lead acid battery for standalone photovoltaic system. It consists of solar panel, charge controller and lead acid battery.

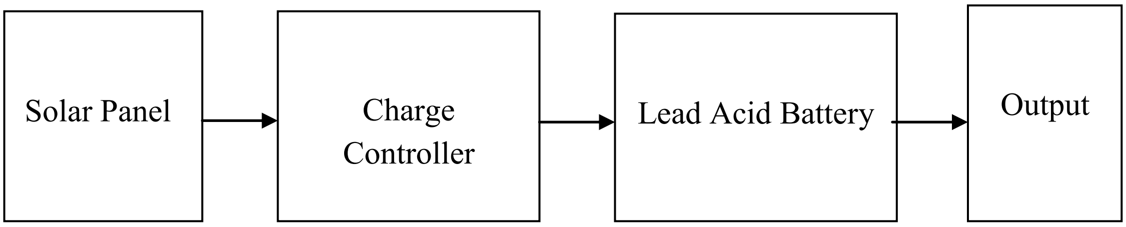

Figure 1.1: Basic Block Diagram of Experiment

Every cell of battery has their own nominal voltage and it works for lead acid or lithium ion battery. In both applications of lead acid and lithium ion battery, the charge controller is set to voltage setting to perform charging process and to avoid from over charging.

## 1.2 Problem Statements

Aquaculture sector contributes millions of Ringgit Malaysia (RM) in our national income. One of the aquaculture products is fresh waterfish such as cat fish, tilapia andArowana. The fresh water fishes need a balance ecosystem to ensure they can live healthier.Water is exposed to many kinds of waste and contamination, which can disturb the ecosystem of fish. Fish will die if they are exposed to the polluted water, even though just for a few hours. A continuous WQMS is needed to monitor the water quality at all time.Application of WQMS is not limited at pond for fish farming but for all activities to identify the condition and quality of water. At certain area there is no electrical power provided, hence a system that isbattery powered and portable is needed for continuous usage. However the problem is on how frequent the battery should be changed.Thus the continuous input power from natural sources is needed to charge the battery. In this application, solar energy can be a potential power source. Electrical storage such as battery is important to store this energy by using input from sun to propose a PMS for WQMS.

Lead acid battery is widely used as an electrical storage for solar energy. However the drawback of lead acid battery is the bigger size and it is heavy. Lithium ion battery is one more option available in the type of rechargeable battery. Lithium ion battery is claimed to perform well in high temperature or in low temperature, has better power delivery and better discharge performance. The problem in lithium ion battery is, its charger is only for single cell/double cell and the suitable application or device are required low than 4.2V/8.4V of power source.The capacity can be increased by connecting the battery in parallel configuration and voltage can be increase by connects in series configuration. WQMS required continuous 12V from power supply, since lithium ion comes with 3.75V/cell its need to used a booster to achieve 12V output. During voltage increment there could be losses, and the system requires many batteries which is not cost effective.Hence this research is conducted to see the possibility of using a single charger for series configuration (more than 2 cells) of the battery where it can reduce the cost ofinstallation.Compared to lead acid battery are stable for 12V application in term of electrical storage and its charger. This research also focuses to reduce thecontinuous usage of power supply and managed the main power supply from continuous charging in one cycle of fully charge. Continuous charging can create stress factors and the discharge process during batteries in high state of charge can reduce the life time of lithium ion batteries.Two mode of charging have been explored, which are continuously mode and periodic mode. Continuously mode is a condition where the lithium ion battery are continuously charged and dischargedwhereas in periodic mode charging process are regular at certain voltage level. In both modes, the batteries are connected in series and parallel connection. The overall process of the development of PMS uses solar energy as the main.

## 1.3 Research Objectives

In the thesis, lithium ion battery is investigated whether it can be a portable power supply together with solar power to ensure continuous power supply can be outputted to the WQMS. Hence the following objectives have been set to solve the problem.

i. To estimate the capacity of Li-ion battery based on the load requirement for WQMS.
ii. To compare the battery charging process in series and parallel configurations; and
iii. To propose the hybrid power supply using the Li-ion battery and solar power.

To support the objectives, the following four (4) experiment (Models) setup have been presented where Models 1 and 2 are for objective (ii) and Models 3 and 4 are for objective (iii). All models are using solar power as power source.

i. Model 1 : Li-ion batteries in parallel configuration using MCP1630 as the charger;
ii. Model 2 : Li-ion batteries in series configuration using LM2577 step up voltage regulator as the charger;
iii. Model 3 : Model 1 plus solar power;
iv. Model 4: Model 2 plus solar power.

