Session 2793

DESIGN OF A ROBUST AND LOW COST SOLAR LANTERN AS A ONE SEMESTER PROJECT

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Abstract - The purpose of this project was to develop a rugged and efficient solar lantern. The lantern was designed to meet the requirements of persons who reside in areas where access to the electrical grid is limited and whose resources do not permit import of electrical generation capabilities. A representative of a missionary organization operating in Africa developed the original set of specifications for the solar lantern that will be used by the local school children for doing homework in the evening. These specifications prioritized reliability, ease of operation, rugged construction, portability and low cost. The resulting design was realized in a single prototype. The design and construction of the prototype was completed as a student/faculty project in the Junior Engineering Clinic course at Rowan University in Glassboro, NJ. It was funded and directed by ETM Solar Works, a NY based corporation.

Introduction

Rowan University's College of Engineering is committed to providing their students with significant laboratory and design experiences throughout their full four years as engineering students. In the Freshman year they are given an opportunity in the first semester to explore all four of the disciplines taught at Rowan (Electrical & Computer, Civil & Environmental, Mechanical, and Chemical) while learning about engineering measurement techniques. Then that same year in the second semester the principles of design are introduced through the use of an experience in competitive assessment. Small groups of students work on the investigation of a single product during the full semester. Along the way they are introduced to new analysis techniques and computer tools while learning in a "hands-on / minds-on" method the multidisciplinary nature of product design. By the sophomore year these students are ready for the next stage – actual design assignments in a well supervised but open environment. In the sophomore year the students are given a design assignment and, again in small (4-6 students) groups they all work on a single design project. We maintain the multidisciplinary nature of the design process by not grouping the students by discipline, even though at this point they have chosen their majors and begun taking the introductory discipline-specific courses specified by their program. Finally, at the junior level the students are ready to begin working on individual projects. The Solar Lantern project was assigned to three junior level Electrical and Computer Engineering students.

Background

Electric lamps or lanterns provide superior lighting for almost any application and are preferred over lighting from any other fuel source for general, localized and orientation lighting. Candles and kerosene-type lanterns are a common source of lighting in remote areas where electric power is not routinely available. Additionally, few non-western countries have a reliable supply of electric power, even in the more developed parts of those countries. So many times even those who are connected to the electric grid find that they have a need for supplemental lighting during times when electricity is not available. The goal of this project was to develop lighting potential to meet these needs.

The criteria that were specified by the sponsor of this project prioritized reliability, ease of operation, rugged construction, portability and low cost. These criteria informed many of the decisions that we made regarding components, materials and physical design. We will address each of these items here to provide explanation and justification for our design decisions.

<u>Reliability</u>

Persons who normally use energy sources other than electricity for lighting will find advantages to having the brighter and more directional light provided by electrical lighting units. Usually, however, a relatively large investment must be made to acquire a lantern such as the one that we have designed. Candles and kerosene can be purchased in small quantities on a regular basis but the lantern purchase can consume significant resources up-front. Over the life of the lantern the user should realize a savings, but not initially. In addition, persons in remote sites do not have access to repair services. Taken together these factors mean that any substitute light source should provide a maximum length of reliable service. For our design we specified a minimum uninterrupted service length of 1 year.

<u>Ease of Operation</u>

There are basically two reasons for designing a lantern that is easy to operate. The first reason relates to the previous topic, reliability. To as great an extent as possible we have designed this lantern to be free of complicated maintenance or operating procedures. There are only three control settings: *On, Off* and *Charging* and a low voltage indicator. The control settings are labeled symbolically rather than with words in any particular language. The internal protection circuits prevent the battery from over-charging or from deep depletion, either of these conditions can reduce battery life. The photovoltaics are an integral part of the lantern so no connections are required and they operate simply by being exposed to the sun with the control set to *Charging*. The fully integrated nature of the lantern makes it simple to use. This is particularly important if the lantern is going to be used in many different physical settings and by people with different languages and different levels of exposure to technology.

