Smart Solar Powered Street Light

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1 Introduction

1.1 Objective

Humanity currently faces many challenges that will depend on new developments and techniques to create a sustainable future. With one of the biggest challenges being energy consumption, there is a reason that renewable energy sources like solar and wind are seeing dramatic growth. While the demand for energy is expected to keep increasing, there is a need for technological developments to improve the efficiency of devices that use large amounts of energy. In order to help with this problem, we are proposing a change to the current lighting system outdoors to illuminate streetlights. With advancements in semiconductor technology, Light Emitting Diodes (LED) have become more suitable for various uses like outdoor lighting. [5] These lights have been known to have energy savings costs of around 50%, which is beneficial not only because they save energy but because half of the street lights in the U.S. are operated using public funding. [2] This means by using more efficient street light fixtures, less taxpayer money will need to be spent on the energy cost to utilize these lights.

Our group saw that there was an opportunity to make these LED street lights even more efficient by equipping them with solar panels/energy storage, along with sensors to indicate when there is someone approaching the vicinity. Using solar panels, the street lights will be able to harness their own energy during the hours that the light fixture is not functioning, and utilize that stored energy at night to illuminate our streets. Cost reductions in solar photovoltaics have led to an increase in the use of solar energy, which had lead to the development of different solar powered devices like street lights. These street lights are becoming more common, and have many advantages like using green energy, independence from the grid, and energy savings costs. They do come with disadvantages like higher installation cost, battery replacement cost, and susceptibility to reduced energy production from moisture, snow, or dust. In order to combat some of these challenges with solar street lights, we are proposing to use sensors in order to detect when the lights need to be on at full intensity and when they can idle at a lower intensity for energy savings. Also, we believe it would be beneficial for the design to incorporate a connection to the grid for safety reasons during events that the solar power generation does not meet the needs of the lighting system. This can occur when the solar photovoltaics are damaged or incapable of harnessing energy due to coverage or weather conditions (including areas with limited sunlight exposure).

1.2 Background

With the world's energy usage on the rise and not slowing down, there is a need to improve efficiency in order to reduce usage and operating costs. This rising trend can be seen in figure 1 that comes from the U.S. Energy Information Administration. [10] One of the new technologies being implemented today is the solar street light that uses LEDs to illuminate streets and neighborhoods. We plan to incorporate this technology and develop a way for these lights to consume even less energy using doppler sensing. With this method, the streetlights will be even more energy efficient and cost-effective.

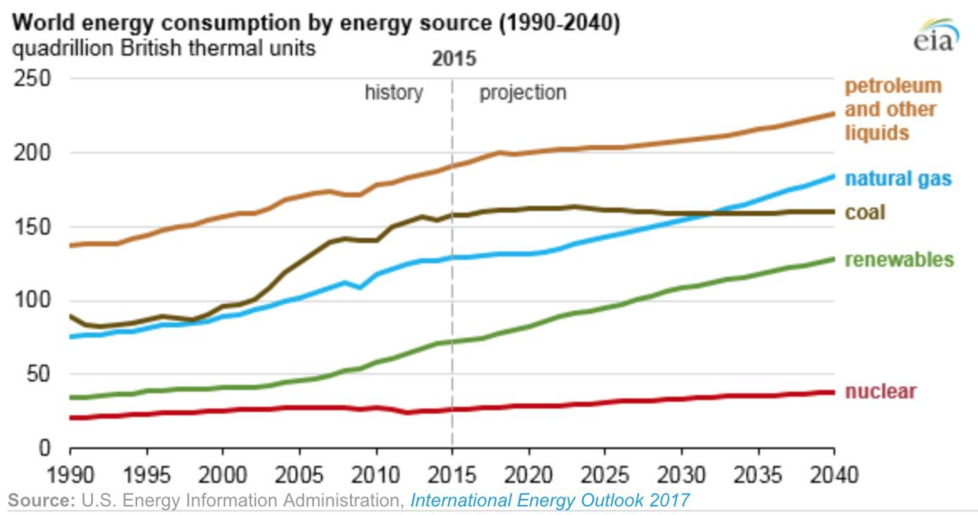

Figure 1: World Energy Consumption Trends and Projections

1.3 High-Level Requirements

- Streetlight must be able to supply and sustain at least one typical nightly use, based on local Champaign specifications and regulations as well as applicable state and national requirements.
- Doppler sensing method must be capable of detecting a typical United States road-legal passenger vehicle, cyclist, or pedestrian at a maximum of 30 MPH speed toward the sensor with an average United States residential lane width of 12 feet.
- Intensity control must maintain the minimum legal illumination at all times, while also increasing brightness as necessary based on doppler detection.

