Light sensor control for energy saving in DC grid smart LED lighting system based on PV system

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The high use of conventional resources in electricity production and the fact that these resources diminish with every passing day have increased the studies carried out on renewable energy sources. However, the use of renewable energy sources in the most efficient way possible is one of the topics that come to the foreground. The fact that LED technology is used in the illumination systems provides energy saving. In this study, the DC electric energy that is obtained from PV (Photovoltaic) panels is accumulated in battery groups, sensitive to illumination intensity and motion taken from an ambient of light sensor, a proposed algorithm that controls the light level of LED which are in DC (Direct Current) characters. In comparison with normal LED illumination systems, 50.6% energy saving has been attained.

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1. Introduction

The main energy source of illumination system nowadays is generally the electricity obtained from conventional sources. Electric energy is not used only for illumination purposes. For this reason, it is essential that the electricity used for illumination is obtained from other alternative energy sources and that these sources are used efficiently. For the U.S.,U.K., and China, a target of at least %20 of the total electric power generation coming from renewable energy sources has been set for 2020, it is envisaged that renewable energy sources will contribute to over %50 by 2050 in some countries [1]-[3] It has been advantageous that with the LED technologies the power values needed for illumination have lowered. As they are durable, environmentally friendly and require low consumption the development and use of LED technologies increase with every passing day [5]-[8]. Energy efficiency, smart buildings, green buildings have recently come to the foreground as some striking topics. However, an illumination control designed according to the needs of spots in the buildings is to decrease energy consumption. [9]-[10]. With LED luminaires, it is possible to control the light output of the luminaire easily and accurately. Together, these technologies enable flexible adaptation of a lighting system to its environment [11]. Artificial lighting accounts for a major fraction of global electrical energy consumption. In office building, in particular, the energy consumed due to artificial lighting can be up to %40 of the total energy consumption [12]. Some propose an illumination model-based method and algorithm for intelligent open-loop lighting control, and present the results of a simulation using a simplistic virtual room[13]-14], Other than that, techniques such as daylight harvesting and automatic dimming control with wireless sensor, illumination balancing, KNX, stochastic hill climbing optimization are applied to lighting control [15]-[17].

In this study, in the PV-equipped building the batteries are charged and the 8 LED illuminating armatures installed in the ceiling are controlled by the light sensor with their AC (Alternating Current)/DC being disconnected. The features of the system are as follows: 1) 6 PV panels each with 65 Watt 2) The PV panels have been grouped as 24 V and 12 V and these have been integrated to PWM (Pulse-Width Modulation) charge regulators together with battery groups. 3) The outputs of charge regulators have been serial connected and 12+34=36 V has been obtained. 4) With the switch on the power panel, when there is no PV energy system and battery voltage is diminished, the option to switch to grid is made possible. 5) By way of disconnecting LED panel's drivers, the system has been set as DC. 6) With the LDR (Light Dependent Resistor) light sensor installed on the working surface, the light level of the ambient has been measured. 7) The value measured through LDR and the reference value have been compared. 8) Bearing the reference value in mind, the light volume has been brought to an optimum level.

It integrates a PV system with a daylight responsive dimming system, which can generate electricity and save electrical lighting energy at the same time. In addition, using LED lighting resulted in greater dimming efficiency compared to conventional fluorescent lighting [18].Fluorescent and LED lamps' functioning in AC cause converter loss; as the nature of the LED lamps is DC, it is more efficient that they function in DC [19]. The DC voltage taken directly from PV system is transferred to LED illumination system and thus AC converter loss is avoided.

The rest of the paper is structured as follows: in the second part, the PV system installed in the building, the LED illuminating system which is set on DC grid and the positioning of the LED lamps will be discussed. In the third part, the flow chart of the proposed system and the control of the LED illuminating will be tackled. In the fourth part, the test results of the applied system and its comparison with the normal LED system will be handled. In the fifth part, the results and findings will be presented.

