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نظام إنارة مكتبي ذو تحكم ذاتي و مجدي في استهلاك الطاقة

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الملخص:

من دون شك أن لأشعة الشمس مساهمة غير مهملة في تحديد كمية وشدة الضوء داخل المكاتب الإدارية. فمن هذا المنطلق قام الباحثون باستخدام مستوى شدة ضوء الشمس المحيط بالمكتب للتحكم في مستوى إنارة المكتب.

تتبلور فكرة التحكم في تحقيق الاستراتيجية التالية: حين تزداد شدة أشعة الشمس المحيط بالمكتب ينبغي تخفيف استهلاك الطاقة الكهربائية، وحين تنخفض شدة أشعة الشمس المحيطة بالمكتب ينبغي رفع استهلاك الطاقة الكهربائية. وبغية تحقيق الاستراتيجية السابقة قام الباحثون باقتراح ثلاث حلول تحكمية عملية: حلان تحكميان طبقا عمليًا باستخدام برنامج حاسوبي معروف باسم (LABVIEW)، بينما طبق حل ثالث بانجاز أو تركيب دائرة كهربائية اعتمد في بنائها على عناصر الكترونية متفرقة. تتميز الحلول التحكمية الثلاثة بميزة التحكم الذاتي.

تمخض عن تطبيق الحلول التحكمية بأحد مكاتب جامعة البحرين في توفير 5.40% من الفاتورة الكهربائية مع ثبات مستوى الانارة داخل المكتب.

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A self-controlled energy efficient office lighting system

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Abstract The fact that ambient sunlight can add significant contribution to the lighting level of an office, has motivated the authors into using the level of sunlight to control the demand of the electric lighting in an office. The control strategy is such that the level of the surrounding light increases the supply voltage, hence electric power consumption, to the electric lighting system is reduced. Similarly, when the surrounding sunlight decreases the supply voltage, the electric power consumption, to the electric lighting system is increased. The objective is to save the overall electric energy used for office lighting. Three controllers have been proposed to fulfill the previous control strategy. Two controllers were implemented and tested using LABVIEW. A third controller designed and constructed using discrete electronic components. All three controllers were self-regulated. The implementation of the control strategy in a university office showed that a 5.40% saving in the electricity bill was achieved whilst maintaining an almost constant lighting level.

1. Introduction

Most of the offices worldwide have shifted from using incandescent bulbs to fluorescent lamps. The primary reason behind such a shift is that fluorescent lamps are more energy-efficient. As a matter of fact, standard incandescent bulbs use three to four times more electricity than fluorescent lamps (Chugach Electric Association, 2011). Moreover, fluorescent lamps last up to six times longer than incandescent lamps. In spite of the tremendous cut in the energy requirement by the fluorescent lamps those days, research had not stopped from looking further in saving more energy. One alternative of the saving is the development of compact fluorescent lamps (CFLs). CFLs own several advantages (Greenfeet, LLC, copyright 1999–2008) when compared to their counterpart lamps: classic fluorescent lamps as well as incandescent lamps.

The present contribution treats office lighting electric energy saving from another perspective. Such a perspective is documented as follows: It is well recognized that when an employee enters his/her office, the first thing that he/she will do is to switch-on the light and let it shining fully during the whole working hours period. A careful glance at the working hours period, can easily make one notice that there is an additional free source of energy that can be considered as a second contributor to the overall office lighting. This second contributor consists of the surrounding natural sunlight (i.e., sunlight or day light). The sunlight intensity is probably low at the earliest hours of the working-hours period but starts increasing as time passes. It reaches a maximum point around noon time. In the afternoon, the natural sunlight starts decreasing. This increase and decrease behaviors of the sunlight are actually

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dependent on the location of the office towards the sun position.

This paper uses the variation of the surrounding sunlight in saving some electric energy needed by the lighting system of an office during working-hours periods.

