Light & Engineering
Vol. 27, No. 6, pp. 73–81, 2019 *https://doi.org/10.33383/2017-018*

DEVELOPMENT AND PERFORMANCE ANALYSIS OF A COST-EFFECTIVE INTEGRATED LIGHT CONTROLLER

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ABSTRACT

An integrated sensor based daylight responsive light controller has been designed and developed. The developed cost-effective light controller performs on logical decision derived from output of integrated sensor circuit comprising of daylight sensor and occupancy sensor. The performance analysis has also been carried out to understand the actual operating condition of the system using different sensors to control lamp circuits in small indoor lighting applications. The sensitivity levels of the photo sensor (i.e. a Light Dependent Resistor or LDR) and the occupancy sensor (i.e. a Passive Infrared Sensor or PIR) circuits can be adjusted through in-built tuning facility in developed circuit after experimental measurement of the response characteristics of the both sensors. By monitoring the indoor lighting system with the developed controller, it is possible to reduce the usage of electrical energy during the absence of occupant in any room. It is also possible to vary lamp output according to the seasonal variation in daylight level by selecting different reference voltage level and to use minimum electrical energy by utilizing the available daylight. It is a low cost solution due to the advantage of components and the sensors in the market at low cost.

Keywords: energy saving, LDR, light controller, PIR sensor

1. INTRODUCTION

Electrical energy is one of the most important resources in economic development for any country. To meet the increasing demand of electrical energy for rising population and rapid urbanization, optimal utilization of energy is very necessary. Previous research shows that energy used in lighting system is (20–40) % of total electrical energy consumption for commercial buildings [1] and 50 % in case of residential buildings [2]. Therefore saving in lighting systems can save a considerable amount of electrical energy. Saving in lighting energy can be done by the improvement in lighting energy management system with proper lighting control strategies. Lighting automation enables automatic control of electric lights based on occupancy, daylight levels, personal preferences of the user regarding the lighting environment and even peak demand [3, 9]. Proper use of daylight with the artificial lighting system can save a considerable amount of electrical energy. This can be achieved with a photosensitive light control system by adjusting the output of artificial lighting system based on the available daylight [4]. The photosensitive light control systems generally operates based on the detectors like occupancy sensor, photo sensor etc. [5–8, 10–16]. The lighting control systems that are commonly available are based on different technologies. The Philips ActiLume (1–10) V has been developed to achieve ambitious energy savings (up to 70 %) by combining presence detection and natural daylight [17] where the ActiLume Wireless (1–10) V system consists of the ActiLume (1–10) V sensor and the ActiLume Wireless (1–10) V Switch Box[18]. There are few systems also available based on DALI protocol [19, 20]. In this paper we have presented a light controller that can sense daylight level and occupancy and to control the light output of the artificial lights accordingly. Therefore, the developed controller can be used as On-Off controller and as well as dimming controller. Due the high price of the available lighting controller sometimes they are avoided. Therefore, the aim is to develop the cost effective controller to encourage the users towards minimal use of electrical energy.

2. OBJECTIVES

The specific objectives of the work are energy saving, automatic light control and low cost solution by developing a light controller which consists of occupancy sensor and photo sensor to make an occupancy based and daylight responsive lighting control system for maintaining the required illuminance value in presence of occupancy. At present, there are lots of technologies available for dimming control of lamps but in this paper a simple dimming controller for indoor applications has been developed utilizing the pulse width modulation (PWM) technique and using triac firing by generated pulse for different firing angles. A LDR, which is used as photosensor, is a very low cost solution and the PIR sensor is also easily available in market at low cost. The most commonly used lamps in indoor lighting i.e. fluorescent lamps (FTL), compact fluorescent lamps (CFL) are used for measurement purposes.