## 1.4 Research Scope

The study is defined with a few requirements and specificationwhich as listed as follows;

a) Engineering Specification: Investigate the changes of the method of combination energy between lithium ion batteries and solar energy for sensor network. The combination two energy to power up 12V application. To investigate the best method of charging in series or charging in parallel to identify a fast charging and investigate durability of lithium ion batteries in term of using four unit of battery pack.
b) Hardware specification: A microcontroller PIC-based system is developed to perform Power Management System\in order to manage a power between two source, cut off voltage during fully charge and control a charging process for continuous mode or periodic mode.
c) Test Specification: Evaluate the performance for every each model of PMS in term of durability and voltage change in the lithium ion battery. Every model will test with detail experiment from performance discharging and charging process with WQMS

## 1.5 Thesis Layout

The thesis is organized into five chapters. The first chapter discusses on the background of water quality monitoring system, lithium ion battery, problem statements, research objectives, and the outline of thesis. Chapter 2 explains on the literature review whereby it describes theresearch and studies on application of lithium ion battery in market, method of charging, state of charge and battery model.

In the third chapter, the work flow of the project is discussed and illustrated by a flow chart and block diagram. A detail explanation of experiment that is used in this research is also presented in this chapter. It is followed by the cultivation process and the development of four batteries that are investigated in this project.

Chapter 4 explains about results and discussion, which contains the identification of solar positions and angles at a few places at north area of Malaysia, data collection, graphical analysis, development of portable power supply, combination of storage with solar source and posttest analysis. Finally, chapter 5 indicates the conclusion of the research, limitations and suggestions for future work.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter discusses about literature review of this project. Some research works that have been carried out by other researchers are presented in detail in this chapter.

## 2.2 Water Quality Monitoring System in Aquaculture Application

According to (Laham et al., 2012), fish is a main source of protein and fat. It has become an alternative meat source due to health problems such as overweight and cardiovascular disease. Since the demands arevery high, many countries cannot just depend on the ocean fishing activities. Hencefresh water fish is an option for commercialization. There are many methods in agriculture to develop fish farming such as using pool (Nawi and Zaharah, 2010) and canvas (Safiai, 2009). All methods of fish farming must be monitored.

Research by (Afrianto and Liviawaty, 1999) reveals that the population of fish decreases because of some interference in fish ecosystem such as bad microorganism growth in water,high concentration of ammonia, unstable temperature, pH and very low concentration of oxygen. All of these factors can bestress factors to fish in pond. Because all of this problems many farmers or investors stop to grow their fishes business. Hence a continuousmonitoring system is required and the example of continuous WQMS can be illustrated in Figure 2.1. Sensors can be placed in every pond and data are transferredwirelessly to the receiver terminal. Radio Frequency (RF) is used as a transmission medium either for small range or large range, and wireless sensor network can be adopted in the system. The receiver send data to databaseatserver through internet. Finally user canreceivedthe data through computer or phone regarding to their water quality of fish farming.

A research in WQMS has been conducted by (Ding QiSheng, 2010), they have developed WQMS based on a microprocessor in aquaculture application. Data are collected through RS232 cable. The drawback of the system is,it uses wire, whereas for this application wireless is more suitable. For outdoor application need this system to change a few equipment and the system required portable power supply.

Another related research is from Yee et al,(2012). The research focuses on ammonia or $NH_3$ detection system. According to the paper, ammonia $NH_3$ is dangerous to fish where it can cause a stress to fish.$NH_4^+$is not dangerous to fish, however currently only $NH_4^+$ sensor is avaiable in the market. $NH_3$ is measured using spectrophotometer in lab. The paper explains in detail the process of calculating the concentrationof$NH_3$by using $NH_4^+$ sensor which is very important in WQMS. However power management system is not explained in the paper.The research is also not focused on power management by using any type of power supply and full analysis on the result of water monitoring. If there are applied at the system at the place without electricity should be explain the potential renewal energy to supply to their system continuously.

One more research in WQMS is presented by Razemi et al (2012). The system uses microcontroller to analyze data from sensor. Three parameters are used in the development of the system. The parameters are pH, temperature and dissolvedoxygen. These parameters are important to ensure that the fish can live in a good ecosystem or habitat. It is good for fishes health, life span and can decrease their vulnerability to disease. This paper also did not explain on power management system.

In a research by Ahmed and Sulaiman, (2010) power management system is designed based on power consumption that is required by load. The bigger the power demand from the load, the more capacity of the battery and the solar panel is needed. This is important to ensure that the power supply can supply current to load continuously without any disturbances. In power estimation, normally the increment of at least 5% is included in calculation. This is important to cover up the losses in instrument. In solar application, sometimes a low radiation from sun will affect the estimation of power supply. In a research by Pang et al.,2001 state that the problem due to the power estimation is a accuracy and need to be solve by put extra power to ensure capacity of storage can supply energy to the load. The estimation is depends on weather and budget. Normally in calculation, to estimate the power capacity, the system should be able to standby at least for one or two days power backup.