Rugged Construction

The solar lantern must be able to withstand a wide variety of both climatic and use conditions. Particularly at remote sites, it may not always be possible to prevent rough use. All components of the lantern have been designed to minimize damage from collisions and from harsh weather conditions. The prototype lantern is constructed from aluminum with a clear plastic shield protecting the light source. The photovoltaics are attached to the top surface of the light shade where they are protected from the elements by a film coating. The production version of the lantern will be constructed from injection molded plastic that will provide durability and protection for the electronic components.

Portability

To provide the most effective use of the lantern it is important that it be easy to move from place to place in the home. The lantern will have to be set in a sunny location for charging, perhaps at a window or literally outside in the sunlight. The use location may be at a single chair for reading or at a table where people would gather to work. In a situation where the living arrangement is temporary (e.g. camping) the lantern would have to be easy to transport. Moving the lantern should be convenient, our design is as light as possible given the battery requirements and the shape is as compact as possible given the requirements for extent of the lighted area.

Low Cost

Finally, the cost must be adequately low for the lantern to be available as a replacement for other common forms of lighting in remote areas. Since our initial motivation was to provide lighting at a remote mission in Africa and not to create luxury camping gear, we tried to keep the cost of materials and construction as low as possible. The criteria which the students used was to keep the cost less than a single year's worth of candles or kerosene.

It is clear from the above expanded list of design criteria that the students were faced with a very challenging project. But it is the type of project that motivates the students from both a personal, social, and technical point of view. Below we will describe the design process that the students persued and describe the results that were obtained by the end of the first semester's work.

Description of the Design Process

We began the semester by setting the task schedule that we thought would be required to complete the lantern design and construction in a single semester. In retrospect this was overly ambitious, however it did set a high standard for the group. Table 1 shows how we planned to organize the tasks for the semester. The students were very excited about the project and planned to see it to completion in the span of the semester.

Table 1. Task Planning for Solar Lantern Project

TASK	JAN	FEB	MAR	APR	MAY
Needs Assessment	▬				
Selection of Electrical Components		▬			
Design of Lantern Body		▬	▬		
Design of Circuitry		▬			
Circuit Prototyping			▬	▬	
Physical Construction of Lantern					▬
Installation of Electrical Components					▬

The needs assessment was a very important aspect of our project. This was an opportunity for the students to research the context in which their product would be used and to plan a design that not only met the technical criteria but also met the personal and social needs of the young students who would be using the lantern. To accomplish the needs assessment our students used a combination of WEB searches, phone calls to relevant organizations (e.g. UNICEF and The American Red Cross) and personal interviews with faculty and students who have had contact with Third World countries.

One of the most interesting aspects of the project was the opportunity the students had to use new technologies. Although the use of solar power for battery charging is not novel, we were able to take advantage of some of the new forms of construction. Specifically, we used the thin film photovoltaics for our lantern. LEDs (Light Emitting Diodes) are also not a new technology but the development of white LEDs gave us the opportunity to construct an extremely efficient lantern that would provide many hours of light on a single battery charge. Below we provide a technical description of the lantern components to illustrate the depth of understanding and extent of design coordination that the students were able to achieve.

White LED's

The heart of the solar lantern is the array of white LED's. Recently developed by the Siemens company in Germany, white LED's offer a long lasting (hundreds of thousands of hours) light source that is very power-efficient [1,2,3]. The efficiency is critical in the solar lantern since we want to be able to provide light for long periods of time using only a battery. In addition, white LED's are much less fragile than incandescent bulbs. This will make our lantern more rugged than lanterns that use incandescent bulbs as their light sources. Thus, white LED's are the perfect light source for our solar lantern.

Nine white LEDs output approximately the same amount of light as one 20-watt incandescent light bulb [4]. Using this as a guide, we decided to use 30 white LEDs in our lantern to produce an amount of light equivalent to that produced by a 60W incandescent bulb. The LED's are wired in ten parallel rows each row consisting of three LEDs in series (see Figure 1). Each row of LEDs will draw about 20mA of current, and so the power dissipated by each LED can be found from $P = VI = (3.3V)(0.020A) = 66mW$. The total power dissipated by the thirty LEDs is $(30)(66mW) \approx 2W$.

