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Dynamic Illumination Control of Luminaires of Pathways in Large Establishments for Optimized Use of Energy Using BFO Strategy

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Abstract: The paper provides a way of saving energy by smart lighting of a large establishment using BFO strategy for switching, illumination and dimming control via Wi-Fi communication network. The switching and dimming occurs according to time of the day, weather and day light. Parameters used include dimming levels, power consumption and area covered by each fixture. The whole system can be divided into two main parts, a sensor-data collector part (SDCP) that is composed of a sensor circuitry with a Wi-Fi chip on it interfaced with the Lua programming language, and a pattern generator part (PGP) that is purely a Lua programming code that generates the optimized lighting patterns. PGP analyse and process the data received from all SDCPs. The combo of SDCP and PGP is to be installed on each fixture that determine all the switching and dimming patterns and send commands regarding switching of various luminaires to on/off state and about controlling various dimming levels of luminaires. The importance of this dynamic scheduling is that it is especially applicable to the lighting system with different types of lights installed in it. Simulation of the proposed dynamic scheduling was done many times with changed parameters and the results have shown a considerable amount of energy savings.
Keywords: BFO Scheduling, Dimming, Lua programming language, Power Consumption, Smart Lighting

I. INTRODUCTION

The demand of energy for day to day work is increasing and expanding exponentially. There is a great need for the creation of devices and electronic systems capable of working on less energy. According to a report published in 2015 by International Energy Agency (IEA) 20% of energy used is spent on lighting purposes. This considerable amount of energy spending on the lighting purposes, urges for the development of smart lighting systems to reduce the aforesaid energy consumption percentage. The hardly earned energy generated by the use of non-renewable sources must deserve consumption that is judicious, efficient and according to the need. There are numerous research works regarding more rational use of energy inside buildings [1] and the same strategy with some modifications can be applied to street lighting systems [2], [3]. Lighting systems are also getting interconnected, with wireless technologies providing a flexible way to communicate data across sensors and controllers [4], [5], [6]. There is a great possibility in street lighting to integrate the luminaires to implement a remote-control system based on Wi-Fi network to send commands and receive status information, e.g. fault events and daylight changes, using SDCPs and PGP for to improve maintenance tasks. Moreover, it is possible to generate energy consumption reports that will help authorised users in their tasks of manually controlling the system or a part of it as per need. In addition, the devices are also equipped with a real time clock (RTC) to control real-time based pattern and dimming level determination thus providing a way to perform two-step optimization.

The STEP-1 optimization is day-time based energy saving in which energy saving is done by keeping only a certain percentage of luminaires “ON” according to the amount of illumination provided by the sun and the rush of pedestrians e.g. 80-90 % during twilight and 90-100% during peak hours. In STEP-2 optimization, a series of dimming patterns are applied to the set of luminaires that are “ON” at that period of time. The transition from one dimming pattern to another is smooth and continuous thus minimising the visual perceptible change in illumination and saving energy at the same time. It also has a current sensor in order to measure the current supplied to the luminaire for monitoring purposes, allowing the determination of energy consumption for different types of dimming patterns. The information transmission from sensor are event-triggered and this information is processed by the PGP to determine all the switching and dimming patterns.

The remaining part of the paper discusses about related works done before in section-II. The methodology is discussed elaborately in section-III. The results of the simulations done of the proposed system in the form of tables and graphs are shown in section-IV. Section-V gives the conclusion of the whole research work and then are the references in section-VI.

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II. RELATED WORKS

The research work related to the proposed system was first done by the authors in [7]. Street lighting control based on various types of communication networks have been done like by using the General-Packet Radio Service (GPRS), ZigBee technology, Power-Line Carrier (PLC), Global Systems for Mobile Communications (GSM) transmissions etc., as in [8]-[11]. A similar system have been proposed using different modules for parameters collection and a control module for communication and another module for supervision. Parameters included detection of pedestrians, day light etc. such systems have high hardware requirements and a lot of sensors employed thus increasing the implementation and maintenance cost [12]. A distributed lighting control system with multiple networked lights, each fixture is equipped with a light and presence sensor, and a local controller. Using local sensor inputs local controller determines the optimum dimming level of its luminaire so that the lighting power consumption is minimized, done under net illumination constraints specified in terms of light sensor set-points. Such optimization problem requires knowledge of the illumination gains, i.e. the contributions of luminaire light output to the light sensors [13], [14]. In another research regarding the illumination control of lighting systems requires an occupancy sensor and a sensor capable of sensing the occupancy sensor's radio frequency but such sensor implementation is neither feasible nor possible in street lighting systems [15].