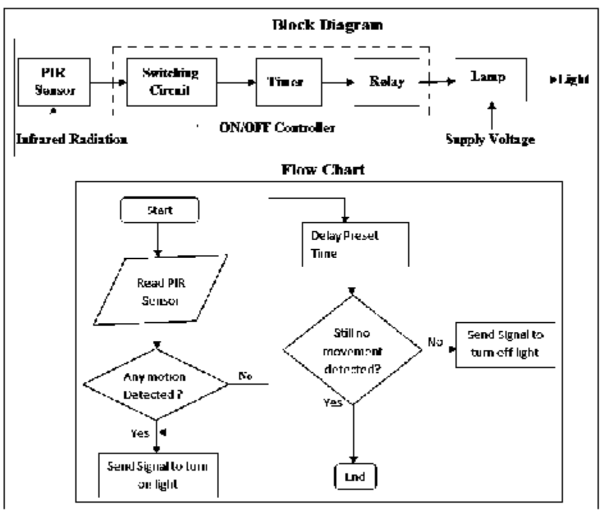

Fig.1. Representation of Scheme I

However, any LED modules with in-built driver can be controlled using this light controller. In this work performance of the developed controller is evaluated using some conventional lamps viz. FTLs and CFLs as test sample, by measuring electrical and photometric parameters. Therefore, the system can be used in rural areas as well as in different indoor lighting application areas to reduce the use of electrical energy in lighting system.

3. DESIGN AND DEVELOPMENT OF LIGHT CONTROLLER

Two different sensor circuits were designed and electronically integrated with the controller circuit through various schemes for continuous control of lamp circuit by using both PIR and LDR sensors.

3.1. Light Control Scheme I

In this scheme the lamp circuit is automatically switched on/off by monitoring the occupancy using LHI 968.

Passive Infrared (PIR) LHI 968 with typical responsivity of 3.8kV/W is used as the occupancy sensor in the circuit. It is a commercially available and very cheap occupancy sensor which perceives, measures and responds to the infrared radiation being emitted from an object in its field of view to detect presence or any motion of objects. This sensor is termed as passive because it does not emit any energy itself, but generates a signal based on the pattern of infrared radiation within its detection area. PIR sensors elements are usually designed in a symmetrical form and placed in discrete manner to separate thermally induced charges from the piezoelectrically induced charges and for better rejection of the in-phase signals. These discrete elements are called inter digitized electrodes. A Fresnel lens is used to focus the IR radiation from objects on its sensing element and also protects from outside hazards. The PIR sensor is most sensitive to the radiation of 10 μm which is the peak wavelength of radiation coming from a human body. However PIR sensors require an unobstructed view of the occurrence of motion and cannot easily discern between humans and small animals. They are susceptible to "dead spots" which are areas where motion cannot be detected within the field of view.

The lamp controller circuit was designed with proper electronic circuitry for automatically switching on/off by monitoring the occupancy of a room. The power voltage level has been converted to dc control voltage to operate the circuit. The block diagram and corresponding flow chart are shown in Fig.1. When any motion is detected, a higher voltage signal is applied to the base of the transistor and it switches on and triggers the relay to glow the lamp.

The necessary circuit consists of:

- Power Supply;
- Sensor Circuit;
- Control Circuit;
- Lamp Circuit.

3.2. Light Control Scheme II

In this scheme, LDR is used as daylight sensor. A Cadmium Sulfide (CdS) Light Dependent Resistor (LDR) has been used as the photosensor. It is a small, round and passive semiconductor device with variable resistance according to the amount of light falling on its surface. The value of the resistance decreases as the amount of incident light increases, and vice versa. In the absence of incident light, LDR exhibits maximum resistance in the order of mega-ohms which is termed as "Dark Resistance". The typical value is 100 MΩ in this case. The LDR sensor was covered with a white diffuser to collect the light from all the directions as well as to minimize cosine error.

The block diagram representation and the flow chart of this scheme are shown in Fig.2. The circuit works by incorporating a balancing bridge and one comparator IC741. The comparator compares LDR output voltage with the set reference voltage and accordingly operates the relay to switch ON/OFF lamp. One capacitor and diode were used to avoid