2. Problem motivation and rationale

In order to evaluate the contribution of the surrounding sunlight to the overall light of an office, a small experiment was held in a university office. The office light is provided by 6 pairs of florescent lamps. Each florescent is rated 36 W. The experiment consisted of recording the effects that may occur on any light sensor device during the office working hours. In this investigation, the office working hours were pretended to be between 08:00 and 16:00. A light dependent resistance (LDR) was considered to be the light sensor device. It is worth mentioning that the LDR presents large resistance value at low levels of light (i.e., dark environment) and small resistance value at high levels of light (i.e., shining environment) (Radio Spares (RS) Components, 1997).

Four LDRs are connected to four potentiometers as shown in Fig. 1. The LDRs are located in four different places in the office. This was done in purpose to find out which LDR was the most sensitive to the light. The most sensitive LDR will be taken as a reference signal in the controllers that will be discussed later. The DC voltage supply was fixed at a 12 V. Each potentiometer of the four legs of Fig. 1 was adjusted so that its resistance was close to the corresponding LDR resistance value at 08:00 on the day of the experiment. It is expected that the voltage across the potentiometer to be near 6 V at 08:00. It is worth stating that once each potentiometer resistance is set at 08:00, it is left unaltered during the day of experiment. The voltage across the four potentiometers terminals were recorded during the time from 08:00 to 16:00 h on December 17, 2008. The day of December 17, 2008 was a clear and bright day in the kingdom of Bahrain. Measurements were taken using LABVIEW software facilities and PCI-6221 as a data acquisition card (National Instruments, 2008). Voltage measurements across the four potentiometers were recorded every second as depicted in Fig. 2.

After a glance at the obtained patterns of the measurements, the next remarks can be noted:

- All voltage drops across the four potentiometers have been set to be near 6 V at the start-up of the measurements (i.e., at 08:00).
- LDR1 and LDR2 indicate that the surrounding sunlight peaks up around 10:00.
- LDR4 measurements indicate that the surrounding light exhibits a maximum contribution at the sensor position around 13:30. This can be justified by the fact that the LDR4 will face the sun in the afternoon rather than the morning. This was not the case for LDR1 and LDR2.
- The contribution of the surrounding light is manifested by 4 V voltage drop between 10:00 and 16:00 for LDR1 and LDR2. The last two LDRs seem to be more sensitive than LDR4 and LDR3.

The main observation that can be deduced from the measurements is that any anticipated occupant of this office will witness more light in the morning and less light in the afternoon but what is interesting is that the office occupant(s) will feel comfort in both sessions. Therefore, it might be a good idea to reduce the main electric supply partially in the morning session and use it fully in the afternoon session.

