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Development of an outdoor lighting control system using expert system

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ABSTRACT

In this study, an intelligent energy-efficient outdoor lighting control system was developed that could be used in green buildings as well as intelligent building functions, and contribute to the reduction of carbon dioxide emissions by using more conservation of electric energy and daylight more efficiently. The intelligent energy-efficient lighting control system was based on expert system is one of the artificial intelligence techniques and has four functions running in real-time. The first function is controlling and monitoring of the lamp groups. The other functions are fault diagnosis in lambs and power lines connected to the lamp groups and the load estimation of lamp groups. The expert system was written in two separate computer and microcontroller based environments by using knowledge-based rules.

The rule base of real-time control and monitoring function contains 213 rules. During the education semester operation mode which real-time control and monitoring function was implemented, an average of 33% conservation was achieved in energy consumption.

The system is the first expert system application in which an expert system is used to control and monitor outdoor lighting as well as perform load estimate and fault diagnosis.

1. Introduction

Nowadays, in which the importance of sustainable development increasingly understood, the value of the efforts directed to energy efficiency increases at the same rate. In this framework; enhancing energy efficiency, preventing unconscious usage and dissipation, decreasing energy intensity either in sectoral base or in macro level are preferencial and important components of national energy policies in all the stages from energy production and transmission to the final consumption [1].

As an indicator of energy efficiency, the "Energy Intensity", in other words amount of primary energy consumed per GDP (Gross Domestic Product) is one of the most significant indicators. According to 2013 energy statistics of International Energy Agency (IEA), the energy intensity of Organisation for Economic Co-operation and Development (OECD) countries is recorded as 0.13 on average and 0.11 on average for European Union (28 countries) while this ratio was 0.18 in Turkey (based on USD in 2005) [2]. These ratios indicate that Turkey uses energy less efficiently than OECD and European Union countries. When these ratios are considered, different methods need to be adopted for energy efficiency and conservation, and on a national scale extended to all fields using energy.

One of the fields in which energy can be used more efficiently with broad individual and corporate participation is lighting.

Worldwide, grid-based electric lighting consumes 19% of total global electricity production, slightly more electricity than used by the nations of OECD Europe for all purposes. Lighting requires as much electricity as is produced by all gas-fired generation and 15% more than produced by either hydro or nuclear power. The annual cost of this service including energy, lighting equipment and labour is USD 360 billion, which is roughly 1% of global GDP [3].

Global lighting-related CO_2 emissions are estimated to be 1 528 million tonnes (Mt) from grid-based electric lighting, 190 Mt from fuel-based lighting and 181 Mt from vehicle lighting. This makes a total of 1 900 Mt of CO_2, which is 70% of the global emissions of light-duty passenger vehicles [3].

Globally an estimated 218 TWh of final electricity was consumed by outdoor stationary lighting in 2005, amounting to about 8% of total lighting electricity consumption [3].

In indoor and outdoor lighting, by:

- Selecting elements fit for purpose,
- Using lamps that consume less energy while performing the same task,

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- Utilizing more daylight,
- Using control and monitor systems,

it is possible to achieve considerable conservation in energy consumption and contribute to the reduction of carbon dioxide emissions. Among these methods, one of the most important aspects is controlling and monitoring the lighting. In an uncontrolled lighting system, it is extremely difficult to achieve energy conservation. Lighting control systems are used in controlling and monitoring a lighting system by running either integrated into the building automation system or as a stand-alone unit.

When studies conducted in recent years on energy efficiency and economic usage of indoor lighting are analyzed, the main areas of concern can be summarized as: the criteria for energy efficient lighting in buildings [4], new methods based on a sensor network for designing lighting control systems for industrial buildings [5], seeking an adaptive control strategy for lighting control in office spaces with the aim to reduce energy consumption and provide occupant comfort [6], the savings in various lighting control systems used in commercial buildings as well as factors affecting their performance [7], and the analysis of factors that influence a lighting control system's energy performance [8].

