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Design and Implementation of Electronic Illumination Control System

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Abstract:

Power saving todays is the most important requirement, specially lighting where it consumes a sizable portion of total electric energy. Therefore, controlling the brightness of the light is necessary to save electrical energy. For achieving this, an electronic illumination control system is essential. This paper aims to design and implement a simple and low-cost illumination control system with high efficiency, based on some power semiconductor devices such as triode alternating current (TRIAC) and diode alternating current (DIAC). In this concern, the performance of the electronic illumination control system, as well, the electrical parameters (break over voltage, latching current, holding current, on-state voltage and off-state leakage current) of the proposed power devices were investigated, where it is proved that the achieved power saving of the present electronic illumination control system in the order of 27% was obtained- while retaining more than 90% of the original light intensity. Therefore, the proposed system can be applied to saving power in our daily lives.

Keywords: Power saving, illumination, triode alternating current, diode alternating current, firing angle and power factor.

1. Introduction

In many countries, electric energy consumption is currently a significant concern for both individual consumers and governmental agencies [1-4]. As a result, for saving electricity, a controlling light brightness is required. For many years ago, the light control circuit is constructed based on variable transformers and resistors, which have been applied in a variety of public settings. These techniques have some disadvantages; expensive, bulky and inefficient, as well, they are particularly challenging to use in distant places [5]. To overcome these disadvantages, the present paper is concerned with designing and implementing an electronic illumination control system based on triode alternating current (TRIAC) and diode alternating current (DIAC).TRIAC is used to control the output voltage and the power flow to the light

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source, in an efficient way by allowing only a part of the sine wave passing through the light source by changing the TRIAC firing angle (α) utilizing the variation in time constant (RC) by regulating either the variable resistor or capacitor of the TRIAC's gate firing circuit [6].

In this concern, the following electrical performance parameters of the control system could be evaluated using the following equations [7, 8]:

(i) The system output voltage could be calculated using Eq.1

$$V_{O\,(RMS)} = V_S \sqrt{\frac{1}{\pi}\left[(\pi - \alpha) + \frac{1}{2}(\mathrm{Sin}2\alpha)\right]} \qquad (1)$$

Where:

$V_{O\,(RMS)}$: RMS value of the output voltage

V_S : input voltage

α : TRIAC firing angle

(ii) The system power factor (PF) could be calculated using Eq.2

$$PF = \sqrt{\frac{1}{\pi}\left[(\pi - \alpha) + \frac{1}{2}(\mathrm{Sin}2\alpha)\right]} \qquad (2)$$

(iii) The percent of power consumption ratio (ρ%) of the system could be evaluated using Eq. (3):

$$\rho\% = \frac{P_{AFU}}{P_{BFU}} \times 100 \qquad (3)$$

$$\rho\% = \frac{100}{\pi}\left[\frac{1}{2}\mathrm{Sin}(2\alpha) - \alpha + \pi\right] \qquad (4)$$

Where:

P_{AFU} : power consumption after using the proposed system.

P_{BFU} : power consumption before using the system.

(iv) System power saving (P_{SAV}) could be found as:

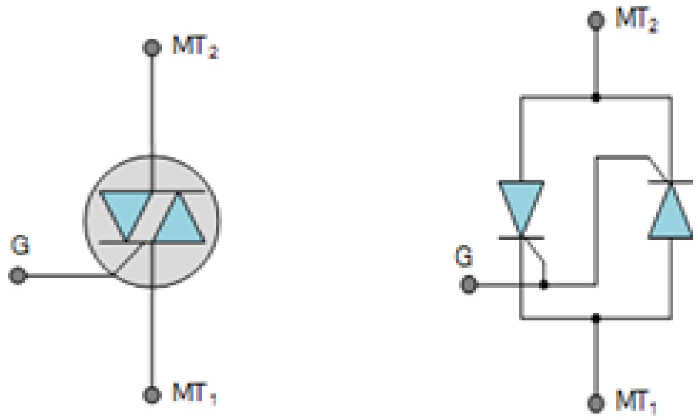
$$P_{SAV} = P_{BFU} - P_{AFU} \qquad (5)$$