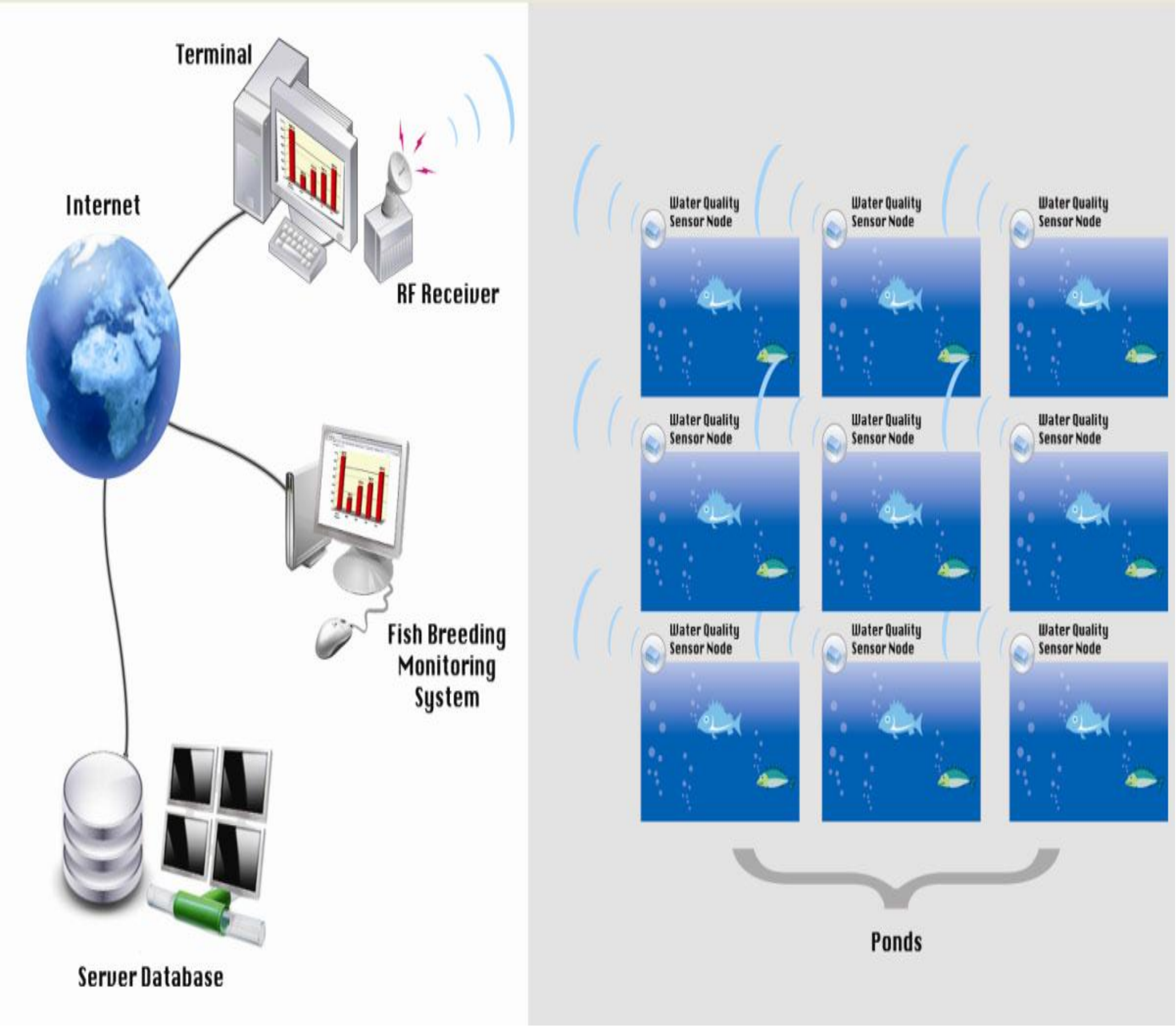

Figure 2.1: Illustrate of water quality monitoring system (Razzemi et al., 2011)

## 2.3 Potential Renewable Energy in Malaysia

The usage of energy in Malaysia increases every year. In 1980 the usage of electrical energy increased 5% and 12% in 2009. Table 2.1 shows electrical sale to different sector in 2009. In 2009, industrial sector has the highest demand of electricity, followed by commercial, residental, agriculture and public transport. Total power demand in Malaysia in 2009 is 92753GWh(Loganathan and Subramaniam, 2010).

Table 2.1 Electrical Sale in 2009 (Loganathan and Subramaniam, 2010)

| **Sector** | **Sale of Electricity (GWh)** | **Percentage ( % )** |
|---|---|---|
| Industrial | 40233 | 43.4 |
| Commercial | 31435 | 33.9 |
| Residental | 19584 | 21.1 |
| Agriculture | 243 | 0.3 |
| Public Lighting | 1208 | 1.3 |
| **Total** | **92753** | **100** |

According to Muhammad and Lee (2004) the Malaysian Government targeted about 5% of energy comes from solar and this 5% can save about RM5billion over a period of 5 years. Wind power, hydroelectric, micro hydro and solar energy are examples of renewable sources of energy available in Malaysia(Azman et al., 2011). Thesesource of energy can be used to supply energy in many application such as in domestic application and industry application.