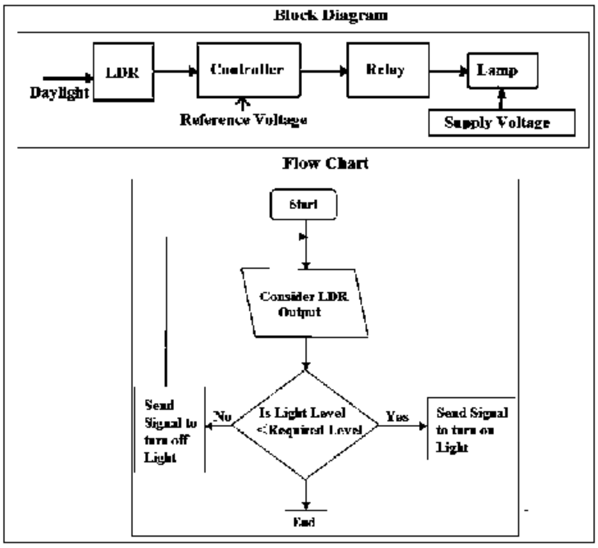

Fig.2. Representation of Scheme II

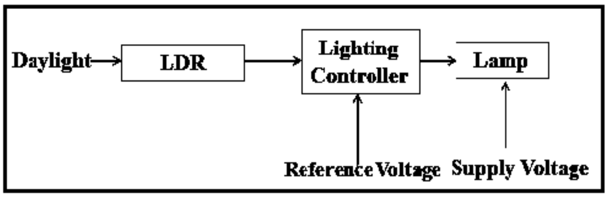

Fig.3. Block Diagram representation of Scheme III

relay-chattering and sparking of relay coil during operation.

The necessary circuit consists of:

- Power Supply;
- LDR Control Circuit;
- Lamp Circuit.

3.3. Light Control Scheme III

In this scheme, the controller has been developed for continuous dimming and also to meet the required illuminance level in response to the

