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Energy savings analysis and harmonics reduction for the electronic ballast of T5 fluorescent lamp in a building's lighting system

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ABSTRACT

Lighting is one of the major energy end uses, which accounts for approximately 20–30% of electricity consumption in buildings. In fact, the fluorescent lamp is the most employed lamp in a lighting system for both inside and outside the building. The ballast is one of the major components of fluorescent lamps; it exists commercially as an electromagnetic ballast, a low loss ballast and an electronic ballast. To reduce energy consumption in a lighting system, the electronic ballast has already been introduced for profit in terms of its peak demand reduction and energy conservation in the building. However, when the electronic ballast functions, harmonics will be generated. Hence, this paper investigates energy savings and the generation of harmonics when using a fluorescent T5 lamp with electronic ballast in a building. The efficiency indices in terms of illumination, energy savings, and harmonics are also evaluated and compared with the fluorescent T8 lamp operating with a low watt loss electromagnetic ballast, which is also widely used. The obtained results are useful for the design and decision to install a fluorescent T5 lamp with electronic ballast in building lighting system to conserve energy and/or reduce energy consumption for the future of the country.

1. Introduction

Energy is an important factor in our daily living for improving quality of life and for the economic development of the country. In particular, energy demand in Thailand [1,2], a developing country, has been continuously increasing. According to the 2010 study on future energy consumption in Thailand over the next 20 years [2] based on the "Business as Usual" scenario with the annual average economic and population growth rate at 4.3% and 0.3%, respectively, the energy demand during this period is forecast to increase annually by an average of 3.9%. Energy consumption in the year 2030 will rise to 162,715 ktoe or 2.3 times. However, Thailand's GDP growth rate in 2011, by the National Economic and Social Development Board (NESDB) [1] rebounded to grow 0.1% because at the end of the third quarter and throughout the fourth quarter of the year, Thailand faced a disastrous flood situation, which heavily affected Thailand's industrial sector. For the electricity of Thailand in 2011, the total installed capacity stood at 31,447 MW and was divided into the installed capacity of the Electricity Generating Authority of Thailand (EGAT) at 48%; Independent Power Producers (IPP) at 38%; Small Power Producers (SPP) at 7%; and imported electricity from the Lao PDR and exchange with Malaysia at 7%. Moreover, in 2011, electricity generation was at a level of 162,343 GWh, while the peak load occurred in May 2011, reaching 24,518 MW.

From past literature reviews [3–16], it was found that there is enormous potential for energy efficiency improvement and energy conservation in developing countries [4–8,11,12]. The focus is on the viability of various technologies for reducing the residential peak demand and improving the energy efficiency of houses, which is analyzed with a program for thermal efficiency in [3]. The results are presented and compared with the net present cost for a similar house. In [9], an optimal design method with genetic algorithm (GA) is established for building energy systems. The results showed the potential to provide useful information when making decisions in a practical design process. A novel approach to study renewable energy options for four buildings (residential sector, commercial building, institutional building, and industrial building) to make them more efficient, cost effective, environmentally sound, and technologically attractive was proposed in [10]. The results obtained indicate that solar electricity through PVs is technologically the most suitable solution to meet the electricity demand, and hybrid systems provide better advantages, such as higher efficiency, reduced cost, and reduced emissions. In [14], this paper

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proposes techniques to enable the correct energy use in buildings and achieve a better use of energy without time-consuming tasks dealing with sampling and inexpensive management actions in existing buildings. The building-integrated photovoltaic (BIPV) design and implementation was applied in [16]. Energy management is performed by considering grid time-of-use tariffs, grid access limits, storage capacity, load and PV power shedding. The result showed that, based on experiment, the BIPV with energy management is easy to implement and gives perspectives on better integration of a small urban PV plant in the power grid. As a result, energy conservation plays an important role in strengthening energy security, alleviating household expenditure, reducing production and services costs, reducing trade deficits and increasing competitive edge, including the reduction of pollution and greenhouse gases (GHG), which cause global warming and climate change.

Lighting is one of the major energy end uses for approximately 20–30% of electricity consumption in buildings and exterior applications. Electricity use for lighting has many impacts apart from the consumption of non-renewable resources; thus, lighting has been one of the prime targets of mandatory standards to reduce energy consumption. There has been a long history for researchers to reduce energy consumption for the lighting system, and there are several techniques that have been developed for energy efficiency improvement and energy conservation [17–30].