III. METHODOLOGY

On the basis of the literature review certain parameters were identified and framework has been developed for lighting scheduling algorithm to optimize the use of energy. Programming language 'Lua' has been used for coding and simulation of algorithm. The proposed smart lighting system is simple in complexity as well as in working and incurs less implementation cost as compare to the systems discussed in section-II. This lighting system is capable of working autonomously without any manual intervention with the exception of certain emergencies like bad weather and need of administrable changes.

In this algorithm Real Time Clock (RTC) embedded in SDCP determines, the start and end of the illumination and dimming control. The optimization process employs BFO strategy to generate the optimized lighting pattern depending on the time of day (e.g. dusk, night, mid-night, dawn) to cover a certain percentage of the total area covered by the whole lighting system of the large establishment as shown in Table 1. The percentage of area to be illuminated is decided, by providing it an acceptable range that is fixed according to time of the day, when some or no amount of illumination is being provided by the sun.

The *cost function* used is as follows:

$$F=\left(\sum_i^s A_i / \sum_j^n A_j\right) * \left(\sum_j^n E_j / (\sum_i^s E_i\right) \qquad (1)$$

Where '*n' is total number of luminaires* and 's' is selected number of luminaires that are "ON" and $1 \le i \le s$ and $1 \le j \le n$. And '*A*' represents the area covered by i^{th} luminaire of a particular selected pattern. When the value of "F" is within the permissible limits as shown in Table 1, that pattern is selected and applied.

A Lighting Pattern is an array of the status of all the light fixtures in the establishment e.g. in this work twenty such fixtures are consideredFor Example:

L_1 = [10111001010100011101]

L_2 = [10111011010101011101]

Where '1' implies ON state and '0' implies OFF state.

Once a lighting pattern is selected then another sub-algorithm generates the *dimming patterns* of the selected lighting pattern covering certain percentage of area of the establishment. A *Dimming Vector/Pattern* is an array of all illumination levels of all luminaires defined as:

$$D = [I_i, \ldots, I_n] \qquad (2)$$

Where $(1 \le i \le 20 \ and \ 0 \le I_i \le 1)$ and I_i represents intensity between MAX (i.e."1") and OFF (i.e. "0") of i^{th} luminaire.

For Example: Considering *lighting pattern* L_1, its *dimming patterns* will be as follows:

D_1 = [10231002030100023102]

D_2 = [20312003010200031203]

D_3 = [30123001020300012301]

In this work three dimming levels "1", "2" and "3" are considered excluding OFF state dimming level i.e. "0". These dimming levels corresponds to high, medium and low intensity respectively, having area coverage values as 100%, 95% and 90% of the original intensities of the luminaires in terms of area covered by each of them. Such dimming patterns persist for certain fixed time. Each D_i is designated as a dimming cycle thus, a dimming cycle is the duration over which a particular D_i is applied over whole

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lighting system that is equivalent to the $1/n$ units for 'n' dimming patterns to be implemented for one selected pattern say L_1. The dimming patterns will have smooth, flickering free transition from one dimming level to another and may go unnoticed as far as pathway lighting is concerned. Ultimately, leading us to save some amount of energy. The generation of all lighting patterns (L_i) according to the percentage of area to be covered can be designated as STEP-1 optimization and the generation of all dimming patterns (D_i) can be designated as STEP-2 optimization as discussed in brief in section-I.

IV. RESULTS

The simulation results have shown a considerable amount of energy saving by the application of the proposed optimization process for the automated lighting system of the large establishment. The Table I below provides time period and their corresponding area coverage requirements. Table II shows the period wise result of 1 day simulation with optimized and un-optimized energy consumption.

TABLE I
TIME-PERIODS AND AREA COVERAGE REQUIREMENTS

S NO.	TIME-PERIOD	AREA_PERCENTAGE
1	6 pm - 8 pm	70 % - 80 %
2	8 pm - 12am	90 % - 100 %
3	12am - 4 am	80 % - 90 %
4	4 am - 6 am	70 % - 80 %

TABLE II
ONE DAY PERIOD WISE ENERGY CONSUMPTION AND SAVING.