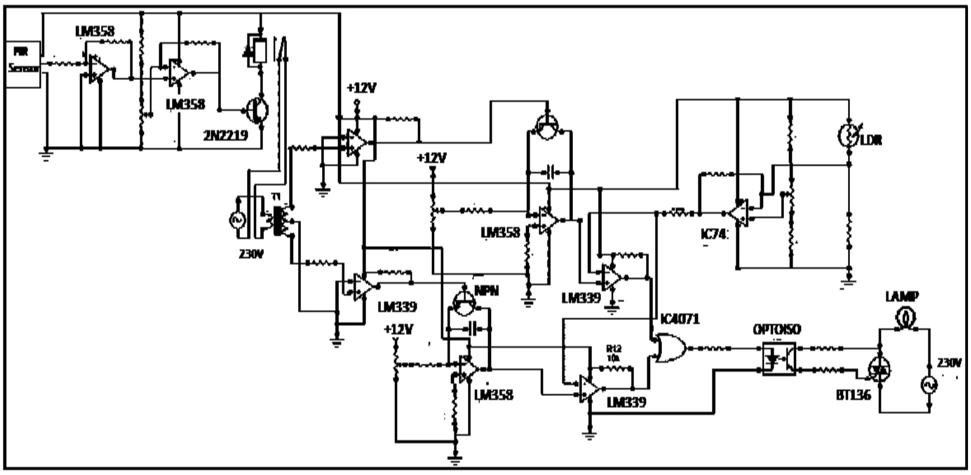

Fig.4. Circuit Diagram of the controller

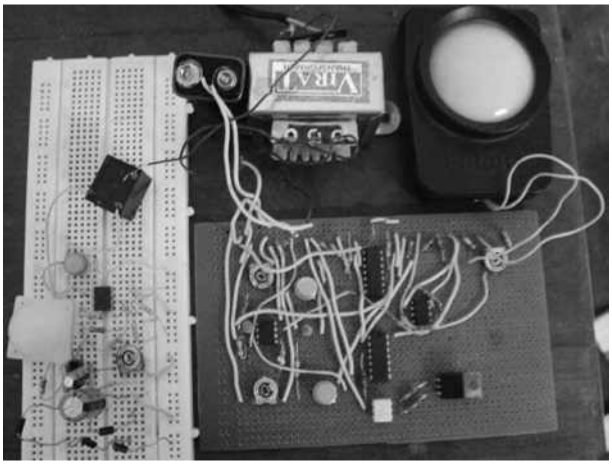

Fig. 5. Developed Light controller

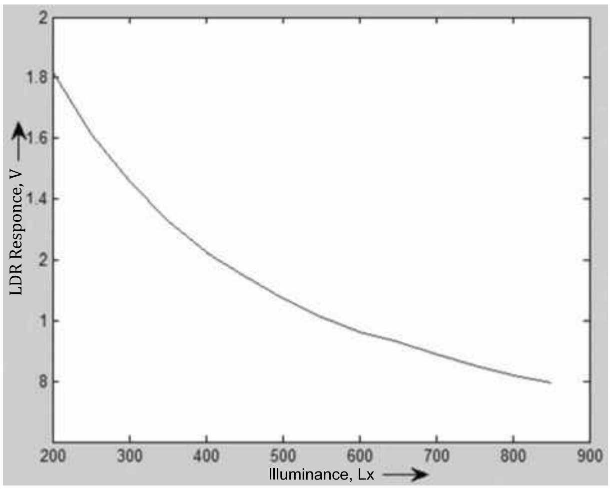

Fig.6. Response Characteristics of the LDR

amount of daylight falling on the LDR. Block diagram representation of the dimming controller is shown in Fig.3. The developed circuit consists of:

- LDR circuit;
- Dimming Controller Circuit;
- Firing Circuit;
- Lamp Circuit.

The DC voltage level corresponding to the required light level is set as controller reference voltage. The firing angle of the triac was controlled by generated PWM signal. One opto-isolator has been used to isolate the low voltage control side from the high voltage power side for safety purposes.

3.4. Light Control Scheme IV

The final circuit is designed for detecting both occupancy and daylight illuminance and also to control the light output of the lamp according to the variation in daylight illuminance. While using in practical cases, the sensors can be used as ceiling mounted applications with a direct line of sight. For some cases, it may happen that daylight illuminance is very low in that position. For those cases, the required illuminance level can be achieved by adjusting the set –point of the pot resistance. The developed circuit consists of three parts:

- PIR Circuit;
- LDR Circuit.
- Dimming Controller Circuit: both the sensor circuits were coupled electronically and integrated with the main controller circuit. The dimming controller circuit operates only when the PIR sensor circuit detects occupancy. The lamp output can be dimmed according to the required illuminance level by varying the firing angle of the triac as per the width of the PWM signal.

The photograph and final developed controller circuit of the controller is shown in Fig. 4 & Fig.5.

4. EXPERIMENTAL RESULTS & PERFORMANCE ANALYSIS

The developed dimming controller was experimented and analyzed through various stages. The

