AUTOMATED HYBRID WIND-SOLAR SYSTEM USED FOR OUTDOOR LIGHTING (INDUSTRIAL USE)

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ABSTRACT

This project addresses one of the major issues in the power engineering industry where power generation and distribution companies are often faced with situations where the consumer power demand is very high, thus resulting in temporary blackouts or the re-scheduling of a unit's maintenance which increases the risk of the unit's sudden failure. Several transitions have been made in the power industry to try matching today's growing power grid demand. Recently several municipalities converted their street lights from HPS lights to LED as a result of the heavy consumption. The proposed capstone project, if fully integrated in several cities, will remove a large load from the power grid mainly through the use of wind and solar energy. The prototype will optimize power output by utilizing a Vertical Axis Wind Turbine (VAWT) and a photovoltaic polycrystalline solar panel that will provide necessary energy for a LED light bulb. The choice of exploiting wind energy and solar energy is counteractive since wind energy is available at days where solar energy is missing. An IES type III Lighting distribution will be used to meet the minimum illuminance and luminosity that is set by the National Department of Transportation. The team will attempt to include an Arduino programmed dual-axis solar tracker that is expected to increase the solar panel's electricity output by more than 25%. The team will try to overcome the complexities posed by the integration of this automated system, however a study has been done on optimizing power output by accurately calculating and positioning the solar panel in a way that it meets the exact altitude angle (α) and azimuthal angle (β) that are desired for a maximum energy output by the panel. Undergoing research will determine the specific type of polycrystalline panel, battery, controller, pole material, stepper or servo motors, and VAWT that will be featured in the system.

Due to the mobility of the prototype, this lighting system could potentially be the ultimate solution to reach certain remote areas in third world countries that do not have electricity or lighting in the areas concerned because power companies and governments do not want to spend a large sum of money to set up transmission lines.

INTRODUCTION

This capstone design project addresses one of the major issues in the power engineering industry. Currently, power generation and distribution companies are investing billions of dollars on emerging technologies such as lithium-ion battery storage systems to address the continuous convergence of global electrification in the world. Numerous power plants struggle at times when the electric grid's high demand is hard to match by the output energy; as well as times where certain units are down for maintenance purposes. Despite the ongoing technological advances, there are several regions in the world that are not reached by electricity thus not having access to lighting. The mobility of the prototype will make it possible for these regions to be reached by lighting since the system uses renewable energies; therefore there is no need for transmission lines that are needed to provide power for the lighting lamp.

ENGINEERING DESIGN PROCESS

The engineering design process is an approach used by engineers to guide them as they solve problems. Engineers must first start off by identifying a need or problem. The two main problems that urged the pursue of this project are the following: the first being that power plants are often faced with situations where they cannot supply enough power to the grid and the latter being the inability to reach certain regions with lighting due to the location (this is very common in 3rd world country). After identifying the problem, the team conducted heavy research on lighting, wind energy, and solar energy to ultimately combine them together and provide a solution. Currently the team has completed for the most part the first 4 steps of engineering design: identifying the problem, identifying the design constraints, developing possible solutions, selecting best possible solutions. The next step is to create a preliminary model/conceptual plan before proceeding to testing and evaluating the solution.

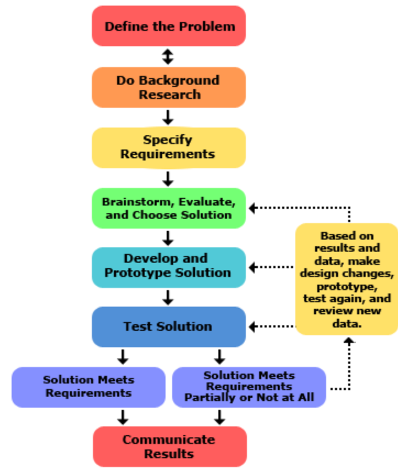

Figure 1. The Engineering Design Approach

HOUSE OF QUALITY

The House of Quality shows multiple customer requirements that were considered which brought up a lot of possible engineering characteristics to the team's attention. Each customer requirement is listed, and is then ranked on a scale of 1-5. The team decided that safety would hold the most value because it will be the most important to the customer. Next, each engineering characteristic of the project is listed. A matrix is then created, and the numbers 1, 3 and 9 are used to signify if the engineering characteristic significantly (9), moderately (3), or slightly (1) affects that particular customer requirement.

Each item was ranked, and it was determined that the mounting surface was the most significant part of the design. While it may seem obvious, if the light pole assembly is mounted in a soft/weak surface, the pole could fall, which would create a huge safety issue.

Also It was found that the wattage generated by the renewable energy sources was the second most important; Even if the battery is well over the capacity to hold charge for a few days, insignificant power generation would mean that the system would not work in the long run.

The house of quality is a work in progress and should not be considered final. One of the most important steps with the House of Quality is to show it to the customer(s) and see if they are satisfied with the ranking of the engineering characteristics.