2 Design

Each streetlight is responsible for generating electricity through its solar panel as well as being tied to the grid in order to make up for any deficiencies in solar generation. As a result, there are both AC and DC power inputs which must be taken into consideration before supplying power to the light fixture. On the control side, the voltage will be stepped down in order to operate the microcontroller and sensors necessary to correctly adjust intensity based on vehicle detection. Doppler sensors will communicate with the microcontroller in order to perform this intensity control. In addition, local electricity rates will be taken into account in order to actively determine which source of power is the most cost-efficient.

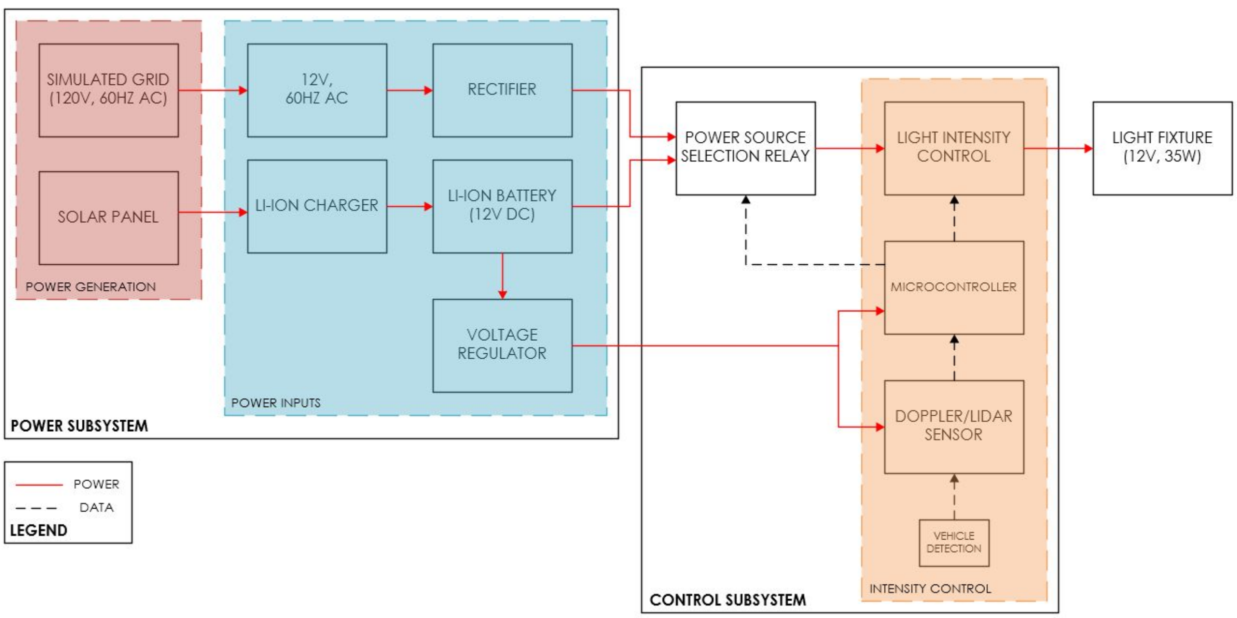

Figure 1: Block Diagram

2.1 Power Generation

Street lights are powered by local electrical infrastructure in various daisy chain formats. To make our street light proof of concept as close to real street lights we will pull from a simulated AC grid. The other form of generation will come from the DC solar panel on top of our steer light. Both these forms of generation will provide 35W for our light.

2.1.1 Solar Panel

A solar panel will be placed on top of our pole, higher than actual light, and angled in a sufficient manner. In the northern hemisphere, fixed panels should be oriented pointing true south. To increase our panel efficiency we would require the angle to change for summer and winter. For this class, we will orientate our panels for the summer case, which falls on March 30th and goes to September 29. UIUC sits at a longitude of 40° and according to common solar panel tilt equations [1]

$$(latitude \ * \ .93) - 21 = Tilt\ Angle \quad (1)$$

This gives us a tilt angle of 16.2°. This angle and longitude gives us an average Solar Insolation according to resource [1] of $6.0 \frac{kw}{m^2}$. It is also understood we will need to verify this insolation and take into account our losses. With this angle we'd be getting 75% of the energy out of these panels compared to if we did a sun-tracking system. Thus in an ideal world, we would need at minimum a solar panel of size $8.833m^2$.

