The design and manufacture of photocell control units

By S. Marais

The use of photocell controllers can cut both installation and running energy costs of streetlighting. The chosen controller must be cost-effective, reliable and of high performance in order to satisfy the requirements. Initial thinking centred around unit cost in the hope that 'technology' would take care of unit function. This paper describes the design and development of controllers and the associated pitfalls in an attempt to enlighten manufacturers and to guide consumers.

In a world of advancing technology one may be forgiven to assume that the design and manufacture of a 'simple' photocell controller is an easy task. The function of the controller is simply to switch lighting on at dusk and off at dawn. It must repeat this process efficiently for many years and require no maintenance. Murray Cronjé (SANCI 1988) has shown the energy saving in effective switching and given the vast number of controllers used in a typical reticulation an additional burden is placed on the controller in terms of sample variation and cost.

Increasing performance/cost ratios have opened up new possibilities. Instead of using one controller to switch a row of streetlights, what about using one controller per streetlight? The advantages are:

1. No need for a dedicated (switched) cable. In urban areas the consumer reticulation runs past the streetlighting anyway, making it cost-effective to supply streetlights from adjacent CDUs (consumer distribution units).
2. The failure of the controller only affects one streetlight. All too often, large areas are plunged into darkness because of the failure of one controller.
3. Effective lighting distribution. Local ambient light levels would determine when each streetlight switches on. It is not uncommon to see a streetlight on top of a hill shining brightly whilst the ambient light levels are still high because its controller is many metres away, covered by a tree.
4. Lower switch-on surge. The streetlights will switch-on randomly at dusk inducing less mains-borne interference.
5. Increased flexibility. If the streetlight fittings are designed to accept the controller directly, there will be no need for on-site wiring. This becomes more advantageous in rural areas where streetlight spacing is greater or irregular.

Requirements

The requirements facing the designer are cost, performance and reliability.

The unit must be cheap enough to be cost-effective in an installation and be treated as a consumable. No end-user is interested in forming a repair facility for photocell controllers. Initially, the photocell controller had only to compete with the cost of the timeswitch but the increasing cost of electricity and the corresponding drive for efficiency has placed new demands on unit cost.

Given the energy savings possible with effective switching times, it is important that the units maintain their switching threshold over their operating life. This must be the case whilst being subjected to temperatures varying from freezing winters to sweltering summers. This temperature cycling ages the uinit due to repeated expansion and contraction of its components. Cycling also places heavy demands on sealing. The ingress of moisture and dirt would adversely affect the unit's performance by corroding the electronic circuitry and switching element.

The continued exposure to UV rays from the sun places further demands on the design. Stabilised plastics must be used and expansion coefficients of different materials matched. The light sensor must also not degrade with prolonged UV exposure.

The unit must also contend with physical abuse. The sensitive electromechanical switching element must be tough enough to withstand vibration induced by transportation and rough handling. The units may spend weeks rattling around at the back of a service truck before installation.

Reliability is of prime importance. Maintenance is both expensive and time-consuming. Modern semiconductor technology has produced components with a service life of many years and it must be the designer's aim to produce a product whose service life tends toward that of the components. Reliability is adversely affected by load and line conditions. The repeated switching of high currents into reactive loads places heavy demands on the switching element. The design must prevent contact chatter. This undesirable effect reduces both streetlamp and contact life as well as producing interference.

The mains supply can also be a problem. The unit must be designed to operate effectively with widely varying mains voltages. Fluctuations in the supply must not cause spurious switching. The sensitive electronic circuit must be protected against mains-borne surges. This problem is aggravated in areas with high incidence of lightning.

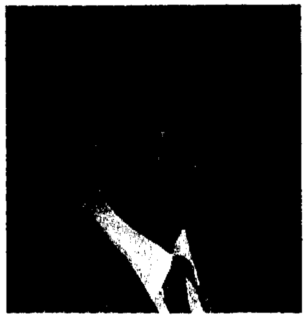
The energy saving in correct switching time would be offset by high unit quiescent power. It must use a small fraction of the power consumed by a single streetlamp. The unit must also have dead time to negate the effects of passing motorists at night. The transient incidence of the car's headlights on the controller must not affect switching.

The failure mode must be predictable. The unit must fail with its switching element closed, thereby switching the streetlighting on permanently providing illumination at night and serving as an indication for maintenance teams during the day.