		Engineering Characteristics						
Improvement Direction		Up	Down	Up	N/A	Up	Up	Up
Units		lbf/in^2	mph	h	N/A	N/A	N/A	Watts
Customer Requirements (Score 1-5)	Importance Weight Factor (1, 3, or 9)	Mounting Hardware/Pole Strength	Wind Speed to Turn Blades	Time Sunlight Hits Solar Panel	Mounting Surface	Durability of Turbine	Durability of Solar Panel	Wattage Generated by Turbine/Panel
Weather Proof	4	3			1	3	3	
Long Lasting Battery Charge	4		3	3	9			3
High Input to Battery	4		9	9				9
Safe	5	9			9	3	3	
Efficient	4		3	3				3
LED Brightness	3			1	1			1
Raw Score	385	57	60	63	88	27	27	63
Relative weight %		14.8	15.6	16.4	22.9	7.0	7.0	16.4
Rank Order		4	3	2	1	5	5	2

Figure 2: House of Quality

MANUFACTURABILITY

One of the primary concerns when doing any design project is how the project or product will be manufactured. As a preface to the rest of the report, this project will consists of doing a single, handmade custom built product.

All projects have three main types of manufacturing process. **Primary**, which is taking raw material to create a shape or frame. **Secondary**, where a shape or frame is modified. And finally, **Finishing**, where the product is painted and touched up. The team's project will consist mainly of secondary and finishing manufacturing. There are also multiple factors that have influence on the selection of what process to use. These include [1]:

- Quantity of parts required
- Complexity—shape, size, features
- Material
- Quality of part
- Cost to manufacture
- Availability, lead time, and delivery schedule

For this hybrid project, the most important of these things will be the **complexity**, because of how inexperienced the team members are with some of the components and procedures, such as electrical wiring. **Cost** is important as well because of the team's current funds and budget. Lastly **lead time** is critical as well since the team is unsure of how long some of these components will take to be available.
Finally, the team must consider repeatability in the project. If a component ever gets damaged, the design needs to be able to account for being disassembled and put back together multiple times over the course of its life.

On the other hand, if the team were tasked with creating a large number of the Hybrid systems, the manufacturing process would be almost completely different. The pieces would need to most likely send to contractor groups to assemble, as current small team of four members would not be enough. Quality also plays a big part when a manufacturing process consists of making multiple units over a short period of time. This means that personnel would need to be hired for the sole purpose of checking to make sure that the manufacturing process accurately represented the design.

MATERIAL SELECTION

Material selection is possibly one of the most vital areas of a design that needs a lot of special care and attention. Choosing wrong material can mean the difference of having a design that will last for decades, or a design that fails in less than a year and can potentially be harmful to the consumer using it.

For the Hybrid Powered Lighting team, there are very few areas of the design that actually require the team to select the material to be used. Most of the components that will be used in the design will be purchased from other manufacturers who have already performed material selections for their products. However, there are things like the base and the pole that will require careful material selections by the team members.

Because the base and pole will be subjected to harsh weather conditions their entire service life, they will need to be corrosion resistant. Some metals that are considerably corrosion resistant that the team will consider are stainless steel, aluminum, and possibly galvanized steel with a corrosion resistant coating. The metal chosen will also have to have high fatigue strength and fracture resistance as especially the pole will be exposed to high stresses during windy conditions coupled with the weight of the solar panel and wind turbine mounted near the top.

The team will carefully analyze and compare these materials using weighted decision matrices before making a final decision on the material to be used. Some factors that will be compared are corrosion resistance, fatigue strength, fracture toughness, cost, and availability, with the possibility of others to be considered later when the decision will actually be made.

ENVIORNMENTAL CONCERNS

One of the main aspects of this project is the environmental concerns associated with it. The most important part of renewable energies is how much better they are for the earth compared to using fossil fuels. While things like coal and natural gas will eventually be depleted, there is essentially an unlimited amount of air, water, and solar energy that can be harvested with minimal impact to the environment.

One of the largest environmental concerns with wind turbines in general is how they typically account for a lot of bird deaths. On the other hand, many solar panel farms take up a large amount of land space. While renewable energies are not without their issues, a small scale project like the one presented would have neither of the aforementioned issues, and would have extremely minimal impact on the environment compared to larger scale renewable energy producers or traditional power plants.

The environmental impact when creating a project such as the renewable energy powered street lamp are miniscule compared to the amount of power that would need to be outputted by a power plant using coal or natural gas.

For example, there is almost no impact to the environment when manufacturing solar panels or small wind turbines compared to that of a traditional power plant, as they do not require any type of large scale destructive process.

Traditionally, one of the biggest concerns would be what would happen to the battery after it ran out. This was one of the largest issues with hybrid cars. After the battery pack wore out, the battery would typically have to be thrown in a landfill. However, there have been multiple projects put in place that use old batteries as mass storage cells [2]. This allows the batteries to have a much longer life without havening to waste them.

OPTIMIZATION OF SOLAR ENERGY YIELD

Before making any design decision the team opted to follow the use of a decision matrix which helps eliminate ideas that are not feasible after taking into account several factors such as those shown in the figure below. The decision making process has been used to help the team select all the major components and design features of the prototype.

	Cost	Installation Time	Overall System Efficiency (Expected)	Reliability	Complexity	Learning	Innovation	Sustainability	Total
	25%	15%	15%	10%	5%	10%	10%	10%	100%
Sun Tracker	3	1	2	2	1	3	3	2	2.25
No Sun Tracker	3	3	1	3	2	1	1	3	2.25
Secondary Panel	1	3	3	3	2	1	1	1	1.85

Figure 3. Sun Tracking, No Sun Tracking, Secondary Panel Decision Matrix

In order to achieve optimum solar power generation, the team opted to research and analyze different options that could enhance our lighting system. The following three options were being considered by the team: including a sun tracker system that would increase the power output of the PV solar panel, not including a tracking system and focusing more on the tilt angle, or adding a secondary panel to generate more power.