(v) The percent of power saving (δ%) is defined as:

$$\delta\% = \frac{P_{BFU} - P_{AFU}}{P_{BFU}} \times 100 = 100 - \rho\% \qquad (6)$$

$$\delta\% = 100\{1 - \frac{1}{\pi}\left[\frac{1}{2}\mathrm{Sin}(2\alpha) - \alpha + \pi\right]\} \qquad (7)$$

Now concerning TRIAC, which is a semiconductor power device [9], it has four layers [10] with three-electrode terminals [main terminal 1 (MT_1), main terminal 2 (MT_2) and gate (G)] as presented in Fig. (1a). It is a bidirectional device that operates in both directions by applying positive or negative gate voltage between the gate and main terminal 1 (MT_1). It is mostly used in power control circuit for providing full wave controlling, because it consists of two silicon control rectifiers (SCRs) connected in anti-parallel [11] as shown in Fig. (1b).



(a) (b)

Fig. (1): TRIAC device: (a) electronic symbol, and (b) its equivalent circuit.

Consider the second power device DIAC, which is a two-junction bidirectional semiconductor device that is frequently employed in AC switches to aid in triggering of a TRIAC [12, 13]. It is designed to break down when the AC voltage across it exceeds a certain level; breakover voltage (V_{BO}), and passing current in either direction. Its electronic symbol is displayed in Fig. (2).

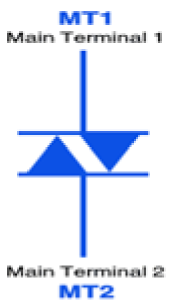
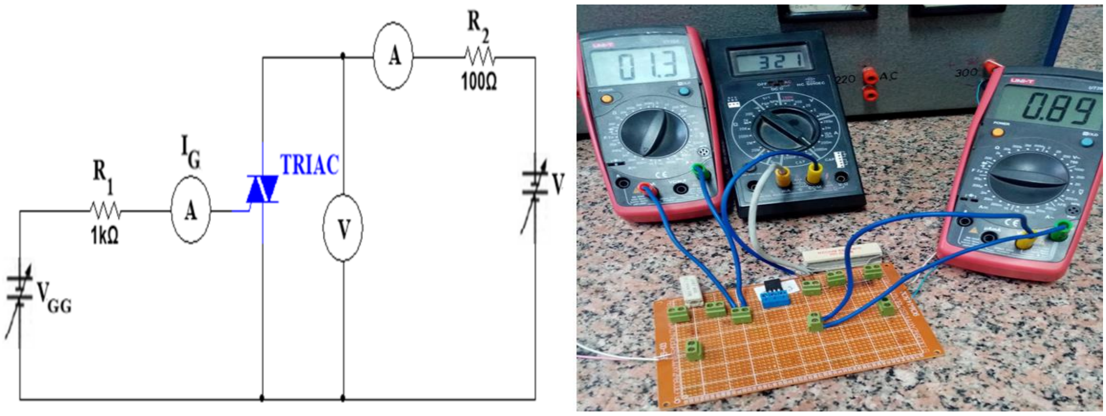


