Cost Benefits of Solar-powered LED Street Lighting System

Case Study-American University of Sharjah, UAE

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Abstract - *This report describes the cost effectiveness of using solar powered LED (Light Emitting Diode) streets. The case study selected is the AUS (American University of Sharjah) campus, which still uses the conventional halogen lamps for its lighting requirements. The unit charge for current is 0.45 fils/KW.hr (fils-UAE currency subdivision) and based on this rate, it costs AUS, AED 373,852 per annum (AED-UAE currency) due to the usage of conventional in their street lighting. In this project, the aim is to reduce the cost of energy in the campus by replacing all of the conventional lamps with LED (Light Emitting Diode) lamps in AUS and then to calculate the economic benefit of using theses solar powered LED lights. Solar radiation energy is used to charge the battery during daytime, and offer energy to the LEDs light equipment at night. A dimmable Modula is designed and integrated to the system to dim the LEDs at night from 01:00-06:00am. This system has a double advantage- it reduces cost as well as utilizes the renewable energy (solar) available to us*

***Key Words*: Cost, Light Emitting Diode (LED), Power, Renewable Energy, Solar Energy**

1. INTRODUCTION

This document is template. Currently, energy crisis is one of the most discussed as well as researched topic in the world. Human depends a lot on the fossil fuels for their energy requirements. But, fossil fuels are limited in amount, expensive and polluting the environment. Now, one of the ways to reduce the dependency on the fossil fuels is to utilize renewable energy resources. Such resources are firstly free of cost and also available in abundance. In UAE, solar energy is the amplest, direct and clean form of renewable energy available. Total solar energy absorbed by the Earth is about 3,850,000 extra joules (EJ) in one year, which is even twice as much as all the non-renewable resources on the earth found and used by the human being, including coal, oil, natural gas, and uranium [1]. Taking this idea into consideration, we are designing a solar-powered LED street lights for AUS campus. This technique utilizes energy-saving technology to reduce energy consumption, electricity bill and hence improve utilization of solar energy available to us.

2. MOTIVATION

The American University of Sharjah currently uses high-pressure sodium lamps for the street lighting purpose. The HPS lamps have several defects. It radiates a large amount of heat and requires 250W for each lamp, thereby increasing the cost of the energy. The AUS campus has a total of 705 posts and every post has 3 or 4 lamps. The power required by a post is 750 to 1000 watts continuously working for 12 hours a day. This would consume a lot of energy at high prices.

Figure 1: conventional Street Lamps in AUS

The current technology which is being used in AUS is:

- Lamps: OSRAM, Vialox, 250 Watts, High-pressure Sodium Lamps (HPS) [2].
- Ignitor: ZONDGERAT, Mzn 400 Sx.
- Ballast: BAG Electronics, HM/HIUAB, 250 Watts for High-pressure lamps.

- Capacitor: DNA, CA /250, 35Mfd 240V.

In AUS, it costs AED 373,852 per annum due to the usage of conventional high-pressure sodium lamps in their street lighting and the per unit rate was 0.45 fils/KW.hr. Shown below is a data of whole of the University City and then per unit rate was 45fils/KW.hr [2].

TABLE 1: POWER CONSUMPTION OF THE UNIVERSITY, SHARJAH

Title	Total-MWhr/day	Total-MWhr/year	Cost/day (AED)	Cost/year (AED)
AUS	5.1	1869	1024.25	373,851.5
Police Academy	1.1	405	222.00	81,030
Higher Colleges of Technology	1.8	665	364.5	133,042.5
Sharjah University	4.7	1743	955.5	348,757.5
City Hall	1.13	413	266.5	82,672.5
Library	1.17	427	234	85,410
Main Roads and Entrances	5.6	2057	1127.6	

Analyzing these facts, we decided to do put forward a plan to overcome the drawbacks of the current lighting system in the AUS campus. The proposed solution is to replace all of the conventional lamps with solar-powered LED lamps and then control them using motion sensors and then to later on use a mobile application to control the switching ON/OFF of the led and at the same time check for defected units. These kind of Smart Led Street Lighting System (SLSL) with a mobile application has been currently implemented in different areas of U.A.E such as on flyover just before Ajman City Centre and also in Abu Dhabi. The aim of this research is to focus on how can we implement SLSL in AUS and how much will be the upgrade cost from conventional street lamps to LEDs and the cost of each of them as well as how much is the saving for long time operation.