When studies conducted on energy efficiency and economic usage of outdoor lighting are analyzed, the main areas of concern can be summarized as: innovative light design model frameworks to provide quality floodlight for outdoor lighting designs [9], integrated approaches for exterior lighting systems' control and design based on formal graph-based models and methods [10], possible methods and recommendations regarding the factors influencing energy savings in street lighting [11], and major factors that needs to be taken into account for energy efficiency in outdoor lightings [12].

In studies where lighting and artificial intelligence are used together, the main focus is usually on lighting system designs [13] and energy management [14,15].

There are also studies in literature about using Power Line Communication technology [16–18] in lighting control systems.

When all the relevant studies reviewed it was noted that there is a need for research focusing on an intelligent energy-efficient outdoor lighting control system that could contribute to the reduction of carbon dioxide emissions by using electric energy more conservation and that could also minimize the disadvantages presented by existing outdoor lighting control systems.

There are three main methods for controlling the lamps in an outdoor lighting control system. These are lamp control based on level of illuminance (photocell), lamp control by using modular clocks and finally lamp control by motion sensors. However, none of these three methods are sufficient for energy savings. The disadvantages of these methods used in controlling the lamps can be listed as follows:

- Typically high level of electric consumption, inability to set modular clocks and limited range of settings in photocells,
- Potential risk in terms of safety,
- Inability to interfere to the faults in the system,
- Inability to generate reports for energy consumed,
- Inflexibility of the construction,
- Difficulty in controlling and monitoring from a specific centre.
- Lack of a communications technology,
- Inability to integrate into building management systems.

In this study, one of the artificial intelligence techniques, an Expert System (ES) was selected and used in various functions of the outdoor lighting to convert an intelligent system. This also proves the feasibility of artificial intelligence in different functions of outdoor lighting. The functions of the developed intelligent energy-efficient outdoor lighting control system were run in two separate environments based on a computer and a microcontroller. The developed system is the first expert system in which an expert system is used to control and monitor an outdoor lighting system as well as perform load estimate and fault diagnosis.

The Expert System was written with programming languages within the Human Machine Interface (HMI) and the microcontroller's own software development platforms.

While the system created in the computer environment is called the Central Real-Time Expert System (CRTES), the system developed in the microcontroller environment is referred as the Expert System Based Intelligent Control Nodes (ESICN). This system composed of CRTES and ESICN systems is named as Intelligent Energy Efficient Outdoor Lighting Control System (IEEOLCS).

Since the outdoor lighting area in CRTES was large, a fieldbus technology was utilized. The I/O modules connected over the Programmable Controller (PLC) and the fieldbus were the interfaces where required input and output connections were made for running the CRTES. The fieldbus (Bit Serial Fieldbuses – Fieldbus) is the generic name for industrial communication networks.

The purposes of four functions implemented in CRTES are as follows:

- To contribute to the reduction of carbon dioxide emissions by using electrical energy more conservation and daylight more efficiently,
- To control the lamps through with a phase angle technique (30% to 100% with triac) in the most appropriate time slot based on HMI, manual, daylight, real-time, the usage of university campus in specific time periods of the year (education semester, weekend and national holiday operation modes), the security level and motion,
- To monitor whether the lamp groups are activated,
- To diagnose the faults in the power lines the lamp groups are connected,
- To diagnose the faults in the individual lamps of the lamp group,
- To estimate the load connected to a specific phase.

In the structure of IEEOLCS, in case of a fault on a fieldbus technology with a central control structure or deactivated modules on the fieldbus, CRTES functions cannot be performed in the block or blocks where the signal is cut off. In this case, to ensure continuity in control of the outdoor lighting, microcontroller based circuits were placed in each block of the buildings. By writing the ES rules to the microcontroller, expert system based intelligent control nodes were installed that control the outdoor lighting independent of the centre.

The purposes of ESICN system are:

- To contribute to the reduction of carbon dioxide emissions by using electrical energy more conservation and daylight more efficiently,
- To control the lamps manually in the most appropriate time slot based on the real-time and motion.

The developed IEEOLCS was implemented in a 5-blocks building in Marmara University's Goztepe Campus.

2. Materials and methods

2.1. IEEOLCS setup

This research was implemented in the exterior lighting system of the buildings of Marmara University, Faculty of Technical Edu-