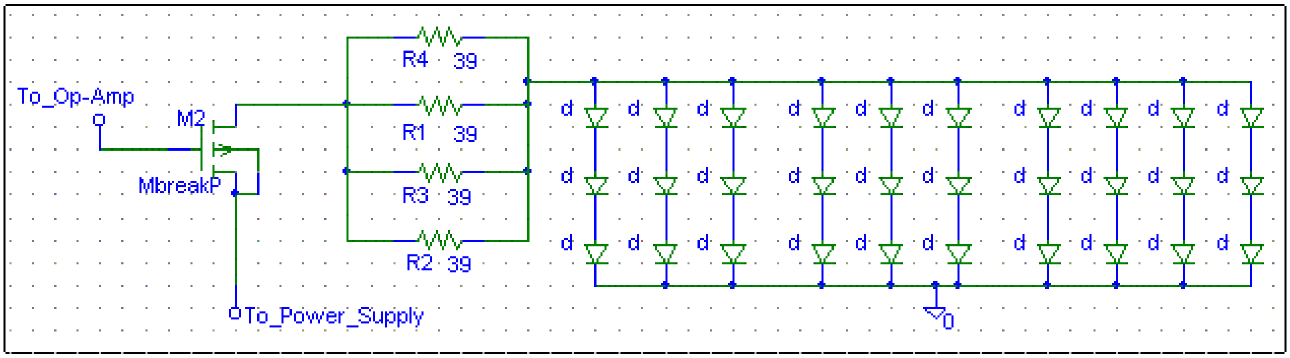

Figure 1: Circuit diagram for LED array.

Tests were also conducted to compare the light emitted by 27 LED's to that emitted by a 60W incandescent bulb. Light measurements were made in a dark room directly above each light source. No measurements were made to the sides of the light sources, since the LED's are very focused and do not emit much light to the sides. The results are shown in Table 1 below.

Table 2: Comparison of light from LEDs and 60W bulb.

Distance above light source (inches)	**Light emitted from LEDs (foot-candles)**	**Light emitted from 60W bulb (foot-candles)**
6	230	180
12	114	62
18	68	37
24	42	26
30	27	17
36	19	12

The LEDs produced more direct light than the 60W incandescent bulb. We used a reflecting cone with the array of these devices and for our lantern so that the light would be more diffuse.

Battery

Two battery technologies were considered for the solar lantern: lithium-ion and sealed lead-acid (SLA). The main advantage of lithium ion batteries is that they are completely environmentally friendly. When finished with them, the user needs only to throw them in the garbage. Virtually all other rechargeable batteries cannot be disposed of in this manner without harm to the environment. However lithium-ion batteries do not necessarily protect against overcharging; and they do not source as much current and voltage as sealed lead-acid batteries. Thus, more than one lithium-ion battery would be necessary. Another issue is their availability. Lithium-ion batteries are less readily available for purchase.

Sealed lead-acid (SLA) batteries were chosen for our application. They can source more voltage and current than lithium-ion batteries, which means that only *one* SLA battery needs to be used in comparison to the many lithium-ion batteries needed to achieve the same capacity. SLA batteries also charge quickly, protect against overcharging, and are maintenance-free. SLA batteries are fully recyclable, but pose a threat to the environment if disposed of like regular trash.

A large capacity (7 Amp-Hours) SLA battery was chosen for two reasons: 1) the weight (5.7 LBS) will ensure that the base of the lantern, which is where the battery will reside, will be heavy enough to prevent the lantern from being easily tipped over, and 2) the larger the capacity of the battery, the longer the overall life span of the battery will be. At a battery voltage of 13.02V, the load the battery will see is 283mA (as shown by tests). At this load, a 7 amp-hour battery will last for approximately 30 hours before needing a recharge. As for overall battery life, if the lantern is used for 9 hours a day (and also recharged daily), the battery will last about 1200 cycles (1 cycle equals 1 charge and 1 discharge), or equivalently 3.28 years. At the end of 1200 cycles, the battery will have been reduced to 60% of its original capacity.

A battery indicator circuit is provided to monitor the charge state. It is comprised of three separate, but identical indicator circuits. The schematic for one of these circuits is shown in Figure 2. Green, yellow and red LEDs turn off consecutively as the battery voltage drops. This feature allows the user to know approximately how much time is left on a single charge of the battery.