3. LED's (proposed solution):

It was found that AUS street lighting system has 705 lamp posts. Some have 3 lights and some have 4 lamps per post. Each light consumes 250 watts [8]. The proposed design is to replace each lamp with 40 watts LEDs:

- LED's (proposed solution)
- Energy Consumption for 705 lamp posts each with 4 lamps:
  705 x 40 W x 4bulbs = 112.8 kW
- Per night consumption
  112.8kW x (12hours/day) = 1353.6 kW.hr
- Annual consumption in MW.hr
  1353.6kW.hr x (365 days) = 494.064 MW.hr
- Annual consumption in AED, with the rate 0.45 fils/KW.hr
- Cost = AED 2,22,328.8 / annum

4. ADVANTAGES AND DISADVANTAGES OF LED STREET LIGHTING SYSTEM

- 80% less energy use in addition to savings from high- efficiency lamps.
- 50% or more savings per year in operating and maintenance costs.
- Better living environments with more reliable and safer lighting.
- The ability to mix lamp technologies to suit the needs of the city and accommodate new lamp types.
- An expandable infrastructure that supports multiple applications such as traffic, weather, and motion monitoring.
- A Tremendous reduction in CO2 emissions.
- Longer lifespan of LED lamps compared to HPS lamps.
- Doesn't take any time for dimming and it is an instant process.

SLSL also has disadvantages which are as follows:

- Higher initial upgrade cost from conventional lamps to LEDs.

5. SMART STREET LIGHT SYSTEM WITH ENERGY SAVING FUNCTION

Currently, we waste enormous amounts of energy by using street lamps in a non-efficient way; that is, they turn on automatically when it is dark and light up automatically when it is day time. So the system they have proposed in this project is similar to ours because are using motion sensors, light sensor, and a short distance communication network. Basically, the motion sensor detects either the pedestrian or a vehicle approaching and it lights up or dims and even switches off at times when no motion is detected. [7]

There are some attempts being made to reduce the energy wastes of street lamps, such as, a sensor light which will be controlled by a light sensor and optionally a motion sensor are used. But there is a delay in switching on the light using the motion sensor because the person or vehicle should be in close proximity to the street lamp instead it should switch on before the desired object comes close so that it lights up the street. Some companies and universities have developed central systems to control the street lights smartly using one central computer. These systems are suitable for controlling street lamps on a large scale and are not at all suitable for small scale project.

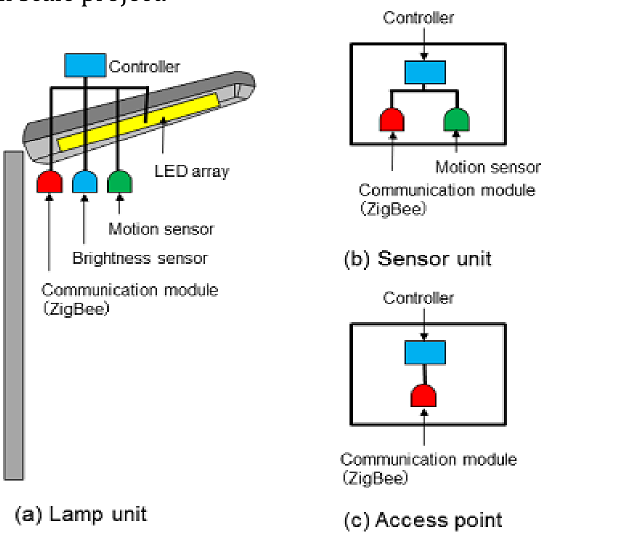

Figure 5: Components for the Smart Street Light [7]