Fig. (2): Electronic symbol of DIAC

2. Experimental Work

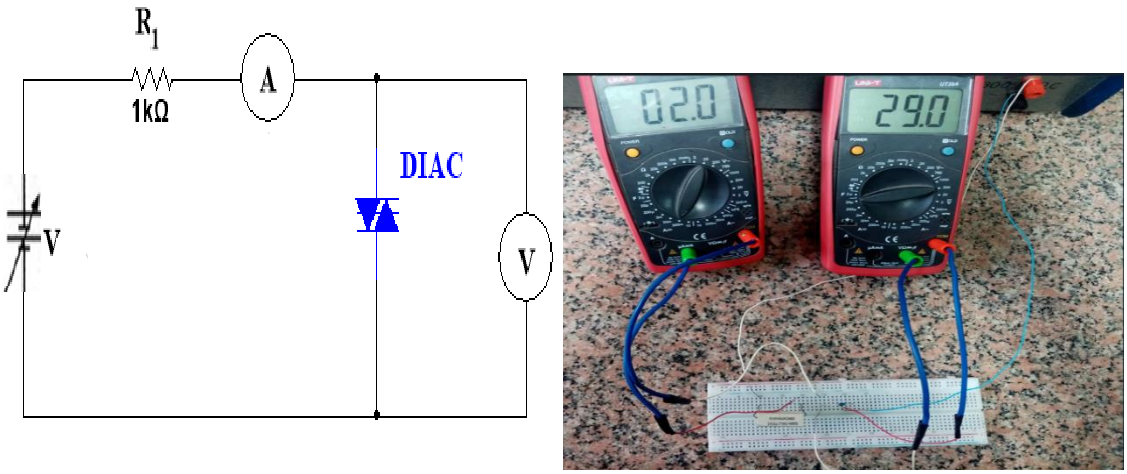
The constructed circuit for studying the static characteristic curves of TRIAC in normal operating conditions (room temperature) at different gate currents (I_G) applying forward and reverse bias is shown in Fig. (3a), while the practical implementation system is shown in Fig. (3b). The proposed circuit can accurately determine the device electrical parameters, i.e. gate triggering current / voltage (I_{GT}, V_{GT}), breakover voltage (V_{BO}) and latching current (I_L) as well, holding current (I_H), are investigated.



(a) (b)

Fig. (3): The characterization circuit of TRIAC (a) and its practical implementation (b)

Moreover, the static characteristic curve for DIAC is plotted at normal operating conditions (room temperature), applying forward and reverse bias using the circuit as shown in Fig. (4a), while the practical implementation system is shown in Fig. (4b). Where it is proved that the plotted electrical parameter (breakover voltage" (V_{BO})) is determined, and its value is shown to be in excellent agreement with that published for the investgated device.

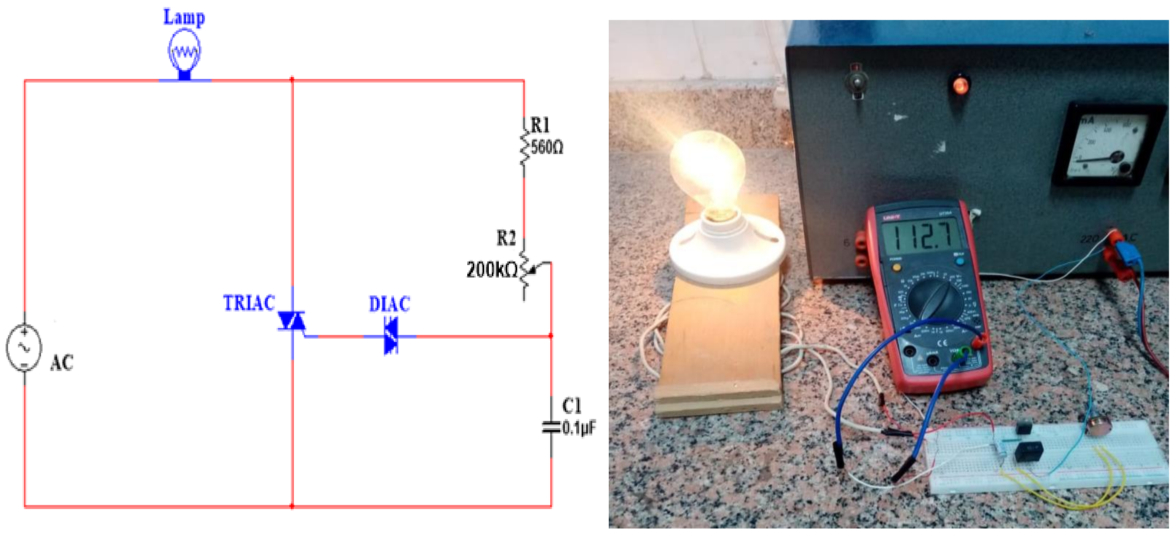


(a) (b)