The solar tracker option includes the primary use of an Arduino Uno microcontroller board. An Arduino Uno is based on ATmega328; it has 14 digital input/output pins, 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, and an icsp header. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board. [3] The choice of an Arduino module is the most likely choice because it is inexpensive (costs less than 30 dollars) and it is relatively easy to use for beginners and carries out all the necessary functions that you want it to do.

The parameters that were considered when making a choice were cost, time of installation, overall expected efficiency, reliability, complexity, learning curve, innovation, and sustainability. The parameters were weighted based on the limitations and scope of the project. Cost had the highest weight at 25% since this is not an industry-sponsored project and thus the funds are very limited. The project also has a very tight time frame since the team will part ways upon graduation, thus being required to complete everything by then. The overall efficiency of the system was one of the main criteria since we want our system to be as optimum as possible and reduce most of the possible efficiency losses. Another factor in consideration is reliability since it is not desired to make a decision that will improve the efficiency in the short run and cause problems and breakdowns in the future. As undergraduates, learning is vital and important to our growth as new engineers. Innovation is also considered since it will be key if the final product enters the market. Sustainability was also an important factor when making a decision since it is not desirable to have a breakthrough technology that threatens sustainability and well-being of our daily lives.

Cost which was given the most weight in the overall decision was determined using the following criteria:

- Score: 3, given to options that will cost between 0 and 100 dollars
- Score: 2, given to options that are between 100 and 200 dollars
- Score: 1, given to options that will cost more than 200 dollars.

The choice of not having a sun tracker system will not have any additional costs in the system thus given a score of 1. However a sun tracking system that uses an Arduino program, sensor, and DC rotor will cost about 100 dollars or less. The Arduino Uno microcontroller board which was selected by the team costs 25 dollars. [3] The sensor and DC rotor will cost about 50-70 dollars depending on the quality that is needed. The last option was the addition of a secondary solar panel in the system which is the most expensive option thus given a low score of 1.

The senior capstone project is time-limited therefore time is an important factor when trying to make decisions. The following criteria was considered when trying to evaluate the three options in regards to time:

- Score: 3, given to the option that is predicted to take less than 3 weeks.
- Score: 2, given to the option that will require 4-6 weeks of additional work
- Score: 1, given to the option that will require more than 6 weeks of additional work.

The sun tracker option is expected to take about 6 weeks or more since it involves Arduino programming which is not an area of comfort and prior knowledge that the team acquires.
The other two options are not time consuming because there is minor if not any additional time that will be need to install a secondary panel or not include a sun tracking system.

The main objective of the final decision is an increase in the overall efficiency of the system, thus giving efficiency the second highest weight in the decision making matrix.
- Score: 3, given to an expected system efficiency gain of 50% or more.
- Score: 2, given to an expected overall efficiency increase between 15% and 50%.
- Score: 1, given to an expected overall efficiency increase below 15%.

According to a subcontract report from the National Renewable Energy Lab (NREL), “single-axis tracking, in which PV is rotated on a single axis, can increase energy output up to 25% or more. With dual-axis tracking, PV is able to directly face the sun all day, potentially increasing output up to 35% or more.”[4] Several other reports claim that a tracking system in PV panels increases the output energy by about 20% or more. For this reason the sun tracking system was given a score of 2. The decision to add a secondary panel is definitely the best option when trying to increase the systems overall energy output and thus was given a strong score of 3. Not making any additional tracking system will not have any effect on the system and therefore the rated score of 1 was given to that option.

Reliability was also taken into account as the prototype is desired to be as close to being maintenance free as possible. Reliability is weighted at 10% and is given rated scored based on the following

- Score: 3, given to the option that will not be a threat to involving maintenance issues to the system.
- Score: 2, given to the option that could be a threat to involving maintenance issues to the system.
- Score: 1, given to the option that will most probably require constant maintenance to the system.

Adding a sun tracker to the system entails more electrical and mechanical components that will be added to the overall prototype which could result in occasional electrical or mechanical breakdowns that require maintenance. For this reason the option of adding a sun tracker was given a score of 2. The two other options are not expected to pose any additional maintenance threat to the overall system.

Complexity is the factor given the lowest weight since none of the options require an invention or major enhancement of the system. The scoring criteria of complexity is as follows:
- Score: 3 given to the option that is simple and would not require any assistance.
- Score: 2 given to the option that is somewhat complex but can be done with assistance
- Score: 1 given to the option that will definitely require assistance from professors or professionals.

The sun tracker option was given a score of 1 because the team is entirely made up of mechanical engineering students that do not have a great background in programming and electrical engineering, which means that assistance from professors or working professional will most probably be needed. The other two options are less complex but could require help from professors as well.

Learning is an important aspect of this senior capstone project and therefore it was also considered as a determining factor. The scores are as follow

- Score: 3 given to the option that has an extensive learning curve to it.
- Score: 2 given to the option that will require some learning of new concepts.
- Score: 1 given to the option that will require minimal learning.

Adding a sun tracker will require a lot of learning of Arduino programming language and electrical engineering and thus was given a high score of 3. The two other options will require minimal learning of new material and for this reason a score of 1 was given to both.

Another determining factor that is given the same weight as learning, reliability, and sustainability is innovation. The team desires to make a prototype that is highly innovative; one that could attract investors and customers.

- Score: 3 given to the option that will add major innovation to the system.
- Score: 2 given to the option that will not add any major innovation to the system.
- Score: 1 given to the option that will not contribute any innovation to the system.

