Design and Implementation of an Environmental-Friendly Solar Energy Powered Lamp

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Abstract-
Global interest in controlling energy resources has dramatically increased due to many reasons. We cannot continue to depend on fossil fuels for our requirements. This is where solar energy comes into picture. The advantages of using solar energy are the cost reduction of installation in the case of non availability of electric grid and contribution to the protection of the environments as solar energy is a clean and renewable energy source. This research focuses on the employment of a solar lighting system which can make a 3 watt lamp glow. The device can be used for small-scale lighting applications in remote areas that are far away from the power grid. The system consists a panel to collect the sun's energy, a battery to store that energy and a light source to use the energy.

Index Terms- Battery, Energy, Integrated circuit, Light source, Solar lamp, Solar lighting system, Solar panel.

I. INTRODUCTION

We have designed and constructed a solar lamp fit for studying purpose (A minimum of 1ft X 1ft area is illuminated with 300 LUX of light) and which can survive in dusty conditions. It has been designed so that the lamp components and body can be easily assembled because of simplicity of circuit. All the user needs to do is charge the lamp in 6hrs of full brightness for full battery. The lamp lasts for 6 hrs in full brightness mode, 7.5 hrs in medium brightness mode and 9 hrs in dim brightness mode. The lamp would cost around Rupees 490, including assembly of the lamp which is a very reasonable rate.

1) Research Elaborations
2) Results or Finding
3) Conclusions

II. RESEARCH ELABORATIONS

It's the solar lamp also known as solar light or solar lantern, is a lighting system composed of an LED lamp, solar panels, battery, charge controller and there may also be an inverter. The lamp operates on electricity from batteries, charged through the use of solar photovoltaic panel.

Solar-powered household lighting can replace other light sources like candles or kerosene lamps. Solar lamps use renewable energy with infinity supply which is cheaper than standard lamps. In addition, solar lamps reduce health risk as kerosene lamps have a bad impact on human health. However, solar lamps may have higher initial cost, are weather dependent.

In the past solar panels used large crystals mainly made out of silicon which produced electricity when it was exposed to light. When electrons in silicon are exposed to light, they start to vibrate from their fixed positions following thermodynamics rules. Furthermore, it produces heat from the vibration and the movement. Through this, silicon turns a large portion of light energy into electricity. However, manufactures found silicon too expensive to make and to put in as a component of solar lamps. On the other hand, nowadays solar panels are made out of smaller and cheaper crystals.

These new crystals can be used to form thin flexible films. However these cheaper crystals are less efficient at turning light energy into electricity. Therefore, it is an ongoing project to find a cheaper, efficient silicon substitute material that can be easily produced in mass and convert light into electricity very easily.

Solar panels are made out of crystals that are made out of covalent bonds between electrons on the outer shell of silicon atoms. Silicon is a semiconductor which is neither metals that conducts electricity nor insulators that do not conduct electricity. Semiconductors normally do not conduct electricity but under certain circumstances they do in this example with exposition to light. A solar cell has two different layers of silicon. The lower layer has less electrons and hence has a slight positive charge due to the negative charge nature of electrons. In addition, the upper layer has more electrons and has slightly negative charge.

A barrier is created between these two layers however when the stream of light particles called photons enter, they give up their energy to the atoms in the silicon. It promotes one electron from a covalent bond to a next energy level from upper layer to the lower layer. This promotion of an electron allows freer movement within the crystal which produces a current. More light shines through, more electrons move around hence more current flows between. This process is called photovoltaic and photoelectric effect. Photovoltaic systems literally mean combination of light and voltage and they use photovoltaic cells to directly convert sunlight into electricity.

Solar panels are made out of layers of different materials, in order of glass, encapsulate, crystalline cells, encapsulate, back sheet, junction box and lastly frame. The encapsulate keeps out moisture and contaminants which could cause problems.

A battery is usually housed within a metal or plastic case. Inside the case are electrodes including cathodes and anodes where chemical reactions occur. A separator also exists

between cathode and anode which stops the electrodes reacting together at the same time as allowing electrical charge to flow freely between the two. Lastly, the collector conducts a charge from the battery to outside.