Time-Period	Area-Cover (%)	Lgt-Patterns	Dim-Patterns	Energy-Consumed (UN-OPT. in kwh)	Energy-Consumed (OPT. in kwh)	Energy-Saved (kwh)	Energy-Saved (%)
(1) 6 pm - 8 pm	70 - 80	12	120	42.000	29.220	12.780	30.43
(2) 8 pm - 12am	90 - 100	24	240	84.000	71.118	12.882	15.34
(3) 12am - 4 am	80 - 90	24	240	84.000	64.165	19.835	23.61
(4) 4 am - 6 am	70 - 80	12	120	42.000	29.132	12.868	30.64

TOTAL NO. OF LIGHT PATTERNS = 72
TOTAL NO OF DIMMING PATTERNS = 720
TOTAL ENERGY CONSUMPTIO OF UN-OPTIMIZED LIGHTING (12 hrs) = 252.000 kwh
TOTAL ENERGY CONSUMPTION OF OPTIMIZED LIGHTING (12 hrs) = 193.635 kwh
TOTAL ENERGY SAVED DUE TO OPTIMIZED LIGHTING (12 hrs) = 58.365 kwh i.e. 23.16 %

It is clearly shown that there is reduction of the energy consumption of the lighting system upto 77% only thus, there is saving of about 23% of energy.

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TABLE III

HOURLY BASED RESULT WITH/WITHOUT DIMMING CONTROL

HOURLY COMPARISON OF ENERGY CONSUMPTION WITH AND WITHOUT DIMMING CONTROL (1 Day) :

Time-Period	Patterns	Energy-Consumed(kWh) (without dimming)	Energy-Consumed(kWh) (with dimming)	Energy-Saved (kWh)	Energy-Saved (%)
6 pm - 7 pm	6	16.167	14.535	1.632	10.09
7 pm - 8 pm	6	16.333	14.685	1.648	10.09
8 pm - 9 pm	6	19.600	17.637	1.963	10.01
9 pm - 10pm	6	19.933	17.937	1.996	10.01
10pm - 11pm	6	19.667	17.697	1.970	10.02
11pm - 12am	6	19.833	17.847	1.986	10.02
12am - 1 am	6	17.433	15.696	1.737	9.96
1 am - 2 am	6	17.750	15.985	1.765	9.94
2 am - 3 am	6	18.250	16.429	1.821	9.98
3 am - 4 am	6	17.833	16.055	1.779	9.97
4 am - 5 am	6	16.183	14.556	1.627	10.05
5 am - 6 am	6	16.200	14.575	1.625	10.03

The Table III provides 1 day hourly simulation results with energy consumption without applying the dimming procedure over the selected pattern of luminaires and also shows the energy consumption and saving by applying the dimming control over selected luminaires. It is clearly shown that the energy consumption of the lighting system is more when dimming control procedure is not applied and there is a considerable amount of energy saving of about 9-10% per hour when dimming procedure is applied to it. Thus, it can be said that the proposed optimization process is able to save a considerable amount of precious energy.

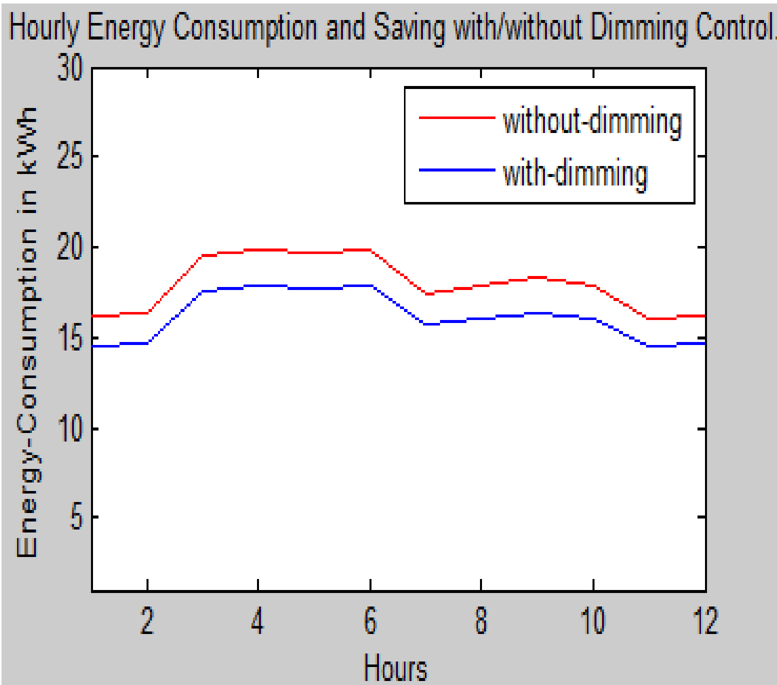

Fig.1.One day with/without dimming control results as shown in Table III.