According to Chiang et al (2003), wave power in East Peninsular Malaysia was recorded from 1985 to 2000 shows that the power is below than 5.0kW/m and the highest power comes from the place that faces South China Sea with 4.5kW/m. This is much higher compared to wind speed that is between 1.2m/s to 4.1m/s and the highest result is at the Peninsular Malaysia where the range is between 3.3kW/m to 4.1kW/m. Hence this energy has limitations in some applications.

Hydro power is one type of renewable energy and this energy comes from the movement of hydro turbine, where it converts water pressure into mechanical power. Mechanical power will drive generator to convert to electrical power. Hydro energy is the largest renewable source of electricity where it covers around 15% of the worldselectricity. However this application is not suitable even though, with the implementation of mini hydro. This is because according to Mohibullah et al.(2004), it is costly to develop a hydro turbine and not all places have source of water.

Another potential source of renewable energy is wind energy (Nurul Razliana et al., 2012, Mekhilef and Chandrasegaran, 2011). This energy comes from air flowing cross the earth surface. Energy comes from the conversion of kinetic energy to electrical energy. Even though the cost to generate this energy is very cheap, which is three cents to five cents per kilowatt hour, the implementation of this energy needs a suitable infrastructure. This is because if no wind or low air flowing during harvesting, it needs a storage to back up the energy. Mohammad et al (2012) reveals that at NibongTebalPulau Pinang Malaysia, the average of wind power is 64w/$m^2$. In order to generate this energy, an open area space with certain height is needed. Nurul Razliana et al (2012) has reported that in Perlis, the maximum power that can be produced by the wind energy system is 64.206w/$m^2$ and from 2005 until 2009, the highest speed of wind turbine is 3.5m/s. Mohammad and Lee (2004) has reported that Malaysia has low output power from wind turbine compared to Netherland.

Malaysia is a tropical country that receivesconsistent energy from sun every year. Sun delivers energy on the earth surface and the energy can be converted to electrical energy by solar photovoltaic (PV). The energy is well recognized, free of cost and a clean energy. In

1975, the cost to produce 80MW is 1.4billion dollar and after 10years of technology growth for the same cost can produce 230MW (300% growth)(Ahmed and Sulaiman, 2003).

## 2.4 Implementation of stand-alone photovoltaic power system

Grid connecting photovoltaic consists of solar photovoltaic (PV), power conditioning units, grid connection equipment, solar inverters and Maximum Power Point Tracking (MPPT). The system is not suitable for small area and small capacity applications and it is also costly and not practical. As for WQMS, the solar photovoltaic stand alone system is an alternative where it consists of a few basic components such as battery, charger and solar photovoltaic.

In a research byIdris et al (2010),stand-alone photovoltaic power system has been studied, which directly converts solar energy into electricity. There are a lot of advantages such as pollution free and inexhaustible components. This is better than generator whereby generator has low cost of installation but high running costs. Stand-alone system is suitable to be used either in direct current (DC) application and hybrid system where it combines energy in a power system.

Nowadays, the price of electricity keepincreasing and makes people search for alternative energy. Solar energy isclean and sun radiation is stable in Malaysia. Many applications are apply with off grid system, which is very useful for remote area, electric cars(Alnunu et al., 2012), roadsides emergency telephone(Tuttle and Dluehosh, 1979), remote sensing(Adams, 1974, Hammer et al., 2003), in rural electrification(Chakrabarti and Chakrabarti, 2002), water pump for remote villages(Mina, 2001) and solar roadways(Wu et al., 2009, Bayrak and Cebeci, 2011).

In a research by(Nisha and Madhumitha, 2010), solar panel has been used as an input power supply for food processing machine. The process involved drying, water pasteurizing and distillation. This machine is very helpful especially for rural area or a placethat has very limited source of electricity. The system can reduce 1160kWh, 650kg of re-wood or 205liter of kerosene (LPG) in 4monthsfor water heating and drying process.

## 2.5 Improvement of Solar Panel Output

Research from Ponniran et.al (2011) has revealed that a solar panel with sun tracking system from 8.00A.M to 6.00P.M has power collections of 1056.17W and 802.265W respectively. However this system is not practical for grid system because it is costly. The position of solar panel is very important to identify a best output voltage. The solar panel must be facing to the sun to produce a good output. V.Mesarik (2003) has done an experiment at University Science Malaysia Engineering Campus, with the coordinate at 5'25N to investigate the position of solar panel. In his experiment the solar panel was positioned to face east, south, north and west. The angle that are used in experiments were 35°, 50°, 60°, 75°’and 90°. Results show that the position of the solar panel facing south and north are recommended with 90° as the best option.

## 2.6 Electrical StorageandBasic Principle of Lithium Ion Battery

Experiment based on lithium ion started with G. N. Lewis in 1912(Davenport, 1984). Sony Energy Tech ® started developing technology using lithium ion since 1990. Sony had developed lithium ion battery where it consists of carbon as anode and $LiCoO_2$ as cathode part. The battery produced 3.6V and its ability was 1200deep discharge cycles. This technology has started a few decades ago but after Sony announced lithium ion battery to be implemented, this technology is widely explored by many manufacturers (Levy and Cieslak, 1994, Sack et al., 2001). Some advantages of lithium ion battery over lead acid battery have been identified, where lead acid battery has 55% of depth of discharge whereas lithium ion can achieve 20% of depth of discharge. It shows that lithium ion battery is 98% better to be used (Stevens and Corey, 1996).

