AN EFFICIENT MICROCONTROLLER-BASED ELECTRONIC BALLAST FOR HIGH PRESSURE SODIUM LAMPS USED IN STREET LIGHTING

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A thesis submitted in fulfilment of the
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Dedicated to

My wife Nurul Ain binti Roslan and my son Muhammad Ammar Amsyar bin Mohd Hamizan

My family and my family in law

&

Special dedication to

My beloved parents

Who did not live to share the happiness in my achievements

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ABSTRACT

Conventional street lighting system with magnetic ballast is cheap and robust, but its operation cannot be dimmed, thus requiring more energy due to 12 hours daily at full load operation. The total energy consumption for street lighting at Universiti Teknologi Malaysia (UTM) reaches approximately 1,238.24 MWh or 2.08% of total energy consumption per annum including core and cable losses. The energy requirement and operating cost for such a system is significantly high and can be possibly reduced by incorporating the potential of microcontroller based electronic ballast. This thesis proposes a control scheme using Pulse Width Modulation (PWM) Atmega32 dimming electronic ballast to replace the existing system. The main aim is to develop a lighting system that is more energy efficient and environmental friendly by using the PWM method to regulate the dimming system. Testing was done on one unit of a 150 W HPS lamp and the result was projected for 956 units. Results show that this new system can provide energy savings of 32.17% with a payback period of 25 months. This translates into 2082.79 metric tons reduction of Carbon Dioxide (CO_2) emissions annually. The findings also show that the current Total Harmonic Distortion (THDi) for the whole system is 7.6% for full load operating system, 8.4% for 80% dimming and 10.1% for 50% dimming street lighting. The results conform with all the related standards used for the purpose of this study.

ABSTRAK

Sistem lampu jalan konvensional dengan balast magnetik adalah murah dan kukuh tetapi penggunaan tidak boleh dimalapkan yang memerlukan tenaga sehingga 12 jam sehari pada penggunaan kuasa penuh. Jumlah penggunaan tenaga untuk keseluruhan lampu jalan di Universiti Teknologi Malaysia (UTM) mencapai lebih kurang 1,238.24 MWh bersamaan 2.08% daripada jumlah keseluruhan penggunaan tenaga di UTM dalam setahun termasuk kehilangan teras dan kabel. Keperluan tenaga dan kos operasi untuk sistem konvensional tersebut adalah lebih tinggi dan mungkin boleh dikurangkan dengan meneroka pengawalan tenaga menggunakan balast elektronik dan pengawal mikro. Tesis ini mencadangkan satu skim kawalan menggunakan Pemodulatan Lebar Denyut (PWM) Atmega32 balast elektronik untuk memalapkan lampu jalan dan seterusnya menggantikan sistem yang sedia ada. Tujuan utama adalah untuk membangunkan satu sistem lampu yang lebih cekap dari segi penggunaan tenaga serta mesra alam dengan menggunakan kaedah PWM untuk mengawal pemalapan lampu. Ujian telah dilakukan ke atas satu unit lampu 150 W HPS dan hasilnya telah diunjurkan bagi 956 unit lampu 150 W HPS. Keputusan menunjukkan bahawa sistem baru ini dapat memberi penjimatan tenaga sebanyak 32.17% dengan kadar tempoh bayaran balik selama 25 bulan. Ini bermakna pelepasan Karbon Dioksida (CO_2) dapat dikurangkan sebanyak 2082.79 metrik tan setahun. Hasil kajian juga menunjukkan bahawa semasa Jumlah Penyelewengan Harmonik arus (THDi) bagi keseluruhan sistem ini adalah 7.6% bagi sistem operasi beban penuh, 8.4% untuk 80% pemalapan dan 10.1% untuk 50% pemalapan lampu jalan. Keputusan mematuhi semua piawaian yang digunakan untuk tujuan kajian ini.

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LIST OF SYMBOLS

L	-	Inductor
C	-	Capacitor
V_S	-	Voltage supply
ω	-	Switching frequency
ω_o	-	Resonance frequency
Cs	-	Shunt capacitor
Cr	-	Parallel capacitor
I	-	Current
K	-	Impedance
χ	-	Scaling factor
t	-	Time
f	-	Frequency
α	-	Phase shift angle
D	-	Duty cycle
Ton	-	Time ON
$Toff$	-	Time OFF
R	-	Resistance
C_F	-	Passive power factor
Vgs	-	Voltage gate source
Vcp	-	Ignition peak voltage
Q	-	Quality factor
Vs	-	Voltage supply
$Resr$	-	Series equivalent resistance
δ	-	Delta
m	-	Modulation index
lx	-	Lux

