

A COST EFFECTIVE SOLAR POWERED LED STREET LIGHT

FREDERICK WONG TSUN KIONG

A project report submitted in partial
fulfillment of the requirement for the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

JULY 2014

For my beloved mother and wife



ACKNOWLEDGEMENT

The author would like to express his sincere appreciation to his supervisor, Dr. Kok Boon Ching, for the support given throughout the duration for this research.

The cooperation given by Dewan Bandaraya Kota Kinabalu and also Compugates Sabah Sdn Bhd are also highly appreciated. Appreciation also goes to everyone involved directly or indirectly towards the compilation of this report. Last but not least, I would like to express my appreciation to my family for giving me the love and support throughout this Master's program.



PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

ABSTRACT

A cost effective solar powered LED street light was designed based on the current solar powered street light installed at Masjid Nurul Huda, Kampung Gentisan, Sepanggar, Sabah, Malaysia. A new load profile is obtained based on a thirty day data collection at site utilizing motion sensor to record movement at the area. A proposed algorithm to control the LED light intensity was presented. The new load profile was processed based on the proposed algorithm. Simulation to design a new solar powered LED street light was done using the new load profile. The design uses 180W Solar Panel, with 8 x 6V (10Ah) batteries. The system has the design capability to last for 38.6 hours. Results are compared with existing solar powered LED street light and also existing mercury vapor street light. An economic analysis for 25 years is also performed to determine the cost effectiveness of the new system where the Life Cycle Cost is found to be RM 11,143.00 compared to the existing conventional design of RM 13,626.00 which is equivalent to 18.22% of cost savings.

ABSTRAK

Satu sistem lampu jalan LED yang berkuasakan solar yang kos efektif telah direka berdasarkan lampu jalan LED berkuasa solar yang telah dipasang di Masjid Nurul Huda, Kampung Gentisan, Sepanggar, Sabah, Malaysia. Profil beban baru diperolehi berdasarkan pengumpulan data selama tiga puluh hari di tapak menggunakan sensor gerakan untuk merakam pergerakan di kawasan itu. Satu algoritma dicadangkan untuk mengawal keamatan cahaya LED telah dibentangkan. Profil beban baru telah diproses berdasarkan algoritma yang dicadangkan. Simulasi untuk reka bentuk solar lampu jalan LED baru telah dilakukan dengan menggunakan profil beban baru. Reka bentuk ini menggunakan 180W Panel Solar, dengan 8 x 6V (10Ah) bateri. Sistem ini mempunyai keupayaan reka bentuk untuk bertahan selama 38.2 jam. Keputusan dibandingkan dengan solar lampu jalan LED sedia ada dan lampu jalan yang menggunakan lampu wap raksa yang telah sedia dipasang. Analisis ekonomi juga dilakukan untuk menentukan keberkesanan kos sistem baru dimana kos kitaran hayat ialah RM 11,143.00 berbanding sistem sedia ada iaitu RM 13,626.00 yang bersamaan 18.22% penjimatan kos.

CONTENTS

ITEM	PAGE
TITLE	i
DECLARATION	ii
DEDICATION	iii
ACKNOWLEDGEMENT	iv
ABSTRACT	v
CONTENTS	vii
LIST OF TABLES	xi
LIST OF FIGURES	xii
LIST OF SYMBOLS AND ABBREVIATIONS	xiv
LIST OF APPENDICES	xv
CHAPTER 1	
INTRODUCTION	1
1.1 Project background	1
1.2 Problem statements	2

1.3	Project objectives	2
1.4	Project scopes	3
1.5	Project structure	4
CHAPTER 2	LITERATURE REVIEW	5
2.1	Introduction	5
2.2	Theories	6
2.2.1	Solar panel	6
2.2.2	Battery	8
2.2.3	LED lamp	10
2.2.4	Charge controller	11
2.2.5	Lighting measurement theory	12
2.2.6	Key equations	13
2.3	Description of Previous Methods	14
2.3.1	Method on using LED in solar powered street light	14
2.3.2	Utilising sensors to obtain energy-efficient solar powered street lights	14
2.3.3	Designing and simulation of systems using HOMER Energy	15
CHAPTER 3	METHODOLOGY	17
3.1	Project Methodology	17
3.1.1	Literature reviews on previous works in LED technology, standalone solar powered systems and automatic control in street light	17