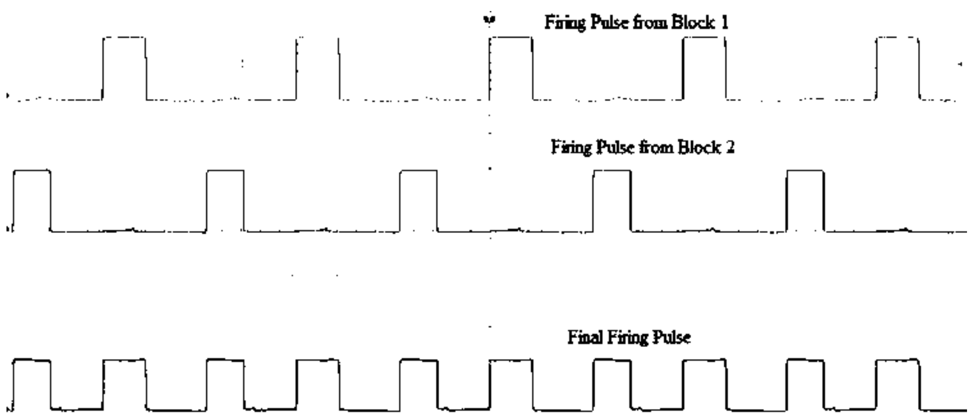

Fig.7. Final Control Pulse

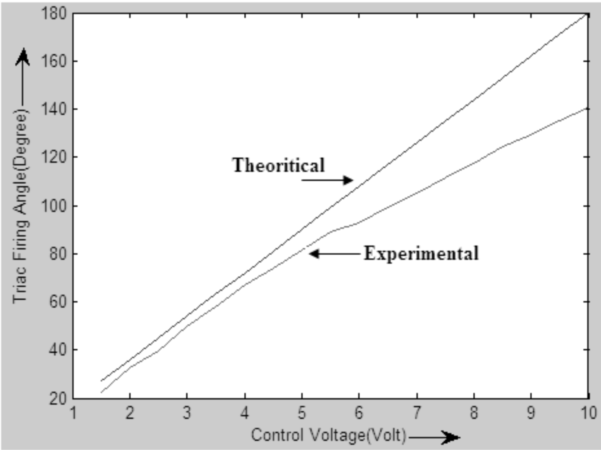

Fig.8. Variation of Triac Firing Angle with Control Voltage

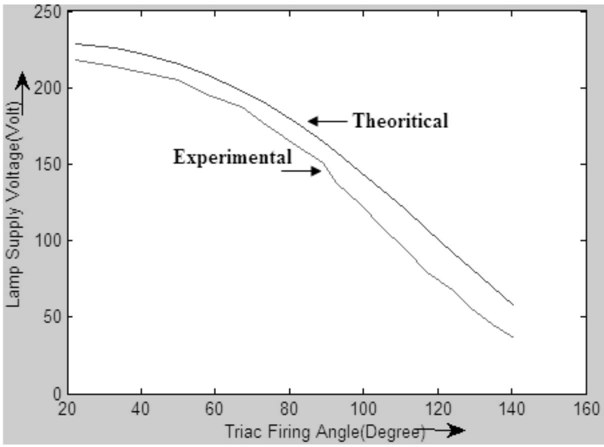

Fig.9. Variation in Lamp Supply Voltage with Firing Angle

dimming characteristics of the lamps for indoor applications were observed experimentally using the developed controller.

4.1. LDR Response

The spectral response of the LDR is close to the V(λ) curve i.e. human eye responsivity curve. In this study the LDR sensor was not provided any colour correction. The illuminance values were measured by using a Konica Minolta Chromameter, CL 200. The LDR response with variation in incident illuminance level is shown in Fig.6.

4.2. Lamp Voltage Control Signal

The generated waveforms from each block of the developed controller were observed and recorded through 4 channels Digital Phosphor Oscilloscope DPO 4034 of Tectronix. The generated control pulse (i.e. PWM signal) of the controller circuit is shown in Fig.7.

4.3. Experimental Setup & Analysis

The developed daylight responsive dimmer circuit can be used to dim the lamps generally used in indoor lighting for general purposes. A 60 W, 230V Incandescent lamp, 36 W fluorescent lamp with magnetic ballast and three non-retrofit compact fluorescent lamps (CFL) of 15 W and sample 1 of 23 W and sample 2 of 23 W lamps were dimmed using the developed circuit. Here all three 15 W CFLs are non retrofit type. But in case of 23 W CFLs, the sample 1 is non retrofit and cool white type and the sample 2 is retrofit and warm white type. According to the daylight variation, the width of the control pulse changes which results in firing of the triac for different firing angles. The variation of lamp supply voltage with different firing angle has been measured & compared with theoretical values using the expression:

$$U_i = U_r[\frac{1}{\pi}(\pi - \alpha + \frac{1}{2}\sin(2\alpha))]^{1/2},$$

where U_i is the lamp supply voltage (V), U_r is the RMS value of system voltage (V), and α is the firing angle of the triac (degree). Variation of 1 V of the control voltage is equivalent to corresponding change in the pulse width of 18 degrees of control signal. The experimental and theoretical values of triac firing angles and corresponding variation in lamp supply voltage (as shown in Fig. 8 & Fig. 9) are compared to validate the response of the controller. It is found that with the increase in the value of the control voltage i.e. with the increase in the pulse width, the triac triggering angle increases and vice versa. Again with the increase in the triac firing angle, the lamp supply voltage decreases, and as a result the lamp output also decreases. It is observed that there is a slight difference between the theoretical values and the experimental results of triac firing angle and lamp supply voltage.

The generated control voltage output from the controller and the corresponding lamp voltage output are shown in Fig.10, Fig.11 for two different types of lamps of different power as sample cases which are generally used in indoor applications.