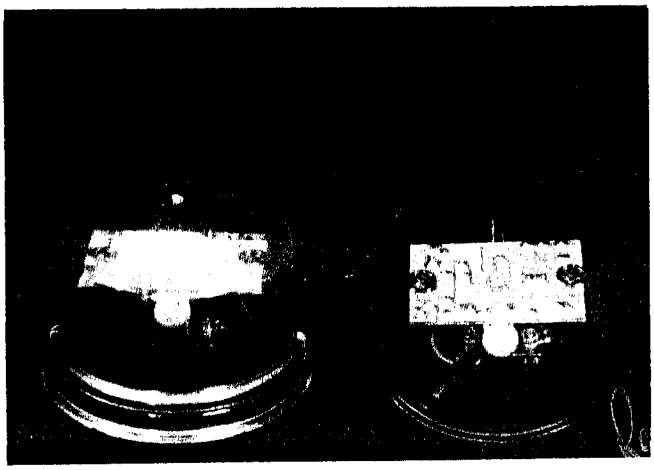
In the absence of a South African standard, the British Standards Institution specification BS 5972 should be used as a guideline for development. The specification details the form, fit and function of photocell controllers for road lighting to ensure compatability and reliability. The specification details:

1. *Marking*. This shall include the manufacturer's ID mark, the model and type number, rated voltage and current, switch-on level and the month and year of manufacture.
2. *Construction*. It must plug into a NEMA-type socket. It must survive instantaneous accelerations of 40 *g*. The unit shall be sealed to prevent the ingress of moisture and the pins shall be fabricated from a corrosion-resistant metal such as brass.
3. The unit shall have an insulation resistance of greater than 5 MΩ.
4. The creepage and clearance distances shall be greater than 0,2 and 0,1 mm respectively.
5. *Electrical performance*. The unit must be capable of switching loads of 10 A at 240 V at least 2500 times (the load is specified in BS 5972). The switch-on level shall be within 20 % of the declared level and the switch-off level shall not be greater than twice the switch-on level.

The Author



Stirling Marais matriculated at Westville Boys High School in 1974 and then studied at the Natal Technikon, receiving a Higher National Diploma in heavy current and a Masters Diploma in light current. During his studies he received numerous awards for academic achievement (including SAIETE most outstanding student of 1979). He gained experience in heavy current (consumer distribution, switchgear and protection systems) at the Durban Corporation and then pursued a career in electronic design. His experience includes feedback control systems, microprocessors and system modelling. Stirling is the technical director at Dynamic Electronics in Durban and is currently involved in the design of photocell controllers, fluorescent light inverters and automated test equipment.



A photocell control unit

Design

The designer is now faced with the various circuit options. He needs a light sensing element, some sort of control to provide dead time and a switching element.

CdS Cell and relay

A CdS cell (cadmium sulphide cell or LDR) is used as the light sensing element and a relay is the switching element. Some designs drive the relay directly from the cell without any control (gain) stage. This was one of the original configurations chosen because of cost, simplicity and low quiescent power.

These early designs encountered a number of problems, one of which was contact chatter. Contact chatter is the rapid opening and closing of the relay contacts during switch-on and switch-off caused by insufficient hysteresis (relays have inherent hysteresis) or system dead time. Commercial quality relays were chosen with marginal contact ratings and contact chatter not only lead to premature unit failure but also reduced lamp life.

This problem led to the widespread opposition to the use of relays in photocell controllers.

CdS cell and thermal switch

This configuration overcomes the problem of contact chatter because of the inherent dead time of the thermal switch. The CdS cell drives the thermal switch directly, so during switch-on and switch-off the temperature of the cell may rise appreciably due to its power dissipation. The thermal switch and/or the CdS cell must be specially designed to ensure correct switching threshold. The advantages of this system are cost and simplicity but the disadvantages are:

The stability of the CdS cell. Prolonged exposure to UV radiation (sunlight) and high power dissipation results in parameter shift and hence reduced reliability.

Lack of forward gain. As the ambient light intensity approaches the threshold, the cell resistance changes increasing the current through the heating element of the thermal switch. The current at this point is determined by the mains voltage, the resistance of the cell and the resistance of the heating element. The switching instant depends upon the temperature of the heating element and the properties of the bimetal strip. Switching is thus determined not only by the properties of the cell but also upon mains voltage fluctuations and ambient temperature. These problems manifest themselves in unreliable illuminance switching thresholds. The problem is compounded by variations in bimetal, heating element and cell properties with age.

Phototransistor and thermal switch

A phototransistor replaces the CdS cell and a gain block is added to increase forward gain. The effects of mains fluctuation can be cancelled by providing a regulated supply. The resulting configuration has the following advantages:

Sensitivity independent of mains voltage.
Sensitivity independent of heating element and bimetal switch properties.
No degradation in performance due to UV radiation exposure and hence longer service life.