	3.1.2 Load pattern gathering	17
	3.1.3 Design and simulation of system	18
	3.1.4 Analysis of new design and simulation	18
	3.2 Design of Solar Powered LED Street Light System	18
	3.3 Determining the Load Pattern	19
	3.4 Algorithm for LED Lamp Controller	22
	3.5 Motion Sensor Data Processing based on Proposed Algorithm	23
CHAPTER 4	DATA ANALYSIS AND RESULTS	27
	4.1 Setting Up HOMER ENERGY Software	27
	4.1.1 Primary load input setting	28
	4.1.2 PV inputs setting	30
	4.1.3 Battery inputs setting	33
	4.1.4 Solar resource inputs setting	35
	4.2 Results of Simulation	36
	4.2.1 Simulation results – PV requirement	42
	4.2.2 Simulation results – Battery requirement	43
	4.2.3 Simulation results - Cost summary	45
	4.3 Lighting Calculation Results	47
CHAPTER 5	DISCUSSION	48
	5.1 Comparison between designed Cost Effective as with Existing Conventional Solar Powered LED Street Light	48
	5.2 Comparison between Cost Effective with Existing Conventional Street Light connected to the Grid	51

CHAPTER 6	CONCLUSION AND RECOMMENDATIONS	52
	6.1 Conclusion	52
	6.2 Recommendations for future work	53

REFERENCES	54
-------------------	-----------

APPENDIX A – C	56 - 73
-----------------------	----------------

VITA



PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF TABLES

2.1	Initial Installation Cost for Solar Powered LED Streetlight System	15
3.1	Sample of Raw Data from Motion Sensor	21
3.2	Motion Sensor Data Processing (add 10 Seconds to TIME END)	23
3.3	Motion Sensor Data Processing (with TIME DIFFERENCE)	24
3.4	Motion Sensor Data Processed (Completed)	25
4.1	Summary of Load Profile	29
4.2	Cost of PV Panel with Replacement and O&M	31
4.3	Costing of Battery	34
4.4	Simulation Summary Result	36
4.5	Complete List of Simulation Results	37
4.6	PV Array Results	42
4.7	Battery Results	44
4.8	Net Present Cost	46
4.9	LED Lamp Specification	47
4.10	LED Lamp Result at 100% and 70% Brightness	47
5.1	Comparison in Load Profile	48
5.2	Summary of Comparison of Simulation	49
5.3	Comparison of Power Consumption	49
5.4	Comparison of Total Cost of System	50
5.5	Cost Summary Comparison	50
5.6	Comparison of Life Cycle Cost (Cost Effective with Mercury Vapor)	51
6.1	Cost Summary Comparison	52

LIST OF FIGURES

1.1	Kg. Gentisan, Solar Powered Street Light for Masjid	3
2.1	Structural Schematic of Solar Powered LED Street Light System	6
2.2	Types of Solar Panels	7
2.3	Equivalent Circuit of Solar Panel	7
2.4	a) I-V Curve of a Solar Panel	8
	b) How Intensity of Sunlight Affects the I-V Curve	8
2.5	Comparison of Different Battery Technologies	9
2.6	Types of Batteries for Solar Power Application	10
2.7	Examples of LED lamp for Street Lighting Application	10
2.8	Three Stage Charging	11
2.9	Examples of Charge Controllers	12
2.10	Configuration of Solar Power Management System	14
2.11	Typical Set-Up in HOMER Energy Software	16
3.1	Load Pattern Gathering Method	17
3.2	Block Diagram of a Cost Effective Solar Powered LED Street Light	18
3.3	a) Motion Sensor Range	20
	b) Placement of Motion Sensor on Street Light	20
3.4	Proposed Algorithm for LED Controller	22
3.5	Motion Sensor Total Time from 1 April 2014 to 30 April 2014	26
4.1	HOMER Energy Software – Configuration and Results Window	27
4.2	Primary Load Inputs Window	28
4.3	Daily Load Profile	29
4.4	Seasonal Load Profile	29
4.5	PV Inputs Window	30
4.6	Cost Curve (Capital + Replacement)	32
4.7	Battery Inputs Window	33