The sun-tracking system will definitely make the product unique and different than all other hybrid lighting systems in the world, thus given a score of 3. The two other options do not bring any major innovation to the overall system and therefore the team gave the options a score of 1.

The scoring of sustainability was considered after researching the following criteria:

- Economic Development
- Social Development
- Environmental Protection

1- The sun tracking system will be economically beneficial since it could potentially create more jobs but less jobs than the addition of a secondary panel option. On the other hand the 2nd option of not having a sun tracker will not create more jobs compared to the other two choices.

2- Social development is the protection of people's health from pollution caused by the different three choices. For all three choices the same score was given since the objective of our prototype is to reduce load on the grid thus less emissions from power plants.

3- The environmental protection is where the addition of a secondary panel choice was determined to be the least sustainable and given a score of 1. The manufacturability of PV solar panels is not as green as what is displayed. Fabricating the panels requires caustic chemicals such as sodium hydroxide and hydrofluoric acid, and the process uses water as well as electricity, the production of which emits greenhouse gases. [7]

The two options of adding a sun tracker and not adding a tracking system both came in tied in first place with a total average weighted score of 2.25. The team decided to automatically eliminate the third option of adding a secondary panel due to the criteria discussed above. Since the two options were tied the team decided to invest time and money in adding a sun tracker and try to go as far as possible and if any major obstacles are met underway then the second option of not having a tracking system will be used.

SOLAR PANEL SELECTION

A comparison was done on the two types of solar panels, monocrystalline and polycrystalline, and is shown in Figures 4 and 5. The factors analyzed were: cost, reliability, efficiency, size, aesthetics, and availability. Cost was weighted the highest because the team has a rather low budget to work with, and the components must efficiently be selected within that budget. Reliability and efficiency were weighted the next highest. When looking at reliability, the team compared average warranty years the manufacturers of the solar panels offered with their products, since most products will outlast their warranties. Size was less of a deciding factor, but still important especially considering the locations the street lights may be in. Aesthetics is also important because the final product will ultimately be in the eye sight of the public. If the product is appalling and causes disrupting distractions or comments, the cities and businesses are less likely to purchase this design. Lastly, the team looked at availability. It may not matter how great a product is if it's nearly impossible to find for purchase.

320 Watt Solar		Monocrystalline	Polycrystalline
Cost	30%	2	3
Reliability	20%	3	3
Efficiency	20%	2	1
Size	15%	2	2
Aesthetics	10%	3	2
Availability	5%	2	3
Total	100%	2.3	2.35

Figure 4 - Solar Weighted Decision Matrix

	(3)Strong	(2)Moderate	(1)Weak
Cost	$0-300	$300-600	$600+
Reliability	25+ Years	15-25 Years	0-15 Years
Efficiency	20%+	16%-20%	10%-16%
Size	<5'X3'	5'X3'-7'X4'	>7'X4'
Aesthetics	Blends in	Stands out	Distracting/Out of Place
Availability	Easiest to Find	Moderately Difficult	Very Difficult

Figure 5 - Solar Rating Scale

Looking at the comparison chart for comparing monocrystalline and polycrystalline, it's clear to see that neither one really stood out over the other. The polycrystalline scored slightly higher, but mostly because of its availability and lower cost. Both types are considerably reliable, with most coming with a 25 year warranty for power output warranty. The monocrystalline is slightly more efficient with ranges from 16-18% vs 13-16% for polycrystalline, however because of the lower power consumption of this design this is not a sole deciding factor. The monocrystalline is also slightly more aesthetic as it doesn't stand out or draw as much distracting attention as the polycrystalline type.

Since neither the polycrystalline or monocrystalline panel proved to be a clear winner, the team could still decide on either one based on other factors presented later on in the project. Obviously, if the other components in the project exceed the expected budget, cost may be the true final deciding factor since either type of solar panel should work great for this project.

HAWT VS VAWT

In the wind energy industry the horizontal axis wind turbines (HAWTs) are usually the most popular and dominant throughout history. Recently the introduction of vertical axis wind turbines with competitive power yields as the HAWTs of a similar scale. For this project, the team decided to continue with a vertical axis wind turbine (VAWT) after evaluating both options for safety, maintenance, cost, feasibility of design, and appearance of the system.

Maintenance is definitely one of the most important factors when choosing the VAWT for this system. The preliminary design of the prototype includes the wind turbine at the very top of the pole. The wind turbine will be placed about 15 feet above the ground with all of its components on the ground level. Generator failures and connections could be maintained from ground level. Vertical wind axis turbines also do not rely on wind direction and also provide a low rotational wind start up speed. Depending on the size

STREET LIGHT ANALYSIS

The location of where the customer desires to install the system is a major determinant in the type of lighting distribution that should be used to optimize the lighting area as well as adhering to the government lighting standards. The team was able to obtain a report from the National Lighting Product Information Program (NLPIP) that was published by the National Renewable Energy Lab. The report, "Streetlights for Local Roads" from Volume 14, Number 1 is one the fundamental pieces to the decision on the streetlight bulb for the prototype. This report shows experimental studies where 6 different types of bulbs from different manufacturers were evaluated to determine how many light poles are needed in a 1-mile stretch road. Six light bulbs that were tested include 4 light-emitting diode (LED) modules, one high pressure sodium bulb, and one induction bulb.