2. PV system in the building, the LED illuminating system set on DC grid and the positioning of LED Lamps.

As the sunlight hits on PV cells, photo-voltage and photocurrent act like a forward diode on a large surface. The current expression emerging because of the sunlight hitting on the cell is given in equation 1.

$$I = I_{PH} - I_S \cdot \left\{ \exp\left[\frac{q}{A \cdot k_B \cdot T} (V + I \cdot R_L) \right] - 1 \right\} - \frac{(V + I \cdot R_S)}{R_{SH}} \quad (1)$$

In this expression, photo-current, saturation current, load resistance, series equivalent circuit resistance, parallel equivalent circuit resistance, terminal voltage, load current, diode ideality factor, Boltzman's constant and temperature of PV panel are denoted by I_{PH}, I_S, R_L, Rs, R_{SH}, V, I, A, k, and T respectively. The equivalent circuit diagram for a solar cell is displayed in Fig. 1.

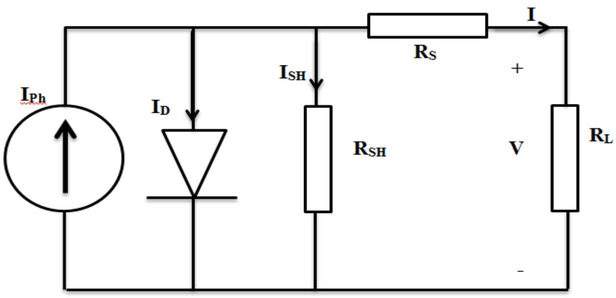

Fig. 1. Equivalent circuit diagram for solar cells

In the LED illuminating system there have been used 6 PV panels each one with 65 W. There are 2 serial connected PV panels on each hand of the 2 parallel connected panel group and it has been connected to charge regulator: 24 V DC has been obtained. The 2 parallel connected PV panel output has been given to PWM charge regulator and 12 V DC has been obtained. The PWM charge regulators' outputs have been serial connected and 36 V DC output has been obtained. Fig. 2 shows the connection of PV panels and Table 1 shows electrical parameters.

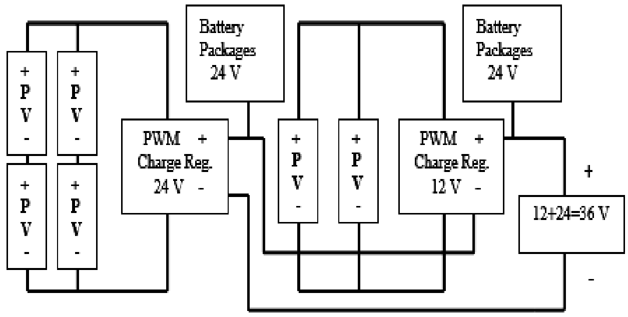

Fig.2. PV panels DC system composed of charge regulators

Table 1. Electrical parameters of PV panel

Module specifications	**Parameters**
Open-circuit voltage (Voc)	21.6 V
Short-circuit current (Isc)	4.2 A
Voltage at Pmax (Vmp)	17.24 V
Current at Pmax (Imp)	3.74 A

The voltage value obtained from PV system is 36 V DC. Each one of the LED panels used to illuminate indoors has a value of 36 W and the driver output of AC/DC LED 36 Volt. That is why, when the LED drivers are disconnected, the PV system output is 36 V and it is strong enough to foster illuminating system. The maximum power of the PV system and the maximum value to be taken from this system:

$$\sum P_{pv} = P_{pv}.\text{Sum of } PV_{panel} = 65.6 = 390\text{ W} \quad (2)$$

$$I_{max} = \frac{\sum P_{pv}}{U} = \frac{390}{36} = 10.83\text{A} \quad (3)$$

The efficacy factor of the LED panels used in illuminating systems is 88 lm/W, the maximum flow of light is 3200 luminous and the cancelled LED driver's output voltage is 36 volt. Each one of the LED panel's pulling current, the total current and power of illuminating system in conventional LED illuminating system is as follows:

$$I_{LED} = \frac{P_{LED}}{U_{LED}} = \frac{36}{36} = 1A \quad (4)$$

$$\sum I_{LED} = I_{LED}.\text{Sum of } LED_{panel} = 1.8 = 8\text{ A} \quad (5)$$

$$\sum P_{LED} = P_{LED}.\text{Sum of } LED_{panel} = 36.8 = 288\text{ W} \quad (6)$$