A low-voltage cutoff circuit is used to prevent the battery from discharging beyond the manufacturers recommended value. A schematic is shown in Figure 3. It is simple in nature and is composed of a voltage divider, a shunt regulator, a comparator (the op-amp from an LM614 IC chip), and a pMOS transistor. When the battery voltage is reduced to 10.5V, the output of the voltage divider can be calculated by the equation $Vout = \frac{(1000)(10.5)}{1000+130+27}$, and equals 9.075V. If the battery voltage falls below 10.5, the voltage at the comparator's negative terminal will fall below 9.075 and turn off the current supply to the LEDs.

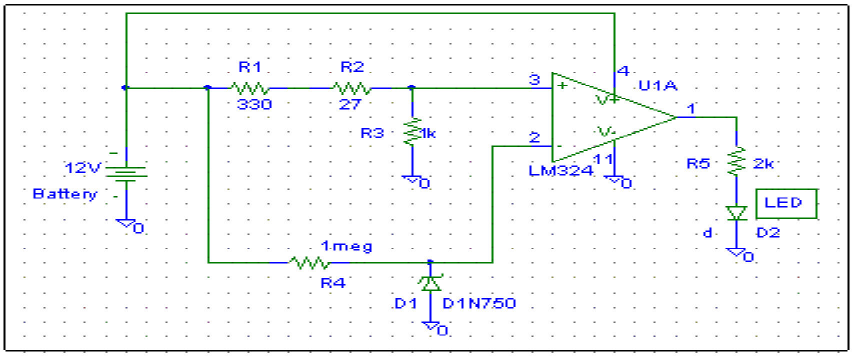

Figure 2: Battery low-voltage indicator circuit.

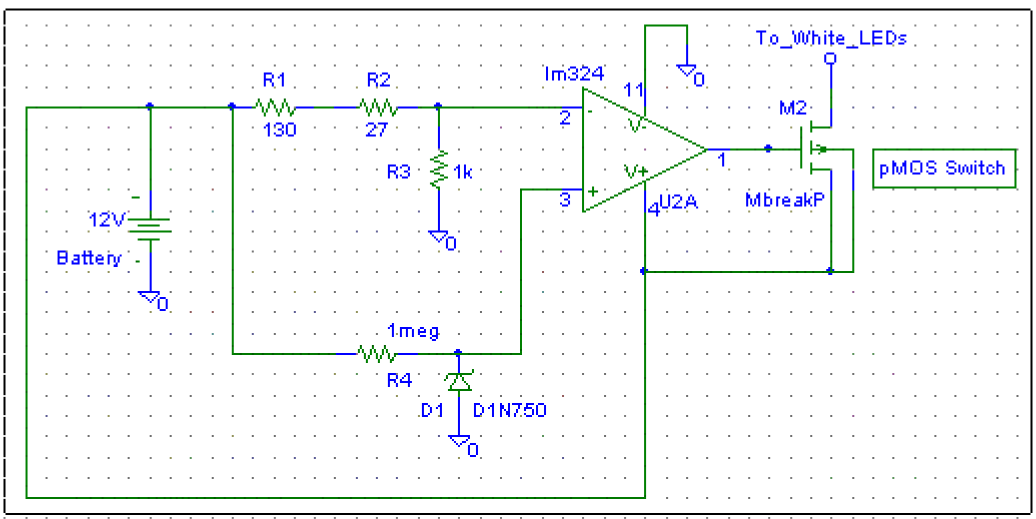

Figure 3: Low voltage cutoff circuit.

<u>Solar Panels</u>

There were three main types of solar panels to be considered: monocrystaline silicon, polycrystalline silicon, and silicon amorphous cells [5]. Monocrystaline silicon cells are the most common and also boast the highest efficiency levels. Polycrystalline silicon is also fairly common, although it does not have the same high-energy production as monocrystaline silicon. Amorphous silicon is the newest product available on the market [6,7]. It is available in thin sheets, and thus allows for more versatile placement. Unfortunately, it is not as efficient as the other two types.