Streetlight Selection was determined after exploring three major fields: identifying the base case criteria, identifying the different brands of bulbs that could be purchase, and identifying the exact models to purchase. In addition, the street light selection was also determined after studying light output and distribution, energy use, special glare effects, life cycle costs, and spacing of the poles in a 1-mile local road stretch.[5]

The base criteria is essential in the installation of lights in the city or highway. The NLPIP report used AASHTO (2004) design policies to choose the base criteria: IES Type II. The team researched this and decided that the base criteria should be disregarded since a type II distribution is "used for wide walkways, on ramps and entrance roadways, as well as other long, narrow lighting. This type is meant for lighting larger areas and usually is located near the roadside. You'll find this type of lighting mostly on smaller side streets or jogging paths." Type II light distributions have a preferred lateral width of 25 degrees as shown in the following figure. Also this distribution is applicable to luminaires near the side of narrow roads where the width of the roadway is less than 1.75 times the designed mounting height.

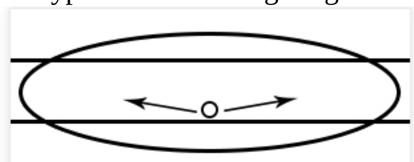

Figure 6. IES Type II Distribution [5]

When deciding on the base criteria it is essential for the team to choose the AES Type III distribution which is "meant for roadway lighting, general parking areas and other areas where a larger area of lighting is required." Type III light distributions have a preferred with of 40 degrees and are used for luminaires mounted near the side of roadways where the width of the roadway does not exceed 2.75 times the mounting height. This means if the roadway is 24 feet wide the mounting height should be a minimum of about 9 feet high. The figure below shows a Type III distribution.

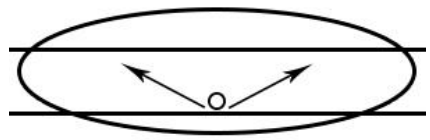

Figure 7. IES Type III Distribution [5]

The lighting distribution will be different depending on the desired area the customer wants to install the lighting. The following figure portrays the lighting distribution that should be considered if the lighting system is to be used to provide lighting for roundabouts or complex intersections.

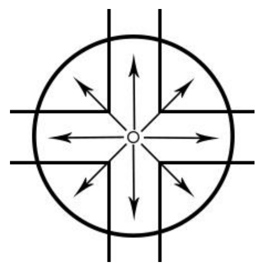

Figure 8. Type V Lighting Distribution [5]

Lighting professionals that have worked in the installation of various lighting projects in major cities in the United States were contacted by NLPIP to conduct a survey to determine the most popular streetlight bulb brands that were used in the projects that they have worked on. The survey was divided into two parts; the most used brands for high pressure sodium (HPS) streetlights, and the most used brands for LED streetlights. In the previous report the team decided to choose an LED lighting system since the recommendations by the Lighting Design Standards and Guidelines led city officials in New York and Los Angeles to change most of the streetlights from 150 Watt HPS to 110 W LED fixtures. Figure 9 shows the results which were yielded from 42 lighting professionals. The survey narrowed down the search to the top 3 brands for LED streetlight brands which are Beta Lighting, General Electric (GE) Lighting, and Leotek Electronics.

NLPIP chose the following four different types of LED lighting for further analysis and evaluation: Beta Lighting "STR-LWY-2M-HT-04-C-UL-SV", American Electric Lighting "LEDR 10LED E35 MVOLT AR2", Leotek Electronics "GC1-40C-MV-CW-2M-GY", Philips Lumec "GPLS-65W49LED4K-LE2-VOLT-BKTX". GE lighting was chosen for the HPS and Induction bulbs that were tested.

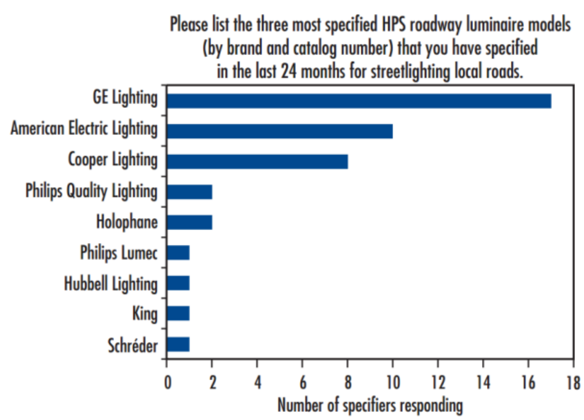

Figure 9. US Lighting Professionals Survey [6]

Pole spacing another design criteria that is crucial. NLPIP simulated a 26 ft. wide road with two lanes to perform experimentation. Also the recommended roadway lighting design criteria and standards from the RP-8 standards rule book were used. Upon choosing the exact light bulb, the criteria in the following standards should be met or exceeded.
According to U.S. Department of Energy report, calculation of Light Loss Factors are essential when choosing between HPS, LED, or Induction streetlight types. Light Loss Factors (LLF) are calculated because luminaires age over time resulting in reduced lumen output and LLF allows the forecasting of system performance over a given lifetime that would guarantee that the lighting system will meet the minimum lighting standards. [6]

Streetlight Type	Lamp Lumen Depreciation	Luminaire Dirt Depreciation	Light Loss Factor
HPS	0.84	0.88	0.74
Induction	0.70	0.88	0.62
LED	0.79	0.88	0.70

Figure 10. Light Loss Factors [6]

NLPIP evaluates the maximum pole spacing with the different types of bulbs that have been selected.

