Hybrid AC/DC Light Bulb

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Abstract

A hybrid AC/DC house aims to maximize the use of AC electricity from the utility grid and DC electricity from renewable energy sources such as roof-top solar panels. The hybrid system will therefore improve the reliability of the electrical by enabling power to be delivered to the loads even when one of the sources is not operational. One of the critical loads that every house needs is lighting. The hybrid AC/DC system should therefore be reliably facilitating the power delivery to the lighting. In this project, a localized hybrid AC/DC for LED light bulbs is designed and constructed. The hybrid AC/DC light bulb system will also be made portable by utilizing battery such that users may use the light bulb system as a portable light or a flashlight. Hardware prototype of the proposed hybrid AC/DC light bulb was constructed and tested. Results demonstrate the system functions properly with both AC and DC sources in conjunction with the batteries.
Chapter 1: Introduction

In today’s world, there is a very high dependency upon electricity that is often overlooked. The majority of populations depend on electricity for their daily needs; however, third world countries do not have access to a reliable power grid system. The high cost of electric power is not always affordable, the 1.2 billion people in rural areas that live without electricity can account for that [1]. Therefore, for those communities relying upon an energy or power independent home becomes a necessity [2].

In order to implement the required infrastructure to expand the power grid and provide electricity to many of the developing countries and rural communities, it will take a costly endeavor. With an increasing rise in the renewable energy generation front, many urban areas, as well as companies, are turning to solar for alternative means of generating or storing electricity. Although this method is great and environmentally beneficial, it is very limited to geographical areas and the amount of sun exposure the photovoltaic cells receive to convert the energy to DC power for operational use [3][4].

A possible alternative to this, could be to establish micro-grids and generate the power locally and directly generate power in the area. Many researchers have studied different architectures and ways to implement microgrids such as those presented in [5]-[9]. Other researchers focus on strictly local DC generation and DC electricity such as the DC House project [10]-[14]. This idea then expanded to the development of the AC/DC hybrid house to enable the use of both AC power from the grid and DC power from solar panels or other renewable DC generation methods [15].
The AC/DC hybrid light bulb integrated design was created for the DC House project and proposed the concept of a residential electrical system operating fully on DC electricity and utilizing renewable power sources to generate electricity that the light bulb will utilize [10]. The DC House is a living environment that utilizes DC power to provide the needed electricity for lighting when power outages occur [11]. For the AC/DC hybrid house, the device will also provide energy transfer when the grid is not conducting, by an implemented back up battery. The motivation behind the AC/DC Hybrid System is to have a house compatible to run on both AC and DC reliably and decrease power loss; therefore, increasing efficiency of the overall electrical system in the house. To make this possible, a method to combine the AC and DC power sources must be employed. At Cal Poly, an approach utilizing the Multiple Input Single Output converter has been studied and developed which allows multiple sources including AC to be connected together to produce the combined power for a single DC bus [16]-[18].

Environmental extremes play a significant role in safety of power systems distribution as well. In recent years, California has been hit with extremely hot weather where utility companies have had to deal with grid outages in higher numbers. Therefore, formulating a solution to resolve the random outages and unreliability of the grid system is quite a difficult task. The light bulbs will have their own respective integrated circuitry to save energy and be utilized at times when blackouts do occur.
Chapter 2: Background

In the last decade, the United States has seen a growing divergence in the utilization of electricity with regards to how it is supplied. Currently, the majority of houses are powered by a standard $120V_{ac}$, and this range is often supplied from a power distribution grid. The residential consumers utilize alternate sources for electrical supply such as wind turbines, or solar cell generated DC power. Most often, the residential areas run internally on hybrids of both AC and DC loads.

In 2020, the Solar Energy Industries Association reported that the state of California is first in the country in solar installations [19]. The total investment in solar in the state of California is $76$ Billion and the growth projection is $22,300$ MW. This pattern should be recognized as it serves as an indication that the state of California is preparing for a high demand in Electrical Consumption. Figure 2-1 shows the gradual increase of residential solar installations since 2012. California was chosen as a case study for our research since its grid system is often under strain of harsh weather conditions, and environmental extremes like wildfires. This results in an unreliable power grid system [20]. Furthermore, California was chosen as a specified location of study due to receiving high amounts of sun exposure as well as a high average for peak sunlight hours. The range of geological distance that the state of California covers allows for the solar implemented design at various environmental settings [21].
Figure 2-1: California Solar Installations Growth in the Past Decade [19].

With this, it is apparent that California residents are moving toward a new sustainable energy. While this can bring savings in money from homeowners, there is still a catch. Solar installations do not completely get users off the grid. There are two ways solar panels can be connected. There is “on the grid,” which means it is tied to our utility companies and there is “off the grid,” meaning fully self-sustaining.

Living off the grid means that the solar panels are able to store energy through battery backups. While this seems like the way to go with energy, it is worth noting the cost and the amount of equipment needed. Solar cells are known to be insufficient compared to the grid to power all devices at home. The power can be depleted quite rapidly depending on the connected load; therefore, an efficient storage system will need to be implemented. As a regular homeowner, it may not be efficient to fully load an off the grid system without considering how much electrical storage is needed to have it be usable and last longer periods.

Most homes powered by solar panels remain dependent on the power distribution grid system as a main supply source, since it has a non-depleting behavior and can be fully loaded.
without the worry of losing all stored energy [22]. By relying on the grid, homeowners can still use power from the sun and only pay for what is used by the utility company. By tying to the grid, you are also not relying on battery backups or equipment when living off the grid. Overall, it is clear to see the cons of living off the grid. But there are also problems living on the grid. By living on the grid there is still a chance of utility transmission lines malfunctioning. Not only can lines malfunction, but there are times when scheduled outages in grids happen, especially in California. Power utility companies have become more unreliable in supplying power not only due to extreme weather conditions, but also due to aging utility infrastructure. These two conditions combined makes it difficult to meet the increasingly high demand of consumers. Therefore, a residential power supply system becomes a necessity. It is cost effective to the consumer while also serving as a safe net to rely on during mass black outs.

Other than the most prevalent and popular centralized power grid that we rely on today, new technology such as microgrids are being introduced to communities today. Microgrids are electrical systems just like power grids, but they just operate within a confined area. Instead of relying on the utility grid, users can now rely also on the community grid that they live in. Figure 2-2 illustrates a microgrid [23].
Figure 2-2: Microgrid System [23]

While this is also another alternative to solving an energy crisis, it still has its drawbacks. These systems are becoming highly expensive, especially in continents such as Africa [24]. Even with new technologies developing, there are still problems that we must face to create reliable electricity systems for communities.

One major obstacle we are facing is predicting whether power outages come from climate or from faulty equipment. By implementing a system that operates off an AC and DC sources, we are able to assure reliability from one line when there is a problem with another. This project will focus mostly on lighting applications that utilize LED since they are a small percentage of the overall power utilized at homes, usually in the range of approximately ~ 5-8%. This project will integrate AC and DC sources to increase the efficiency of residential power systems.