As grid voltage used in the buildings has the values of AC 220 V, 50 Hz; in the grid-connected illuminating systems AC/DC drivers are needed. The positioning of the 8 LED panels and LDR light sensor in the classroom ceiling is shown in Fig. 3 and the space to be illuminated is 9.6=54 m^2 The classroom has two windows of the length w=3.1 m. The distance between LED panels and the distance between the LEDs and the walls have the following values: 2a=6m, a=3 m, a/2=1.5m, 4b=9m, b=2.25 m, b/2=1.125 According to universally standard values, the illuminating value for the classroom ambient has been determined as 300 lux. [20]

In the applied PV-based illuminating system there exists the option of switching to the grid. The view of the system is given in Fig. 4 and the block chart is given in Fig. 5.

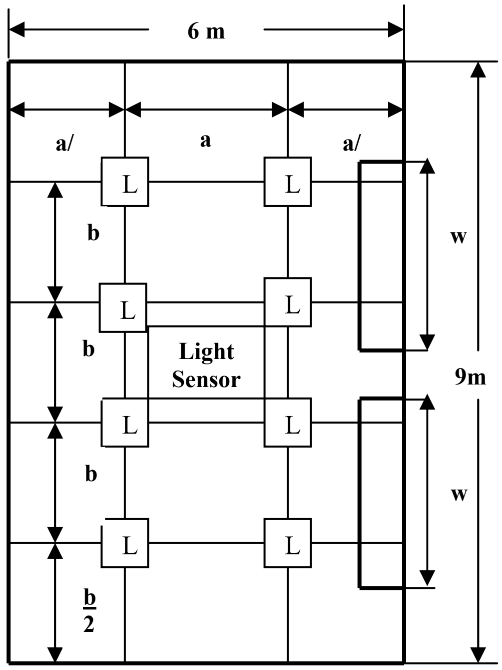

Fig. 3. Layout of LED panels and Light Sensor on Ceiling

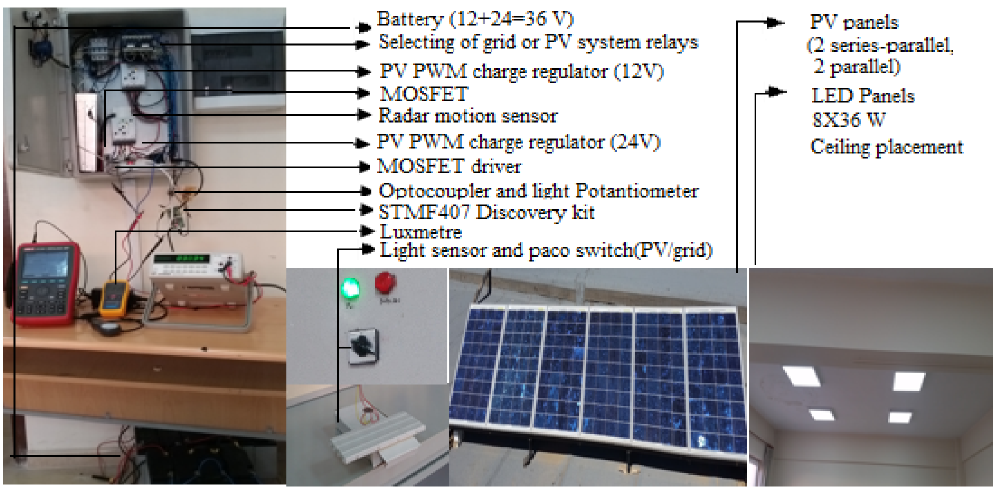

Fig. 4. PV-based smart LED illuminating system.