Monocrystaline silicon, by far, has the highest and most stable output. It has the highest cost of any of the three major types as well but is one of the most rugged and rigid panels. Polycrystaline silicon allows for faster energy production than either of the other two types. It is also slightly cheaper than the monocrystaline silicon. Amorphous silicon comes in extremely thin sheets, and is thus lightweight. These are the lowest cost solar panels, and the quickest to manufacture. They are also fairly resilient to outdoor conditions.

Unfortunately, there are drawbacks to each of these. Monocrystaline silicon is one of the heaviest solar panels available. This places restrictions on where you can mount your solar panel because some materials may not support the weight. Polycrystalline silicon is also fairly heavy. It also plagued by lower energy output, and the fact that it is less efficient than monocrystaline silicon. Amorphous silicon solar cells are the least efficient of the three.

Because of its lower cost, small size, and ruggedness, we chose to use the amorphous thin-film silicon solar panels. For our prototype, we used thirty small panels; each rated at 3V and 50mA. They are wired up in 6 parallel rows of 5 panels in series. This configuration is rated at 300mA at 15V. Tests done (see Table 3 below) on the small solar panels showed that the open circuit voltages and short circuit currents of the panels were less than specified by the manufacturer. So, it is expected that the panel array will not output the full 15V and 300mA.

Table 3: Test results for thin film solar panels*

Panel Number	Time of Day	Open Circuit Voltage	Short Circuit Current
1	1:15pm	4.10 V (dc)	32.6 mA
1	2:30pm	4.03 V (dc)	34.5 mA
2	2:46pm	4.01 V (dc)	40.6 mA

*According to manufacturer's specs, open-circuit voltage should be 4.4V, short-circuit current should be close to 64mA. Weather conditions were sunny and clear. The panels were inside and pointed towards the sun through a window.

To simplify manufacturing of an actual production model, one large panel would replace the thirty smaller ones. Such a panel is available from Uni-Solar and is less expensive than the small panel array. The Uni-Solar panel has its own polymer lamination to shield it from the weather, and will remove the need to wire up 30 individual panels.

These are the major components that were used in the construction of the prototype solar lantern. The integration of these components into the final product design will be described next.

Product Integration

Figure 4 shows the overall physical design that was used in the construction of the prototype. The individual components labeled here have been described above. The body of the lantern was constructed from aluminum. This is not the best material for the particular application which we have in mind, however, it was available to us an option for the prototype. Our recommendation for the "use" or production version is that it be crafted in injection molded plastic. Injection molded plastic would be an ideal material for conditions that the lantern will be used in.

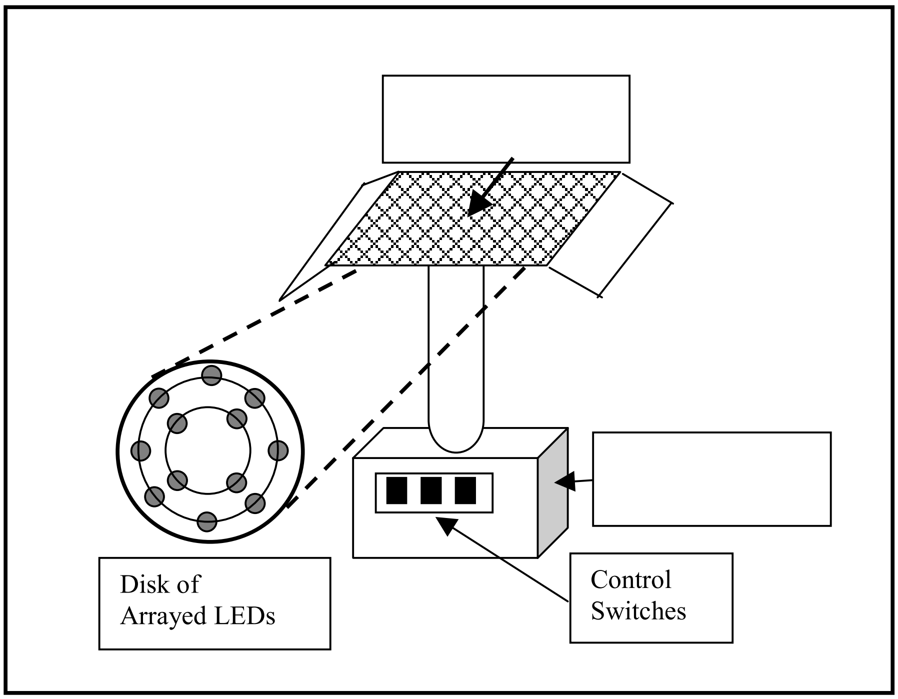

Figure 4: Overall physical design of the lantern.