Disadvantages of this system are cost, the spectral response of the phototransistor and the variation of dead time. The response of the phototransistor extends into the infrared region (see Figure 1). Research is being done into the variation of ambient spectrum with the changing of seasons. Infrared radiation also depends upon colour, so variation is cloud cover at a given ambient temperature provide variations in infrared intensity and hence switching threshold. Blue corrected phototransistors (blue filters are used to filter out infrared radiation) are available but at prohibitive cost.

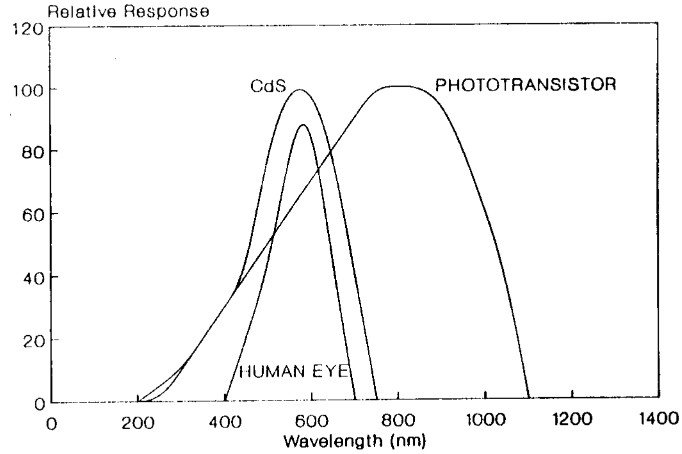


Figure 1. Spectral comparison

The effects of dead time upon switching instant also need inspection. The ambient light level decreases nonlinearly at dusk (see Figure 2). At midday and midnight the rate of change is at its lowest and reaches a peak at both sunrise and sunset. The maximum lux level rate of change is about one lux per second. Around a light level of 55 lux this rate of change is nonlinear. The rate of change variation alters throughout the year and depends upon cloud cover. These changes affect the instant at which switching occur.

For example, if the controller is set to initiate switching at 60 lux and the dead time is 10 s, the instant of switching would be at a light level of 50 lux if the rate of change in ambient light was one lux per second. However, this rate of change varies and the designer may find his unit switching at light levels ranging from 58 lux to 50 lux. This problem can be compounded by dead time variations. At dusk, the lux level rate of change decreases, working in one's favour but at sunrise it increases rapidly and can result in large errors. This problem is encountered mainly when using a thermal switch where its dead time is not accurately predictable. Ageing techniques and careful adjustment are needed to achieve success.

In spite of its minor flaws this design was chosen because of its reliability. It provides a long service life and its parameters do not vary significantly with age. The design of a quality unit by no means assures market success. Good mechanical design, small production sample variation, continued development and customer support are all required in large doses.

Pre-production testing

Time studies are conducted in order to assess production man hour cost. Pre-production runs ensure that most teething problems are solved.