Lithium ion battery is a rechargeable battery and research on this type of battery shows that lithium ion battery has high energy density,no memory effect, no pollution(green environmental friendly), higher power and lower self-discharge rate compared to other battery type nickel metal hybrid (Takeda et al., 2003, Kim et al., 2009, Wang et al., 2009, Nagasubramanian and Jungst, 1998).Lithium ion battery consists of three partswhich are positive electrode, negative electrode and separator. Japan Storage Energy Co. in 2003 haddeveloped a lithium ion battery with life cycle that can achieve until 10 years(Suzuki et al., 2003). Experiment by PatrikK.Ng, (2005) shows that lead acid has bigger discharge current comparedto lithium ion when both batteries are connected in parallel. Lead acid discharge from 350A to 300A compared to lithium ion that dischargesfrom 43A to 40A and it could maintain the current. This experiment is run with lead acid battery,capacityof 1630A and 43A for lithium ion battery with discharge current of 350A(Mathiesen et al., 2005).

Mitshibishi Electric Corporation had developed a lithium ion battery to be implemented in space. Compared with Nickel-Hydrogen or Nickel Cadmium it is found that lithium ion has two times energy density and three times discharge voltage(Gonai et al., 2003). Lithium ion is better because the size is small with higher capacity and the performance of electrical storage is better(Ng et al., 2005, Megahed and Scrosati, 1994). Some applications such as gadget and portable devices are suitable to perform with lithium ion battery compared to other types of batteries such as lead acid and Nickel Metal Hydride (Sinkaram et al., 2012). Table 2.2 shows comparison of batteries andthecost, which are below than $200. Lithium ion gives the best result of energy density, power density and life cycle. These batteries had been implemented inthe first hybrid satellite in the geostationary orbit in

Korea By Korea Aerospace Research Institute (KARI) and also ASTRIUM with 3000platform on the EUROSTAR(Koo et al., 2009).

Table 2.2:Battery Comparison(Sinkaram et al., 2012, Siguang and Chengning, 2009)

| **Categoryofbattery** | **Energydensity(Wh/kg)** | **Powerdensity(W/kg)** | **Cycle life(time)** | **Cost ($)** |
|---|---|---|---|---|
| Lead-acid | 30~50 | 200~400 | 400~600 | 120~150 |
| NiMH | 50~70 | 150~300 | >800 | 150~200 |
| Lithium | 120~140 | 250~450 | 1200 | 150~180 |

For high load applications such as electrical vehicle, military and aerospace safety, cost, power consumption and weight are the main issue. Lithium ion is the best choice compared to lead acid and NiMH especially during war need to move fast and in space should all equipment are low weight(Ritchie and Howard, 2006). Many small devices or gadgets such as laptop, video camera, power tools and mobile phone use lithium ion battery as electrical storage because the capability of lithium ion easy to fix in device and have a better long life (Wang et al., 2009).

Because of the performance, size, weight and high energy density many manufacturers choose lithium ion as anelectrical storage. Many types of material have been used in electrode such as lithium cobalt and manganese cobalt. Lithium cobalt has better parameter but the price is higher compared to manganese cobalt and it is better for smaller scale. However in larger scale, manganese cobalt is considered. To store energy into lithium ion with 100% SOCis easy since the charging duration can be accurately predicted, produce only a little heat and can operate in ambient temperature(Takeda et al., 2003).

Many researches had been done in cathode material lithium phosphate ($LiFePO_4$)(Yin-quan et al., 2011). The reaction mechanism of $LiFePO_4$can be explained in equation charging and discharging of lithium ion.In charging process, as equation 2.1;

$LiFePO_4 - xLi^+ - xe^- \rightarrow xFePO_4 + (1-x)LiFePO_4$[2.1]

In discharging process,the formula is as equation 2.2;

$FePO_4 + xe^- + xLi^+ \rightarrow xLiFePO_4 + (1-x)FePO_4$[2.2]

Referring to the above formulas, the charging and discharging process are carried between $LiFePO_4$ and $FePO_4$ in two parts. During the charging process, lithium-ion converts$LiFePO_4$ to FePO4. When the discharging process occurs, lithium-ion converts $FePO_4$ to $LiFePO_4$(Yin-quan et al., 2011). According to(MeÌ•nar d et al., 2010), $LiFePO_4$ is cheaper, safer, produce a higher voltage and higher current compared to lithium cobalt oxide $LiCoO_2$.