Fig.1 shows the graphical representation of the simulation result of the Table III. In Fig.1 it can be seen that the red line depicting the energy consumption without dimming (i.e. without optimization) is always above the blue line which depicts the energy consumption when dimming control is applied. Thus, shows the energy saving area i.e. the gap between red and blue line. It can be said that more is the gap the more is the energy saving. Each pattern is applied for 10 min thus amounting to 6 patterns per hour. Each dimming pattern persists for 1 min each, amounting to 10 dimming patterns for each selected L_i.

TABLE IV

TEN DAY SIMULATION RESULTS

TOTAL ENERGY CONSUMPTION OF WHOLE LIGHTING SYSTEM IN A DAY (UN-OPTIMIZED) : 252.000 kWh

DAYS	Energy-Consumption (kWh)	Energy-Saved (kWh)	Energy-Saved (%)
1	192.277	59.723	23.70
2	193.480	58.520	23.22
3	192.476	59.524	23.62
4	193.052	58.948	23.39
5	192.745	59.255	23.51
6	192.325	59.675	23.68
7	193.084	58.916	23.38
8	193.451	58.549	23.23
9	192.660	59.340	23.55
10	193.883	58.117	23.06

UN-OPTIMIZED ENERGY CONSUMPTION FOR 10 DAYS .. : 2520.000 kWh
AVERAGE ENERGY CONSUMPTION FOR 10 DAYS .... : 192.943 kWh
AVERAGE ENERGY SAVING FOR 10 DAYS .... : 59.057 kWh
AVERAGE ENERGY SAVING PERCENTAGE FOR 10 DAYS . : 23.44 %

The Table IV shows ten day simulation results. It can be seen that each day there is fluctuation in energy saving between 23-24% approximately. The average energy consumption and average energy saving is also shown. The overall energy saving is about 23.44%. Fig.2 shows the graphical representation of data acquired after simulating ten days of working of the proposed optimization procedure over the lighting system.

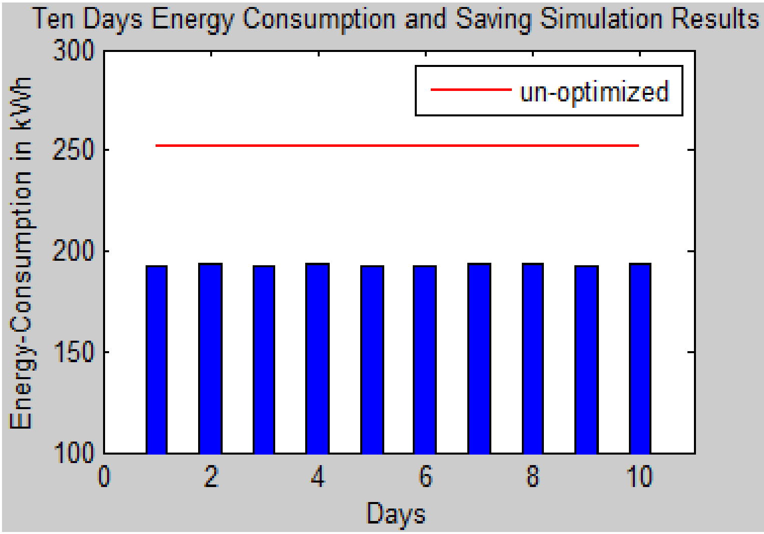

Fig.2.Ten day energy consumption and saving simulation results as shown in Table IV.

In Fig.2 it is clearly seen that the red line depicting the energy consumption per day (un-optimized) is always above the blue bars that depicts the energy consumption per day (optimized). Hence, a considerable amount of energy saving is achieved

V. CONCLUSIONS

This work proposed a pathway lighting control system that is capable of saving a considerable amount of energy simulated by a simulator developed in Lua programming language suitable for embedded systems for implementation. Such systems with additional number of sensors installed like a camera, microphone etc. is also capable of performing the task of surveillance etc. Above results have been acquired when only three dimming levels are taken into consideration. Dimming levels can be increased to further smoothened the transition from one intensity level to another and further energy saving can be possible. The proposed scheduling for lighting of pathways in large establishments can prove one of the good ways of energy conservation.