Fig. (4): The characterization circuit of DIAC (a) and its practical implementation (b)

For controlling the intensity of the artificial light source, an electronic illumination control circuit (Fig. 5a) is designed and practically implemented (Fig. 5b) based on the power devices, TRIAC (type BT136) and DIAC (type DB3). As AC power supply voltage increases at the starting of each half-cycle, the capacitor (C_1) begins charging through the series combination of the fixed resistor (R_1- limiting resistor) and the rheostat (R_2- control resistor), until reaching DIAC's break over voltage (V_{BO}), the capacitor discharges through DIAC making it “ON”. Thus, producing a sudden pulse of current (I_{GT}) that triggers (fires) TRIAC into its conduction mode, TRIAC firing angle (α) at which it is triggered can be varied using R_2, which controls the charging rate of C_1. Limiting resistor (R_1) limits the gate current to a safe value when R_2 is at its minimum.

At the end of the half-cycle the supply voltage falls to zero, reducing the current through the TRIAC below its I_H turning it “OFF” and the DIAC stops conduction. The supply voltage then enters its next half-cycle, the capacitor voltage again begins to rise and the cycle of firing the TRIAC repeats over again [14-16]. In this concern, regulated dc-power supply, model PW36-1, DC/AC power supply, digital multimeter (model UT39A), programmable automatic LCR meter type PM-6306 (manufactured by Fluke) and digitizing oscilloscope model TDS2024C (manufactured by Tektronix) were applied for precise measurements [17-19].



(a) (b)

Fig. (5): Schematic illustration showing proposed electronic illumination control circuit (a) and its practical implementation (b)

3. Results and Discussions

3.1. Static Characteristics Curve of TRIAC

Static characteristic curves (I-V) of TRIAC (BT136) are investigated and plotted (Fig. 6) at different gate current values (I_G), ranging from 1.2 up to 1.5 mA in the forward bias, whereas in the reverse bias are ranging from 1.7 up to 3 mA. Where, it is well known that forward bias mode requires low gate current, while reverse bias mode requires more gate current. Fig. (7) shows that V_{BO} decreses by increasing I_G values [20]. Finally, Table (1) illustrates the obtained electrical prameters of TRIAC.

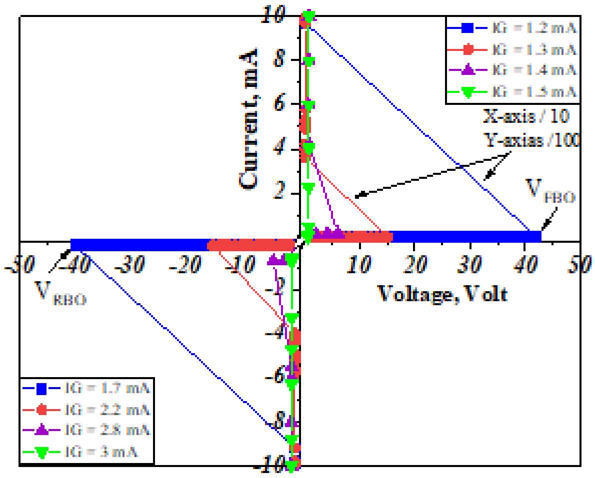


Fig. (6): Static characteristic curves of TRIAC (BT136)