According to Yusuf et al., 2010, a few parameter need to consider to identify the performance of lithium ion battery. Some battery can be trust base on looking the specification but some battery is come with low priority of material of lithium ion. Parameterssuch as coefficient of electrolyte (Kharton, 2009), micro porosity process of the electrode(Chen and Tsao, 2006), material of electrode and size of separator (thickness) (Djian et al., 2007), purity of electrolyte (Mohan et al., 2007) affect the performance of lithium ion battery. Other factors that determine the performance of lithium ion battery arethestate of charge, deep of discharge, temperature, charging rate, discharging rate, and charging-discharging performance(Abraham et al., 2005, Hund and Ingersoll, 2008, Santhanagopalan et al., 2008, Thomas et al., 2003).

## 2.7 Application of Lithium Ion Battery

There are a lot of applications that use lithium ion battery to provide a power supply. For example, in 2009 in Korea a few researchers implemented lithium ion battery in geostationary orbit for hybrid satellite. It consists of 10 cell modules in series and 5 cells in parallel to provide the maximum requirement of power, voltage and energy for satellite(Koo et al., 2009).

Under the program Mars Surveyor Program MSP 01, lithium ion battery has been explored with the development of lithium ion battery with a capacity of 28V, 25Ah and 9kg in a mission to Mars and outer planet. NASA needed an electrical storage with a high duty cycle, high power density and that can work in wide range of temperature(-20°C to +40°C)(Smart et al., 2004). So, lithium ion battery is a better choice since its ability to produce energy, high power density, longer time and safe(Rubino et al., 2002). Based on the same reasons, lithium ion also has been implemented in other applications such as in telecommunication devices(Brunarie et al., 2011), electrical off road vehicle(Baronti et al., 2013), high power application (Butler et al., 2004), navy devices(Govar and Banner, 2003), Pico satellite(Aziz et al., 2009) and marine application (Crowell, 2005).

## 2.8 Connection of Lithium Ion Battery

In a research by (Bonfiglio and Roessler, 2009)lithium ion battery and ultra-capacitor can be a good electrical storage. However one unit of lithium ion battery is not enough to support any application. Normally lithium ion batteries are connected in series or parallel to improve the capacity of batteries. Battery arrangement can be expressed as "3 P 50 S". This term means 3 units of lithium ion battery are connected in parallel and 50 batteriesareconnected in series.

## 2.9 Charging Method of lithium ion battery

One of the common methods to charge lithium ion battery is constant-voltage and constant current (CV-CC). This method is simple and cheaper in terms of hardware development. Figure 2.2 shows a block diagram of the designed system and the lithium ion battery is directly supplied with a voltage for the charging process. Basic component to charge lithium ion battery is power input as a main source, PI controller used to control a charging process, and lithium ion battery as a storage. This is the basic component to charge the lithium ion battery (Weixiang Shen, 2011).

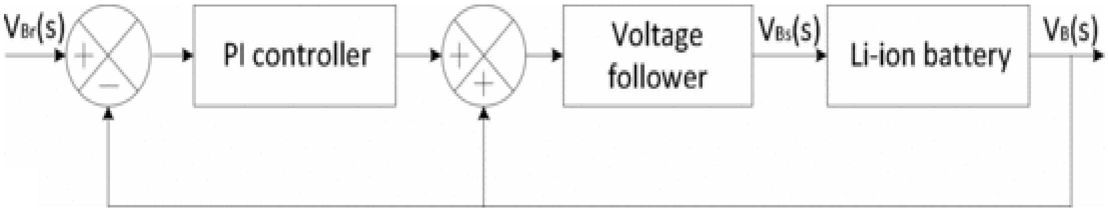

Figure 2.2: Block Diagram of Double Loop Control Charger(Weixiang Shen, 2011)

Figure 2.3 shows the result obtained where lithium ion model CGR17500 is used in this experiment. The purpose of the experiment to prove of concept of charging lithium ion battery using method CV-CC. Lithium ion had been charged with constant current 1C and followed by contant voltage of 4.1V and achieve fully charge in 120 minutes. Lithium ion can be charged with 4.1V ± 1% and this is called as voltage setting (Liu and Teng, 2006). During the charging process, the voltage of lithium ion battery has been slowly increased until it was fully charged at 4.2V and current started when it achieved the voltage (Bergveld, 2001). Different manufacturer will set a different voltage setting but the common values are 4V,4.1V and 4.2V(Isaacson et al., 2000).

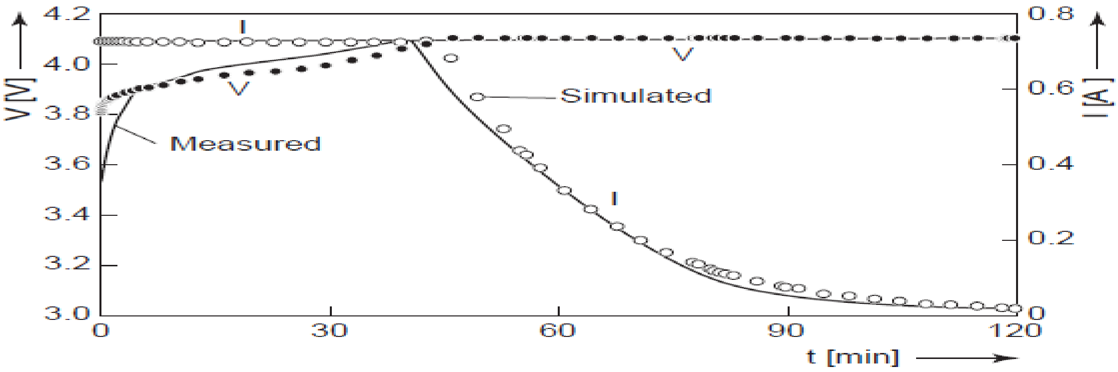

Figure 2.3: Charging Method Constant Current(CC) and Constant Voltage(CV)(Bergveld, 2001)