In previous works, former Cal Poly Electrical Engineering student started a design for a DC lightbulb. The design was intended for the lightbulb to operate in DC, as compared to the AC power most houses use, and is also made to be portable [25]. With the use of DC-DC converters and charging circuits, the lightbulb was able to implement these capabilities. The motivation for
this design was made to be utilized in the DC house project. While the concept of this device is similar to what will be implemented in this project, there are a couple of things to note. That is, power lost to the DC line will still result in an outage. With this problem in mind, it is apparent that there should be a light bulb that has the capabilities to operate in AC and DC in case outages to any line are interrupted. Also, in order to supply as much power for longer periods of time, we need to utilize a more efficient light source. The use of a standard incandescent light bulb would not be as efficient as an LED. An LED offers more power, more control and longer life [26]. By including this technology, along with the portability feature, into a new design of this previous work, the problem of outages can be fixed with a more efficient light source device.

In the past couple of years, California has experienced some of the most extreme weather conditions. PG&E has begun shutting off some of its systems due to the strain that is imposed during the hot summer months [20]. In turn, residents in some areas of California homeowners had to deal with their power being shut down for some time. Ultimately, there is no solution to completely solving power outages. It is hard to calculate when an outage can occur, other than the times PG&E makes it clear that they will be turning off power. Other factors including overloading, and damages in power lines can cut power off to many. In all, there needs to be some technology that makes this sudden inconvenience less dreadful to those who rely on electricity. Simple things we take for granted, like outages in the lights from our homes to outages in the streetlights. These outages can cause inconvenience and even dangers.

As we look into the future, one solution is for houses to eventually become hybrid powered. This means the power systems operating in our homes will be powered off AC and DC power. While refrigerators, and other power-hungry appliances will be challenging to implement,
this project will start from a small load: a lightbulb. This design will take in power from an AC or DC bus, meaning if one line experiences any outages, the other can take over. Through the use of DC-DC converters, the inputs could be stepped down to usable voltages for charging and lighting LEDs. Through the use of charging circuits, this device would also offer portability in its operation. In all, the design of this device aims to use power electronics in hopes of advancing the solutions to power outages.
Chapter 3: Design Requirements

As represented in Figure 3-1, the general block diagram of the overall system will have two inputs and a single output. The Hybrid AC/DC will have one of the inputs as the AC input, which would represent a standard wall plug. The secondary input is a DC bus which is the alternate source to the grid system. These two inputs will be active one at a time and will power the adapter “black box” shown below which will ultimately be used for a lighting application.

![Figure 3-1: Level 0 Block Diagram](image)

Figure 3-2 and Figure 3-3 show the modules needed to power the LED. Figure 2 shows the type of modules needed to power the LED. Shown in Figure 2 are the modules and the flow of each module. This system requires a rectifier, a combiner, a DC/DC converter, a battery management system, and batteries.
Figure 3-2: Level 1 Block Diagram

Figure 3-3 further explains Figure 3-2 in more detail. In Figure 3-3 each module and the voltages that they will be operating in are shown. Furthermore, it is worth noting the dotted box. This dotted box represents the BMS and the battery modules, which can be used as the source to the system if the DC and AC source are not powered on.

Figure 3-3: Level 2 Block Diagram
3.0 System Design
The AC and DC hybrid integration in the lighting application allows for the utilization of an 120V AC bus as well as the 48V DC bus within our AC/DC lightbulb design. The adapter device will output a current of 2.5A nominal or 3A maximum through a parallel configured LED load. The significance of having parallel loaded LEDs, rather than LEDs in series, is due to dimensioning intensity per LED component in the series load topology. Therefore, to ensure that the overall sum of the individual forward voltages across the LEDs meet the output voltage of the desired design specifications a combination of parallel-series LED loads will be used. The reason behind the functionality of both AC and DC buses is to improve reliability and quality of the lighting application. In terms of reliability, the lighting component is not reliant or dependent on a single source. Therefore, if power goes out on one of the buses, the alternate source can power the overall circuitry and provide the current required for the LEDs. Not only will this system be reliable, but it will also introduce portability. If both sources are out, the system will be able to power off of a battery system.

3.1 Rectification of AC Bus Voltage
The 120 V\text{AC} coming from a respective grid is obtained from a wall plug. The rectifying device used will rectify and step down the AC input voltage to a 48 V\text{DC} potential. The input AC voltage will have a 60 Hz frequency. The device converting the AC sinusoid to DC flat of 48 V will most likely have ripple at the combiner node. This is a possible aspect to be concerned of if the ripple is not below 5%. By rectifying and stepping down the AC signal of 120 V to a DC signal of 48 V, we expect the current to double to sustain power across the device. With the
device we are planning to use, the current ratings are 1.8 A input and 3 A DC at the output. The 48 V$_{DC}$ output will then be used as an input to an OR diode.

3.2 OR Diode Module

The OR-diode device behaves as a combiner or a Multiple Input Single Output (MISO). The device will decide which input to allow through to the overall system circuit. The input to the or-diode device on both lines will be approximately in the voltage potential ranges of 44 - 48V$_{DC}$. Another functionality of the device is to serve as a safety diode and current blocker and not allow any current from the overall system to leak back into the supply source. The current blocker will also ensure that current does not leak into the supply sources when the BMS is operating and utilizing voltage from the battery storage. Figure 3-4 shows an example of how the module ideally works. This module will take in the rectified AC voltage and the DC voltage and output whichever is on. As shown below, only one input could be on at a time due to the diode on the other branch. This allows for full isolation of the two sources and allows for testing and operation using either the AC source or the DC source.

![OR Diode Circuit](image)

Figure 3-4: OR Diode Circuit
3.3 DC/DC Converter and LED driver

The DC/DC converter will function as a buck converter and LED driver. The module will be stepping down and converting the 48 V\textsubscript{DC} input from the OR-Diode node and supplying a maximum of 3 A\textsubscript{DC} across the load. The buck converter ensures that the output voltage will be at an operating point that could be handled by an LED lightbulb. The LED driver will ensure the output receives constant current across the load, allowing for the LED load to have constant intensity of lumens. Some parameters of consideration while choosing or designing a DC LED driver is to ensure a constant input voltage, input and output efficiency, and thermal insulation for device heating. The nominal output range for the LED driver within the scope of the design specifications is approximately 1.5 - 2A range.

3.4 Battery Management System

The battery management system of this design will operate as a controller of when to charge the batteries in storage and when to supply voltage to the LED Driver to light the LED load. This module will use the 48 V\textsubscript{DC}, either from the rectified signal or from the DC source, and effectively charge batteries when needed. The BMS will be bidirectional; therefore, it will not only charge the batteries, but also provide energy flow to the main lighting application system.

The bidirectionality of the device allows for current flow to the system when it is operating only on batteries for when the input buses are disconnected. This functionality allows for a portability aspect of the design.
3.5 Battery

The battery storage will serve as an alternate source of supply to the LED load when both AC and DC buses are disconnected. The implementation of a battery storage will also aid with having a portable LED light bulb device. The battery in this system design will require rechargeable capabilities and will need to be arranged in a specific orientation to be able to supply 36V voltage range for the Battery Management System (BMS).

3.6 LED Light Bulb

Finally, the light bulb used will be capable of taking in a DC voltage, this DC voltage will be the voltage stepped down in the buck converter. The light bulb will also be capable of handling the constant current that is sourced from the LED driver.