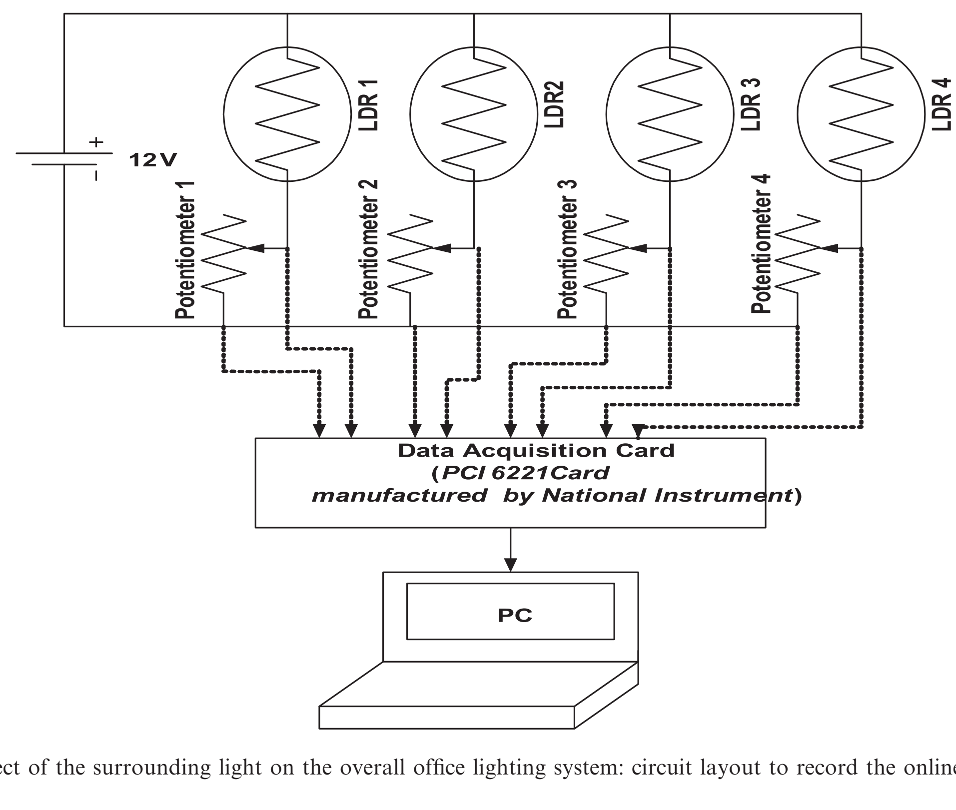

Figure 1 Effect of the surrounding light on the overall office lighting system: circuit layout to record the online sunlight effects.

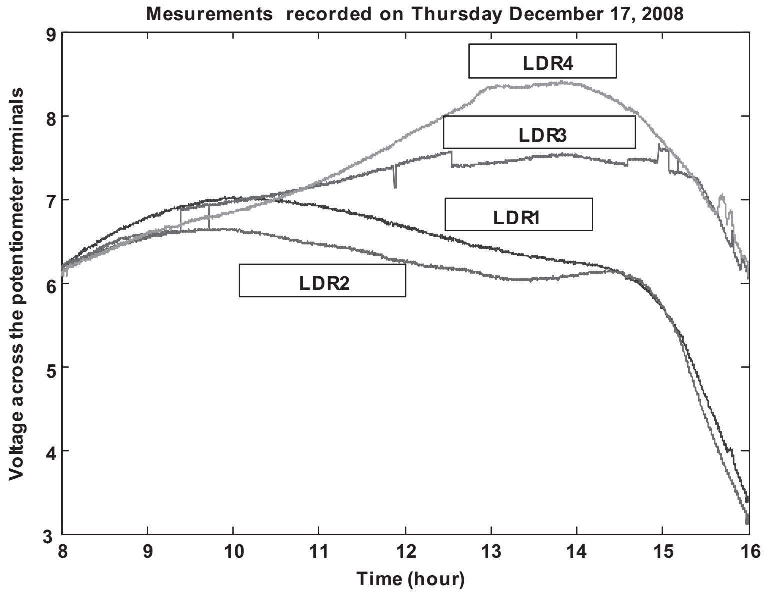

Figure 2 Effect of the surrounding light on the overall light in the office under test.

3. Control strategy

The transition from full use to partial use of the main electric supply is possible through the application of power electronics circuitry. This is possible through the implementation of the circuit of Fig. 3. Fig. 3 represents actually the schematic diagram of an AC converter. The theory and analysis of an AC converter using a triac are documented in several power electronics textbooks (e.g., Mohan et al., 2003). Three firing angle controllers are suggested to control the operation of the triac of Fig. 3.

3.1. Firing angle controller

This controller serves at monitoring the instant of firing the gate triac with a periodic train of pulses. The controller is designed in such a way that the firing angle can be adjusted between 0° and 90° and between 180° and 270° during the positive and negative cycles of the main voltage supply, respectively. This is possible through designing a block diagram similar to the one shown in Fig. 4a. Fig. 4a can be split into two parts: an upper part and a lower part. The upper part guarantees a train of pulses to triac gate when the mathematical product of the main supply voltage signal with its derivative is negative. This is possible between 90° and 180° and between 270° and 360°, respectively. Note that 0° corresponds to the zero-crossing point of the main voltage supply. The lower part provides a train of pulses when the absolute value of the main supply voltage is greater than a certain level. The latter level is actually the output of a limited integrator. The integrator is positive and it is adjusted online during the working office hours period. That depends on the input sign to the integrator.