LIST OF FIGURES (CONTINUED)

4.8	Battery Details	34
4.9	Solar Resource Inputs Window	35
4.10	Result of Simulation in HOMER Energy	36
4.11	PV Output Distribution vs Hour of the day (Monthly)	42
4.12	Monthly Battery State of Charge	43
4.13	Monthly Battery Bank State of Charge Distribution Map	43
4.14	Frequency Histogram (Frequency vs State of Charge)	44
4.15	Cash Flow Summary (by Cost Type)	45
4.16	Cash Flow Summary (by Component Type)	45
4.17	Cash Flow for the System	46



LIST OF SYMBOLS AND ABBREVIATIONS

π	-	pi = 3.142
η	-	Luminous Efficacy in lumens/watt (lm/w)
Φ	-	Luminous flux in lumens (lm)
A	-	Area in m ²
cd	-	candela
lm	-	lumen
lx	-	lux
P	-	Power in Watt
sr	-	steradian (squared radian)
CFL	-	Compact Fluorescent Light
DBKK	-	Dewan Bandaraya Kota Kinabalu
DOD	-	Depth Of Discharge
HID	-	High Intensity Discharge
HOMER	-	Hybrid Optimization of Multiple Energy Resources
HPS	-	High Pressure Sodium
LA	-	Lead Acid
LDR	-	Light Dependent Resistor
LED	-	Light Emitting Diode
LI	-	Lithium Ion
LP	-	Lithium Polymer
MPPT	-	Maximum Power Point Tracking
Ni-Cad	-	Nickel Cadmium
PWM	-	Pulse Width Modulation
UTHM	-	Universiti Tun Hussein Onn Malaysia
VRLA	-	Valve Regulated Lead Acid

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Raw and Processed Motion Sensor Data	56
B	Pictures	62
C	Data Sheets	64



PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER 1

INTRODUCTION

1.1 Project background

Recent advances in LED lighting have brought very promising opportunities for application in street lighting. Combining LED's low power, high illumination characteristics with current photovoltaic (PV) technology, PV powered street light utilising LED has become a norm in many places [1][2].

Compugates Sabah Sdn Bhd, a company that specializes in design, installation and maintenance of solar power systems in Sabah, had successfully installed 30 standalone street light utilising PV and LED for Dewan Bandaraya Kota Kinabalu (DBKK) as part of its pilot project to implement green initiative in its area of governance. These street lights are located at the outskirts of the city for the society such as balairayas, mosques and churches. These street lights are designed to operate in such away it will work on a timer basis from 6pm – 6am (12 hours) daily.

Even though utilising LED in street lights have minimised the energy load, which has contributed in minimizing the size of PV and batteries, there are other ways to make the system more energy-efficient, which further reduces sizing and cost.

Studies have shown utilising sensors and also varying the LED's illumination, the system can be more energy-efficient [14]. In this study, a motion sensor is used to capture the movement around an installed Solar Powered Street Light at Kampung Gentisan's Masjid, ie Masjid Nurul Huda for 30 days (date – date). The LED's light intensity is varied based on the movements captured by the

motion sensor. When there is movement, the LED's light intensity will be 100% for a specific period. When there is no movement, the LED's light intensity will be around 70%.

With the motion sensor data that is captured, an algorithm can be used to manage the LED's light intensity percentage and its period. The algorithm will also determine the new energy load that the LED requires for the particular system for the area mentioned. This new energy load is used to design a new Solar Street Light System. The design is simulated using HOMER software. With this, a smaller size of PV and battery could be used, thus reducing the cost further, and a more energy-efficient system is achieved.

1.2 Problem statements

Current practice of Solar Powered LED Street Lights is still considered NOT energy-efficient and cost effective. This will lead to increase of cost on all aspects mainly PV and battery. In addition, the structure to hold the LED lamps is affected due to the size and weight of the system on the structure.

Utilising sensing devices, one can reduce the solar power system sizing thus minimizing power losses between generation and load demand. Cost saving is achieved with a smaller system size and less complicated structure to mount the system. It is hoped with this study, more and more LED based solar street light will be installed by DBKK in Kota Kinabalu as to decrease the cost of operation DBKK has to incur every month.

As this study is only done at Kampung Gentisan's Masjid, the data will not be suitable for design at other location.