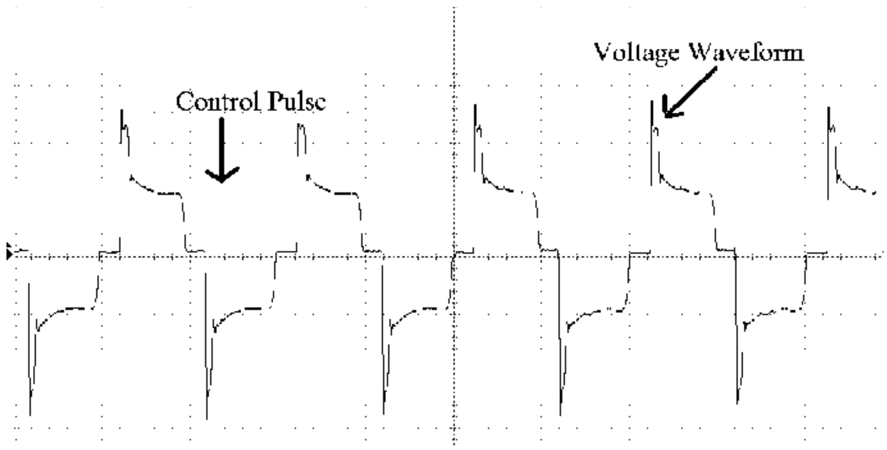

Fig.10. Control pulse & Lamp Voltage waveshape of FTL at 70 % dimming

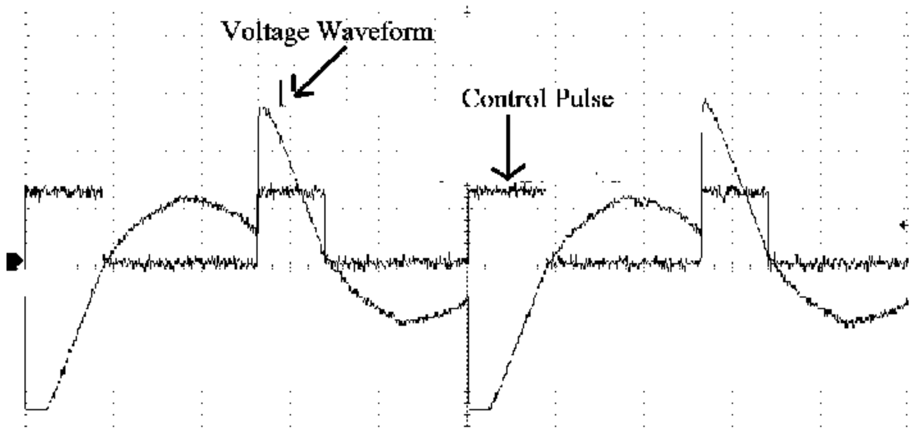

Fig.11. Control pulse & Lamp Voltage wave shape of 15W CFL at 70% dimming

4.4. Dimming of Lamps

The performance of developed controller was verified with few lamps. The luminous flux of lamps was measured using large integrating sphere of 2.5m diameter and luminous flux standard lamp. The dimming characteristics of the incandescent lamp (GLS), fluorescent lamp (FTL), and three retrofit compact fluorescent lamps (15W CFL, 23W CFL1, 23W CFL2) are shown in Fig.12.

From the above plots, it is clear that with the increase in control voltage, the lumen output of the lamp decreases. For the 15W CFL lamp the light output can be dimmed upto 36 %. But in case of 23W lamps, two different samples were used to verify the performance of the dimmer. The sample 1 was of lower luminous flux (i.e. 1300 lm) and lower power factor (i.e. 0.85) than the sample lamp 2 (i.e. 1350 lm and 0.89 pf). But the sample1 (non-retrofit) was cool white and the sample 2 (retrofit) was warm white. Now if the characteristics of these two lamps are observed then it is evident that sample 2 was dimmed upto only 10 % and the sample lamp 1 was dimmed upto 30 %. As we have used dimmable and non-retrofit CFLs with 4 pins, where ballast is not integrated, rather the ballast is to be connected externally. However, the retrofit CFLs are generally non-dimmable. This is due to the fact that at present, all the retrofit CFL lamps are so designed that they can prevent the variation in the light output due to voltage fluctuation. So it can be stated that the sample lamp 1 was designed properly to resist the variation in light output due to voltage fluctuation. But in case of sample lamp 2 more dimming is possible and the luminous flux reduces almost linearly.