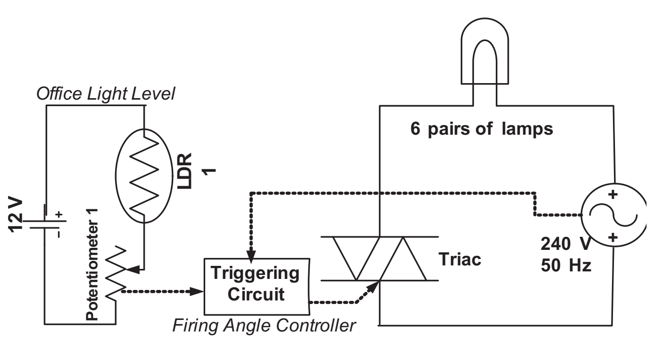

Figure 3 Controllable AC converter.

The input to the integrator is a constant. It can be positive, or negative or zero. It is positive when the overall office lighting is above an upper limit level, negative when the overall office lighting is below a lower limit level, and zero when the office lighting is between the two upper and lower limits. The upper limit and the lower limit levels correspond to $V_{\text{reference}} + \Delta V$ and $V_{\text{reference}} - \Delta V$, respectively. In this paper, $V_{\text{reference}}$ and ΔV were taken as 6 V and 0.2 V, respectively. When the voltage across the potentiometer terminals ($V_{\text{potentiometer}}$) of the left sensor exceeds $V_{\text{reference}} + \Delta V$ (i.e., 6.2 V) the integrator output level increases and consequently the generation of firing pulses to the triac gate will be delayed. Delaying firing pulses generation will lower the office light level. Similarly, when the measured voltage across the potentiometer terminals of the left sensor is below $V_{\text{reference}} - \Delta V$ (i.e., 5.8 V), the integrator output level decreases and consequently an early generation of firing pulses to the triac gate is noted. Early generation of firing pulses results in an increase in the office lighting level.

Fig. 4b depicts the different waveforms that can be expected at the output of the different blocks of Fig. 4a. In Fig. 4b, it is assumed that the office lighting level is above an upper limit (i.e., 6.2 V) and the firing angle needs to be increased. The firing angle keeps increasing automatically until the office lighting falls below a preset upper limit.

It is worth mentioning that the proposed firing angle controller provides a zero firing angle at minimum office overall lighting level and 90° at maximum office overall lighting level.

The firing angle controller of Fig. 4a has been translated to a LABVIEW code. The developed LABVIEW code is used to