Batteries inside solar lamps usually use gel electrolyte technology with high performance in deep discharging, in order to enable use in extreme ranges of temperature. It may also use lead-acid, nickel metal hydride, nickel cadmium, or lithium.
This part of the lamp saves up energy from the solar panel and provides power when needed at night when there is no light energy available.

A solar cell is a device people can make that takes the energy of sunlight and converts it into electricity. In a crystal, the bonds (between silicon atoms) are made of electrons that are shared between all of the atoms of the crystal. The light gets absorbed, and one of the electrons that's in one of the bonds gets excited up to a higher energy level and can move around more freely than when it was bound. That electron can then move around the crystal freely, and we can get a current.

In general, the efficiency of photovoltaic energy conversion is limited for physical reasons. Around 24% of solar radiation of a long wavelength is not absorbed. 33% is heat lost to surroundings, and further losses are of approximately 15-20%. Only 23% is absorbed which means a battery is a crucial part of solar lamp

Solar lamps can be easier for customers to install and maintain as they do not require an electricity cable. Solar lamps can benefit owners with reduced maintenance cost and costs of electricity bills. Solar lamps can also be used in areas where there is no electrical grid or remote areas that lack a reliable electricity supply. There are many stories of people with lung disease, eye deterioration, burns and sometimes even death simply because they do not have a healthy alternative to light at night. Women have felt unsafe walking to the toilet outside after dark. Babies are being delivered by midwives using only a candle, and students cannot study when the sun goes down for lack of light leading to increased illiteracy and perpetual poverty. These are the realities for over 1 billion people around the globe. Lack of lighting equates to continued poverty felt around the world.

III. RESEARCH AND FINDINGS

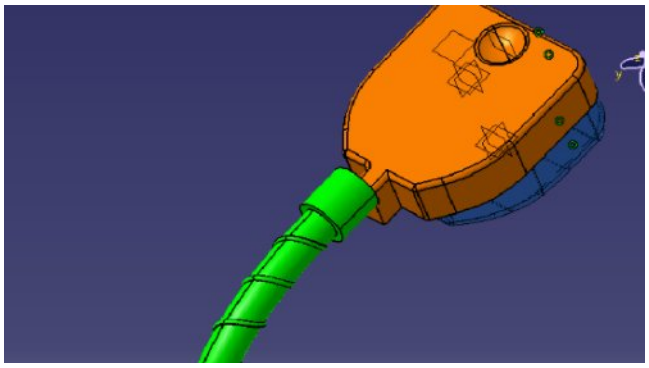
The physical body of the solar lamp is printed out using a 3D printer which uses 3D Modeling designs designed using AutoCad software. The model is printed using thermoplastic material (200 microns). An alternative for the structural body of the lamp is to make it using Acrylic sheet. Acrylic Sheet is nothing but a plastic whose chemical name is *Poly(methyl methacrylate) (PMMA)*, also known as *acrylic* or *acrylic glass* as well as by the trade names *Plexiglas*, *Acrylite*,*Lucite*, and *Perspex* commonly used in the market. It is a transparent thermoplastic often used in sheet form as a lightweight or shatter-resistant alternative to glass.
Small stainless steel screws are used for fitting.

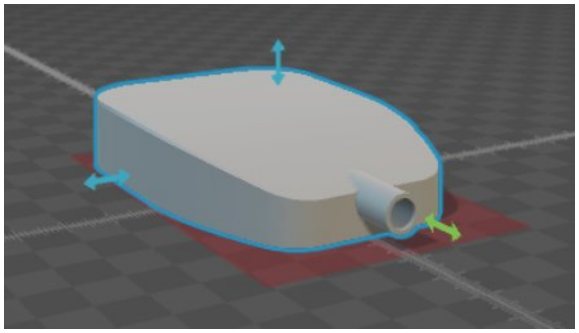
The solar lamp consists of four parts namely,