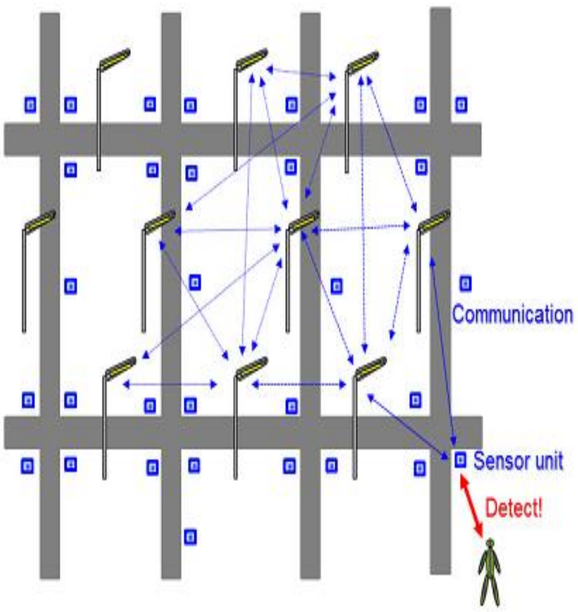

Figure 6: Object Detection Network [7]

6. DESIGN

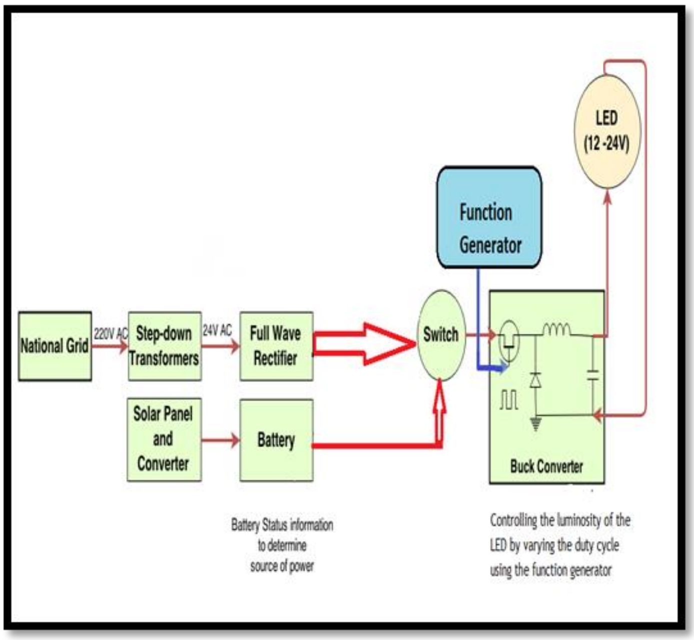

Figure 7: Overall System

7. SYSTEM DECOMPOSITION

The following are the main parts used for proposed solution:

1. Solar Panel

The solar panel is one of the most important parts of solar street lights, as solar panel will convert solar energy into electricity. There are 2 types of solar panel: mono-crystalline and poly-crystalline. The conversion rate of the mono-crystalline solar panel is much higher than poly-crystalline.

2. Lighting Fixture

LED (Light Emitting Diode) is a solid state semiconductor device which can convert electrical energy into visible light. It is usually used as a lighting source of modern solar street light. It is because of the fact that it has a small size, low power consumption ad long service life. The spectrum of the LED is mostly concentrated in the visible light spectrum, so it has a high luminous efficiency. Also the energy consumption of LED fixture is at least 50% lower than HPS (High-pressure Sodium) fixture which is widely used as a lighting source in traditional street lights. Another advantage is that LED lacks warm up time that adds to its efficiency.

3. Rechargeable Battery

The electricity from the solar panel is stored in the battery during the day and it provides energy to the fixture during night. The life cycle of the battery is very important to the lifetime of the light and the capacity of the battery will affect the backup days of the lights.

4. Controller

It is the controller which decides the switch on /off, charging and lighting and the dimming of the SLSL.

5. Pole

Strong Poles are necessary to all street lights, especially to solar street lights as there are components mounted on the top of the pole: Fixtures, Panels, and sometime batteries. And wind resistance should also be taken into consideration when choosing the pole.