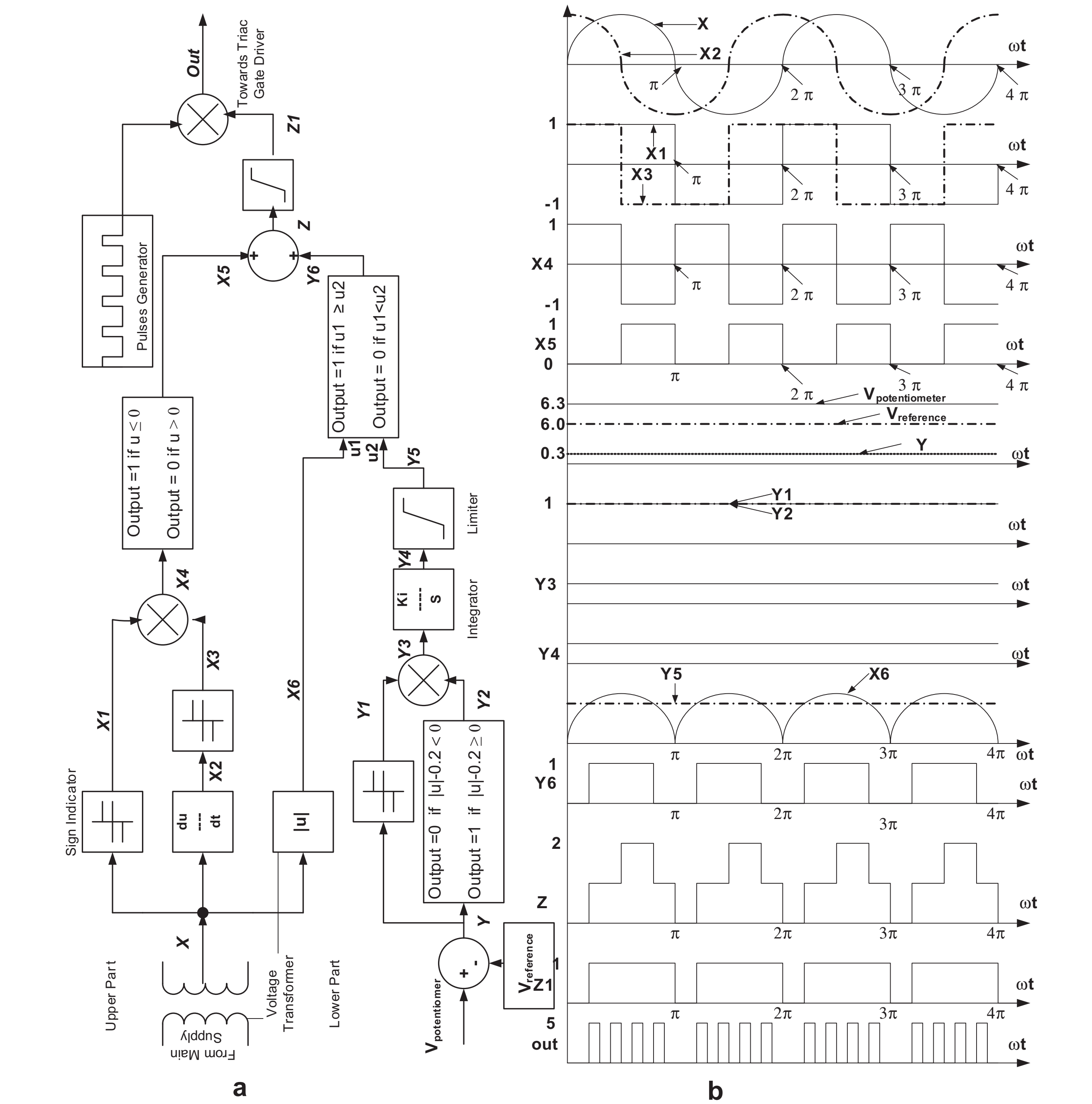

Figure 4 Firing angle controller: (a) control block diagram, (b) expected waveforms at different stages of the control block diagram.

control the triac of the power circuit of Fig. 3 through an insulating gate driver shown in Fig. 5.

3.2. Integral cycle controller

The idea of this controller it to force the triac of the power circuit to conduct fully during certain cycles and to be off (i.e., non-conducting) during other cycles. The ratio of the number of cycles corresponding to the conducting mode of the triac to the total number of cycles (i.e., such total number of cycles = cycles corresponding to the conducting mode + number of cycles corresponding to the non-conducting mode) defines the duty cycle of a certain pulse that can be generated from the upper part of the block diagram shown in Fig. 6a.

The value level of the duty cycle is decided or controlled by the lower part of Fig. 6a. The duty cycle level keeps increasing as long as the office overall lighting is greater than a certain pre-set upper limit (i.e., 6.2 V). If the duty cycle reaches 100% level, the triac will be completely off. Similarly, when the office lighting is below a certain pre-set level the duty cycle starts decreasing and the triac is offered with more cycles to conduct. If the duty cycle reaches 0% level, the triac will be conducting fully in each cycle. Under such situation, the main supply is contributing fully to the overall office lighting. When

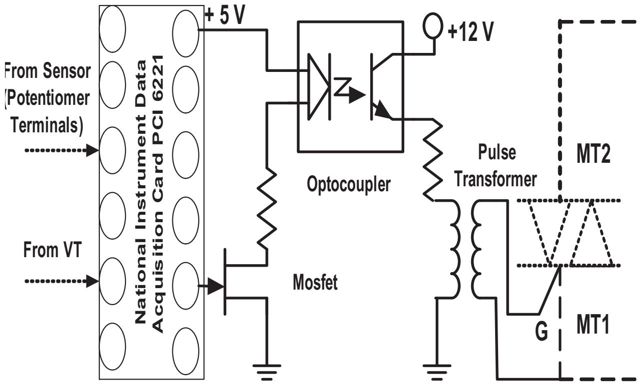

Figure 5 Insulating firing angle controller from power circuit.

the duty cycle reaches 100% value, no firing pulses will be provided to the triac gate and consequently no contribution is marked from the main electric outlet.