LIST OF ABBREVIATIONS

AC	-	Alternating current
ANSI	-	American National Standard Institute
C_F	-	Passive power factor
CF	-	Crest factor
CO_2	-	Carbon dioxide
CRI	-	Colour rendering index
DC	-	Direct current
EMI	-	Electromagnetic interference
GDP	-	Gross domestic product
GHG	-	Greenhouse gases
HID	-	High-intensity discharge
HPS	-	High Pressure Sodium
IEA	-	International Energy Agency
IEC	-	International Electrotechnical Commission
LCC	-	Series-parallel inductor capacitor-capacitor
LCL	-	Series inductor capacitor
LED	-	Light emitting diode
LPS	-	Low pressure sodium
MOSFET	-	Metal-oxide-semiconductor field-effect transistor
P	-	Power
PF	-	Power factor
PFC	-	Power factor corrector
PIC	-	Peripheral Interface Controller

PWM	-	Pulse width modulation
RFI	-	Radio frequency interference
rms	-	Root mean square
SESB	-	Sabah Electricity Sdn. Bhd.
SESCO	-	Sarawak Electricity Supply Corporation
THD	-	Total harmonic distortion
THDi	-	Current total harmonic distortion
TNB	-	Tenaga Nasional Berhad
UTM	-	Universiti Teknologi Malaysia
UV	-	Ultraviolet

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CHAPTER 1

INTRODUCTION

1.1 Background

The world today faces a critical issue over rising energy prices. Energy demand during the first half of the twenty-first century has been predicted to increase more than two times compared to the previous century due to increasing number of the world population and continuous technology development. Some other related constraints include limited fossil fuels and the need to reduce carbon emission.

Energy is vital in society to ensure the quality of life and to strengthen all other elements in the economy. The demand for energy is expected to continue to increase worldwide over the coming years [1] in the industrialized countries and particularly in developing countries, where rapid economic growth is expected. The energy demand for Malaysia in the years 1999, 2002, 2005 and 2010 [2, 3, 4] are as shown in Figure 1.1. It can be seen that the energy demand in Malaysia increased rapidly at almost 20% annually within 3 years (from 1999 to 2002). The energy demand is further expected to increase to 18,000MW by the year 2010 [2, 3, 4]. Utility providers in Malaysia are using mixed fuel provide the power needed by the country. The generation fuel mix in Malaysia in 2012 is 48.36% coal, 39.43% gas,

7.35% hydro and 4.86% from other forms of fuels [5, 6].

In Malaysia, the electricity is being generated from coal and natural gas as the main energy source, by Tenaga Nasional Berhad (TNB) in the Peninsular together with a few independent power producers, by Sabah Electricity Sdn. Bhd. (SESB) in Sabah and by Sarawak Electricity Supply Corporation (SESCO) in Sarawak [7].

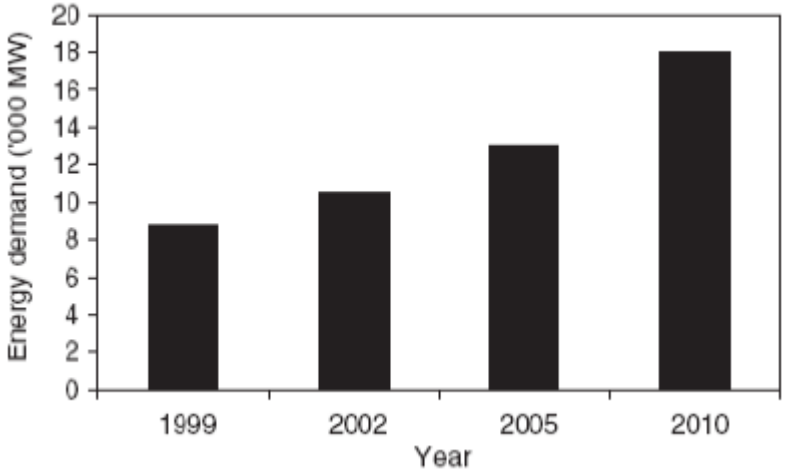

Figure 1.1 Energy demand in Malaysia [2, 3, 4]

In July 2009, the Malaysian government began what would be a series of initiatives promoting green technology. One of the green technology strategy is called Energy Saving Solution for the energy sector [8]. The energy sector covers the energy supply and energy utilization issues [9]. In response to the government's campaign, Universiti Teknologi Malaysia (UTM) has participated in an energy efficiency programme in a campus wide programme themed "Green and Sustainable Campus". The reason is to explore energy saving solutions to address the rapidly increasing trend of energy demand and operating cost. One of the applications in energy saving solution is through the installation of electronic ballast for street lighting.