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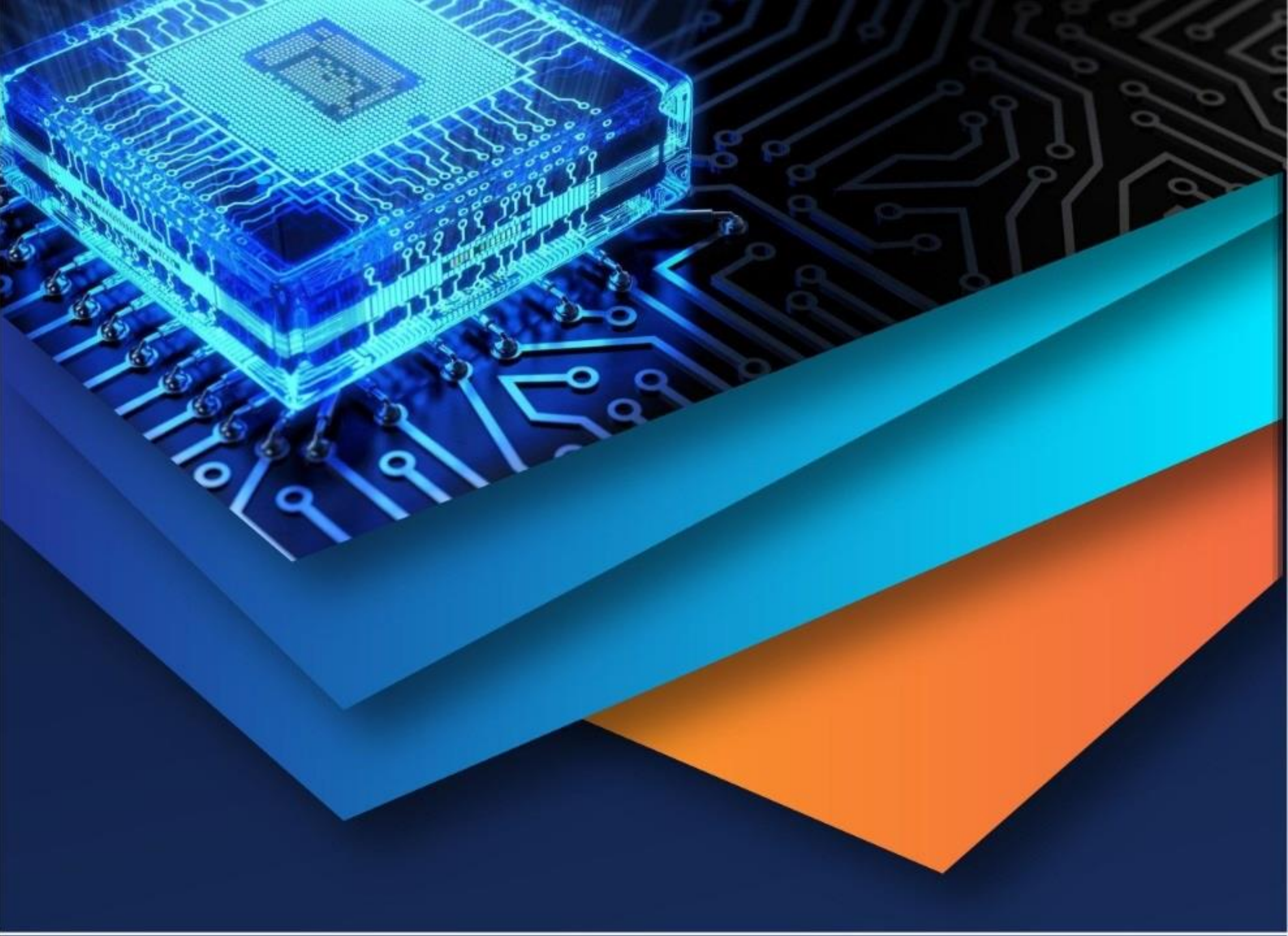
NOTE: # All the tables are screen shots of simulation output in Lua Programming Language.

* All the figures are screen shot of Matlab program output.



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