1.3 Project objectives

The major objective of this research is to design a solar powered LED street light that is energy efficient using motion sensor to measure the appropriate amount of load demand required.

Its measurable objectives are as follows:

- (i) To determine the load demand of the system by using motion sensor and appropriate algorithm to control the light intensity of the LED lamp.
- (ii) To carry out design of the new solar powered LED street light using the new load pattern data that maximizes energy saving and the system's energy-efficiency.
- (iii) To carry out cost analysis using HOMER software and comparing the results with the conventional design.

1.4 Project scopes

This project is primarily concerned with the energy efficient for an LED based Solar Street Light at Masjid Nurul Huda, Kampung Gentisan.

The scopes of this project are:

- (i) Record the motion sensor data
- (ii) Design new Solar Powered LED street light using HOMER software



Figure 1.1: Kg. Gentisan, Solar Powered Street Light for Masjid

1.5 Report structure

This chapter introduces the background, problem statements, objectives and scopes of the project. In Chapter 2, the theories on solar panel, battery, LED lamp and charge controller is presented. Lighting measurement theory is also established which is used during the simulation and results. Description of previous methods as well as introduction on HOMER Energy is presented.

The methodology for this project is discussed in Chapter 3, where the process of the design of the cost effective solar powered LED street light system is presented. Other than that, the method of determining the load pattern as well as the proposed algorithm used for the LED lamp controller is discussed. The processed load pattern using the proposed algorithm is also shown.

Chapter 4 shows the data analysis as well as the results of the simulation. The new load pattern obtained from the previous chapter is used in HOMER Energy software to simulate the solar power LED street light. Components specifications such as solar panel, battery, load pattern (LED lamp), and pricing were set in HOMER software. Results including cost analysis of the cost effective design simulation is shown.

Discussion on the results of the simulation is discussed in Chapter 5, where comparison between the new cost effective design and the existing conventional solar powered LED street light. Other than that, comparison between the new cost effective design and the existing conventional mercury vapour street light connected to the grid used by DBKK is also discussed. Cost effectiveness of the new design discussed. Lastly, in Chapter 6, conclusion of the report is presented as well as future recommendation is discussed and proposed as a way to improve the design of this system.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The use of Solar Powered LED Street Lights has become an interesting topic of research as well as application in the commercial world. In today's application, most of the common High Intensity Discharge (HID) lamps, often High Pressure Sodium (HPS) lamps are being replaced by more low powered Light Emitting Diode (LED) lamps.

A basic solar powered LED street light system components are:

- (i) Solar Panel
- (ii) Lighting Fixture – LED lamp
- (iii) Rechargeable Battery
- (iv) Controller
- (v) Pole

The Solar Panel will provide electricity to charge the battery during day time. The battery's charging is controlled by a charge controller. The operation of the LED bulb is controlled by a control circuit either by using sensors such as Light Dependent Resistor (LDR). All these components will be fixed on a pole as shown in Figure 2.1. The solar panel is mounted at the top of the pole to minimize the possibility of any shading on the panels.

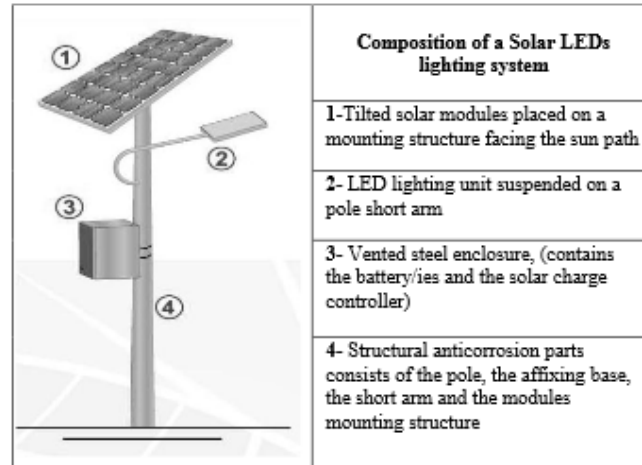


Figure 2.1: Structural schematic of Solar Powered LED Street Light System [1]

2.2 Theories

In this section, theories on solar panel, battery, LED and charge controller is discussed as these are the main components of the solar powered LED street light system.