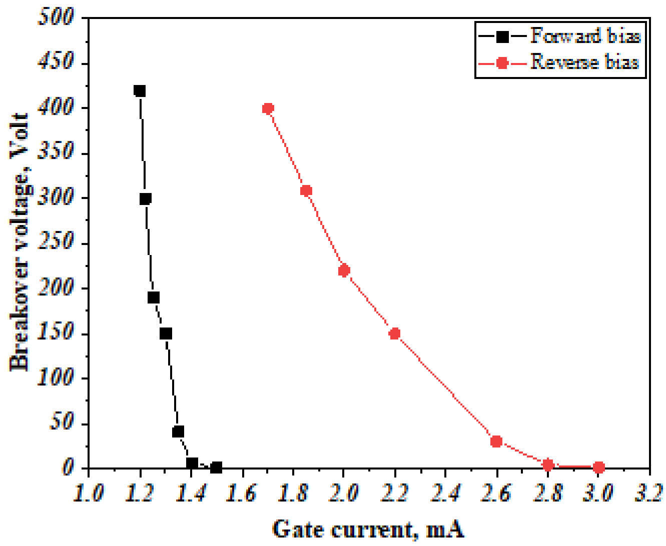


Fig. (7): Dependance of TRIAC break over voltage on its gate current

Table (1): Electrical parameters of TRIAC type BT136

Parameter	Experimental
Latching current (I_L), mA	1.6
Holding current (I_H), mA	1.1
On-state voltage (V_T), Volt	0.91
Off-state leakage current (I_D, I_R), mA	0.1

3.2. Static Characteristics Curve of DIAC

The static characteristic curves (V-I) of DIAC (DB3) are carried out (Fig.8), using the circuit as shown in Fig. (4). When a voltage across the DIAC less than its breakover voltage (V_{BO} = 32 Volt) is supplied in either polarity, only a small leakage current normally flows and the device maintains in its OFF-state. As the voltage increases up to a value exceeds V_{BO}, the current suddenly increases while the voltage across the DIAC decreases and the device will fire and will conduct from the OFF-state into the ON-state [20, 21].

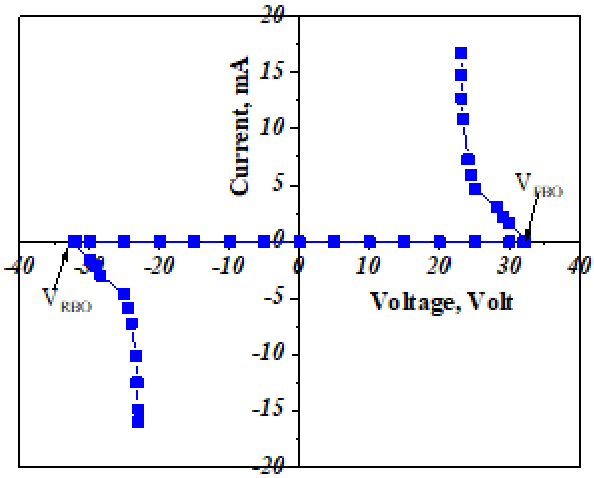
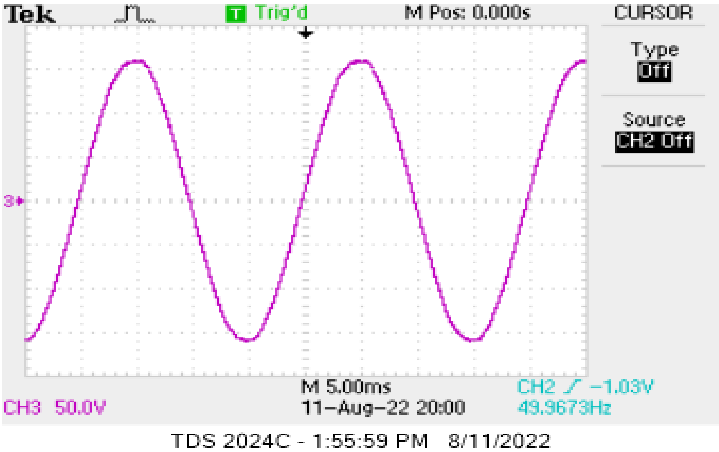


Fig. (8): Static characteristic curves of DIAC (DB3)