5. EXPERIMENTAL RESULTS & PERFORMANCE ANALYSIS

In the developed light controller, the required control voltage to generate the firing pulse comes from the LDR unit. The value of daylight illuminance was transformed into corresponding control voltage level by the LDR circuitry.

5.1. Control Voltage from LDR Unit

The control voltage coming from the LDR unit was varied by varying the incident illuminance level

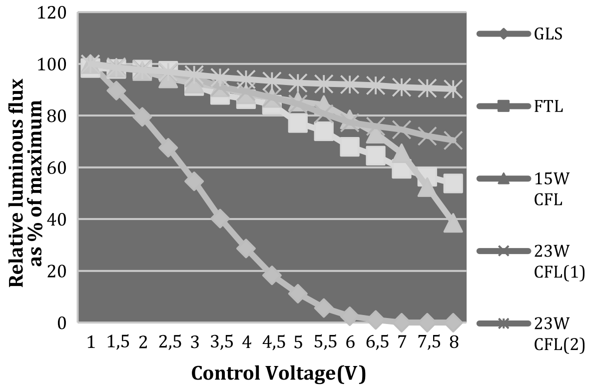

Fig.12. Dimming Characteristics of different Lamps using the developed controller

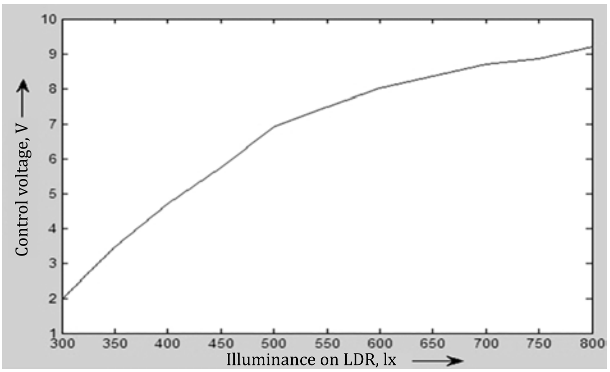

Fig.13. Variation in control voltage with daylight level on LDR

on the diffuser surface. For a fixed reference voltage, the control voltage output from the LDR unit increases with the increase in incident light level. The characteristic is shown in Fig.13.

5.2. Variation of Light Output for Different Reference Voltages

One experiment was carried out to find out the control voltage output from the LDR unit for different reference voltage level of 2V to 10V to dim a 36W FTL lamp. The control voltage was recorded for different reference voltage levels. The reference voltage can be varied by adjusting the pot resistance. The indirect illuminance from integrating sphere was measured by Chromameter while placing the lamp at the centre of integrating sphere. The nature of the variation of the control voltage with daylight level is shown in the Fig.14 for 3 different sets of control voltage. The variation in the light output of the FTL with the natural illuminance on LDR surface for different corresponding control voltage level is also shown in Fig.15.

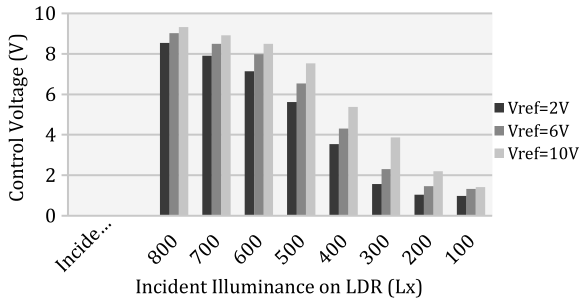

Fig.14. Variation in Control Voltage with Daylight

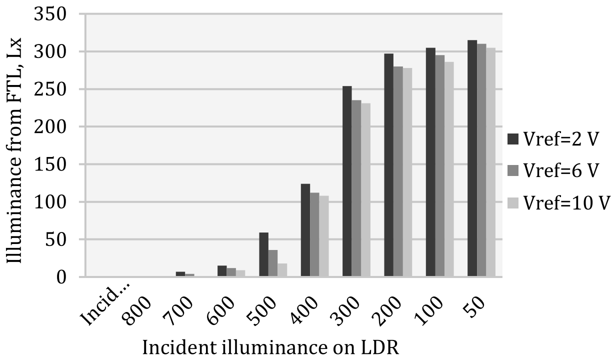

Fig.15. Variation in lamp output with daylight level for different reference voltages for FTL lamp