8. OPERATION PRINCIPLE

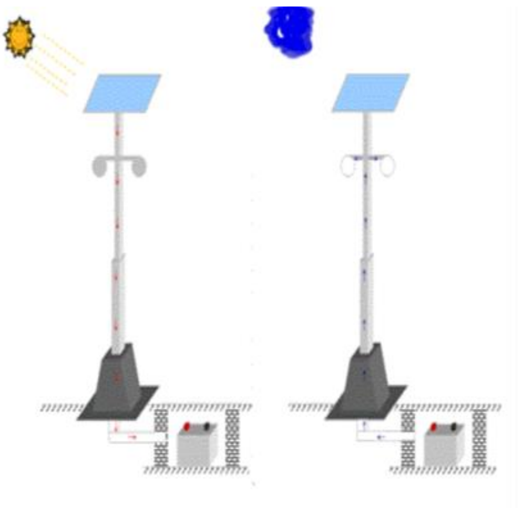

Figure 8: Operation Principle

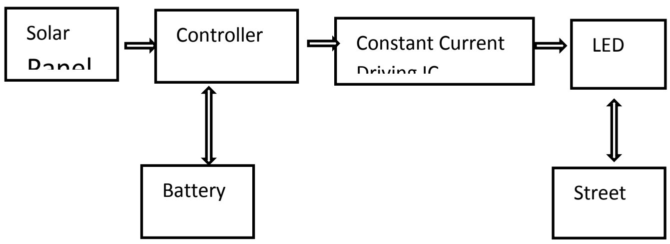

Figure 9: System Work Flow

According to the principle of photovoltaic effect, the solar panels receive solar radiation during the day time and then convert it into electrical energy through the charge and discharge controller, which is finally stored in the battery. When the light intensity reduced to about 10 lux during the night and open circuit voltage of the solar panels reaches a certain value, the controller has detected voltage value and then acts. The battery offers the energy to the LED light to drive the LED emits visible light in a certain direction. Battery discharges after certain time passes, the charge and discharge controller will act again to end the discharging of the battery in order to prepare next charging or discharging again

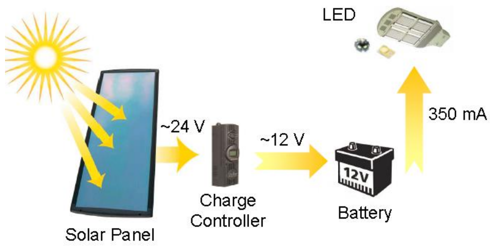

Figure 10: Solar Power- Block Diagram

9 .REQUIREMENT SPECIFICATIONS

The American University of Sharjah (AUS) has a total of 705 no of poles. Each pole consists of 3-4 lamps, but on average we are taking 4 lamps in our system [2]. Therefore the total number of lamps used in AUS is 2820 lamps. Therefore to select an appropriate LED we had to know their technical specifications in order to quote them to a company. By thorough research, we found companies which would suit our requirements to implement the real-time model. The UAE Solar Energy is one of the leading companies in LED industry which fulfills the standard requirement. The following shows the specifications of the street light.

Product Details:

- Model JNYT-40W -Solar panel
- Max power 18v/65W
- Life time 25 years
- Battery type : Lithium-FePo4battery
- Capacity 12.8V/30AH
- Life time 5 years
- LED Lamp
- Max power :12V/40W
- Led chip :Bridge lux from the USA
- Lumen (LM) :4800-5200lmlm
- Led chip :40pcs
- Life time :50000hours

Product Parts:

- Solar Panel
- Li-Fe Battery
- LED
- MPPT controller

- Human intelligence induction System

Product Properties:

- Angle 120 degrees
- Charging by sun light :7 hours
- Full power more than 10hours
- Half power more than 20hours
- Work temp range (*C) : 30-70
- Color temp range(k) :3000-6000
- Height range (m):4-5m
- Space range (m) :8-10m
- Material aluminum alloy
- Certificate CE / ROHS/ IP65
- Warranty 2 years

10. IMPLEMENTED MODEL DETAILS

We wanted to implement the real system in our project, but due to the high cost of an actual system, we decided to build a scaled down model. The cost of one entire set is AED 3500 and this was beyond the allowed range for us students. However, when the university is buying it in bulk, the cost reduces and also the university has to afford only its initial cost of setting up the solar-powered LED. Because once it is set up, the LED then completely works on solar power, thus reducing the overall power consumption .The following are the details of our miniature model. Electrical students had to build the buck convertor on their own to interface the buck converter with the rest of the model.