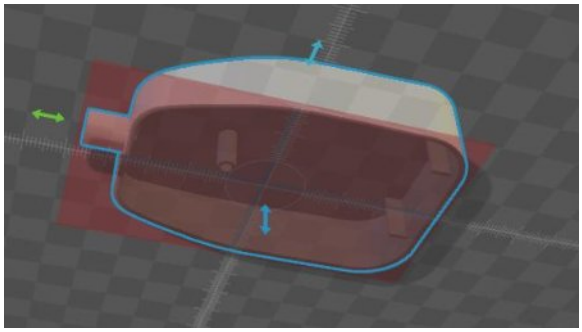
1) Lamp Head
2) Flexible Metallic Gooseneck
3) Base Top
4) Electrical Circuit
5) Base Lid

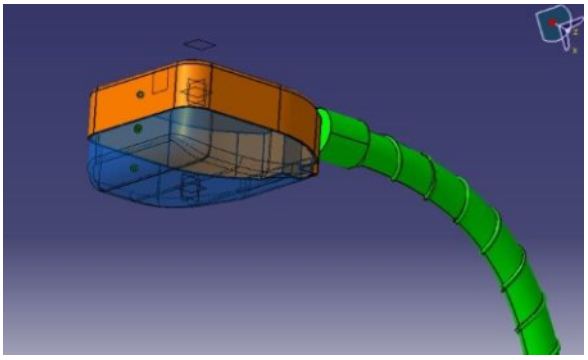
Lamp Head -

1) The lamp head has an opening on the top periphery in which the reflector is fitted. The reflector is covered by aluminum sheet for more illumination of light.
2) The load LED (white LED) is fitted in the middle of the reflector, where a small opening can be found. This is done with the help of screws to hold the LED in place. The LED has been soldered and the wires have also been soldered near the LED which will later be used to connect the LED to the circuit.
3) After assembling the LED at the opening of the reflector material, the reflector is placed inside the head with the LED facing outwards. Hence, the reflector helps in more illumination of the light.
4) Then, the head is closed using a transparent lid made out of transparent acrylic sheet to protect the LED.
5) This entire portion is closed externally with a screw. A hole is provided on the lid which is concentric to a hole made on the reflector, which in turn is concentric to a hole made in the head for mounting.
6) Hence, we have the head ready with the two wires, which were soldered near the LED, coming out from one end of the head.
7) This part can be made using acrylic material and has a hexagonal shape. (As shown in lamp_head.STL in attached files).
8) The transparent cover for the head can be made using transparent acrylic sheet and molding it into the required shape.









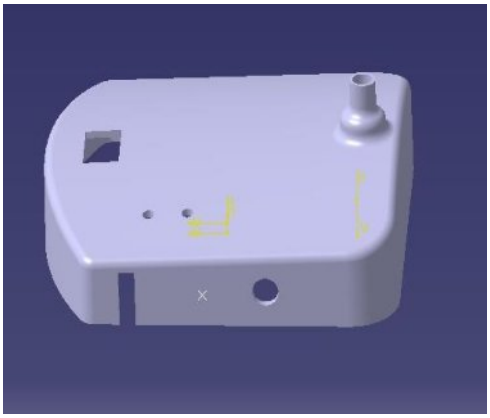
We had a smaller size of the lamp head in mind, but due to unavailability of single piece of reflector material and single transparent lid of that size, we had to change the head size of the lamp based on the size of reflector material and transparent lid that were available in the market to serve our purpose. However, the head size can be reduced if required sized reflector and lid can be produced in bulk. *We did not intend to "copy" the design of any other lamp, if any resemblance can be found with any market product. These parts can be changed in size and shape to obtain a smaller lamp head, as we wanted, provided they can be manufactured in bulk quantity.*

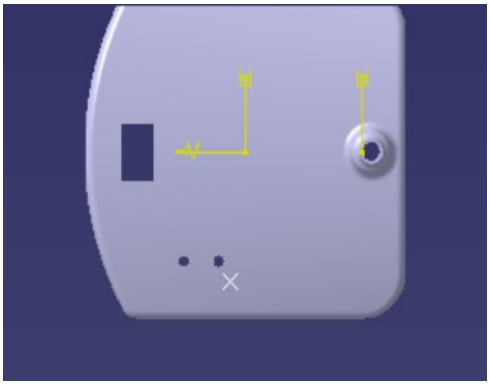
Corrugated Metallic Flexible Gooseneck –