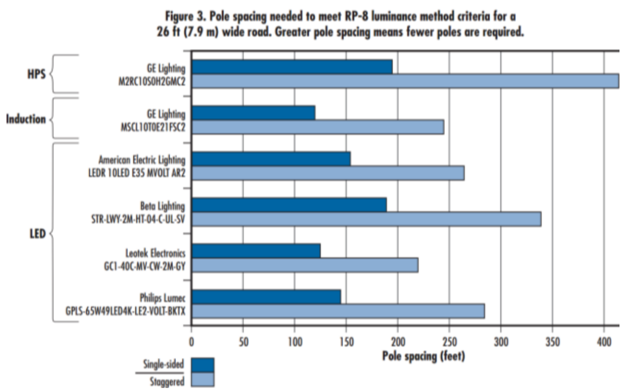

Figure 11. Pole Spacing [6]

Pole spacing could be optimized if using a staggered distribution in a two way highway or roadway. A staggered distribution that the team will use for installation of the systems will be similar to the figure below.

Figure 12. Staggered Positioning of Streetlights
(Image from Elliot Rosenfield Autodesk Blog)

LIGHTING CALCULATION

To determine the lumens needed for the light source, the team used the average pavement luminance of 0.3 cd/m^2 from the NLPIP report discussed previously. Using this value, the following equation was used to find the minimum lumen requirement:

$$\Phi\ (lm) = 0.09290304\ \times E_V(lx) \times 4\Pi r(ft)^2 \quad [9]$$

Where: Φ is the luminous flux measured in lumens;

E_V is the illuminance in lux (1 lux = 1 cd/m^2);
r is the spherical radius of the illuminated area in feet

The team will be using a spherical radius of 100 feet, which is based upon the research conducted by the NLPIP. Using this information the following calculation was performed:

$$\Phi\ (lm) = 0.09290304\ \times 0.3(lx) \times 4\Pi(100\ ft)^2 = 3502\ lumens$$

In order to make a decision on the lighting system to be used in the design, the team first had to identify which lighting distribution type the LED needed to be. In order to do this, a chart was created to easily identify a lighting type for a variety of popular lighting applications. Since this design can be used in a variety of situations, it is impractical to use one lighting distribution for every application, therefore making Figure 13 a valuable resource for future projects depending on where the customer would like the installation of these lighting systems; parking, roundabout, highway, or local road.

	Sidewalks	Narrow Street	Wide Street	Intersections	Parking Lots
Type I	3	2	1	1	1
Type II	2	3	2	1	1
Type III	2	3	2	2	3
Type IV	1	2	3	2	3
Type V	1	1	1	3	3
1	Poor				
2	Average				
3	Good				

Figure 13 - Lighting Distribution Type

For this specific design a Type III light will be used, as the end application will most likely be the narrow streets or parking areas on campus. A Type III light offers the versatility to fit both of these applications very well, and therefore satisfies the requirements of this design.

The team identified two potential light systems that would fit the specifications for the design. The two lights identified were the Cree BXSPA031AUSR XSP1, and the GE ERS10CXCX5402GRAY. Both lights meet the lumen output needed, are LED distribution Type III, and are from very reputable and industry leading companies for LED lighting systems. In order to make a final decision on which light the team will proceed forward with, a weighted decision matrix was analyzed using the following criteria: Cost, Efficiency, Power Consumption, and Life Span. After carefully comparing the two, the team has decided to move forward with the Cree lighting system to use in the design. The decision matrix can be seen in Figure 14.

	Cost	Efficiency	Power	Life Span	Total
	30%	25%	25%	20%	100%
*Cree	3	3	3	3	3
**GE	1	2	2	3	1.9
3	$200-400	>90 LPW	50-60 W	>100k hr	
2	$400-600	60-90 LPW	60-70 W	50k-100k hr	
1	$600-800	<60 LPW	70+ W	<50k hr	

Figure 14 – Lighting Weighted Decision Matrix [10][11]

SOLAR/WIND COMPONENT CALCULATIONS

Before ordering the components for the solar panel and wind turbine, the necessary calculations must be made to ensure the components will meet the power requirements for the lighting system. The following equations will were be used to perform these calculations:

- **Wh = P * t** = 53W * 16hrs = 848Wh
  - Where:
    - Wh = Watt Hours
    - P = Power (W)
    - t = Time light will be used (hr)
  - Used to calculate the power consumption of the light
- **W=Wh/t_s** = 848Wh/3.65hrs sunlight = 232W
  - Where:
    - W = Power output (W)
    - Wh = Watt Hours
    - t_s = Time of sunlight/wind (hr)
  - Used to calculate the needed solar panel/wind turbine power output capabilities
- **I = P/V** = 53W/24V = 2.21A
  - Where:
    - I = Current (A)
    - P = Power (W)
    - V = Voltage (V)
  - Used to calculate the inverter size needed for the system
  - Also used to calculate the charge controller needed for the turbine generator

WIRING DIAGRAM

While looking into component design, the team also researched what types of wiring and leads would be needed to connect all of the components in the project. While most of the components themselves have already been selected, the team needed to make sure that all of the pieces would hypothetically fit together. The following figure shows a mock wiring diagram. Another diagram will be completed once the team decides which style block diagram to use, as well as which energy source/battery setup to use.