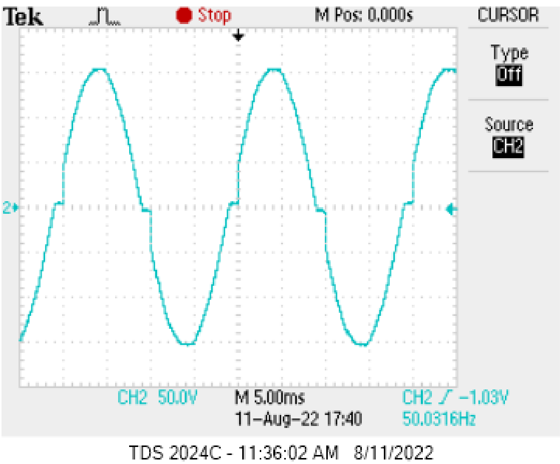
3.3. Illumination Control System

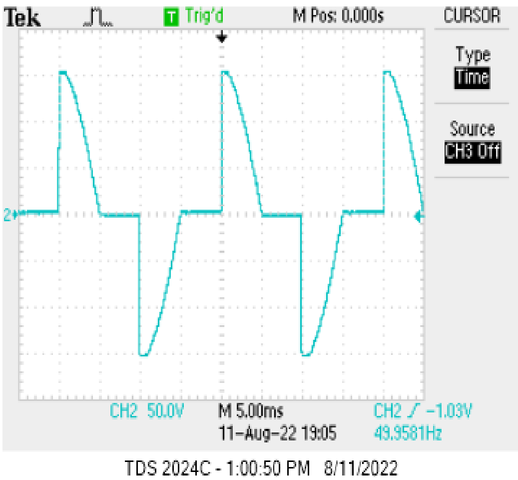
Figure (9) shows the input / output voltage waveforms of the electronic control illumination system, plotted at different firing angles (α = 18°, 90°, 147.6° and 180°).

Changing R_2 values (ranging from 1.0 up to 200 kΩ) while keeping C_1 at constant value (0.1 μF). From which, at RC time constant value of 0.1 ms, the capacitor voltage will approach the breakover voltage within around 1.0 ms, resulting in minimum firing angle of 18° , leading to the changes shown in the output signal (Fig. 9b). On the other hand, for the case of RC time constant value of 19 ms, the capacitor voltage approaches the breakover voltage within 8.2 ms, resulting in the signal shown in Fig. (9d). At that moment, the firing angle will be maximum (147.6^{o}). Finally, for time constant values above (19 ms), the signal is completely diminished (Fig. 9e) due to the fact that the capacitor will never reach DIAC breakover voltage [22, 23].

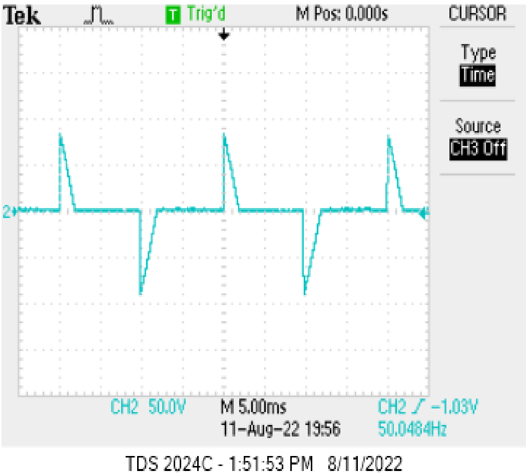


(a)