Tables 3-1 and 3-2 list the customer requirements and engineering requirements, respectively.

|-----------------------|--------------------------------|---------------|
| a, b, c, e            | 1. Input Power  
                        | 2. Output Power  
                        | 3. Input and Output Efficiency  
                        | 4. Current Rating of Components  
                        | 5. Current Draw  
                        | 6. Converter Type  
                        | 7. DC Bus Voltage  
                        | 8. LED type  
                        | 9. Circuit Dimensions | Wattage and component properties must be known for product build and use.  
<pre><code>                                                  | For efficiency, cost, and |
</code></pre>
<table>
<thead>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10. Battery Capacity</td>
<td>11. Types of Lightbulb Operation</td>
<td>reliability we must find out how large the product dimensions are, battery for DC lightbulb mA-hours.</td>
</tr>
<tr>
<td>12. Load Operation Time</td>
<td>13. Component sizing</td>
<td></td>
</tr>
<tr>
<td>e, f</td>
<td>16. Voltage and Current Rectification</td>
<td>For AC and DC conversion.</td>
</tr>
</tbody>
</table>

**List of Customer Requirements:**

a) Quality & Reliability: The quality/reliability of power distribution using AC and DC.
b) Safety: Heat, brightness with regards to the DC Portable Light Bulb and BMS.
c) Portable: Modular implementation of the DC Lightbulb
d) Compact: For Light Bulb circuitry
e) Power Efficient: Implementation of AC and DC sources
f) Smart: Battery Management System (BMS) implementation to charge battery
g) Dependable: ACDC hybrid system allows for dependable and reliable power.
Table 3-2: Engineering Specifications

<table>
<thead>
<tr>
<th>Spec. #</th>
<th>Parameter</th>
<th>Target (units)</th>
<th>Tolerance</th>
<th>Risk (H,M,L)</th>
<th>Compliance (A,T,S,I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,3</td>
<td>Power out</td>
<td>30 Watts</td>
<td>Max</td>
<td>M</td>
<td>A,T</td>
</tr>
<tr>
<td>6,7,8,10</td>
<td>DC Volt Source</td>
<td>48Vdc</td>
<td>Max</td>
<td>M</td>
<td>I</td>
</tr>
<tr>
<td>6,8,10</td>
<td>AC Voltage Source</td>
<td>85 - 260V (Universal)</td>
<td>Max ±10%</td>
<td>M</td>
<td>T,I</td>
</tr>
<tr>
<td>4,5,17</td>
<td>System Output Current Rating</td>
<td>2.5A</td>
<td>Max</td>
<td>M</td>
<td>A</td>
</tr>
<tr>
<td>6,7</td>
<td>DC Bus Path Voltage</td>
<td>48V</td>
<td>Min±5%</td>
<td>M</td>
<td>T,S</td>
</tr>
<tr>
<td>6,7</td>
<td>Output Voltage to LED</td>
<td>12V</td>
<td>Max or 90% Efficiency</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Battery capacity</td>
<td>3000 mAh</td>
<td>Max</td>
<td>M</td>
<td>A,T,I</td>
</tr>
<tr>
<td>9</td>
<td>Device Size</td>
<td>4x4 inches</td>
<td>TBD</td>
<td>L</td>
<td>A,S</td>
</tr>
</tbody>
</table>
Chapter 4: Design

This chapter explains the design process for the proposed system. The design follows the level 2 block diagram as shown in Figure 4-1. As depicted in the figure, the proposed system consists of four main blocks, each of which has their own objective and functionality.

![Level 2 Block Diagram](image)

**Figure 4-1: Level 2 Block Diagram**

4.1 System Input

This project will have two input supply sources AC and DC. The AC source will supply 120V\text{AC} into the system when it operates and the other will supply 48V\text{DC}. The two different input types of help give the versatility aspect of this portable lighting application that can be integrated in the off-grid housing or in the event when the grid is unstable. In this design, the AC input for testing will be directly obtained from a wall outlet. This AC input will then be passed to Module 4.1 in Figure 4-1. The 48V\text{DC} voltage will likely be pulled from an alternate power source. This is usually from a solar grid, or a generator; however, for initial testing purposes a DC power supply will be used to closely emulate the alternate form of a power source. This DC source potential will then be passed to Module 4.2 in Figure 4-1.
4.2 Power Adapter

One of the main priorities for converting from AC to DC voltage with minimal ripple is to ensure we have a stable DC output voltage. Therefore, in the component selection and design considerations phase, our group selected multiple AC to DC converters that fit the criteria from the design specifications. Our initial top choice was the PSC-15148. The device’s output rating is 48V with 3.2A which is suitable for our lighting application. The device allows for overload protection and its power rating meets our specifications with higher threshold. This means the power supply allows for further expansion of the system such as more LED light bulb connection or more batteries.

![PSC-15148 ACDC Converter](image)

Figure 4-2: PSC-15148 ACDC Converter

In our component search and selection, for simple integration of components in the proposed system, we came across an alternative power adapter device which was far simpler to integrate. This device is an AC/DC converter that does not have similar features as that of the product above, but still met our design specifications well. This device has 144W power rating, very close to the 150W of PSC-15148’s wattage rating. It is also a simpler and more portable
design for consumer applications as well. Furthermore, the newly found product was 5x cheaper than the previous supply; thus, it helps lower the cost of the overall system.

Figure 4-3: SIMALY AC/DC Converter

4.3 OR Diode Topology

The hybrid LED light bulb must be able to run on two or more sources. There are various methods to facilitate this objective. However, for this project an OR diode circuit is utilized due to its simplicity and low-cost. The “OR” diode circuit consists of two inputs which are our AC and DC buses. Since diode that has the most positive anode conducts, then the OR diode will enable the highest voltage of its sources and connect the source to the output side (common cathode) of the diode which is connected to the load.

The “OR” diode design also needs to be able to handle a maximum of 48V\(_{DC}\) voltage. Thus, the diode selected for this purpose should have voltage rating > 48V. The MBR10100CT Schottky diode, shown in Figure 4-4, was chosen since its voltage rating is 100V. In addition, the diode has current rating of 10A, and meets the general requirements for single phase, half wave, 60Hz, and resistive or inductive load.
The diode receives its inputs from the input DC rail connected to our perf board. Then our output of 48V will be fed to our LED driver circuit as well as a busbar. The busbar will allow for bi-directional current through our Battery Management System (BMS) in order to have our BMS charge our backup battery.

![Schottky Barrier Rectifier](image)

**Figure 4-4: MBR10100CT Schottky Barrier Rectifier**

### 4.4 Bi-directional Controller for Charging and Discharging

The bidirectional controller module in this design is capable of stepping down voltage and stepping up voltage given the criteria or mode of operation. The module can step down the input DC voltage from the DC bus for charging applications and can also step up the voltage when a rechargeable source is being used as the input. Searching for a controller with buck/boost feature and bidirectional capabilities was the main consideration for this module. Given the specifications of this project, it was best to go with the LT8228 bidirectional controller.

In our design for the proposed system application, the battery chemistry will involve Nickel Metal Hydride (NiMH). This is a common battery utilized for low voltage applications. For our design, the battery storage package consists of 10-12 AA Cell batteries to provide the proper voltage level. The charging voltage in the battery should be charged slightly above 12V range. Given that the potential of each cell is slightly above 1.2V per cell, the chosen controller
should be able to handle the sum load potential of the batteries [27]. While charging a battery with a voltage greater than 12V may cause charging times to increase, due to the battery’s chemistry, it could cause some damage to the battery’s capacity [28]. Given this risk, it was safer to choose a controller that can handle a load slightly larger than 12 V. The bidirectional controller chosen is able to handle a range of 12.8V - 14.2V, which gives an extra 20mV past the regulated 14V needed for charging applications.