2.2.1 Solar panel

A Solar Panel is basically a module that converts light energy (photons) from the sun to generate electricity in DC form. There are two types of solar panels, mainly crystalline and thin-film types.

There are two types of crystalline solar panels (see Figure 2.2 a & b):

- (i) Poly-crystalline Solar Panel
- (ii) Mono-crystalline Solar Panel

As for Thin-film types, there are (see Figure 2.2 c):

- (i) Amorphous Silicon (a-Si)
- (ii) Cadmium Telluride (Cd-Te)
- (iii) Copper Indium Gallium Selenide (CIGS)
- (iv) Dye-Sensitized Solar Cell (DSC)

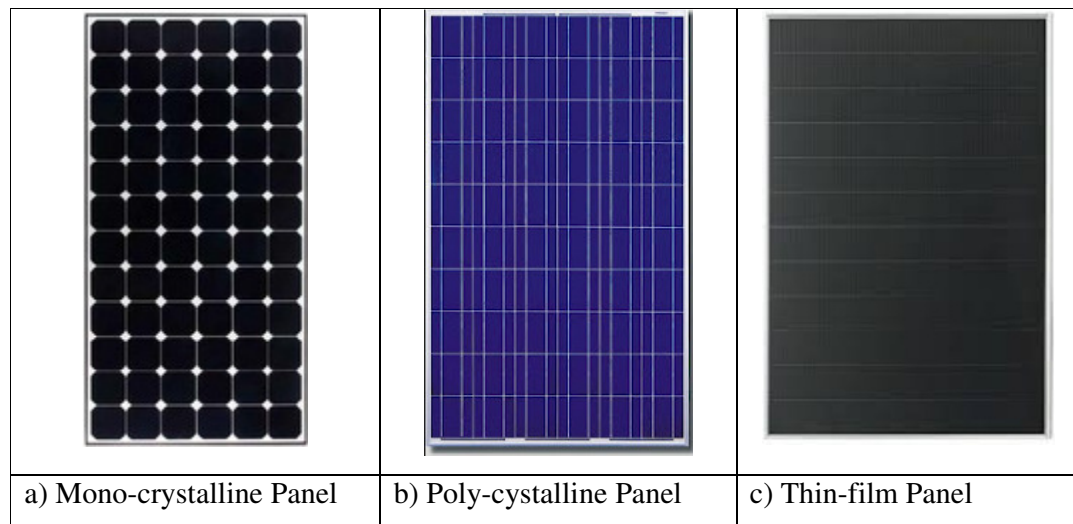


Figure 2.2: Types of Solar Panels

Crystalline based solar panels are commonly used due to its maturity in terms of its technology and price. Even though poly-crystalline solar panels are cheaper compared to Mono-crystalline solar panels, Mono-crystalline panels are preferred in Street lights applications because its smaller compared to poly-crystalline due to its higher efficiency, making the design for the pole to be easier and cheaper too.

Figure 2.3 shows the equivalent circuit of a solar panel, where it shows the diode and ground leakage currents.

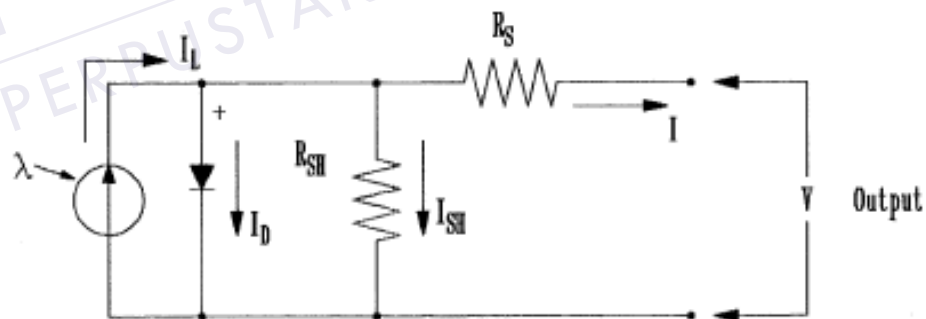


Figure 2.3: Equivalent Circuit of Solar Panel [4]