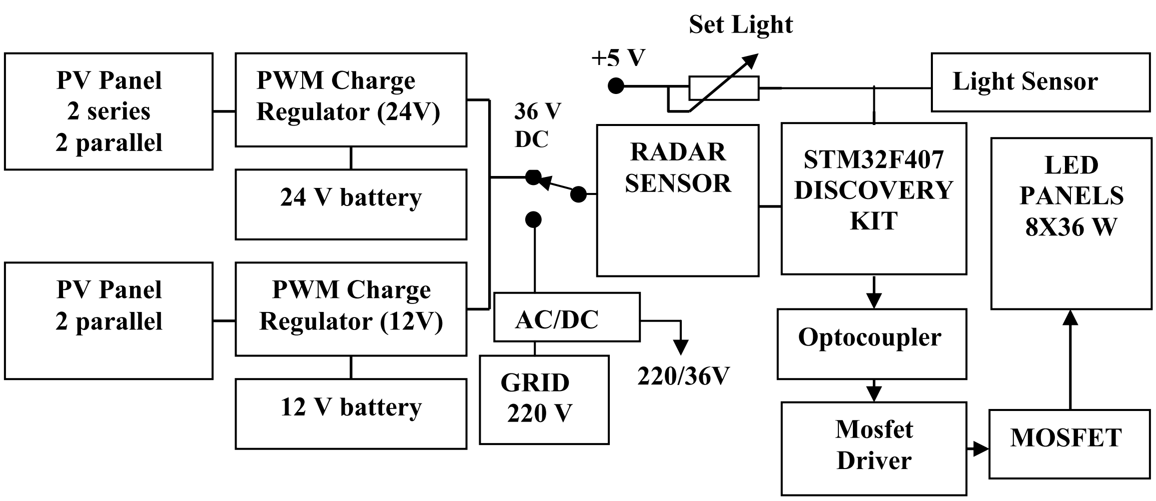

Fig. 5. PV-based smart LED illuminating system block chart

In the PV-based smart LED illuminating system (shown in Fig. 4 and 5) it has been adjusted in a way that, if there is no motion for a certain period of time the system is to turn itself off by the radar sensor. With the potentiometer connected to LDR, the ambient reference value can be picked; the maximum value of this for a classroom ambient is 350 lux while the minimum value is 250 lux. In this respect, the reference value has been determined as 300 lux. If the light information taken from the LDR sensor is below reference minimum limit, by the developed algorithm with the PWM technique the volume of the light is to be increased and if the light information is above the maximum reference limit, the light volume is to be decreased. The sensor light information has been given to STM32F407 discovery kit's analog input. The PWM control output, over optocoupler by adjusting the duty cycle of MOSFET, has brought the illumination level of LED panels to the desired level. The illumination value of the ambient has been measured by the lux meter. In the block structure seen in Figure 5, if there exists solar energy or there is enough of power in battery groups, the obtained DC, without requiring conversion into AC, would be in the position of meeting LED light energy. As shown in Figure 4, LDR light sensor has been placed 1 meter above the classroom floor on the working surface. The lux voltage information obtained from LDR sensor has been given to STM32F407 discovery kit's 32-bit analog input. The value obtained from here, in relation with the reference value by the algorithm, adjusts the MOSFET duty cycle.

3. Proposed smart control algorithm for energy saving in LED lighting system

In the proposed algorithm, Rs signifies 0 or 1 signal value in relation with the radar motion sensor's human motion in the ambient. In order for the microcontroller-connected algorithm to be active, a motion, namely, 1 is expected from this sensor. The active state of the sensor after the motion is perceived has been kept long. S_L signifies illumination reference value. This value has been determined as 300 lux for classroom atmosphere [20]. SL_{min} and SL_{max} signify the upper and lower limit of the reference illumination limit. According the opinions of the classroom residents, the lower value has been determined as 250 lux whereas the upper limit has been determined as 350 lux. L(x) signifies the ambient illumination value when the illumination system is disabled. ΔL signifies the difference between two measured illumination values. If ΔL value is between the lower and upper limit of desired illumination value, at the output of STM32F407 the PWM change is not applied and the illumination is kept at the minimum-maximum interval. If the ΔL value is not at the minimum-maximum interval, the measured L(x) value is compared with the desired SL illumination value. If the L(x) value is below SL, the illumination is increased, if it is above it, the illumination value is obtained by the way of decreasing the illumination. Flowchart of Proposed Algorithm is seen in Fig. 6.