For charging applications, the input of the system should be at 48 V_{DC} and the output should be able to handle approximately 14V_{DC}. In the charging application the module should be able to provide enough power to fully charge a 12-14V potential battery. The charging of the battery is dependent on the number of cells, in our design we are limited to utilizing AA type batteries for cost and availability.

To discharge the battery, the input of the system would be 12V nominally. In this state, the system would act as if the battery was the main source of voltage, as compared to powering the LED through the AC or DC source. This voltage would then be boosted up to 48V to power the LED light bulb. The controller’s output of this state is rated at 47V - 49V, making the controller acceptable to use in this discharging application. The input of the discharging state of the controller is between 8V - 14V, which gives just enough margin in case the battery’s voltage is below or above the rated 12V.
4.5 Battery To Output

Figure 4-6 illustrates the discharge process from the battery, through the bidirectional controller as the controller boosts the DC voltage from approximately 12V nominal to a stable DC voltage of 48V for the load. This assumes that both the DC and AC paths are off, and no current flow is observed as well as no potential at the node on the BUS bar to the lightbulb load.
Features:

- Rapidly charge up and long runtime
- Ideal for DIY usage

Specifications:

- Nominal Voltage: 12V
- Capacity: 2000mAh
- Chemistry: Nickel Metal Hydride
- Battery Configuration: 10S1P AA battery
- Max Continuous Discharge Current: 2A (1C)
- Battery Charging Current: Standard: 0.5A - 1.0A
- Standard Charging: 190mA for 16 hours
- Quick Charging: 380mA for 7 hours
- Rapid Charging: 950mA for 2.4 hours
- Cycle Life: ± 500 cycles
- Weight: Approx. 9 oz / 255g
- Dimensions: Max 2.89"x2.11"x1.20" / 73.5x53.5x30.5mm (LxWxT)
- Connector: Bare Leads

Figure 4-7: Battery Features and Specifications

Calculations:

Taking the efficiency of the controller and 9W LED device into account, the actual power supplied to the load is 9.57W. This is determined after calculating the necessary output current required in determining the longevity of battery life for a pack of 10 AA batteries rated to have a 12V output when connected in series. The capacity of the batteries is 2000mAh.

\[
\text{Battery Life (Hours)} = \frac{\text{Capacity (mAh)} \times \text{Battery Voltage}}{\text{Power Draw from Load (Watts)}}
\]
Table 4.1: Discharging Circuit - Boost Mode at Fully Charged

<table>
<thead>
<tr>
<th>Load (%)</th>
<th>Power of Load (W)</th>
<th>Controller Discharging Efficiency (%)</th>
<th>Power Supplied by Controller (W)</th>
<th>Output Current (A)</th>
<th>Lifetime (Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>2.25</td>
<td>94</td>
<td>2.39</td>
<td>0.047</td>
<td>10.04</td>
</tr>
<tr>
<td>50</td>
<td>4.5</td>
<td>94</td>
<td>4.79</td>
<td>0.094</td>
<td>5.01</td>
</tr>
<tr>
<td>75</td>
<td>6.75</td>
<td>94</td>
<td>7.18</td>
<td>0.141</td>
<td>3.34</td>
</tr>
<tr>
<td>100</td>
<td>9</td>
<td>94</td>
<td>9.57</td>
<td>0.188</td>
<td>2.51</td>
</tr>
</tbody>
</table>

The significance Table 4-1 serves is that it illustrates the correlation of battery life with respect to the current draw from load. At high load, it can be observed that the battery lifetime is very small, approximately two and half hours. While at low load (25%) the battery lifetime extends to approximately 10 hours. This analysis allows us to optimize our design by selecting a lower wattage LED Light Bulb device. For this design, the parallel battery topology was also considered. But due to balancing issues arising with parallel combinations. The idea was dismissed, although it would have increased the amperage capacity for the battery.

Table 4-2: 3W Discharging Circuit - Boost Mode at Fully Charged - 48V Load

<table>
<thead>
<tr>
<th>Load (%)</th>
<th>Power of Load (W)</th>
<th>Controller Discharging Efficiency (%)</th>
<th>Power Supplied by Controller (W)</th>
<th>Output Current (A)</th>
<th>Lifetime (Hours) 24V/ (Wb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>0.75</td>
<td>94</td>
<td>0.797</td>
<td>0.0166</td>
<td>30.11</td>
</tr>
<tr>
<td>50</td>
<td>1.50</td>
<td>94</td>
<td>1.595</td>
<td>0.0332</td>
<td>15.05</td>
</tr>
<tr>
<td>75</td>
<td>2.25</td>
<td>94</td>
<td>2.393</td>
<td>0.0498</td>
<td>10.03</td>
</tr>
<tr>
<td>100</td>
<td>3</td>
<td>94</td>
<td>3.19</td>
<td>0.0665</td>
<td>7.52</td>
</tr>
</tbody>
</table>
4.6 Output - LED Light Bulb

The output of the proposed system supplies a 48Vdc potential to a screw base rated for high wattage and high voltage. The LED light bulb load is rated at 48V. The lightbulb component has an integrated LED driver which provides constant current during operation. The features and specifications are shown in Figure 4-8. The screw base is a standard base of E26 type for the LED lightbulb.

Figure 4-8: LED Lightbulb
Chapter 5: Hardware Test and Results

The hybrid AC/DC lighting application system was constructed and tested in four different individual setups prior to its integration into a system as a whole. The behavior of the AC to DC adapter was observed and tested to analyze the efficiency of AC to DC conversion and the amount of RMS ripple on the output end. The DC path was also tested, using a RIGOL DP832 DC Programmable Power Supply to emulate the battery source or the potential DC source from the consumer, i.e., solar panels. The majority of testing was conducted through the Bidirectional Controller DC2351A. The controller’s testing was completed in both boost and buck mode to ensure the system achieves optimum charging and discharging at full load.

5.1 Building the System Input

The input system consists of the AC and DC sources and the OR diode. The schematic of the circuit is shown in Figure 5-1. The circuit illustrated in the figure will then be transferred onto a perfboard to continue with hardware testing.

![Perfboard Circuit Diagram](attachment:image.png)

Figure 5-1: Perfboard Circuit
The input to the system, considered from the diode terminals, consists of three female banana terminal connectors. The DC and AC ground are shared with the black banana terminal female pin as illustrated in the prototype board depicted in Figure 5-2. The other two red banana pins are DC 48V pin connections where one is assigned to the AC path and the other to the DC path. The circuit design serves as a combiner of the DC input voltage from two different sources. The diode with the highest potential on the anode will conduct if both inputs are on simultaneously. The output of the prototype adapter board has two banana female connectors that supply a 48V voltage potential and current to the busbar. The busbar is a metallic junction component that integrates nodal connection from the bidirectional device and the path to the LED load.