The method is based on the concept of multiplying two fisheye images and the placement of the photosensor that was described in [17]. The occupancy and lighting use patterns of the four investigated offices through the analysis of field measurement data were presented in [22]. The results identified that the occupant's use of lighting in the investigated offices was not statistically related to external illuminance but had a close relationship with the occupancy patterns. In [25], a statistical performance method based on artificial neural networks (ANNs) is evaluated to represent the potential for energy savings through daylight use in office buildings. The impact of the use of natural lighting and artificial lighting on the space cooling system is presented with a lighting control algorithm in [27]. The main purpose was to create a baseline study for an ideal office space. In [28], a control system with a closed loop dimming system for shop window lighting is proposed. This paper used a digital camera as a luminance meter. The control is focused on keeping the constant contrast of the shop window content with respect to its surroundings. To assess the energy efficiency of a lighting installation [19], normalized power density values are often used as references to the overall floor area and target values. A project to replace approximately 1000 compact fluorescent lamps (CFLs) in a rural setting was successfully implemented in [25]. The project saved approximately 8.3% of energy and encouraged positive attitudes toward the purchase and installation of CFLs in the future. The energy savings that can be achieved, including the cost information through renovated buildings, were presented in [18]. The results showed that the improved building systems could greatly reduce energy use (50–70% savings). In addition, a detailed mathematical analysis of the proposed system including the stability analysis, has been given in this paper. Consequently, the energy consumption in the lighting system can be reduced by several factors such as efficient lighting systems, efficient lighting devices (ballasts, lamps, luminaires) [18–20,24,29] and optimal control of the lighting system (dimming, daylighting) [23,25–27].

For the efficient lighting devices in Thailand, the survey investigated the type and number of lamps used per household (residential sector), which is summarized in Table 1. In addition, for the total ballasts in domestic households, 65% is the standard electromagnetic ballast, followed by low loss magnetic ballasts (32%) and electronic ballasts (3%). The low watt loss electromagnetic ballast has a tendency to be more widely used than the standard electromagnetic ballast because it consumes less energy than the electromagnetic ballast and has a substantially lower price compared with the electronic ballast. Therefore, the low watt loss electromagnetic ballast has already been introduced through EGAT. In 2009, under the energy efficiency labeling no. 5 program, EGAT's energy labels for appliances used a scale of one to five (where five is the highest efficiency level, and three is the average of all models tested). The label is widely recognized by the populace as the "No. 5 Energy Efficiency Label". Thailand has provisions for voluntary labeling for compact fluorescent lamps (CFLs), ballasts for fluorescent lamps, fluorescent lamps and luminaires to benefit energy conservation in the building.

Table 1
Lighting devices used in the residential sector [1].

Lighting devices	Number of lamps from survey results (lamps)	Extrapolate to country level (million lamps)	Estimated usage ratio (National level)
Fluorescent lamps	150,241	15.23	45.9%
Compact fluorescent lamps	102,579	11.19	36.1%
Incandescent lamps	23,030	15.23	18.0%
Total	275,850	33.18	100.0%

In fact, the T8 fluorescent lamp is the most used lamp in the lighting system for buildings, and fluorescent tube lamp sales increase 10% per year. Moreover, ballasts used in the residential sector are normal power factor (power factor approximately 0.3–0.5) ballasts, while industrial and business sectors are the most extensive users of higher power factor (power factor approximately 0.8–0.9) ballasts. So, the fluorescent T5 tube lamp was launched by the EGAT to promote fluorescent T5 tube lamps (28 W) to replace the existing fluorescent T8 tube lamp (36 W). By the end of 2013, 2000 MW of the peak demand of the country and 5 million tons of carbon dioxide emissions would be decreased; this is the goal of EGAT, if 200 million of fluorescent T5 tube lamps have been successfully delivered and are used in the residential and business sectors. In general, the fluorescent circuit actually consists of three discrete types of components: the lamps, starter, and ballast. The ballast is usually required to limit current and provide the proper voltage for lamp starting and operation. In addition, the ballast provides power factor correction. For the fluorescent T5 tube lamp, it must be used with electronic ballasts. This indicates an indirect benefit in terms of peak demand reduction and energy savings because the electronic ballasts qualified under this program must have internal losses of less than 2 W. Although the majority of imported fluorescent lamp ballasts seem to be high-quality electronic ballasts, some importers claim to be manufacturers, but they hire other manufacturers to produce ballasts under their brand names; thus, the low-quality electronic ballasts can be found because of their lower cost versus other brands. However, for low-quality electronic ballasts, the effect of harmonics can be occurred from the operation of the circuit within electronic ballasts. Actually, there are a number of studies [31–47] investigating and discussing on harmonics, including electromagnetic interference (EMI). However, few research papers have been reported to consider this problem in lighting systems.

To efficiently reduce the energy consumption and harmonics in the lighting system, this paper proposed the analysis of the impact of energy savings and harmonics for reducing energy consumption in buildings from a fluorescent lamp and ballasts in Thailand. The fluorescent lamp and ballasts are investigated and used with various changes in the experimental setup. The index efficiency