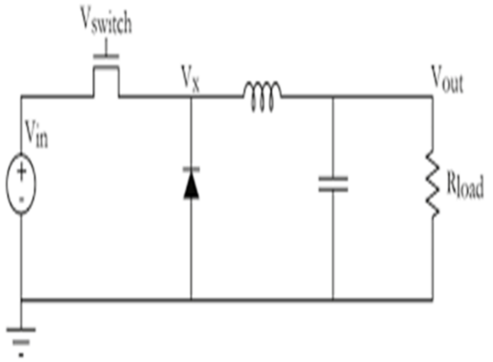

Figure11: Simple Buck Converter Circuit

The figure [10] above shows a basic buck converter circuit. The buck converter is used in our project to control the dimming function of the LED light using a power MOSFET. The MOSFET works as a switching regulator. In other words, the MOSFET voltage depends on the time of the duty cycle in order to have the solar panels voltage (input voltage) to vary by turning the MOSFET ON/OFF in order to control the voltage transferred to the load. Our system is made up of a solar panel that supplies energy of 12 volts and stores it in a battery, the battery discharge this energy to the buck converter input voltage. The switching voltage of the MOSFET is a control signal that controls the duty cycle. When the input voltage is high, the MOSFET turns ON allowing the input voltage to pass which is greater than the output voltage. Then the current through the inductor starts to increase and charges the capacitor. When the MOSFET turns OFF the current through the inductor starts pass through the diode producing a voltage equals to approximately zero. This voltage is less than the output voltage. Then the current through the inductor decreases and the capacitor starts to supply current to the load. This will produce a controllable buck converter in which it reduces the input voltage to any required output voltage for the load. [8]

The Buck Convertor Specifications:

- Output Power: P = 7 Watts
- Input Voltage : Vinput = 12V
- Current through one Led: I led = P / V = 7/12 = 0.5833A

Here we assume the load has 4 LEDs: Total current through the load:

- Current (I) through load =4*0.5833= 2.5 A
- Duty Cycle: D = 0.5
- Vout = D* Vin =6 V
- Ripple Current: Ir =30% * I load =0.75A
- L=(Vin-Vout)*D)/Iripple*Frequency)

Assuming frequency to be 6Khz

- L≥0.77mH
- Vripple =100mV
- Capacitance=((1-D)*I load*D*T)/Vripple >= 1.04mF
- Diode should be able to handle current greater than 2.5A
- Mosfet >= 3* Vin => More than 30V
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- Diode should be able to handle current greater than 2.5A
- Mosfet >= 3* Vin => More than 30V

11. COST ANALYSIS

- Sodium lamps (Current system)
- Energy Consumption for 705 lamp posts each with 4 lamps:

  705 x 250W x 4 bulbs = 705 kW per day consumption:

  705kW x (12 hours/day) = 8460 kW.hr

- Annual consumption in MW.hr:
  8460 x (365days) = 3087.8 MW.hr

- Annual consumption in AED, per fils rate 0.45 fils/KW.hr
- Cost = AED 1,389,510 / annum

11.1 LED's (proposed solution):

- Energy Consumption for 705 lamp posts each with 4 lamps:
- 705 x 40 W x 4bulbs = 112.8 kW
- Per day consumption
- 112.8kW x (12hours/day) = 1353.6 kW.hr
- Annual consumption in MW.hr
- 1353.6kW.hr x (365 days) = 494.064 MW.hr
- Annual consumption in AED, per fils rate 0.45 fils/KW.hr
- Cost = AED 222,328.8 / annum
- This cost estimation leads us to a ratio of 1: 6.24
- Cost of electrical components which includes lamp post, control box, solar panel, LEDs and battery = AED 3500[14]
- Initial Cost of setting up 705 Led lamp posts = AED 3500*705 = AED 2,467,500