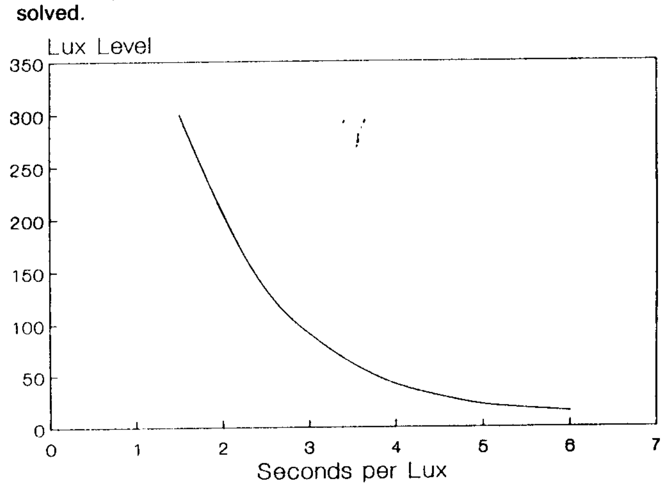


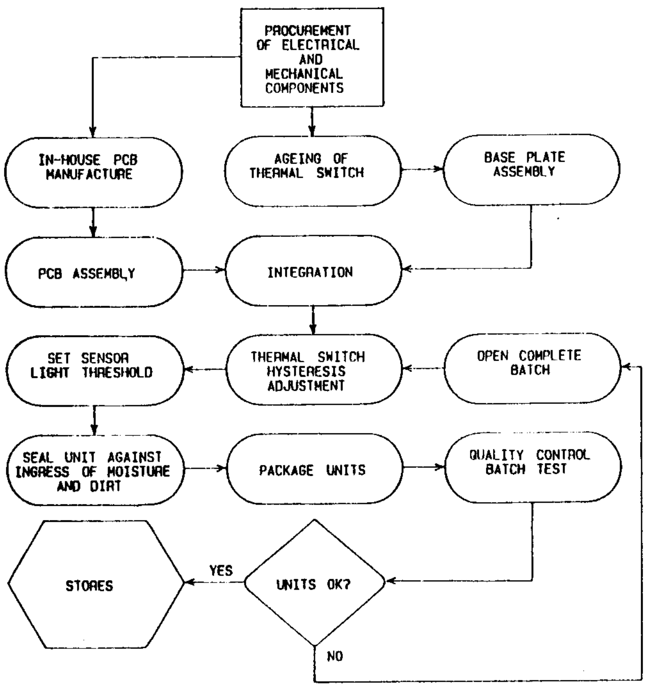
Figure 2. Lux level rate of change (dusk)

The units produced during this phase are subjected to numerous tests. These tests include the verification of performance over the expected temperature extremes (– 15 to + 70 °C). Tests are carried out in accordance with BS 5972 to verify contact reliability and photometric performance. MTBF (mean time between failures) calculations are done to predict product reliability. These figures are obtained via theoretical means and are used as a target during production. But 'the proof of the pudding is in the eating', the preproduction run is subjected to continuous field testing to weed out problems.

Production

The initial phase of production is component procurement (see Figure 3). Here, all components are brought in via a goods inspection to verify component values and injection moulding quality. Simultaneously, the printed circuit boards are manufactured. The bimetal switches are now aged because during manufacture stresses are built up due to minute process temperature variations. Without ageing, these stresses relieve themselves during operation, leading to changes in dead time. The ageing process involves temperature cycling which relieves these stresses.

The printed circuit boards are now assembled and sprayed with a protective coating and then attached to the nylon base.



The next phase is calibration and testing. The switch contact gap is adjusted in accordance with BS 5972. The switching threshold is adjusted using a reference light source to the customer's requirement (usually 30 or 55 lux). The reference light source luminous intensity is adjusted using a reference photocell controller adjusted to operate at say 55 lux in field conditions. The dead time (the time taken for the thermal element to heat up and activate the switch) is now adjusted with the help of a microprocessor-controlled test jig. The jig accurately measures the dead time and indicates which units are out of specification.

The last phase is sealing and packaging. The clear plastic domes are fitted and the units packed. Quality assurance take a sample of each batch and test them for appearance, dead time, switching threshold. If any failures are found then the complete batch is retested and if necessary readjusted. Periodically, batch field trials are conducted to verify switching thresholds with natural light. The units are then booked into stores.

Customer support

During the three year guarantee period, faulty units are returned to the factory for repair. These return units are very important for the development of the product. Evaluation has revealed many production problems ranging from thermal switch changes (before ageing was done), component bending stresses, circuit board spraying techniques and failure modes. Quality control are responsible for evaluating the results and producing a report. All returned units are brought up to specification and returned to the customer with a report.

Sold-state designs

The mechanical switching element can be replaced by a semiconductor device to produce an entirely solid-state unit. This could have the advantage of being cheaper and smaller but suffers from a number of drawbacks:

Reliability. Semiconductor devices are sensitive to load phase angle (switching of reactive loads), load current (increases device dissipation) and supply surges, whereas mechanical switches are generally more robust. This has the effect of reducing one's options because the load must be more tightly specified.

Triggering the semiconductor device (Triac) with inductive loads requires a synchronised burst gate firing with its additional complexity or continuous gate current with its driver dissipation problems. Power dissipation due to device saturation voltage leads to heatsink problems not encountered with a mechanical switch.

Solid-state designs could become more cost-effective and reliable in the future. One major advantage is that the entire circuit could be fabricated on one substrate. This would reduce size dramatically and reliability would be improved with development.

Other developments

More cost-effective designs can be achieved by reintroducing the relay and overcoming contact chatter. The relay must be specifically designed to handle the large current surges and high back-EMF experienced whilst switching reactive loads. A liberal degree of hysteresis must be employed to preclude contact chatter and the device should have normally closed contacts to ensure that unit failure results in permanent load energisation. Another advantage of using a relay is that dead time can be more accurately controlled.

Summary

Trends in energy conservation indicate that efficiency is of prime importance. Just as it is essential that a lamp gives off light it is equally important that it only operates when ambient light levels are low. It is for this reason that photocell controllers are becoming integrated into the design of all exterior lighting.

References

[1] M. Cronjé, 'Die skakeling van kunsmatige verligting met foto-elektriese beheereenhede'. SANCI, 1988.
[2] British Standards Institution specification number BS 5972.