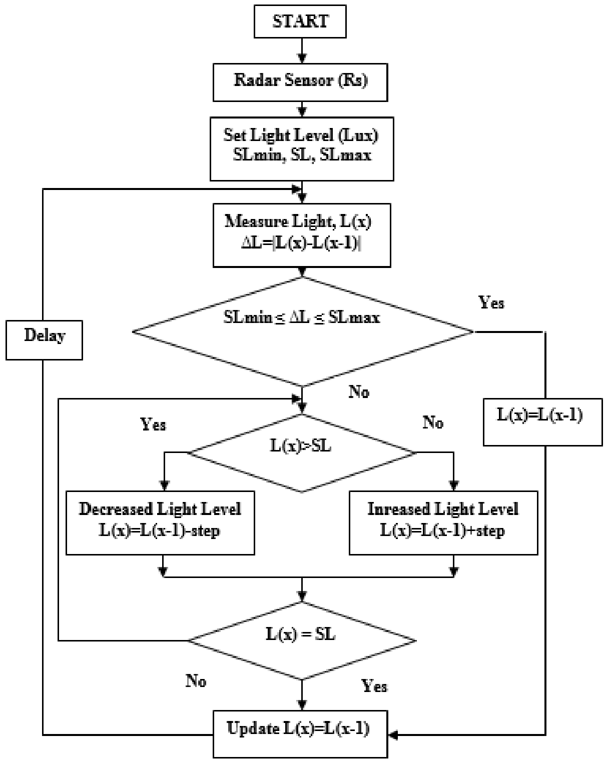

Fig. 6. Flowchart for Proposed Smart Control Algorithm

In the proposed algorithm, the illumination is tried to be kept at a certain value and in minimal changes the MOSFET duty cycle has not been adjusted. This way, the switching losses have been prevented. At the same time, the LED panel power has been adjusted to the desired illumination power, which prevented unnecessary power loss and thus brought about an efficient smart illuminating system. If the step value in the flowchart decreases then the tracking of the MOSFET for regulating PWM will be slower and the time to reach reference illumination value will be longer. If the step value increases then the tracking will be faster. However, a large step value will lead to over-shoot, the value of step is user definable input.

4. Comparison of conventional and proposed lighting system

The smart led lighting system in DC grid based on PV system has been implemented and the experiment results are discussed here. Several experiments were conducted on the developed smart LED lighting system powered by DC grid to understand performance under various ambient of classroom conditions.

The experimental setup used in this paper included a 6 PV panels, 2 PWM charge regulators, a microcontroller board (STM32F407), batteries, optocoupler 4N25, Light Dependent Resistor(LDR), IRFP 460 MOSFET, radar movement sensor, 8x36 W LED panels (6500 K, 3200 lm, 88 lm/W). Experimental setup is pictured in Figure 4.

Experimental setup is explained as follows: The rate of the duty cycle produced by the algorithm that is transmitted into STM32F407 board is taken from the PWM exit and this way power MOSFET is controlled, The illumination data is provided through LDR light sensor and voltage data depend on illumination is provided by between LDR and divider potentiometer resistors, The microcontroller (STM32F407) in discovery board controls the power MOSFET by generating a PWM signal that switches the power MOSFET at a 500 Hz frequency.

In the following experiment, three cases are considered and then to compare conventional and proposed lighting systems.