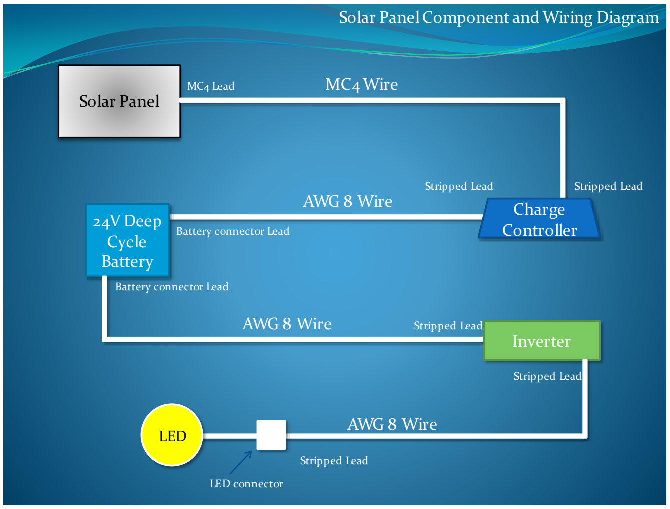

Figure 15: Solar Panel Component Wiring Diagram

CHARGE CONTROLLER

Charge controllers are a key component of any power system that charges batteries, such as solar, wind, hydro, etc. The purpose of a charge controller is to ensure the batteries are properly charged and safe. They achieve this by blocking reverse current from the batteries and preventing the batteries from being overcharged.

When a solar panel or wind turbine produces a charging current, it flows through a charge controller's semiconductor which only allows a one direction flow. So when a solar panel is no longer producing power during the night hours, the semiconductor prohibits the batteries from discharging. An alternative to the semiconductor is a relay, which switches off at night to block the batteries from discharging.

Another key role of a charge controller is to prevent overcharging. If a battery continues to receive energy after it's been charged, the voltage will become too high and may cause damage to the battery or even a small explosion. To prevent additional energy from flowing into a fully charged battery, the charge controller must reduce the flow of energy once the battery reaches a certain voltage. Then, once the voltage from the solar panel or wind turbine drops due to low sunlight or wind speeds, the charge controller will allow the maximum amount of energy to flow into the batteries again. This is also the case when there is an increase in electrical usage [9].

TYPES OF CHARGE CONTROLLERS

There are two types of charge controllers for solar panels: Pulse-Width Modulation (PWM) and Maximum Power Point Tracking (MPPT). Each one serves a different purpose and each work better for certain applications.

A PWM charge controller allows as much of current the solar panel can produce until it reaches a target voltage the controller is set to. The charge controller quickly disconnects the battery bank once the batteries have reached the target voltage, which prevents overcharging and discharging from the batteries.

An MPPT controller uses an adaptive algorithm that adjusts the incoming voltage by following the max power point of a solar panel. This allows the system to be much more efficient when charging the batteries. It also includes a DC/DC voltage converter then converts excess voltage from the solar panel into extra current at a lower voltage. Figure 16 shows an example of a maximum power curve for a solar panel. These graphs give a very good visualization to the benefits of an MPPT controller over a PWM. Because a PWM controller is typically limited by the battery voltage, the system will not be able to reach its maximum power efficiency especially if the battery is only 12V. However, with an MPPT controller, it allows the system to charge the battery at the proper voltage that will produce the maximum power output.[12]

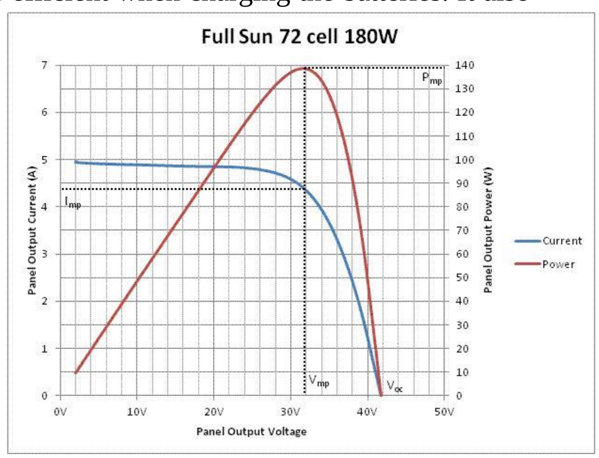

Figure 16 - Solar Panel Power Curve

CHARGE SETUP DECISIONS

There are two feasible charge setups for this project. The first being a hybrid charge controller, where the panel and turbine would both feed into the same controller, feeding the battery. The second setup is having a separate charge controller for each component; the solar panel would have a controller, while the wind turbine would have its own different controller. These controllers would then feed into the same battery. The decision matrix can be seen in the following figure.

Charge Setup	Cost	Application Fit	Availability	Flexibility	Enviornmental Impact	Sustainability	Manufacturability	11/10/2016
	20%	15%	15%	25%	5%	15%	5%	Total Points
Hybrid	3	2	1	2	2	2	2	2.05
Separate solar/wind	2	2	3	3	2	3	2	2.55
(3)Strong	$0 - $150	High	Easy to find	Low	None	High	Easy	Choice: Separate
(2)Moderate	$150-$300	Medium	Moderate	Medium	Low	Medium	Moderate	
(1)Weak	$300-$500	Low	Difficult	High	High	Low	Difficult	

Figure 17: Charge Setup Decision Matrix

As can be seen in the decision matrix, having separate controllers should work better for the project. This will allow each energy generating components be independently upgraded.

Inverter decision matrix

The inverter is one of the main components of the proposed system. The purpose of an inverter is to convert DC voltage into AC voltage, which is an absolute must when attempting to power a light. Luckily, there are many choices for inverters. One of the most important characteristics in an inverter is the type of wavelength. There are three types [19]:

1. Sine Wave 2. Modified Sine Wave 3. Square Wave

Sine Wave is the most common, and most equipment in the American market has been optimized for a Sine Wave inverter. Modified Sine is typically only used on equipment with variable speed drives. Finally, Square waves are typically reserved for cheaper, cruder inverters and are very rare.