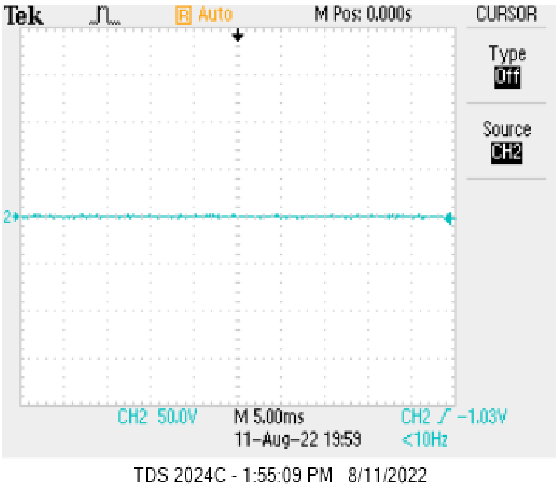




(b) α=18^{O} at R_2 = 1.0 kΩ (c) α=90^{O} at R_2 = 110 kΩ



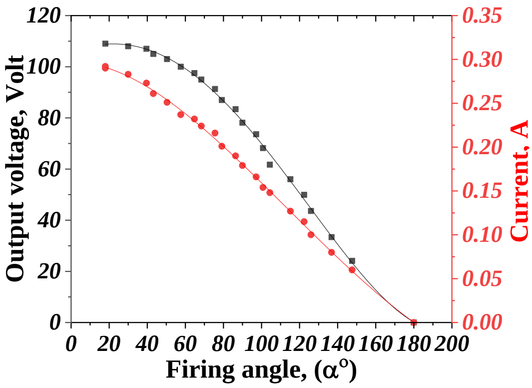
(d) α=147.6^{O} at R_2 = 190 kΩ



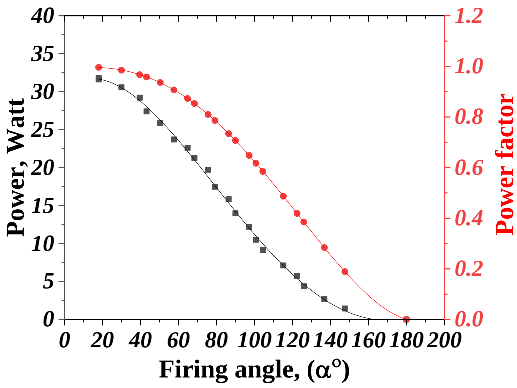
(e) α=180^{O} at R_2 = 200 kΩ

Fig. (9): Input (a) / output voltage waveforms (from b to e) of electronic control illumination system, plotted at different firing angles.

Figure (10) shows the dependence of voltage, current , power and power factor of the system output on firing angle. For the four paramaters, their values are shown to be a function of the firing angle values [23].



(a)



(b)

Fig. (10): Dependence of (a) voltage and current , (b) power and power factor of system output on firing angle.

Figure (11) presents the effect of firing angle on the intensity of illumination, percent of power consumption (ρ%) and power saving ratio (δ %). It can be seen from the figure that, at α equals 18°, the light intensity is maximum (331 Lux), resulting in ρ% = 99.35%, and thus there is approximately not any saving power (δ %= 0.65%). While, increasing the value of α up to 68.4°, the power consumption ratio is decreased down to 73% while the power saving increases up to 27%, keeping the light intensity almost in its maximum value. It's clear that, the power saving will significantly increase by increasing in firing angle while the light intensity and percent of power consumption ratio decreases [8, 24]. Finally, Fig. (12) shows the dependence of the power saving percentage ratio on the controlling resistance (R_2), plotted at different C_1. From which, it can be shows that at low value of C_1 (60 nF), less than the used value (0.1 μF) in the proposed system, the value of power saving is less than that was obtained. While at the high value of C_1 (0.2 μF) above the value used, the value of power saving is almost equal to that was obtained in the proposed system.