Figure 5-2: Adapter Prototype Connector Board with OR Diode Circuit
5.2 Building Manual Toggle for Bidirectional Control of EVM board

![Image of EVM board with toggle switch](image)

Figure 5-3: Enable Switch Setup for Boost and Buck Mode Operation of DC2351A

The circuit of Figure 5-3 was constructed to have external control of the buck and boost operations in the DC2351A EVM board. The EVM controller board has 14 header pins for logic control or monitor pins. The three main pins utilized for operation within this system are pins 1, 9, and 13. In both buck and boost mode, the pin in common is pin 9, which is DRXN. Pin 13 is EXTPWR and is on when operating in buck mode. Pin 1 is GND and is used when operating in boost mode. The pins need to be shorted to determine the charging or discharging direction. On the SPDT switch, when toggled towards “II” direction, the EVM board operates in buck mode. When toggled towards “I” direction it discharges or operates boost mode.

5.3 Bi-directional Controller Boost Mode Operation

The Bidirectional Controller EVM board DC2351A in boost mode has an input of approximately $14V_{DC}$ from either a rechargeable battery or other voltage source during testing. The battery system consists of 12 AA cell batteries rated to have a summed total $\sim15V$ when
connected in series. The battery setup is shown in Figure 5-6. The boost mode operation of
controller and system setup allows for the output voltage to step up from 14V to 56V. The input
voltage of the controller at 14V_{DC} is regulated while using the bidirectional controller regardless
of the higher or lower voltage added. This implies that if the battery cell holders are in the range
from 12V to 15V, the bidirectional controller will still continue to conduct and hold the 14V
potential at the input. The output voltage of 56V_{DC} then supplies the rated voltage for the LED
driver circuit in order to power the LED light bulb. The battery source or alternative “back-up
plan” energy source can supply enough power to the LED light bulbs for approximately 16
hours. The following calculation, shown below, was completed to determine the longevity of
operation. To test the efficiency of the controller as the “back-up plan” energy source, efficiency
measurements were taken, and the procedure is shown below. The procedure of the controller
operating will consist of testing with an electronic load to ensure ideal operating conditions and
will then be tested with the LED light bulb.

\[ \text{Battery Life} = \frac{\text{Battery Capacity Rating}}{\text{Average Input Current supplied to the EVM}} \approx \frac{2000\text{mAh}}{120\text{mA}} \]

\[ = 16 \text{ hours} \]
Figure 5-4: Sample Test setup of DC Power Supply to Emulate a Battery Source

Figure 5-5: Boost Mode Overall System Setup with two Loads
Boost Procedure - Testing with an Electronic Load

Potential Across Battery Pack = 15.119 V

At Full Load: \( P = I \cdot V = 9W = I \cdot 56V \rightarrow I @ Full Load = \frac{9}{56} = .160A \)

1. Set the electronic load to constant current and set current to the full load. This is to resemble a constant current LED driver.
2. Connect Battery Pack jumper wires to the boost input side
3. Connect an ammeter at the input end through a digital multimeter
4. Connect a voltmeter at the input and output of the EVM board
5. Set the DC Power Supply to 48 V
6. Make sure the SPDT switch is toggled in the “II” direction
7. Turn on the DC Power Supply and set the electronic load to full load
8. Measure and note the input current, output voltage, and input voltage readings
9. Do part 6 for .75 of full load, .50 of full load, and .25 of full load
10. Calculate power for the load percentages
11. Take efficiency calculations for each load percentage

Results of measurements are provided in Tables 5-1 through 5-3.

Table 5-1: Output Measurements Readings with Electronic Load

<table>
<thead>
<tr>
<th>Load [%]</th>
<th>Voltage @ Boost Out [V]</th>
<th>Output Current @ Load [A]</th>
<th>Power @ Boost Out [W]</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>56.034</td>
<td>.04</td>
<td>2.251</td>
</tr>
<tr>
<td>50</td>
<td>56.034</td>
<td>.08</td>
<td>4.503</td>
</tr>
<tr>
<td>75</td>
<td>56.034</td>
<td>.120</td>
<td>6.754</td>
</tr>
<tr>
<td>100</td>
<td>56.034</td>
<td>.161</td>
<td>9.00</td>
</tr>
</tbody>
</table>

Table 5-2: Input Measurement Readings with Battery Sources

<table>
<thead>
<tr>
<th>Load [%]</th>
<th>Input Voltage [V]</th>
<th>Input Current [A]</th>
<th>Input Power [W]</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>14.47</td>
<td>.360</td>
<td>5.209</td>
</tr>
<tr>
<td>50</td>
<td>14.23</td>
<td>.529</td>
<td>7.528</td>
</tr>
<tr>
<td>75</td>
<td>14.00</td>
<td>.686</td>
<td>9.604</td>
</tr>
<tr>
<td>100</td>
<td>13.71</td>
<td>.883</td>
<td>12.1059</td>
</tr>
</tbody>
</table>

Table 5-3: Efficiency at Various Load Currents

<table>
<thead>
<tr>
<th>Load [%]</th>
<th>Efficiency [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>43.21</td>
</tr>
<tr>
<td>50</td>
<td>59.82</td>
</tr>
<tr>
<td>75</td>
<td>70.32</td>
</tr>
<tr>
<td>100</td>
<td>74.34</td>
</tr>
</tbody>
</table>
As observed from Table 5-3, the efficiency of the system in boost mode operation is relatively low at lower load currents and reaches roughly 74% efficiency at high loads.

Testing Boost Mode with LED light bulb

Prior to testing the LED light bulb, it was expected that the LED light bulb would draw a constant current. The output current behavior was observed with the use of an ammeter in series with the LED light bulb, and this was tested extensively. We came to find that the bulb was not consuming constant current throughout the whole duration of its operation. The output current would slowly decrease, with a relatively slow transience, from a range of 140mA down to 85mA over a period of approximately 400 seconds. This is shown in Figure 5-8. Since this was a time-based variance, the measurement needed to be automated for optimum or efficient measurement of current across the load. The DMM device Rigol DM3058 was programmed using PyVISA and Spyder IDE to take the time-based measurements every two seconds. The results obtained were later put into a graphic format for better steady state analysis.

Procedure on Automating the Measurement Taking Process

1. Download and install pyvisa and Spyder IDE software onto the computer.
2. Look up the Programming manual guide for instrument automation for your DMM device in your search engine. Use the device model number for reference.
3. Look into how measurement automation commands are written in the manual as shown in the example below for taking DC current measurements from the DMM.
:MEASure:CURRent:DC

Command Format:
:MEASure:CURRent:DC {<range>|MIN|MAX|DEF}

Function:
The command sets the range and resolution of DC current measurement.

Parameter:
<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Range</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; range &gt;</td>
<td>Discrete</td>
<td>{0</td>
<td>1</td>
</tr>
</tbody>
</table>

4. After importing the correct library files and defining an array, create a loop with an integrated timer to take the transient measurement within a specified range. Example code is provided below.