The I-V curve for a Solar panel is shown in Figure . Here it can be seen as the sunlight is shining on the panel, current and voltage is produced at the p-n junction of the solar cells. Since power is the product of its current and voltage, the maximum power is achieved at the knee of the curve as shown in Figure 2.4 a). Sunlight intensity affects the I-V curve where, as the sunlight intensity increases, the current

and voltage increases, making the power output higher. As the sunlight intensity decreases, the current and voltage decreases, producing less power. This is shown in Figure 2.4 b)

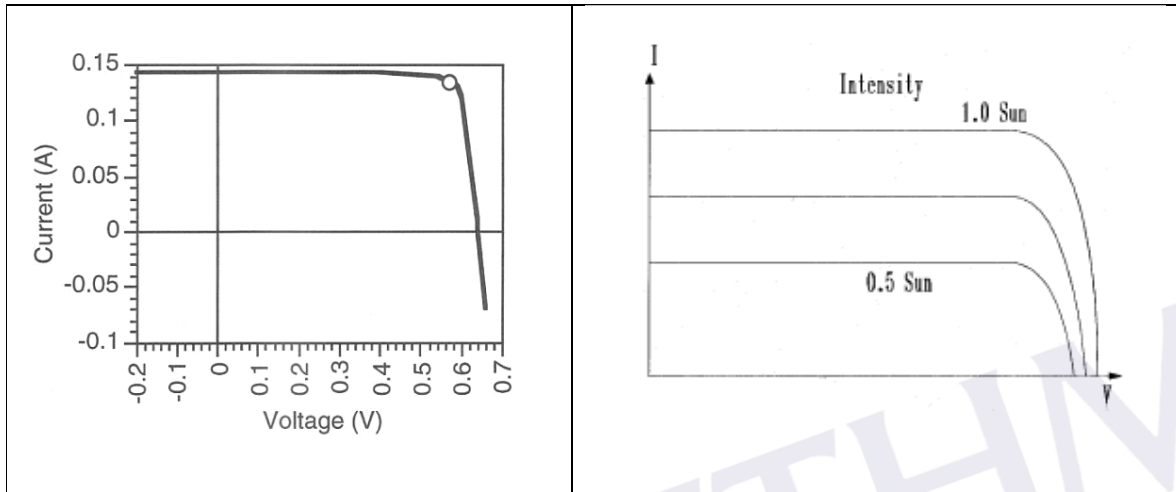


Figure 2.4: a) I-V Curve of a Solar Panel [4] b) How Intensity of Sunlight affects the I-V curve [4]

2.2.2 Battery

Batteries are used to store the electricity generated by the solar panel. During the day, electricity generated by the solar panels are supplied to the battery and/or the load. When the load demand is higher than the energy received from the solar panels, these batteries will provide stable energy to the load.

There are a few types of rechargeable batteries, which are:

(i) **Lead-Acid (LA) Battery**

These batteries are the most commonly used in solar powered systems due to its maturity in technology and low pricing. They can only be used with low Depth of Discharge (DOD) in order to extend its lifespan. Its DOD ranges from 20%-50%. There are two types of Lead-Acid batteries, ie flooded and Valve Regulated Lead Acid (VRLA) batteries which are maintenance free batteries.

(ii) Nickel-Cadmium (Ni-Cad) Battery

Nickel-Cadmium (Ni-Cad) batteries are expensive and disposing of Cadmium are hazardous. Even though they have several advantages over Lead-Acid batteries, such as longer life span, and tolerance for higher discharge, Ni-Cd batteries is not commonly used in solar powered systems due to its high cost and limited availability.

(iii) Lithium-Ion (LI) or Lithium-Polymer (LP) Battery

Lithium based batteries are considered the future of batteries used in solar powered systems. This is due to a number of factors such as high specific energy, high DOD percentage, and higher number of charging cycles. However, due to its higher cost compared to LA type of batteries, they are still not a preferred choice.