In a research by (Tan et al., 2010) lithium ion battery has been charged in series connection using energy from AC source of 200V 50Hz. The input voltage is converted to D.C source and it produces 50V-59V. Two units of lithium ion batteries are connected in series. Every unit consists of 7 cells of lithium ion with 3.8V,40Ah. The capacity of each battery is 26.6V, 40Ah. A total of 53.2V in series connection is used in the experiment and the capacity is 2.128kWh. However the setting to suppress voltage at each cell is not discussed. In the experiment it shows that voltage is suppressed with less than 11%. Thus it takes longer time to fully charge or difficult to achieve fully charge condition.

Charge controller is designed based on certain topology such as buck converter, boost converter, buck-boost converter, fly back and Single-Ended Primary Inductive Converter (SEPIC). Some advantages of SEPIC topology arelowside gate drive and current sense, continuous input current, and DC isolation from input to output. Disadvantages of the SEPIC topology are usestwo inductors and an energy transfer capacitor compared to buck topology, which uses only one inductor. However the buck topology requires additional diode for reverse discharge protection, high side gate drive and current sense(Dearborn, 2006).

A few methods of charging process has been identified such linear method and microcontroller based, charge cycle waveform, switch mode, and pulse width modulator (PWM). Different methods give a different performance and some method are complicated and costly. Linear method has advantages of low cost and simpler. However its efficiency is low compared to other methods. Linear method must have a well regulated input voltage before it can charge a lithium ion battery and it needs a microcontroller to cut off the voltage when battery is fully charged. Every method has a principle of charging such as constant current and constant voltage, which are widely used in many charge controllers for lithium ion battery. This method is similar with boost converter where the boost converter receives input voltage and step up the voltage to another voltage. This voltage is constant and the current is delivered using boost converter and is similar with concept of charging lithium ion battery (Lisbona and Snee, 2011).

In a research by Carter et al., (1996), researchers explored a charging method of charging lithium ion battery, by using lithium ion battery SONY US18650B and charged byusing different voltages. Result from the experiment shows that, by increasing a charging voltage, the capacity of battery and time also increase. The higher voltage charging, the more capacity of lithium ion battery can be storedin term of SOC.

More researches in the charging method of lithium ion battery were conducted by Thomas et al, (2010). Figure 2.4showslithium ion battery that has been charged in series from 10 cells to 16 cells and battery charged directly through solar PV without setting a voltage. The efficiency level drops because of the voltage from solar panel are fluctuating and the voltages are not balance at every cell in string. Suppose every cell need to be charged with 4.2V/cell to avoid the lithium ion battery from over charging or over voltage setting to charge the lithium ion batteries. With the same input, when the number of lithium ion battery is added or increased the suppress voltage became low in every cell of the string. It takes longer time to fully charge, can cause the battery not to be charged and the efficiency became low.

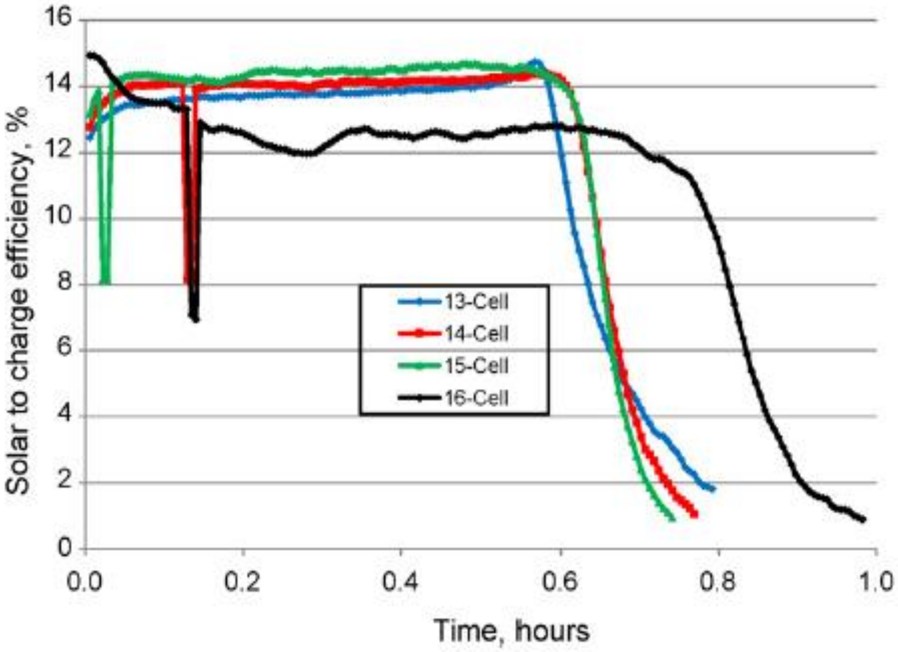

Figure 2.4: Efficiency of Charging Process of Lithium Ion Batteries in Series Connection with Solar Photovoltaic (Thomas et al., 2010)