Lighting plays a very important part in our life. A lot of activities either during the day or night require lighting. Lighting is commonly used in all types of applications (e.g. industrial, commercial and institutional interior lighting). A good lighting system requires several designing tasks. A lighting system is one of the common tasks of an electrical consulting engineer to ensure that the lighting system will consistently provide the most effective illumination at the lowest operating and maintenance cost. Reaching the goal involves providing quality light to occupants and retrofitting energy efficient equipment installation of the existing lighting system to reduce the energy consumption. Developing efficient lighting systems is an essential task today due to the huge amount of energy consumed by lighting sources, as they represent approximately 20% of electrical energy consumed in the world [10].

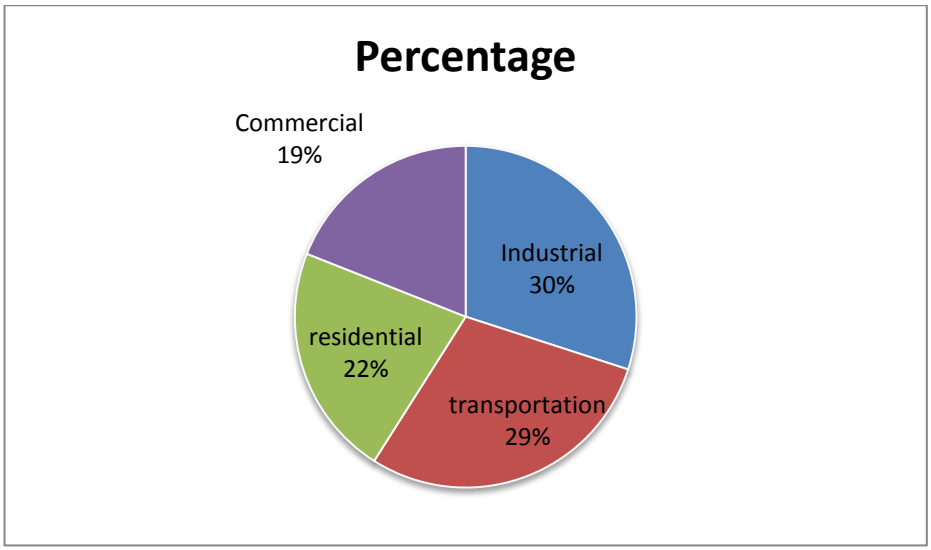

Figure 1.2 Energy consumption by sector

The energy consumption divided by sectors is shown in Figure 1.2. 30% are consumed by industrial, 29% consumed by transportation, 22% consumed by residential and 19% consumed by the commercial sectors [11]. Lighting systems are included in the residential sector and it shows the third largest energy consumption in Malaysia. The lighting system is divided into two parts, indoor and outdoor lighting. Indoor lighting is used inside buildings while outdoor lighting refers to several types,

one of them being street lighting. The main function of street lighting is to illuminate the road during night time or bad weather so that vehicle drivers and pedestrians can navigate their way around safely. Another purpose is to enhance the aesthetic view of the respective areas especially during night time.[12, 13].

With the increasing concern for energy conservation in recent years, much attention has been focused on lighting energy consumption and environment protection. Environmental protection involves two essential factors, namely protection of the atmosphere through the reduction of greenhouse gases, and protection of soil and water [14].

One of the effective ways to protect the environment is by introducing energy efficient lighting. According to the International Energy Agency (IEA) 2010 report, global energy consumption has increased by 75% between 1973 and 2008, and this has led to the increment of CO_2 emission by 80%. IEA also estimated that the potential energy saving by the developments of the technology in street lighting is approximately 133-212 TWh/ year globally, which is equivalent to 86-137 MT/year of CO_2 reduction [15]. So, energy efficiency techniques can help reducing the carbon footprint.

In the year 2009, the energy consumption in UTM is approximately 60, 913,415 kWh. Figure 1.3 illustrates the annual energy consumption from the year 2004 until 2011. The graph shows that the energy consumption in UTM increasing every year at 5-17%. UTM has installed 956 units of 150W and 277 units of 250W High Pressure Sodium (HPS) street lighting lamp with the energy consumption approximately 1,238.24MWh per annum [16]. This is about 2.08 % of total energy consumption in UTM. Furthermore, conventional street lighting installed in UTM has no dimming system that led to high energy usage.