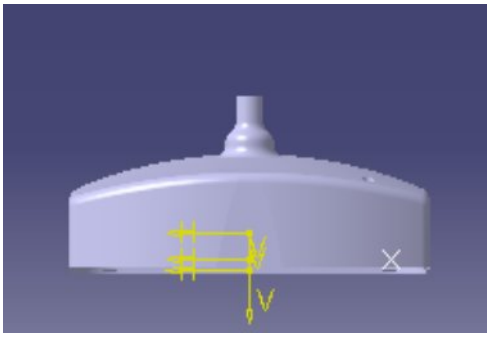
1) This tube is a flexible metallic gooseneck-type conduit which can be bended as per the requirements of the user to change the direction of face of the LED so light can fall where required.
2) It carries the wires, which were left hanging from one end of the head, as mentioned above. This connects these wires from the LED in the lamp head to the circuit mounted in the base portion, which will be explained in the next sections.
3) One end of the tube is fixed to the lamp head and the other end is fixed to the base. This gooseneck provides flexibility to the user, connectivity from the lamp head to base, and protection for the wires connecting the LED to circuit.
4) These can be bought very easily is bulk, but for our prototype we used the gooseneck that fit our requirement, which was part of a USB lamp that we found in the market as we didn't need to manufacture in bulk.
5) After inserting the wires from the lamp head into this gooseneck and fitting the gooseneck to the opening of the lamp head, fit the other end of the gooseneck with the second ends of the wires coming from the LED, to the opening in the base.

Base Top –

1) The base top consists of the main electrical circuit including the batteries.
2) The second end of the flexible metallic conduit, explained above, is connected to the opening of this part to keep the lamp balanced.
3) It protects the circuitry and batteries from external damage and climatic conditions.
4) This part is cubical in shape and can be made using acrylic material.
5) There are two holes made at the surface part to show the red and green indicators.
6) There are two apertures located at one side of this part, one to hold the mini DC connector in place where the solar panel can be connected for charging the lamp and the second for the 1K/V potentiometer with knob which will be used to adjust the brightness of the lamp.