The decision matrix is as follows:

Inverter	Cost	Application Fit	Availability	Complexity	Enviornmental	Sustainability	Manufacturability	11/9/2016
								Total Points
Sine Wave	2	3	3	2	N/A	N/A	N/A	2.5
Modified Sine Wave	2	2	2	2	N/A	N/A	N/A	2
Square	3	1	1	3	N/A	N/A	N/A	2
(3)Strong	$0 - $50	High	Easy to find	Low	N/A	N/A	N/A	Choice: Sine Wave
(2)Moderate	$50 - $150	Medium	Moderate	Medium	N/A	N/A	N/A	
(1)Weak	$150 - $300	Low	Difficult	High	N/A	N/A	N/A	

Figure 18: Inverter Decision Matrix

As can be seen in the decision matrix, the Standard Sine wave type would most likely work best for this application. Most of the inverters that meet the needs of this project are almost identical in terms of specs and pricing. Therefore, the team decided that the only main deciding factor would be the brand of the inverter, as long as the reviews. Because of this, a decision matrix would be a waste of time, considering the only real criteria at this point is the brand name. The team has decided to go with the Cotek 300W inverter. Cost is $162.9, it meets all of the project requirements, and it comes with a two year warranty, unlike similarly priced units with the same specs.

Watts	Input Voltage	Output Voltage	Type
300W	24VDC	120VAC	Pure sine wave

Figure 19: Cotek 24V S300 [14]

RECENT PROGRESS

The team has been looking at two different lights; the Cree XSP1 and the GE ERS10. These options are being looked at because they meet the criteria for what the team needs in a light. The decision matrix can be seen earlier in the report under the lighting section.

Being that the team has yet to complete a weather analysis of the Montgomery region to choose an adequate size solar panel and wind based on the historical weather data from the Montgomery WV weather station. This prototype can be manipulated according to different regions where the weather is different. For example in an area where there is a higher wind energy potential then the prototype will have a larger VAWT compared to an area where there is more solar radiation. For the Montgomery area (and southern WV in general), the wind speeds are not very high, and more resources should be allocated to the solar portion of the system.

As was stated above, solar will take more priority because of the conditions of the area. The panels being compared are the Astonergy Violin 260W and the Canadian Solar CS6K 270W.

	Cost	Reliability	Efficiency	Size	Aesthetics	Total
	35%	20%	20%	15%	10%	100%
Astonergy	2	3	1	2	2	1.9
Canadian Solar	3	3	2	2	3	2.5
(3)Strong	$0-225	25+ Years	20%+	<5'X3'	Monocrystalline	
(2)Moderate	$225-250	15-25 Years	16%-20%	5'X3'-7'X4'	Polycrystalline	
(1)Weak	$250+	0-15 Years	10%-16%	>7'X4'	N/A	

Figure 20: Solar panel decision matrix [15] [16]

Another important recent development was the design aspect of the project. The team has begun construction of a Solidworks CAD model. This is preliminary, and will need to be modified as the design progresses next semester. Below are some images of the solid works rendered model. The lighting has not been placed yet in the model since it will be different depending on the width and distribution on a certain road. As explained earlier in the report the lighting distribution criteria is determinant on the height of the lighting. The size of the base of the prototype also depending on the size of the battery and wind turbine components that will be placed at the bottom of the prototype.

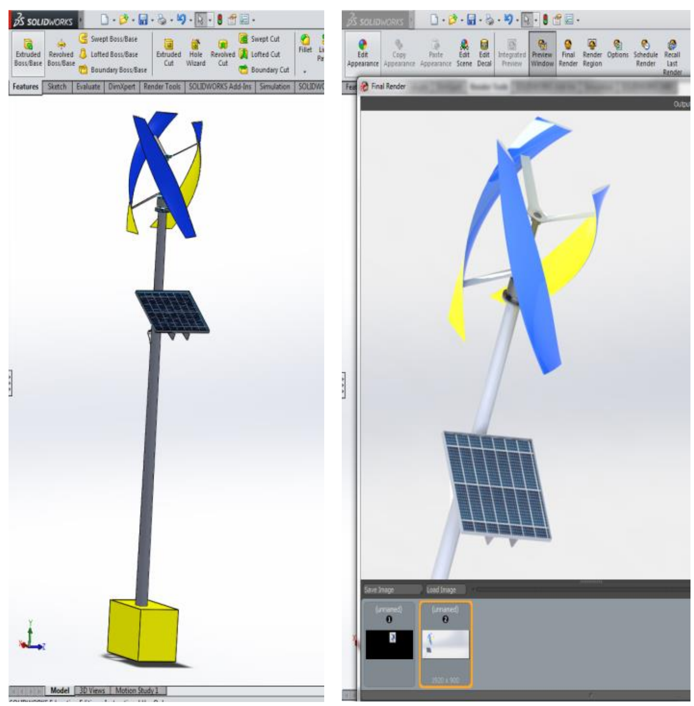

Figure 21: Tentative CAD Solidworks Design

CONCLUSION

After several weeks of research and information gathering this project is very close to the building step of the prototype. The team developed a great understanding of both wind and solar energy fostering and is currently developing a sort of algorithm that will yield the best design of a hybrid prototype based on the weather analysis of the location where a customer or city council would like to install this product.

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