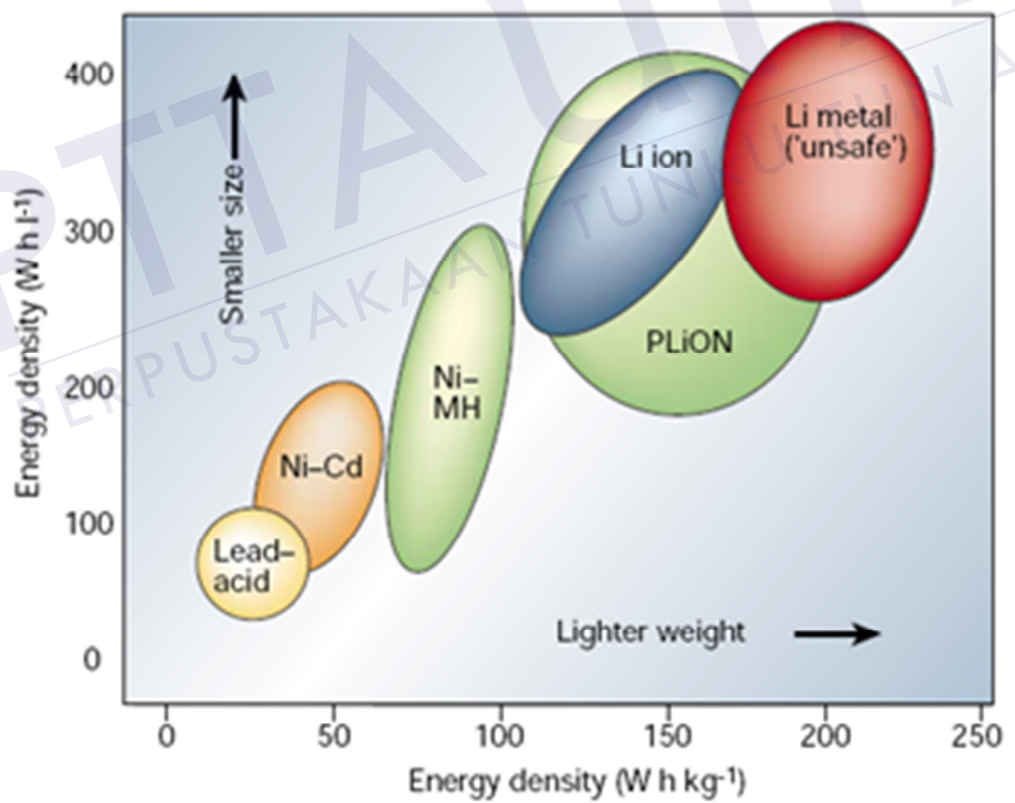


Figure 2.5: Comparison of Different Battery Technologies [5]

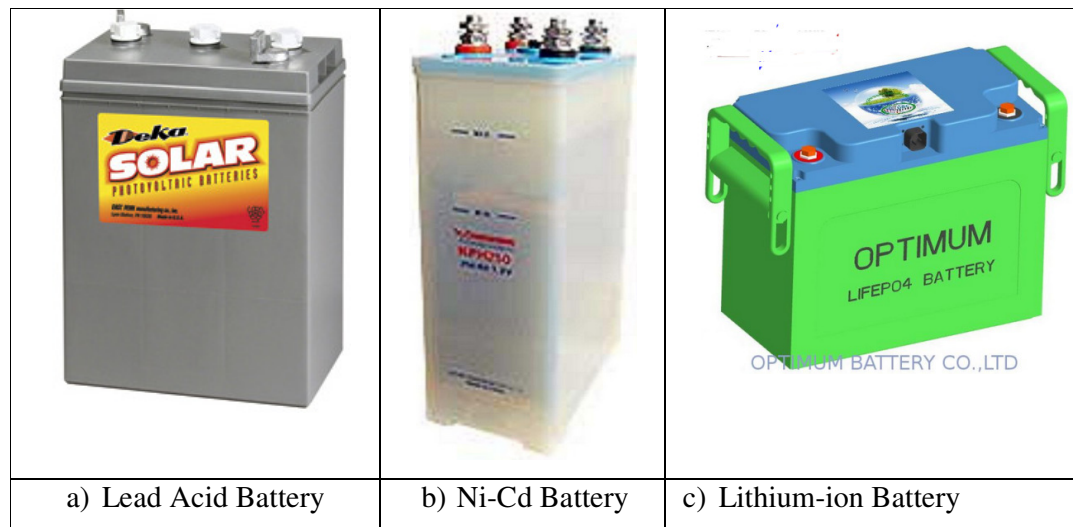


Figure 2.6: Types of Batteries for Solar Power Application

2.2.3 LED lamp

A LED lamp is a light-emitting diode (LED) product that is assembled into a lamp (or light bulb) for use in lighting fixtures. LED lamps have a lifespan and electrical efficiency that is several times better than incandescent lamps, and significantly better than most fluorescent lamps, with some chips able to emit more than 100 lumens per watt.