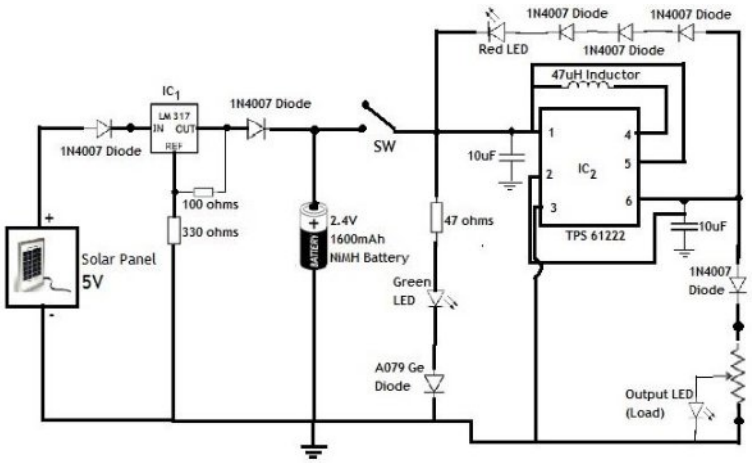






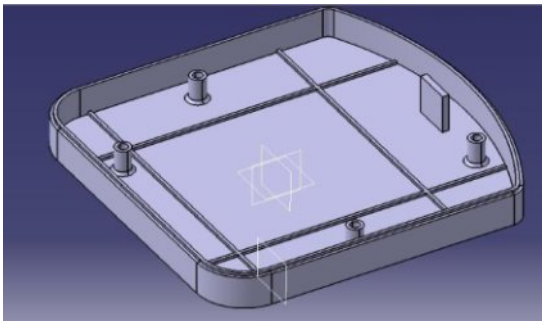
Electrical Circuit –

1) The electrical circuit consists of the main PCB board connected to the battery.
2) This part is placed inside the base top, described above, of the lamp to protect it from external damage and climatic conditions.
3) Two holes are drilled on the PCB which are used to mount the PCB in place, inside the base top so that circuit can be fixed in one place, preventing short circuits and shocks which can be caused if the circuit is allowed to move inside the base.
4) The base top will have two holders with holes where the PCB can be mounted easily with the help of two screws.
5) The battery, potentiometer, and switch will be connected from the PCB using small length single-threaded thin wires for the potentiometer and switch (ON/OFF) while we used small length multi-threaded wires for the battery as these three components cannot be connected directly from the PCB.
6) In our prototype, we have connected the red and green LED also using small length single-threaded thin wires from the circuit but if the length of these LEDs can be adjust perfectly, then these wires would not be needed there. We first mounted the green and red LEDs from outside the base top into the respective holes provided and then connected them to the circuit from inside.
7) We used glue from outside to hold the LEDs in place on the surface of the base top but as mentioned above, this all can be prevented if these two holes for the LEDs can be increased by 0.1cm and if their length can be adjust such that they can directly be soldered onto the PCB.
8) We also used a glue gun to hold the potentiometer is place inside the base so that it doesn't move. A glue gun is safe to use as this glue is a very good insulator so it can also prevent short circuit inside the base.
9) The two wires from the load LED, which come out from the second end of the metallic gooseneck are also soldered to the circuit at its output terminals.

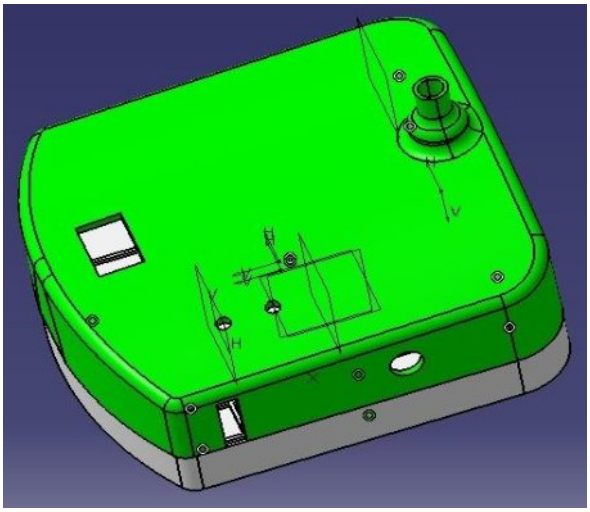


Base Lid –

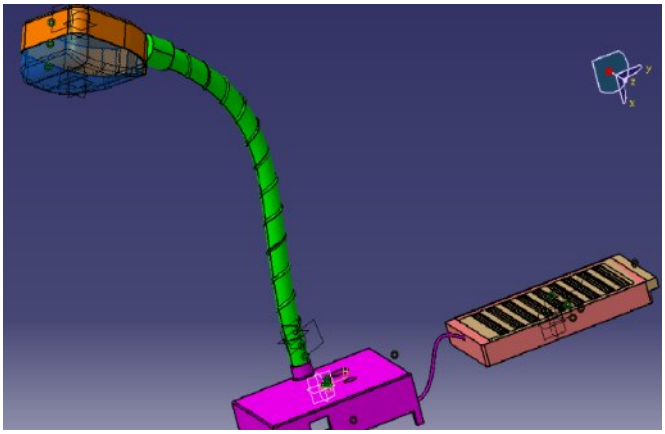
1) The fitting of the lid to the base top is done with two small stainless steel screws.
2) This base lid has mounted holes which allow us to screw the base top and lid externally very easily.
3) The outer surface of the base lid is flat so the lamp can easily stand.
4) Similar to the other parts of the lamp, acrylic material can be used to make this lamp.
5) Hence, after fixing the base lid to the base top we will have the assembled solar lamp, ready to use.



ASSEMBLED LAMP BASE



ASSEMBLED SOLAR LAMP



PROJECT COST ANALYSIS:

Item	Cost (in Rupees)
Solar Panel – 1 no.	160
Batteries - 2 no. (2.4 volts 1600mAh)	70
Circuit board (with components)	220
Flexible Gooseneck -1 no. (25 cm)	30
Aluminum Sheet – 25cm x 25cm	10
GRAND TOTAL =	**Rupees 490/- (approx)**

SOLAR PANEL (FROM SIRIUS SOLAR ENERGY):

- ➔ High efficiency 156mm poly crystalline cells, encapsulated behind glass, with a 3.5mm connector.
- ➔ High quality eva & back sheet to ensure high performance and provide good weather/resistance for rugged environments.
- ➔ Anodized aluminum alloy frame and tempered & textured clear glass with low iron content to enhance high efficiency.
- ➔ Generated approximately 5.5 volts and 114mA current under bright sunlight conditions.
- ➔ Bypass diodes provided to avoid effect of partial shading.