Case 1: The location of the application is Gaziantep city which is in the southeast of Turkey and it is 4.30 pm in March. The output of the PWM signal is %44.06 and about 500 Hz frequency. When both of the illuminating systems are disabled, the illumination level of the ambient is 105.1 lux. When the proposed smart lighting system is active, the illumination level of the ambient reaches 294 lux. While the smart lighting power value is 97.2 W, Conventional W value is 288 W and the difference is 288-97.2=190.8 W. The oscilloscope screen PWM signal of smart lighting system for case1 is given in Fig. 7**.**

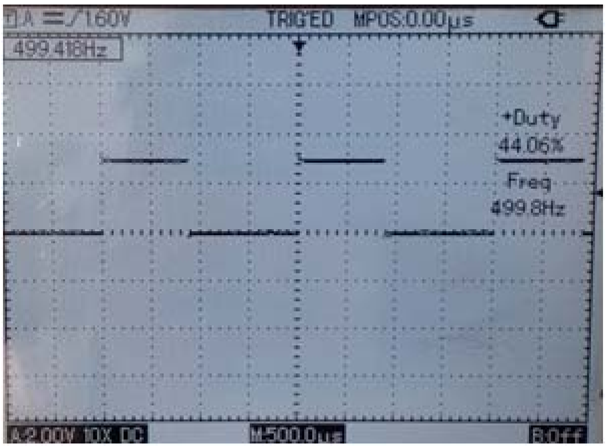

Fig.7. PWM signal of the smart lighting system Case 1

Case 2: It is 05.00 pm. The output of the PWM signal is 64.8% and about 500 Hz frequency. When both of the illuminating systems are disabled, the illumination level of the ambient is 66.2 lux. When the proposed lighting system is active, the illumination level of the ambient reaches 312 lux. While smart lighting power value is 141.8 W, Conventional W value is 288 W and the difference is 288-141.8=146.2 W. The oscilloscope screen PWM signal of smart lighting system for case 2 is given in Fig. 8**.**

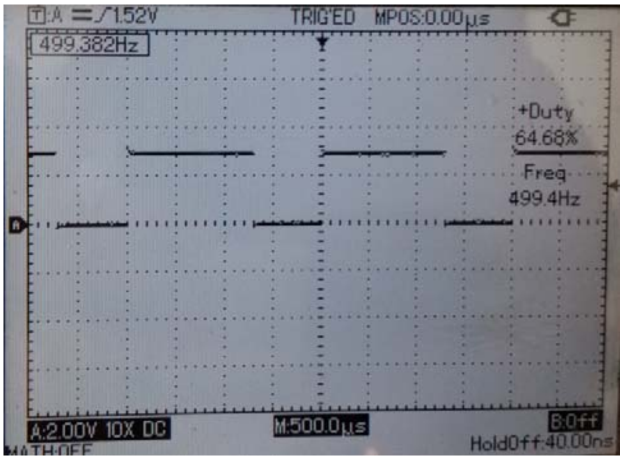

Fig.8. PWM signal of the smart lighting system Case 2

Case 3: It is 05.15 pm. The output of the PWM signal is 98.04% and about 500 Hz frequency. When both of the illuminating systems are disabled, the illumination level of the ambient is 34.8 lux. When the proposed lighting system is active, the illumination level of the ambient reaches 338 lux. While smart lighting power value is 158 W, Conventional power value is 288 W and the difference is 288-158=130 W. The oscilloscope screen PWM signal of smart lighting system for case 3 is given in Fig. 9.

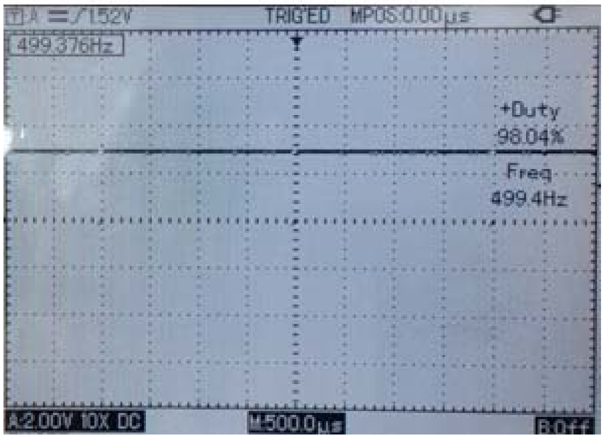

Fig. 9. PWM signal of the smart lighting system Case 3

All three cases above were applied when it got dark and there was need for artificial illumination. At the earlier hours of the day, artificial illumination was not needed as the classroom had windows. The artificial illumination was applied from 04.30 pm until 07.00 pm (the last hour before the classroom is closed). When all 3 cases are analyzed, it is seen that the proposed smart illuminating has been successful in capturing the desired reference values and when compared with the conventional system it is seen that the proposed system provides energy saving. In the proposed system, in line with the PWM changes, the LED panels' use of current change is shown in Fig. 10.