Requirement	**Verification**

2.1.2 Simulated Grid

For our design, hooking our project to the real grid poses a few problems. The first and most important is safety. We are going to avoid working at high power when not needed. Because of that, we intend to step down our AC voltage to a safe voltage of 12/24 V AC. Since this is just for safety and practical purposes we intend to use a commercial transformer to go from Grid AC to our 12/24V AC

Requirement	**Verification**

2.2 Power Inputs into Light

There are three outputs from our power input module. Our solar panel will output DC power into our batteries for storage during the day. The system will also output a rectified DC waveform of our low voltage simulated grid. Both these outputs will be sent to a power relay, where the correct power input will be selected based on our control subsystem.

Requirement	Verification

2.2.1 Battery System

In order to utilize our solar photovoltaics, we must use be able to store the energy harnessed during the day in order to use it at night to power the street light. To do this we must use rechargeable batteries that are capable of outputting enough voltage and store enough energy to run our lighting system for a full night's use. Similar systems use lead acid, gel cell, or lithium ion deep cycle batteries in order to store charge at desired times and discharge during use. This batteries must be able to charge during the day time and then run the lighting system for approximately 10 hours at night, when the street lights are turned on. In order to achieve this the approximate size of our battery would be 350 watt-hours. This battery needs to be rechargeable as well in order for us to use the solar panel. For the battery system, we will be using a charging circuit to go from the solar panel and into the battery.

Requirement	Verification

2.2.2 Charge Controller

In order for us to use solar panels to charge our batteries, we must have a charge controller or charge regulator to prevent from overcharging. This device regulates the voltage and current coming from the solar panel and being used to charge the batteries. Solar panels have a voltage rating that is lower than the value they can actually put out. This is due to the panel being used under certain conditions like sunlight and temperature exposure. The charge regulator is used to make sure the desired voltage for charging the batteries is used and prevents damaging the batteries in the charging process. [8] The charge controller also prevents the power from the batteries draining through the solar panels at night when the panels are not in use.

Requirement	Verification

2.2.3 Voltage Regulator

In order for us to incorporate our microcontroller and doppler/lidar sensor to our system we must have a way to bring them power. To do this a voltage regulator must be used with the battery system. This regulator will step down the voltage from our batteries to the appropriate voltage rating that will be used by these modules.

Requirement	Verification

2.2.4 Stepped Down AC Voltage and Rectifier

When using grid power (or simulated grid) it is necessary for us to be able to go from ac voltage at at a common outlet to dc voltage for us to use in our system. Common household outlets have a rating of 120V ac at 60Hz, which cannot be used with our system. To use this as a power source we need to step down the voltage and use a rectifier circuit to make it dc voltage. To do this we can use a transformer to step down the voltage and a rectifier circuit to convert from ac to dc voltage.

Requirement	Verification

2.3 Power Source Selection

The ultimate goal of our project is to save a residential community money on the cost of powering their street lamps. In order to do that we need the ability to switch between our free power, solar/battery, and the power the community buys from the grid. Therefore our Power relay needs to be able to switch between the 35W rectified DC and the 35W DC from our batteries. On top of that, there are other factors that will determine which power input is selected. Which will include the time of day, $\$/kwh$, and the light intensity needed by our light. The light intensity needed by our light would come from our doppler sensor and microcontroller.

2.3.1 Power Relay

We would use a programmable relay that took into 2 inputs and outputs the power to be used for our lighting. However, the logic used to select our power would come from code we right on time of day, $\$/kwh$, and information from our doppler sensor. This relay would also need protection built in to be a barrier between our power input and our light.

Requirement	Verification

2.4 Intensity Control

2.4.1 Light Intensity Control

In order to properly control the intensity of the light, a minimum of 0.3 cd/m^2 must be maintained as specified by the Illinois Department of Transportation (IDOT) roadway lighting regulations [4]. Depending on the light fixture chosen, it is possible to reduce the brightness of the light upwards of 30% [6].

Requirement	Verification
Maintain at least minimum legal luminance during operation	Light must be able to maintain at least 0.3 cd/m^2 for 13 hours continuous (the average time from 30 minutes after sunset to 30 minutes before sunrise in Chicago during summer)
Automatically adjust the intensity to the maximum based on detection of an oncoming vehicle, return to baseline intensity after the vehicle has passed.	Light must be able to reach peak intensity from its base intensity after a vehicle is detected, and return to its base intensity when no vehicle is detected

2.4.2 Doppler Sensor

The Doppler sensor is the detection method for intensity control, it must be able to communicate with the microprocessor which handles the direct adjustment of the light fixture brightness. This will either be an off-the-shelf module or a custom module developed on a PCB.