To predict the performance of the integral cycle controller of Fig. 6a and b visualizes the expected waveforms that can be generated at the output of the different blocks of Fig. 6a.

The waveforms are drawn by pretending a 25% value for the duty cycle for a generated periodic pulse of frequency 2.5 Hz. The last waveform of Fig. 6b can be interpreted by the fact that the triac of Fig. 3 will be off for 0.1 s (i.e., 0.1 s corresponds to 5 cycles of the 50 Hz main supply) and conducting for the following 0.3 s (i.e., 0.3 s corresponds to 15 cycles of the 50 Hz main supply). The integral cycle controller of Fig. 6a has been also written in another LABVIEW code. Such LABVIEW code is insulated from the power circuit through the hardware of Fig. 5.

3.3. Conduction period controller

The intended task from this controller is to provide conducting and non-conducting portions for the triac during each half cycle of the main supply. Fig. 7 suggests a practical circuit that can provide such intended task. The task is made possible

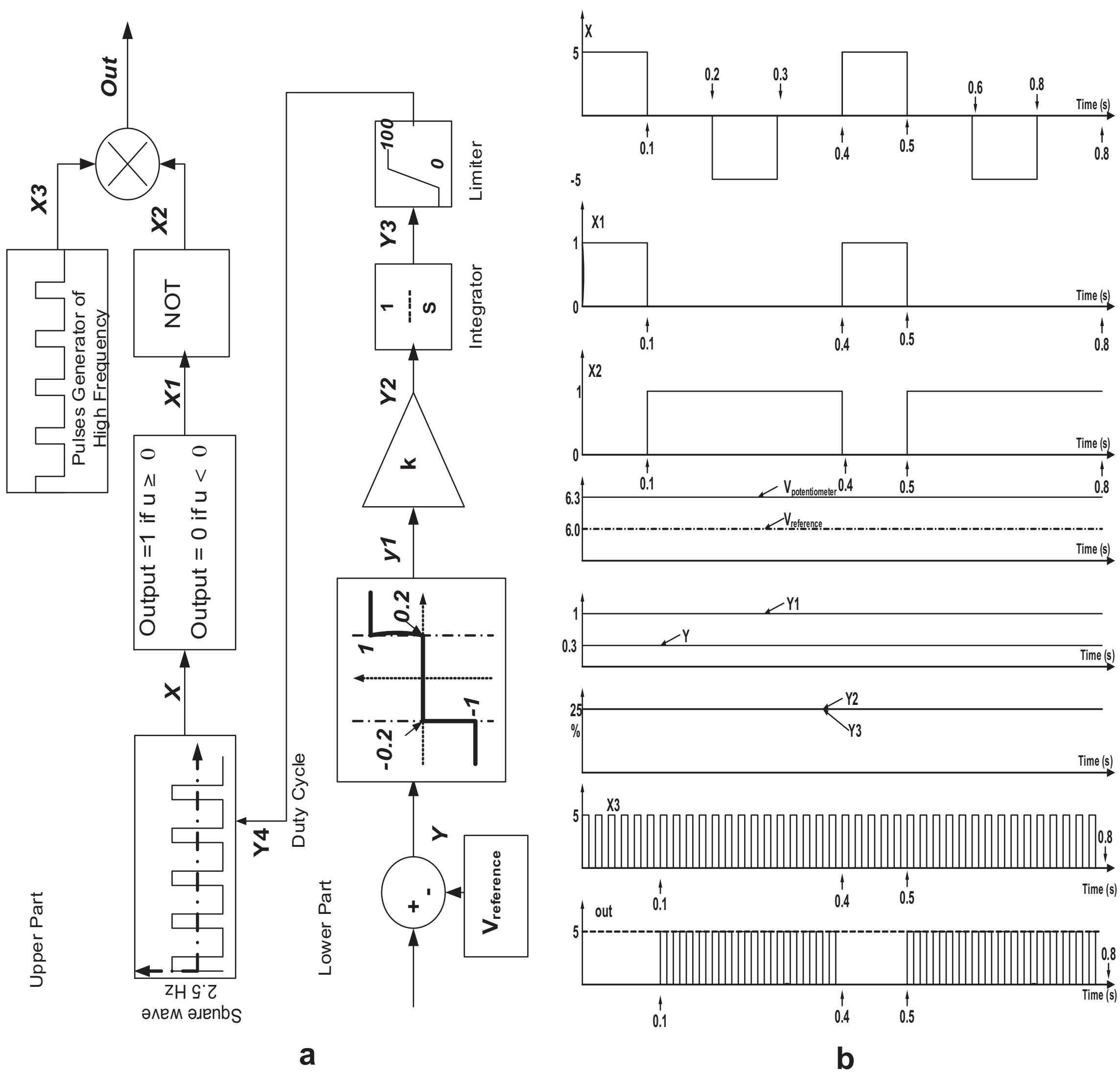

Figure 6 Integral cycle controller: (a) control block diagram, (b) expected waveforms at different stages of the control block diagram.