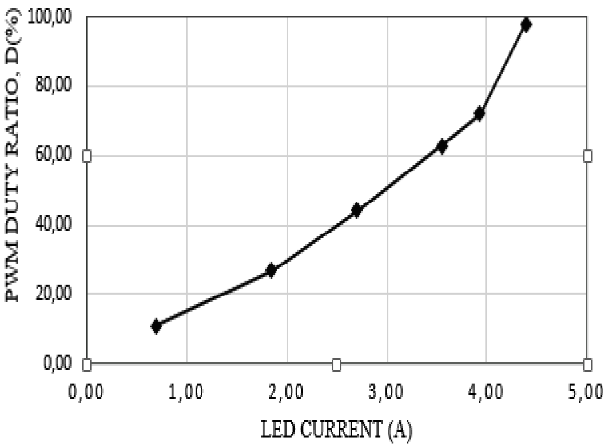

Fig.10. Measured LED panels current over the duty ratio of the PWM signals in proposed lighting system.

When Fig. 10 is analyzed, it is seen that the panels responded to dimmable range applied to LED panels and that current change increased in proportion with the PWM ratio. The limitation of the dimming range depends on reference voltage value which is varying with reference illumination value. If a band of PWM signal is narrow, the range of dimming LED panels is narrow too. If a band of PWM signal is increased, the range of dimming LED panels is increased as well. In conventional fluorescent lamps, the facility of adjusting PWM does not exist. At the same time, conventional LED illuminating systems function with fixed power. With the proposed system, LED panels are self-adapting dimmed and by bringing about an energy saving situation, it has increased the efficiency of the illumination systems. The comparison of the proposed system with that of conventional system is given in Table 2.

Table 2. The comparison of the proposed system with that of conventional system

Time	Ambient (Lux)	Smart Lighting (Lux)	LEDs Current (A)	Smart Lighting Power (W)	Conv. System Power (W)	ΔP (W)
16:30	105.1	294	2.7	97.2	288	190.8
16:45	68	352	3.58	128.8	288	159.2
17:00	66.2	312	3.93	141.8	288	146.2
17:15	34.8	338	4.39	158	288	130
17:30	7.6	317	4.35	156.6	288	131.4
17:45	4.1	315	4.33	155.8	288	132.2
18:00	0	300	4.25	153	288	135
18:15	0	300	4.25	153	288	135
18:30	0	300	4.25	153	288	135
18:45	0	300	4.25	153	288	135
19:00	0	300	4.25	153	288	135
Δmean				145.74	288	97.1

In Table 2, when the power change between Conventional LED illumination System and Proposed LED illumination system is compared, it is seen that the lowest value is 130 W and the highest value is 190.8 W. If we are to make an efficiency calculation according to Table 2:

$$\eta_{efficiency} = \frac{\Delta mean\_smart\_lighting\_power}{\Delta mean\_conventional\_lighting\_power} x100 = \frac{145.74}{288} x100 = \%50.6 \tag{7}$$

It is seen that the proposed LED lighting system is 50.6% more efficient than conventional system and that it works successfully at the universally determined ambient necessity illumination values.

5. Conclusion

In this study, the PV system set up on the building meets the energy need of DC grid LED panel structure whose illumination level has been controlled by proposed self-adapting algorithm based on the information taken from light sensor. The system is comprised of radar motion sensor, light sensor, PV system, and control card and battery elements. As it is known, DC grid LED illumination is more efficient than AC fluorescent illumination. When the Proposed DC smart LED illumination and normal DC LED illumination systems are compared, it is seen that the proposed system comes with 50.6% more efficiency. At the same time, the fact that the proposed system is Building Integrated Photovoltaic (BIPV)-based offers an environmentally friendly approach.

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