Like incandescent lamps and unlike most fluorescent lamps (e.g. tubes and CFL), LED lights come to full brightness without need for a warm-up time; the life of fluorescent lighting is also reduced by frequent switching on and off. Initial cost of LED is usually higher. LED chips need controlled direct current (DC) electrical power; an appropriate power supply is needed. LEDs are adversely affected by high temperature, so LED lamps typically include heat dissipation elements such as heat sinks and cooling fins.



Figure 2.7: Examples of LED lamp for Street Lighting Application

REFERENCES

- [1] Fathi, M.; Chikouche, A.; (2010), "LEDs Application to the Photovoltaic Street Lighting" *International Conference on Renewable Energies*. pp. 101-104.
- [2] Guijian, W.; Yingchun, Z.; (2011). "A New Intelligent Control Terminal of Solar Street Light" *International Conference on Intelligent Computation Technology and Automation*. pp. 321-324
- [3] Jha, A.R. (2010). "Solar Cell Technology and Applications." U.S, CRC Press.
- [4] Patel, M.R. "Wind and Solar Power Systems", New York, CRC Press.
- [5] Kiehne, H.A. "Battery Technology Handbook", 2nd Edition, Germany, Merkel Dekker Inc.
- [6] Lal, D. K.; Dash, B.B.; Akella, A.K.; (2011). "Optimization of PV/Wind/Micro-Hydro/Diesel Hybrid Power System in HOMER for the Study Area", *International Journal on Electrical Engineering and Informatics* pp. 307-325.
- [7] Kazem, H.A.; and Khatib, T. (2013). "A Novel Numerical Algorithm for Optimal Sizing of Photovoltaic/Wind/Diesel Generator/Battery Microgrid Using Loss of Load Probability Index", *International Journal of Photoenergy*. pp 107-114.
- [8] Sharma, A.; Singh, A.; Khemariya, M.; (2013). "Homer Optimization Based Solar PV; Wind Energy and Diesel Generator Based Hybrid System". *International Journal of Computing and Engineering*. pp 199-204.

- [9] Yongqing, W.; Chuncheng, H.; Suoliang, Z.; Yali, H.; Hong, W.; (2009),
 “Design of Solar LED Street Lamp Automatic Control Circuit”.
International Conference on Energy and Environment Technology. pp
 90-93.
- [10] Costa, M.A.D.; Costa, G.H; Santos, A.; Schuch, L.; Pinheiro, J.R.; (2009). “A
 High Efficiency Autonomous Street Lighting System Based on Solar
 Energy and LEDs”. *IEEE Transactions on Industrial Electronics*. pp
 265-273
- [11] Nunoo, S.; Attachie, J.C; Abraham, C.K; (2010), “ Using Solar Power as an
 Alternative Source of Electrical Energy for Street Lighting in Ghana”.
*IEEE Conference on Innovative Technologies for an Efficient and
 Reliable Electricity Supply (CITRES)*. pp 467-471
- [12] Lin, C.C; Yang, L.S.; Chang, E.C; (2013) , “Study of a DC-DC Converter for
 Solar LED Street Lighting”. *IEEE 2nd International Symposium on Next-
 Generation Electronics*. pp 461-464
- [13] Ramadhani, F. ; Bakar, K.A; Shafer, M.G. (2013), “Optimization of
 Standalone Street Light System with Consideration of Lighting Control”,
*International Conference on Technological Advances in Electrical,
 Electronics and Computer Engineering*. pp 583-588.
- [14] Sun, J.H; Su, J.F (2010), “An Energy Saving Control Method based on Multi-
 sensor System for Solar Street Lamp”. *International Conference on
 Digital Manufacturing and Automation*. pp 192-194.
- [15] Ganslandt, R; Hofmann H (1992). “Handbook on Lighting Design”,
 Germany, ERCO Edition.