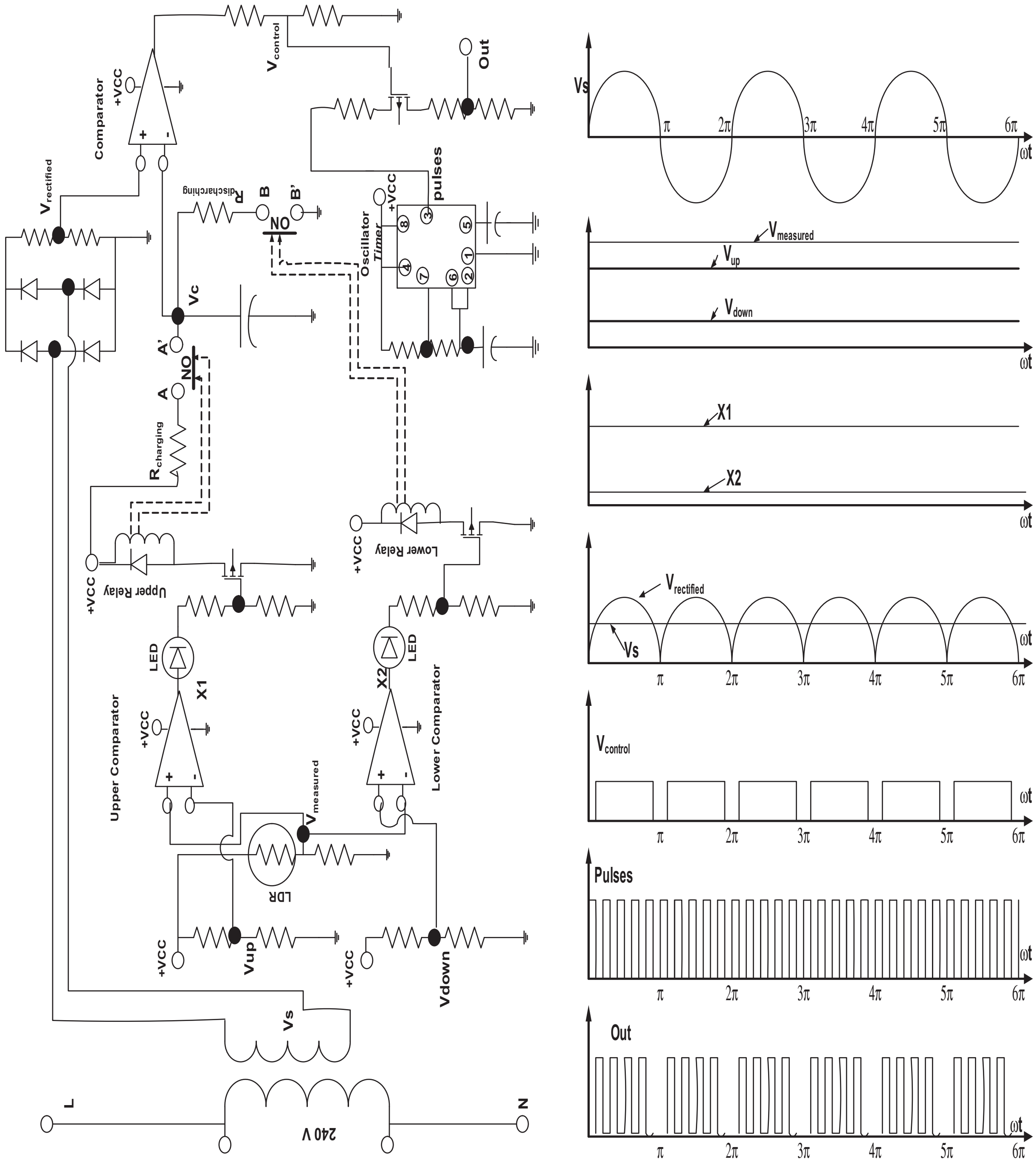

Figure 7 Conduction period controller: (a) control block diagram, (b) expected waveforms at different stages of the control block diagram.

through the result of comparing a rectified signal of the main voltage supply with a voltage level across a capacitor. The voltage level across the capacitor is monitored by the operation of two comparators. The principle of operation of the different active devices in the figure (i.e., Fig. 7a) can be obtained from Maini (2007).

When the office lighting exceeds a pre-set upper limit (i.e., 6.2 V), the upper comparator will allow the upper relay to close its contacts and consequently the capacitor voltage starts increasing through the charging resistance (R_{charging}). Increasing the capacitor voltage shortens the conducting periods of the triac. Similarly, when the office lighting falls below a pre-set lower limit (i.e., 5.8 V), the lower comparator allows the lower relay to close its contacts and consequently the capacitor voltage starts decreasing through the discharging resistance ($R_{\text{discharging}}$). Decreasing the capacitor voltage level extends the duration of the triac conduction periods. When the office lighting is between the preset upper and lower limits, both relays contacts are found open and there is a no-need to either shorten or extend the conduction periods.

Table 1 Controllers performance.

Controller	Electric energy consumed by the office light system	Electric energy saving index (%)
No-controller	2.98 kW h	–
Firing angle controller	2.90 kW h	2.68%
Integral cycle controller	2.82 kW h	5.37%
Conduction period controller	2.85 kW h	4.36%

Increasing the conducting period means that more contribution of the main supply to the office lighting is expected and decreasing the conducting period means that less contribution of the main supply is expected.

Fig. 7b depicts the different signals that can be expected at the output of the different block of Fig. 7a. The output port termed "Out" in Fig. 7a is linked to the gate of the triac of Fig. 3 through the insulating gate circuit of Fig. 5.

4. Controllers performance