Implemented Model Cost:

- Solar Panel with the controller and the battery = AED 500
- LED (7 W- Dc Dimmable) = AED 70
- Buck Convertor Components = AED 40
- Total Cost = AED 610

Types of Lamps	Annual Consumption (705 Lamps posts each having 4 lamps)	Annual consumption, per fils rate 0.45fils/KW.hr
HPS	3087.8 MW.hr	AED 1,389,510 per annum
LED	494.064 MW.hr	AED 222,328.8 per annum

From the above table, we can see that if we switch to solar powered LED street lamps, the university campus can save up to AED 11,67,182 per year, which is a huge amount.

12. SIMULATIONS

A simulation of the miniature was carried out as shown in the figure. We build the buck convertor and interfaced with solar charged battery and function generator and tested the ON/OFF as well as dimming of the 7 Watts Led. The only problem we faced was the heating up of the mosfet. The problem was solved by using a heat sink with the mosfet.

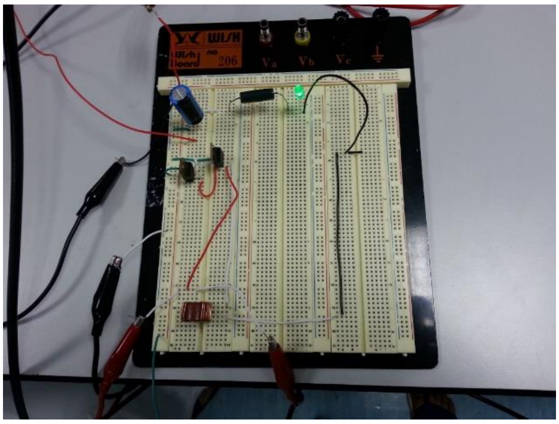

Figure 12: Buck Convertor with Small LED

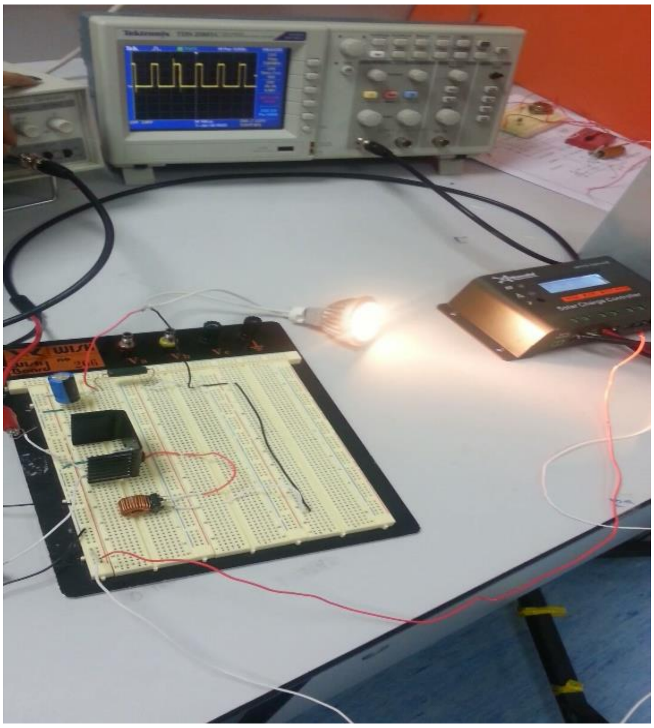

Figure 13: Dimming the 7Watt LED by Varying the Duty Cycle

13. CONCLUSIONS AND FUTURE WORK

Despite the fact that UAE receives solar heat radiation throughout the year, United Arab Emirates (UAE) suffers from high power consumption and other energy problems as the oil reserves are running out. As a solution to this problem, by taking the scenario at AUS campus, we demonstrated that, by using solar powered LED street lights, it is possible to reduce the cost as well as the energy consumption by a huge amount. The aim to reduce the cost was successfully demonstrated in the project.

This solution can further be improved by developing a mobile application so as to monitor these lamps individually and also to detect their faults.

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