Requirement	Verification
The Doppler sensor must be able to detect an oncoming motor vehicle at a maximum of 30 meters away, traveling at a maximum of 40 miles per hour on a United States standard 12-foot residential roadway lane.	The signal received by the sensor must be decipherable and reportable in a manner that represents the detection of a vehicle as described by the requirement.

2.4.3 Light Fixture

The light fixture is the manifestation of the power generation and control processing that makes up the bulk of our project. For this reason, it will be simpler to use an off-the-shelf light fixture to reduce development time considerably. The light will be raised to a height that allows us to simulate it functioning as a normal outdoor streetlight.

Requirement	Verification
The light fixture must be rated for at least the power output that is driven by our battery or grid connection.	The rating of the light fixture must be at least
The light fixture must be able to maintain at least the minimum required brightness while also having the capability of adjusting brightness to below maximum.	The light must be project at least 0.3 cd/m^2 at all times and be able to reduce its intensity to its base value during no detection

2.5 Risk Analysis

The Doppler sensor and corresponding control methodology will be the grandest undertaking for this project. Commercially available Doppler modules typically do not have detection ranges near the 30 meters that we have specified without a cost that is below the limit for this course. As a result, it is very likely that this module will have to be developed independently, which dramatically increases the development time for this specific unit.

With this in mind, the modularity of our design allows us to focus on the detection and control completely separate from the power generation modules. This will alleviate a decent level of strain from a lack of resources or time. Since our group does have members with previous experience developing PCBs in Eagle and Altium, we do not believe that this will add on to a developmental delay. In addition, there are many resources that we can make use of to advance quickly towards a Doppler module that will fulfill our requirements while maintaining a reasonable cost and development timeline.

3 Safety and Ethics

Whenever power electronics are being built, safety has to constantly be the number one thought on our minds. To prevent us from dealing with very high voltages we are ensuring our voltage never reaches above 12/24V compared to dealing with grid voltage. However we are powering a light of 35W, therefore currents can and will be at levels that can kill. This means at all times we need to avoid being in direct contact with live conductors. Another safety concern we need to take is double checking our circuit before ever having it be live. This will prevent careless connections, or accidental shorts or loose wires.

We will also being dealing with lithium ion batteries. These batteries when fully charged and combined with high heats can cause stress on individual battery cells. Constant stress can causes explosions or fires. Stresses can also result in charging or discharging at a faster speed then they are rated for, or overcharging batteries. To avoid over charging we’ll have a charge regulator that won’t allow overcharging or undercharging of our batteries.

Vehicles will be involved in our testing. Taking extreme caution in our surroundings, other cars, and the person driving is important. Getting hit by a car would lead to severe injury. When using the doppler radar we must make sure there is no chance of getting in the cars way.

In terms of ethics, we must remember during this project that #1 “To hold paramount the safety..”[9] is our top ethical dilemma. Street lights are used for public safety at night. We can not cut corners or risk there being no light. That is why regardless of our energy storage and doppler radar, we will be hooked up to the grid and ready to output full power and light intensity if anything goes wrong. Also since we will be dealing with the aspect of saving money, principle #2 would be a dilemma. We’d know how much money a town is saving on their bill. Many parties could be interested in our data and we’d need to maintain our ethics and not give away data that should not be given away.

4 Cost

Part	**Cost**
Solar Panel(s): 100W, 12V solar panels (Ameren)	$0
Battery Pack: 12V, 100Ah flooded lead acid (Previous project)	$0
Charge control: bq24650 MPPT Charge Controller	$15
PCBs: PCBWay (class bulk order)	$10
Radar Sensor: K-LD2	~$50-90
Power Relay:	$
Lighting Module	~$40-60
Total	$

5 Schedule

Week	Group Goals
2/17-2/23	❑ Design Document ❑ Retrieve Solar Panels and Battery (STL trip) ❑ Decide on lighting model (amazon order in case of return) ❑ Visit machine shop with panels for structure
2/24-3/2	❑ Decide on doppler module and place order ❑ Order lighting module ❑ Design proto-PCB for testing ❑ Test panels output during different parts of the day ❑ Check batteries ❑ Prepare for design review
3/3-3/9	❑ Design Review Week ❑ Soldering assignment ❑ Teamwork evaluation I ❑ Order chip for battery charging module ❑ Begin testing of proto-PCB (if available)
3/10-3/16	❑ First round official PCB orders (must pass audit)
3/17-3/23	❑ Spring Break
3/24-3/30	❑
3/31-4/6	❑

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