6. COST ANALYSIS

The components used to develop the circuits are easily available in market. The comparison of cost between different schemes is shown in Fig.16. As the cost of IR sensor is more than the cost of the LDR sensor, the cost for Scheme II is lower than the other types of schemes. The cost comparison is done on the basis of INR (i.e. Indian National Rupee).

7. OBSERVATIONS

It is observed that for the developed integrated sensor based daylight responsive light controller,

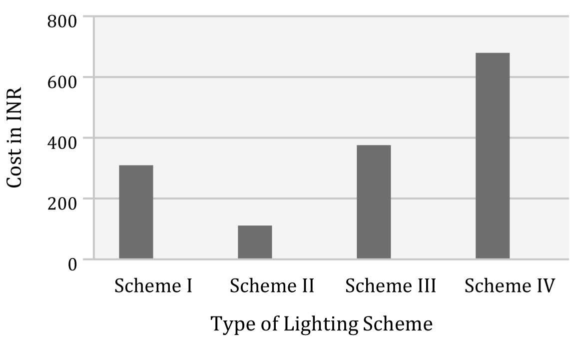

Fig.16. Comparison of light controller cost for different schemes

with the increase in the control voltage the lamp supply voltage decreases and as a result the lumen output of the lamps also decreases. The control voltage is supplied from the LDR unit. The control voltage output from the LDR unit is increased with the increase in daylight level. As a result, the lamp light output is decreased for the decrement of lamp supply voltage. On the other hand, when daylight level is low, the control voltage output is decreased. Therefore, the lamp light output is increased for the increment of the lamp supply voltage. If the reference voltage set for the LDR unit is varied, the control voltage can also be varied. For a higher reference voltage, higher control voltage is achieved for higher illuminance level. From Fig.14 it is evident that for same daylight illuminance, the control voltage values are more for the reference voltage of 10V than the lower reference voltage levels. For the same daylight illuminance, the control voltage values are lesser for the reference voltage of 2V than the higher reference voltage levels. As a result less light output will be available for higher reference voltage level. Therefore, when the availability of daylight is less i.e. during winter season or when the daylight availability is more i.e. in summer, the reference voltage is to be adjusted accordingly to achieve the required illuminance level. However, the control voltage has to be set manually by adjusting the pot resistance.

8. CONCLUSION

The objective of the work was to develop a cost effective integrated light controller and also to evaluate the performance of the developed controller in small indoor applications. In the present work, it is seen that the sensitivity levels of the photosensor and the occupancy sensors circuits can be adjusted through in-built tuning facility in the developed circuit. The artificial lamps can be switched off by using the simple developed controller to reduce the waste of electrical energy in the absence of any occupancy or in the presence of any occupant with sufficient daylight illuminance. The dimming controller can dim the light output of the lamps used in indoor lighting for general purposes, according to the daylight availability. It was also possible to vary light output according to the seasonal variation in daylight level by selecting different reference voltage level. The system will be more effective if we apply zoning control. Another detailed study is also required for understanding the lamp performance using the developed light controller. Commercially available LEDs can be controlled with few modifications in this circuit. The effectiveness of this system in controlling LED lamps is not shown in this paper. Only the results for FTLs & CFLs are shown as sample cases. However, the system can be installed in indoor application areas for detecting occupancy and reducing the use of electrical energy by utilizing the the daylight illumination.

9. ACKNOWLEDGMENT

This work is part of project of M.E. Illumination Engineering done by the first author. We are thankful to Ms. Debjani Ganguly, Associate Professor, Electrical Engineering Department, Indian Institute of Engineering Science and Technology, Shibpur and Dr. Biswendu Chatterjee, Assistant Professor, Electrical Engineering Department, Jadavpur University for their valuable suggestions in carrying out this work.

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