5. Connect the ammeter in series with the output LED light bulb

6. Run the code

7. Tabulate the data and graph the LED output current vs. time. Results of the simulation are shown in Figure 5-8.

![Figure 5-7: Program for Automation of Measurement using PyVisa](image)

Figure 5-7: Program for Automation of Measurement using PyVisa
5.4 Bi-directional Controller Buck Mode

The Bidirectional Controller DC2351A in Buck Mode takes an input of 48V from the output of the AC or the DC path. The AC power system consists of a Simaly AC/DC Converter, while our DC bus is supplied by a RIGOL DP832 DC Programmable Power Supply. In other cases, for consumer-based applications, the DC path can be powered by renewable sources like solar panels as well. The buck mode operation setup allows for output of either of the input sources to step down the input voltage of 48V in order to recharge a battery system. The output of AC and DC path are also utilized to supply the rated 48V in order to power the LED light bulb driver circuit.
The scope capture shown in Figure 5-9 illustrates the output to the LED from the overall system. It serves to present the low peak to peak ripple of 63.2 mV on the steady DC output.

Another important note on the buck mode operation is if the battery potential is below 14.2V. Then the bidirectional controller allows for flow of current to charge the AA cell batteries. Once the node voltage on the output of buck exceeds 14.2V, the controller no longer supplies current to batteries, it regulates at the threshold of 14.2V. This was tested extensively using the electronic load measurement equipment in the power electronics lab.

**Buck Mode Measurement Setup Procedure - Testing with Electronic Load**

1. Set the DC supply voltage limit to 25V and the Value to 24V on both channels. Note that the Rigol DP832 is rated at 30V.
2. Cascade and use two channels in series, set a current limit of < 2A
3. Set the electronic load to constant voltage mode and set voltage value to 14.00V.
4. Connect an ammeter at the output of the EVM board to measure for output current
5. Connect a voltmeter at the input and output of the EVM board to measure for any discrepancies in supply or output voltage.
6. Make sure the SPDT switch is toggled in the “I” direction
7. Start at a voltage slightly lower than 14V, increase the voltage on the electronic load until it exceeds 14.2V or 14.3V and observe the change on the output current. Notice a sudden change or drop from higher to lower amperage.
8. Take input current reading, output voltage, and input voltage for discrepancies between source and load of actual measurement.

5.5 Battery Charging Rate

The bidirectional controller’s main function in buck mode is to provide a charging system to the backup battery pack. To test the charging rate of the controller, a battery capacity meter and a timer is utilized to measure how fast the controller can increase the battery capacity. As shown in Figure 5-14, the time it takes for the battery to go from 5% to 100% is approximately 200 seconds. The procedure is as follows,
Buck Mode Measurement Setup Procedure - Battery Charging Testing

1. Discharge a set of 12 AA batteries by connecting the batteries across a load
2. Disconnect the load when the battery capacity meter reaches 5%
3. Set the DC power supply at 48V and connect to the input end of the bidirectional controller
4. Connect the set of the 12 AA batteries at the output of the controller
5. Power on the Power Supply and start timer
6. Observe the input current on the DC Power Supply until the input current drops dramatically and remains at a steady value
7. When this value is met, disconnect the 12 AA batteries, and connect the Battery Capacity meter across the batteries and take the battery capacity measurement. Pictures of the results are shown in Figures 5-11 and 5-12.

Figure 5-11: Battery Capacity Meter when drained
Figure 5-12: Battery Capacity Meter At Full Capacity
5.6 Testing DC Input Data

To test the DC input data an electronic load will be used to test the perfboard circuit under ideal conditions. The electronic load would be used to represent a constant current source in an LED light bulb. The test circuit is shown in Figure 5-15. As shown in Table 5-4, the use of an electronic load yields a high efficiency system due to its ability to provide constant current.

The procedure of the testing is as follows.

1. Set the electronic load to constant current and set current to the full load.
2. Connect the input DC Supply and set the voltage at 48V
3. Connect an ammeter at the input through a digital multimeter
4. Turn on the DC supply with the load operating at 100% load
5. Take input current reading. Using the electronic load take the output voltage and output current reading
6. Repeat part 5 for 75% of full load, 50% of full load, and 25% of full load
7. Calculate power for each of the load percentages
8. Take efficiency calculations for each load percentage
Figure 5-14: DC Path With Electronic Load

Table 5-4: DC Input Data Test

<table>
<thead>
<tr>
<th>Load %</th>
<th>V_{in} [V]</th>
<th>V_{out} [V]</th>
<th>I_{in} [A]</th>
<th>I_{out} [A]</th>
<th>P_{in} [W]</th>
<th>P_{out} [W]</th>
<th>Efficiency [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>48.01</td>
<td>47.50</td>
<td>0.16</td>
<td>0.159</td>
<td>7.682</td>
<td>7.5525</td>
<td>98.31</td>
</tr>
<tr>
<td>75</td>
<td>48</td>
<td>47.49</td>
<td>0.12</td>
<td>0.119</td>
<td>5.761</td>
<td>5.651</td>
<td>98.09</td>
</tr>
<tr>
<td>50</td>
<td>48.01</td>
<td>47.51</td>
<td>0.08</td>
<td>0.079</td>
<td>3.84</td>
<td>3.753</td>
<td>97.73</td>
</tr>
<tr>
<td>25</td>
<td>48.01</td>
<td>47.55</td>
<td>0.04</td>
<td>0.039</td>
<td>1.92</td>
<td>1.854</td>
<td>96.56</td>
</tr>
</tbody>
</table>

Further testing was done on the DC side with the LED light bulb attached. As mentioned in the boost side testing, since the LED light bulb does not act as a constant current source like the electronic load, time-based measurements were taken to find the steady state value. The testing circuit is shown in Figure 5-15. Through the data acquired, it is shown that the LED light bulb does provide constant current until about 400 seconds into its operation. The procedure of the testing is as follows.

1. Connect the LED light bulb at the output of the perfboard
2. Connect the input DC Supply and set the voltage at 48V
3. Connect an ammeter at the output through a digital multimeter
4. Turn on the DC supply
5. Using the Spyder IDE and using the code shown in Figure 5-7
6. Run the program and obtain output current readings
7. Tabulate data and graph the output current readings throughout time. The graph of the output current readings is shown in Figure 5-16.

![Figure 5-15: DC On With LED light bulb](image)

![Figure 5-16: DC side LED current Behavior reaching steady state](image)

**5.6 Testing AC Input Data:**

To test the AC input data an electronic load will be used to test the perfboard circuit under ideal conditions. Just like the DC side data and the boost measurements, the electronic
load would be used to represent a constant current source. To test the AC-DC adapter, the output voltage ripple would be taken to ensure the ripple was minimal, as shown in Figure 5-17.

\[
\Delta V_o = \frac{2.32mV}{48V} \times 100\% = 0.00483\%
\]

This low ripple output voltage is close to what a purely DC signal at 48 V would be.

![Figure 5-17: Output Ripple of AC-DC Converter](image)

Instead of using a DC input supply, the AC/DC adapter would be used. The test circuit is shown in Figure 5-19. Due to the ideal nature of the electronic load, the power loss is minimal as shown in Table 5-5. The procedure of the testing is as follows.