ELECTRICAL CIRCUIT

Technical Parameters and Specifications:

COMPONENTS	QUANTITY	SPECIFICATIONS
IN4007 Diode	3	
OA79 Ge Diode	2	
LM317 Voltage Regulator	1	
100 Ohms Resistor	1	
330 Ohms Resistor	1 1	
47 Ohms Resistor	1	0.3mm
TPS61222 IC (DC-DC Convertor)	1	0.3mm

Red LED	1	1 Watt (Surface-mount)
Green LED	1	
Load (White LED)	1	Ni-MH (2 in no.) 1.2V batteries connected in series=2.4V 1600mAh
1K/V Potentiometer		
Battery	1	1000w/m^2, Insolation AM 1.5, Cell Temp 25 degrees Centigrade 5.5V Output, 120mAh
Solar Panel	1	
	1	Mini DC Jack Socket
PCB Board	1	
Connectors	9	Single Pole Single Throw (SPST)
Switch		Single-threaded, can handle up to 2A current
Wires		

BATTERY

Technical Specification for Components and Quantity

COMPONENTS	NO. OF BATTERIES
Ni-MH Battery	2 in Series of 1.2V 1600mAh each = 2.4V 1600mAh when connected.

LEDs

Technical Specification for Components and Quantity

COMPONENTS	QUANTITY	COMMENT
White LED	1	1Watt,Surface-mounted
Red LED	1	0.3mm
Green LED	1	0.3mm

LAMP BODY

Technical Specification for Components and Quantity

COMPONENTS	QUANTITY	SPECIFICATIONS
Lamb Base	1	Thermo-plastic
Flexible Gooseneck	1	25 cms
Lamp Head	1	Thermo-plastic
Base Lid	1	Thermo-plastic
Reflector	1	White Plastic
Aluminum Sheet	1	25cm x 25cm
Lid for Lamp Head	1	Transparent Acrylic Sheet
Screws for Base Lid	2	Diameter = 0.5cm Pitch = 0.1cm Length = 1.8cm
	4	Diameter = 0.4cm Pitch = 0.1cm Length = 0.8cm
Screws for PCB and LED Mounting	1	Diameter = 0.4cm Pitch = 0.09cm Length = 1.1cm
Screw for Lamp Head		

Dimensions Specifications

DESIGN	DIMENSIONS
Base	10.5 x 10.5 x 2.5cm

Lame Head	8 x 5.75 x 2.4cm
Base Lid	10.5 x 10.5 x 1cm
Flexible Gooseneck	25cm

CONNECTING WIRES/CABLES
Technical Specification for Components and Quantity

COMPONENTS	QUANTITY	SPECIFICATIONS
Wires	10	Single-threaded for internal connections and Multi-threaded for connection to battery
Cable wire	1	For connection from solar panel to lamp.

SWITCH
Technical Specification for Components and Quantity

COMPONENTS	MAKE	QUANTITY	SPECIFICATIONS
Switch	Astron Switch Craft	1	SPST

SOLAR PANEL (FROM SIRIUS SOLAR ENERGY)
Technical Specification for Components and Quantity

COMPONENTS	QUANTITY	SPECIFICATIONS	COMMENT
Solar Panel	1	1000w/m^2, Insolation AM 1.5, Cell Temp 25 degrees Centigrade	

Performance

PARAMETER	MAXIMUM RATED VALUE
Rated Power	1 Watt
Rated Voltage	4.95 V
Open Circuit Voltage	5.8 V
Short Circuit Current	0.23 Amp
Tolerance	3% (Plus/Minus)

OPERATION:

When the solar supply is given to the circuit, the diode D1 will conduct and then the IC1 (LM 317) will regulate the voltage. The diode D2 will provide charging current to the battery and it also prevents the reverse flow of current from battery to IC1 (LM 317) when the solar supply (solar panel) is not connected.