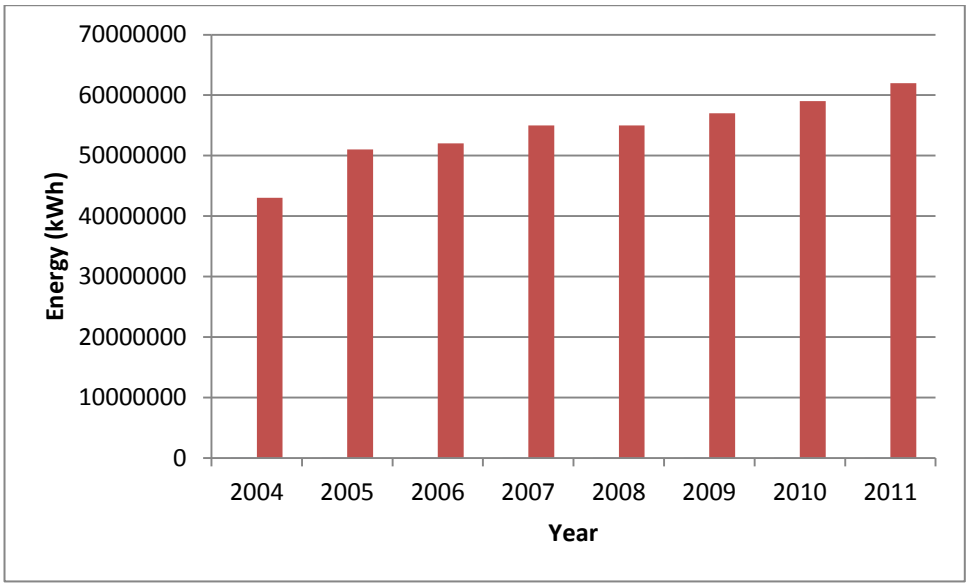

Figure 1.3 Energy consumption at UTM [16]

1.2 Problem Statement

Two-thirds of the currently installed street lighting systems still use antiquated and inefficient technologies, that is, there exists a huge potential to renew technologies for street lighting systems and therefore reduce energy consumption. It is estimated that nearly 5% of the energy used in lighting applications is consumed by street lighting. It is one of the important components of energy use in cities and residential areas.

The conventional street lighting has no dimming system that produces maximum light for 12 hours. The time is set to the timer to turn the lamp on and off. Normally, the time is set from 7pm to 7am. Meanwhile, the main difference between conventional street lighting that using magnetic ballast and electronic ballast is dimming capabilities.

This prompted the idea of street lighting with dimming capabilities using an electronic ballast which is the main part of an intelligent street lighting system. The use of an electronic ballast together with a HPS lamp has the potential to reduce the energy consumption. This saving would then result in a substantial reduction in the equivalent CO_2 emmision to the evironment.

1.3 Objectives

The objectives of this thesis are:

i. To **study** the existing street lighting performance and characteristics in UTM.
ii. To **design** a PWM Atmega32 Dimming Electronic Ballast system using microcontroller Atmega32.
iii. To **implement** a prototype of PWM Atmega32 Dimming Electronic Ballast and 150W HPS lamp.
iv. To **analyse** data in terms of energy consumption, CO_2 emission and payback period.

1.4 Scope of the Thesis

The scope of the PWM Dimming Electronic Ballast for 150W HPS Street Lighting is:

i. Designing a controller circuit using Atmega32 of light dimming process using Atmel AVR and Proteus software.
ii. Testing and validating on a single unit of 150W HPS lamp only and the result is projected for 956 units of the same unit installed in UTM.
iii. Comparing the THDi between full bridge and half bridge inverter in electronic ballast system.
iv. Cost comparison between conventional and proposed PWM Dimming Electronic Ballast in terms of energy consumption and the reduction of CO_2.

1.5 Thesis Overview

In this thesis, the design of an electronic ballast focused on the simulation by using MATLAB Simulink. The design was divided into four parts which are EMI filter, rectifier, inverter and resonant load and each part is inter-related to each other. In the design of rectifier and resonant load, mathematical calculations are also involved. The simulation results determined the energy consumption for three levels of dimming. The implementation of the prototype is based on the simulation designed and the controller was programmed using Atmel AVR and Proteus. The results on simulation and hardware will be compared in terms of energy consumption and CO_2 emission. The results will be analyzed to calculate the payback period for the replacement.

1.6 Thesis Outline

This thesis comprises five chapters. Chapter 1 gives the introduction about the thesis. The introduction contains thesis background, problem statement, objective, scope and also overview of the thesis.

Chapter 2 focuses more on literature review of this thesis and the difference between conventional ballast and electronic ballast. This chapter also describes the development of research for electronic ballast that existed a few years ago. This chapter also describes the technologies of electronic ballast based on literature review. The dimming system controller is also explained more thoroughly.

The methodology used to complete this thesis is described in Chapter 3. The step by step flow of the thesis makes the process systematic. This chapter also includes the calculations of electronic component for electronic ballast and also discusses the process of implementation of hardware. The flow process of the controller programming will be explained in-depth.

Chapter 4 shows the results of the simulation. From the graph, discussion and analysis of the simulation and hardware results is presented. This chapter also shows the cost comparison between using conventional street light and electronic ballast. The graphs and diagrams for three dimming levels will also be presented and the payback period calculation will be shown.

The conclusions and recommendations for further design and simulation of this thesis are stated in Chapter 5.

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