1. Set the electronic load to constant current and set current to the full load.
2. Connect the input AC-DC supply at the input of the perfboard
3. Connect an ammeter at the input through a digital multimeter
4. Turn on the DC supply with the load operating at 100% load
5. Take input current reading. Using the electronic load take the output voltage and output current reading
6. Repeat part 5 for 75% of full load, 50% of full load, and 25% of full load
7. Calculate power for each of the load percentages
8. Take efficiency calculations for each load percentage

Figure 5-18: AC-DC Converter Input With Electronic Load

<table>
<thead>
<tr>
<th>Load %</th>
<th>$V_{in}$ [V]</th>
<th>$V_{out}$ [V]</th>
<th>$I_{in}$ [A]</th>
<th>$I_{out}$ [A]</th>
<th>$P_{out}$ [W]</th>
<th>$P_{in}$ [W]</th>
<th>Efficiency [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>48.61</td>
<td>47.54</td>
<td>.16</td>
<td>.159</td>
<td>7.56</td>
<td>7.77</td>
<td>97.25</td>
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<tr>
<td>75</td>
<td>48.68</td>
<td>47.58</td>
<td>.12</td>
<td>.119</td>
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<td>5.82</td>
<td>97.33</td>
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<tr>
<td>50</td>
<td>48.68</td>
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<td>.079</td>
<td>3.78</td>
<td>3.88</td>
<td>97.30</td>
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<tr>
<td>25</td>
<td>48.68</td>
<td>48.01</td>
<td>.04</td>
<td>.039</td>
<td>1.87</td>
<td>1.95</td>
<td>95.91</td>
</tr>
</tbody>
</table>

As done before, the LED load acts as a constant current source after a certain amount of time. To find the steady state current, time-based measurements will be taken. The procedure and the results are presented as follows.

1. Connect the LED light bulb at the output of the perfboard
2. Connect the input DC Supply and set the voltage at 48V
3. Connect an ammeter at the output through a digital multimeter
4. Turn on the DC supply
5. Using the Spyder IDE, testing measurements were taken using the code shown in Figure 5-7
6. Run the program and obtain output current readings
7. Tabulate data and graph the output current readings throughout time. The graph of the output current readings is shown in Figure 5-20.

Figure 5-19: AC On With LED light bulb

![LED Load Current vs. Time](image)

Figure 5-20: AC On With LED Light Bulb
Chapter 6: Conclusion

This design focuses on the implementation of the Hybrid AC/DC Light Bulb that can also be implemented with the Cal Poly San Luis Obispo’s DC House Project. The Hybrid AC/DC Light Bulb system highlights the use of a bi-directional controller circuit that includes a buck converter and a boost converter. The system is intended to be utilized as a universal lighting application design for any power system. The Hybrid AC/DC Light Bulb system is designed to meet specific electrical requirements while maintaining relatively high efficiencies. The proposed system meets the electrical requirements of the current grid powered homes as well as the DC House Project system. The hybrid system is able to supply power and run the LED Driver circuit of the light bulb while operating under multiple inputs, such as the battery pack, an AC input, or a DC input.

The Hybrid AC/DC Lighting Application System is designed to operate with a wide input voltage range of 36V to 56V. The bidirectional system’s boost converter regulates a 56V output, while the buck converter regulates at 14V output. With a DC input supply present, the proposed system initiates charging operation while also conducting current to the DC light bulb. It is significant to note that similar operation is achieved when the AC input supply is present. As the system is disconnected from the main grid or house power system, 48V DC house bus, the DC LED Light Bulb behaves like a portable flashlight powered by the charged battery pack. The significant difference being that this battery pack can run multiple number of LEDs bulbs for a longer duration. The voltage regulation inherently present with the bidirectional control board allows for charging terminations to offer maximum battery charging while also providing protection from overcharging of the AA batteries.
6.1 Future Considerations

Like all designs, there are always room for improvements. The improvements for this
design include implementation of wider input voltage range, more efficient battery life, and a
sensor circuit in order to condense the system down to one input. The Hybrid AC/DC Light Bulb
was originally designed to function with a very wide input voltage range of 24V-56V. However,
the LT8228 High Voltage Bidirectional Synchronous Buck or Boost Converter ratings reduce the
input range to 36V-56V.

To improve system portability, it's important to take note of size of this system. The
bidirectional controller used is fairly large when looking at the application of this system. When
operating the LED light bulb only off the battery pack, the evaluation board must be present. By
reducing its size, or even creating our own buck-boost regulator on a printed circuit board, the
portability of this device will increase. This means, using a topology for bidirectionality, like the
4-switch buck-boost, and also adding a programmable control stage to regulate the output of the
buck and the output of the boost side would help with increasing the mobility of this device and
the accuracy of the outputs. All these considerations understandably increase the cost for the
project design as well.
References


grid/#:--:text=Flames%20from%20the%20Bootleg%20Fire%20natural%20gas%20fired%20power%20plants.


49

## Appendix A : Bill of Materials

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# Appendix B: Gantt Charts

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*Adjustment Date:*
Appendix C: ABET Senior Project Analysis

Summary of Functional Requirements:
The AC/DC Electrical system is a hybrid system and aims to increase efficiency of
electric use by utilizing either AC or DC. This hybrid system integrates electricity from both
grids and is independent of a DC source by merging a DC bus path into the existing AC system.
Merging this DC bus path aims to lower the losses accumulated from converting between AC to
DC. This system will power a DC load, which will have its own charging and Battery
Management System BMS to allow for portability of a load or DC lightbulb. The environment
this design prototype will be tested in is the DC House Project.

Primary Constraints:
Few major constraints in implementing the AC/DC Hybrid Electrical System are
intertwined with the requirements and specifications. The specifications for the project itself
pertain to voltage rating, current rating, power, efficiency, and size constraints. Specifically for
the portable DC lightbulb application, size will be a major concern constraint wise. For instance,
the design of subsystem circuitry and procurement of components that will have acceptable
ratings, and for it all to fit within an enclosure will be an interesting challenge to undertake. The
integration of BMS and battery management system’s ability to know when to charge and
discharge the battery to allow for portability of the DC lightbulb is another constraint that is
analogous along with size.

Additionally, another primary constraint on the system level is the lack of similarity
among existing electrical systems. There are only a few agreed upon standards for DC, while
there are many accepted standards for AC systems. In the existing AC systems, compatibility to
a modern DC application also poses a challenge. Majority of devices which utilize DC for operation, have internal integrated AC to DC converters. Which will create a challenge of a new DC adaptation since very few operate on DC input voltage.

DC requires closer proximity to power generation sites, unlike AC. The utilization of external DC renewable sources like Solar Panels or Turbines provide a geographical constraint as well, in that not all locations are prime zones for solar energy use or wind turbine use.

**Economic:**

The economic impacts as a result of implementation and installation of the AC/DC Hybrid Electrical system will provide beneficial net financial gain due to lower energy costs accumulated overtime. The purchase and integration of the system will have its initial expense like purchasing any other product. The real and manufactured economic capital from implementing this design will be that more DC loads will be developed which will not require lots of internal circuitry for AC adaptation.

As this implementation gains prominence, more renewable energy will be utilized. As a result, lesser carbon emissions will enter the atmosphere. It will also be applicable in areas, or countries, where implementing a power plant for electricity generation is more expensive than implementing a house to house AC/DC Electrical Integration.

Throughout the products lifecycle, the cost and benefits accrued are through reduction of losses of renewable power sources production by integrating the DC bus path which will supply more power at lesser cost than if it were drawing its power from the grid. Since a connection to the grid system requires conversion from AC to DC, which have unnecessary power losses and are less efficient [29]. Ridding the electrical system from unnecessary conversion losses, saves
the user money, and provides the opportunity for optimal power generation and use at a lower
cost since higher energy supply will not be needed to account for the losses as the power reaches
the user.