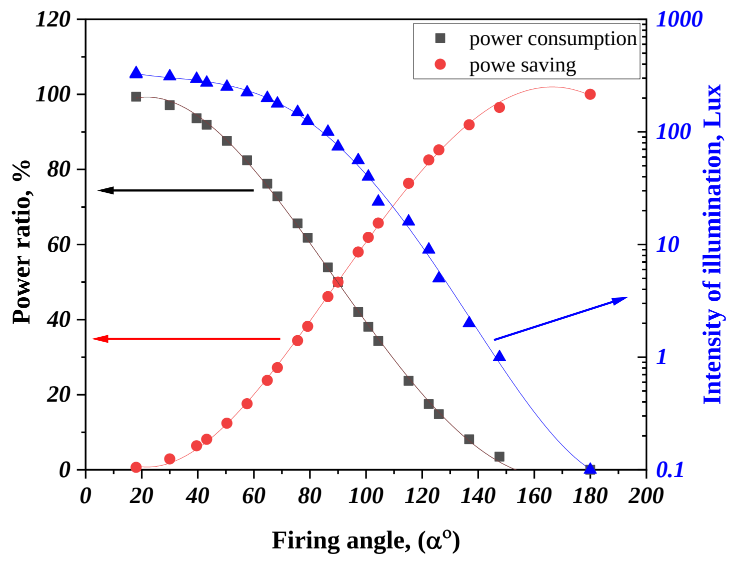


Fig. (11): Effect of firing angle on the intensity of illumination, percent of power consumption and power saving ratio.

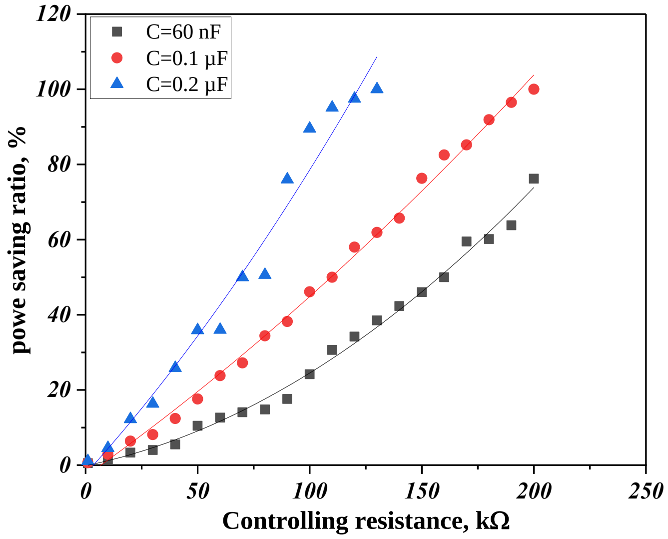


Fig. (12): Dependence of the power saving percentage ratio on the controlling resistance (R_2), plotted at different C_1.

4. Conclusion

In this work, an electronic illumination control system was used to regulate and manage light intensity. Based on the obtained results, it could be concluded that the proposed electronic illumination control system is very simple, accurate, low cost and saving a lot of the electric energy (about 27%) – while keeping the illumination intensity at levels more than 90% of its initial level. The obtained results lead to spread applications in a variety of public settings, including houses, conference rooms, restaurants, and theatres with stage lighting. The proposed system has the ability of working with all AC electric sources.

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الملخص العربى

تصميم وتنفيذ نظام التحكم الالكتروني في الإضاءة

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في الوقت الحاضر، يمثل استهلاك الطاقة الكهربية مصدر قلق لكل من المستهلكين سواء الافراد والهيئات الحكومية وغير الحكومية في القطاع الخاص - في العديد من البلدان، خاصه الإضاءة لأنها تستهلك جزء كبيرا من إجمالي الطاقة الكهربية. لذلك يعد التحكم في سطوع الضوء امرا ضروريا لتوفير الطاقة الكهربية. لذلك يهدُف هذا البحث إلى تصميم وتنفيذ نظام تحكم في الإضاءة بسيط ومنخفض التكلفة يعمل بكفاءة عالية، يعتمد على بعض نبائط اشباه المواصلات وهي الترياك والدياك، ومن ثم تم فحص أداء نظام تحكم في الإضاءة، وكذلك تم دراسة الخصائص الكهربائية للنبائط المقترحة فى تركيب النظام. وقد اثبت النظام المقترح نجاحا كبيرا، وأظهرت النتائج انه باستخدام النظام المقترح يمكن توفير نسبه 27% من الطاقة - مع الاحتفاظ بما يتعدى أكثر من 90 % شدة الاضاءة الاصليه. لذلك، يمكن تطبيق النظام المقترح لتوفير الطاقة في حياتنا اليومية.