The main target of this investigation is to take advantage of the surrounding sunlight in lighting up an office. Excess of the surrounding sunlight means that a partial cut of the main electric supply can be practiced and therefore some savings in electric energy consumption can be expected. The partial cut is done by field implementation of the previous three controllers and testing their performance. The performance consists of recording how much electric energy can be consumed by the electric lighting system of the office during the office working hours period. Table 1 reflects energy consumption when testing the previous three controllers.

As seen from the obtained results, a 5.37% of electric energy can be saved when using the integral controller. The saving energy index in the third column of Table 1 was calculated as: (Energy consumed without using controller − Energy consumed when using a particular controller) * 100/(Energy consumed without using controller).

It should be emphasized that the energy saving is reached while the office lighting level is kept between two pre-set upper and lower limits (i.e., 6.2 V and 5.8 V, respectively). Note that the two pre-set limits do not harm the comfort of the anticipated office occupants. The drawback that was encountered when implementing such controllers is the creation of some minor flickering in the florescent lamps. Such phenomenon has been relatively visible when implementing the integral cycle controller.

5. Conclusion

The presence of the natural sunlight around an office has a significant contribution to the overall lighting of the office. The contribution consists of cutting partially some of the electric energy consumption needed presumably by the office lighting system. The partial cut in the electric energy consumption in this paper has been fulfilled by field implementation of three suggested controllers. In performing the partial cut in the electric energy consumption, a 5.37% as an index of electric energy saving has been reached whilst the overall light level in the office is kept nearly comfortable to the office occupants. Some flickering phenomenon has been encountered when implementing the three controllers. The idea presented in this paper can be extended to a number of real life processes that may require a controlled light level to produce a desired optimum output/level.

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