### 2.10 Analysis on Lithium Ion Capacity

According to (Gibson and Kelly, 2010), to identify the charge flow in the lithium ion battery, the measurement of current must be done by connecting charger and battery in series connection. The current flow through battery at every hour, during charging process is called charge increase and the formula is shown in equation 2.3. The first charge increase represented by $I_{CH1}$ and continue with $I_{CHN}$for the next hours either for charging process or discharging process. All charge increase will be added to get a total charge as shown in equation 2.4. State of charge is thebattery capacitydivided with total charge increase as shown in equation 2.5. Normally it is represented in percentage. The charging rate or C-rate is a ratio between capacities of battery (ampere-hour) divide by current from the charger. It also presented in coulombC, as show in equation 2.6. SOC also can be measured basedonvoltage changing on the lithium ion battery as shown in equation 2.7. The performance of all the experiments in this thesis are based on voltage.

charge increase = current × time [2.3]

$$\text{Total}_{\text{charge increase}} = \text{I}_{\text{CH1}} + \text{I}_{\text{CH2}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.\text{I}_{\text{CHN}} \quad [2.4]$$

$$SOC = \frac{Battery\ Capacity}{Total\ Charge\ Increase} \text{X } 100 \quad [2.5]$$

$$C = \frac{Battery\ Capacity\ (mAh)}{Charging\ Current(mAh)} \text{ X } 1\text{C} \quad [2.6]$$

$$SOC = \frac{Battery\ Voltage\ (V)}{Total\ Battery\ Capacity\ (V)} \text{X } 100 \quad [2.7]$$

Figure 2.5 shows an example of graph of charging process of lithium ion batteryusingthemethod of constant current (CC) and constant voltage (CV). Experiment by Japan Storage Co in 2003 shows that lithium ion battery is charged from 3V until fully charged at 4.2V.Experiment was set with 1.6C from the beginning of experiment. The charging time supposed to be taking half an hour but it takes more hours. This shows that even byusing high capacity of charger of lithium ion, 100% SOC cannot be achieved. The charge increase needs to be identified to get more accurate time of charging process (Suzuki et al., 2003).

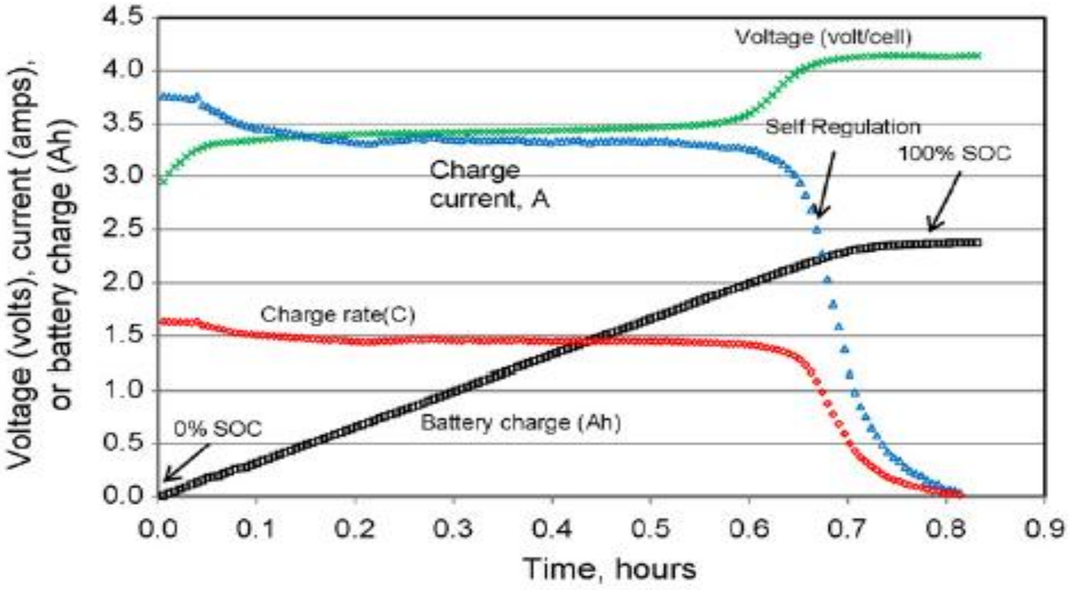

Figure 2.5: Solar charging of a 15-cell lithium-ion battery module—voltage per cell, current charge rate, and battery charge capacity as a function of time. (Suzuki et al.2003)