The integration of the electronics required wiring from the base where the battery and electronics were enclosed to the "shade" where the photovoltaic cells were positioned and the disk of arrayed LEDs was mounted under the "shade." The concave disk for the LEDs was constructed of a reflecting material and the individual LEDs were distributed to create reflections that gave a 4 foot diameter circle of light when the lantern is used at a table. Figure 5 shows the block diagram for the solar lantern's electrical system. The design and construction of this system presented a demanding design challenge for our students and was an excellent learning experience. The experience gave them the opportunity to not simply create a circuit for a single function but to learn how to integrate various electronic and electrical components into a working system.

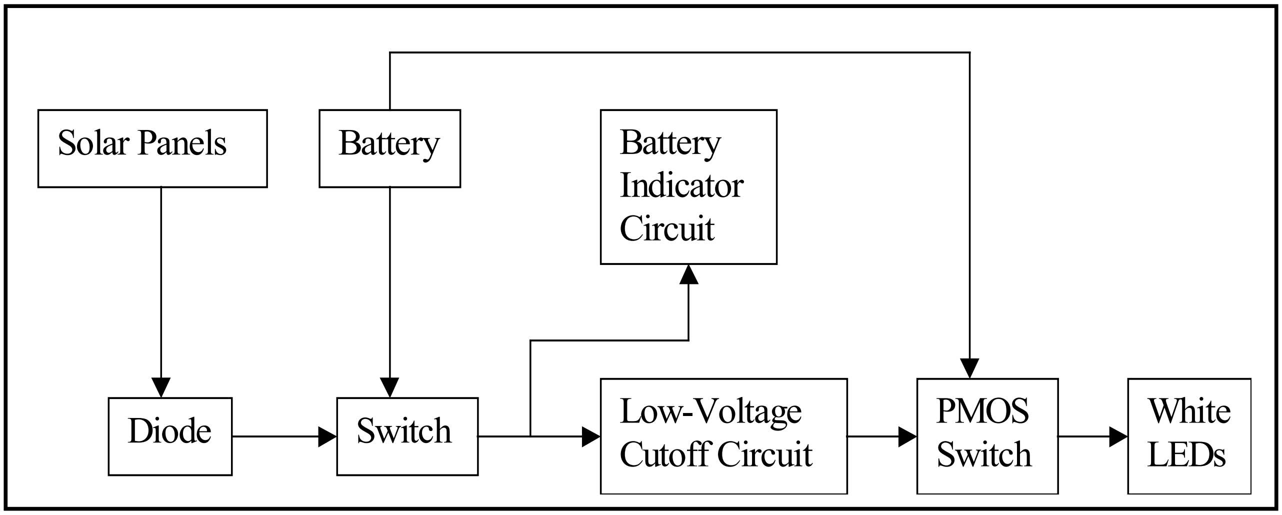

Figure 5: Block diagram for the solar lantern's electrical system

Conclusions

This project was extremely successful both as a design experience for the students and as a learning experience for the faculty who were involved in supervising a "start from scratch" product design. The initial project definition was not specific in terms of the technical specifications that were required. Rather, the charge to the design group was more general. We only had the final goal, to create a solar lantern that is economical to produce and can be used in remote areas by children doing their school work. This created the ideal situation for our students, they were faced with learning more about not only the technology but also about the context in which the technology is to be used. This is a lesson that we often do not have "time" to teach our students in the typical classroom situation. Rowan University's clinic program in engineering is the ideal place to explore not only traditional technical design but also a place where we can create for the students an opportunity to work with the interactions between engineering practice and the broader social concerns that we would all like our students to be aware of.

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Biography

Linda M. Head is an Associate Professor in the Department of Electrical and Computer Engineering at Rowan University. She received her Ph.D. from the University of South Florida in 1991 and worked at the State University of New York at Binghamton prior to joining Rowan University in 1998.

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