When the switch 'SW' is in ON position, then the battery will be connected to the green LED (good battery level indicator), the red LED (moderate and low battery level indicator) and IC2 (TPS 61222) which is a 'voltage boost converter'. This IC2 (TPS 61222) will provide a fixed output voltage of 5V with its input varying from 0.7V to 5.5V.

The load LED is connected through a diode and a potentiometer to adjust the brightness of the light as required. The diode also reduces the voltage by 0.7V – 0.8V when the potentiometer is set for maximum brightness i.e. at position 'A' and no light at position 'B'.

CHARGING PROCEDURE:

- Charge the lamp using the solar panel by inserting the connector at the end of the solar panel wire into the mini DCD socket provided at the base of the lamp. *The lamp must be switched OFF when it is charging.*
- Keep the lamp indoors in shade, while charging, and away from water.
- The light can be charged fully in at least 6-7 bright sunny hours.
- After charging for 6-7 bright sunny hours, you can switch ON the lamp to make sure the green indicator had lighted up to indicate good battery level. Unplug the solar panel from the lamp and store safely.
- Do not let shadows fall on the panel. Keep it directly facing the sun as much as possible while charging.

SAFETY, PRECAUTION, AND HANDLING GUIDELINES:

- Make sure the switch is turned off during charging.
- Wipe the panel and blow dust from the connector pin periodically.

- The panel and lamp are made of tough material. But treat them with care. Dropping or throwing on hard surface could break the solar panel or light.
- Handle the switch gently for long-lasting use.
- On charging the lamp, when the green LED starts glowing, it indicates that the battery has been fully charged.

Note: In case of emergency (i.e., when sunlight is unavailable) the lamp can be charged with a suitable and working mobile AC adapter of the same pin. Charge the lamp with adapter for max 2.5 hours only, irrespective of green indicator.

CARE AND EXPECTED DURABILITY ANALYSIS:

- The battery may fail to recharge if the lamp is kept in ON mode for a long time and may need to be replaced so you must be careful to switch OFF the lamp when it is not in use.
- It is recommended to the charge the battery regularly, preferably on daily basis.
- The lamp is rigid and very strong externally but dropping it can break the lamp. Same in case of the solar panel.
- Do not use in wet places. Use the lamp indoors or where it will not get in contact with water. The solar panel, however, is not harmed if rain falls on it.
- The flexible gooseneck can be used for a long time provided that it is used only to serve the purpose and not used to play. Improper bending can reduce it flexibility or even cause it to break.
- Once the battery is fully charged, it will give the user 6-7 hours of light in bright mode, nearly 8 hours in medium brightness mode and about 9-10 hours in least brightness mode.
- If used with care, this life of this lamp can be expected to be 4-5 years or even more, provided the batteries are replaced and the lamp is treated with care.

REPLACEMENT OF PARTS AND REPAIRING NEEDED:

- The Nickel-Metal Hydride (Ni-MH) batteries can be easily replaced after the batteries are worn out but they usually can last for about 1-2 years if used properly.
- The central circuit board can be easily replaced by a new one in case of malfunction or failure, but it must be done by a semi-technical or technical person only.

OPEN SOUCRE RESOURCES:

- For circuit design – KiCad
- For PCB Design – DesignSpark PCB
- For 3D Designing – Auto Cad

IV. CONCLUSION

The designed lamp has been 3D-printed, assembled and tested. After charging the lamp by placing the solar panel under the sun for at least 4 hrs of brightness (6 hrs for full battery), you must connect the solar panel to the input of the lamp. After switching the lamp 'ON' you will be able to see that the green LED also lights up, indicating full battery. After 5-6 hrs of usage, you will notice that the green LED stops glowing and the red LED lights up, indicating low battery level.

Hence, the solar lamp has been successfully designed and tested for daily use. Making use of this clean and renewable source of energy, we not only reduce electrical power consumption but also contribute to keeping our environment also clean and free from pollution.

ACKNOWLEDGMENT

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- *3W Technologies*, ECIL, Hyderabad
- *Collab House*, Film Nagar, Hyderabad

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[4] TPS 61222
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Manufacturers: Texas Instruments
[5] Places of purchse of components:
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