The inputs the AC/DC Hybrid system requires is the energy from renewable sources and
power from the respective grid the user is connected to. The project development costs nearly
$32,400, including labor costs. If the product is desired and sold in a wide market, for general
use and consumption. The project has the potential of earning quite a decent some. It is difficult
to estimate, since this project is student driven and is first of its kind. As there are no student
built prototypes that are widely marketed and profitable. This is mainly completed as a research
implementation and advancement for the DC House Project at California Polytechnic State
University. When successful, both users and developers of the product would profit from the
developed device. The users will have reliable and stable power at cheaper costs. The developers
would be the Senior Design Team, Polytechnic State University, Power Department, and DC
House Project Team. Equipment costs would be covered by Cal Poly since the design team will
be utilizing resources from school to perform their development research.

Product Prototypes should emerge and be ready for testing towards the end of winter
quarter. The AC/DC Hybrid and DC portable lightbulb will aim for testing and implementation,
as well as debugging around week 6/7 of EE461. Maintenance will possibly be required if the
Hybrid system is used for more than 10+ years. The labor costs for maintenance will not exceed
installation costs. The AC and DC input end of the overall system will be expected to require the
majority of maintenance.
If manufactured on a commercial basis:

If it were to be sold and marketed, the device parts and components alone cost approximately $1000. Assuming a 50% profit margin due to TAM, the system will cost around $2000. With the adaptation technology to solar panels, procurement of quality solar panels would drastically add to the cost as well. Typical Solar panel costs vary depending on wattage desired and range from $6k to $12k [30].

The US installed enough solar panels to power 16.4 million homes [31]. Assuming our device went to the market and accounted for nearly 1 percent. Then our devices will be used in 160 thousand homes. Per device, the cost would be $2k and the project every year would be approximately $160 million for a rough estimate not accounting for losses or employee cost, only parameter used was device sold. Estimated cost for the user to operate the device will only be during the initial installation expense, the user will accumulate the net profit after nearly a year or so by paying much less in bills.

Environmental:
The AC/DC Hybrid Electrical System aims to assist the longevity of the environment through implementation of renewable energy resources. As a result, cutting down the rate of carbon emissions from the power utilities generation and consumption’s end. Although, this project’s intentions are well in going towards an emission free environment. There are little negative aspects to it too, since on a micro level, each component developed to be used for the product will require energy that is not necessarily clean. However, it is worth noting there are some cons when implementing a battery to the system. With batteries having a chemical make-up, corrosion of batteries and disposing of them incorrectly could cause leaks into the environment. Additionally, when the product comes to the end of its operational life cycle, electronics do not have a respectable reputation of being recyclable.

During the operational life cycle of the product, it would mean that more electrical devices will be in use. Since this device makes sure that the user has power even when there are black outs in the power grid. This product will affect the longevity of use in other electrical devices as they would be on for longer, and would be prone to losing their lifetime use faster. Therefore, it implies that it would create more electrical device waste.

Typically, in high power applications and conversions between AC to DC or DC to DC, converters are utilized. The main components in converters are inductors and transformers, these two components are more prone to be damaged and sensitive to unpredictable current exchange. If these components need to be swapped out often for maintenance or unreliable power input. It would create the most environmental impact since they will be difficult to re-use or reduce. Thus, on a macro level, although this system in the long run would benefit the environment. It
does have its negative impact during production, and end life since it can not be reduced or re-used if it is no longer operational.

**Manufacturability:**

Proper form of manufacturing process is very significant in order to make sure that optimal system sustainability is achieved. In the development of the AC/DC hybrid system, manufactured components and available parts will be procured. For the magnetics portion, the transforms will be designed in house using coils wrapped around a ferro-magnetic core. Due to expected size limitations for the circuitry, the components will have to be sized accordingly as well. For instance an 805 SMD standard can possibly be used, which implies surface mount soldering challenges. Another main issue during manufacturing is having the parts in order to use them to build. Therefore shipping of components will be challenged throughout the project and manufacturing of the project.

Although, most customers and consumers of this AC/DC Hybrid System Design will not deal with the development personally and will not experience the process. Proper handling of waste will be crucial. The project will utilize silicon PCBs, components that have their respective max and min ratings for voltage, current, and power. As well as tolerances for temperature. The main concern will be around the input, inductive components, and battery use which would hinder the manufacturing of a complete and operational product.

**Sustainability:**

There are 3 main aspects to consider when referring to sustainability throughout project development, and the respective aspects are society, economy and environment. This project will
promote sustainability throughout its lifecycle. The AC/DC hybrid design will ensure less power loss through removal of excess converters needed. The Hybrid system will require lower input power, since in AC extra input will not be necessary to account for losses accrued throughout the system. The DC parallel path to the existing AC ensures sustainable and reliable power can be utilized even when AC power is not supplied from the grid.

The utilization of lower input power will benefit the economy, since it lowers the dependence of users on the grid and also makes it affordable. This design is environmentally conscious as well in that it allows for storage of energy for users, allowing for power plants to generate power at lower rates, and lowering the rate of carbon emission. This also benefits the society in times of horrendous weather conditions in which grid blackouts could occur, the hybrid AC/DC system can utilize the energy stored to power the homes through DC bus paths.

Upgrades that can improve this design would be simply to implement the modern developed components that are more efficient. For instance, upgraded LED driver modules that can be supplemented in the design in the coming future would improve upon the design. The design framework would practically stay the same, yet it will be modular in order to implement modern or newer components.

**Ethical:**

The application of the AC/DC Hybrid Electrical System in the residential and commercial communities provides them with reliable and efficient power usage of renewable resources like solar energy mentioned previously. Therefore, this product will be beneficial to both the user and the environment. The constant use of electricity through renewables rather than
power plants, although mostly positive, has a couple negative dilemmas associated with it as well.

First being the use of solar panels used to produce the DC for the hybrid system as well as components used within also produces electronic waste, and we do have the expertise of reducing the electronic waste properly. The electronic waste being made of various hazardous chemicals are not biodegradable. This creates a tremendous problem going forward on how the future generations will deal with the challenge of the exponential amount of electrical and electronic waste produced by us. Thus, it's a necessity to lookout for sourcing electronics from environmentally and ethically conscious manufacturers for the development of this project.

Second, the growing dependence on electricity and how the majority of day to day devices will be geared towards a future assuming we would always have electricity. It will be important to find the balance in between. The scope of this project also encompasses this concept, to try and find the balance between using power from the grid which is supplied from generators and power plants. Although in a different framework, it has the potential of creating 2x the amount of waste if it picks its pace to provide results for the political decisions of going Carbon Neutral by 2030 [32].

In any matter, it is pertinent that the IEEE code of ethics is followed for this project. The main one being: "to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, to be honest and realistic in stating claims or estimates based on available data, and to properly credit the contributions of others.” in order to develop a well rounded project with flaws caught early on.
Health and Safety:

The implementation of the AC/DC Hybrid System will require the supplementation of extra check boxes during electrical inspection to ensure it meets the health and safety guidelines for residential homes. The inspection will ensure the compatibility and the products use over time with respect to surrounding circuitry conditions the product will connect to. The AC/DC hybrid system must be able to operate at a range potential or current level draws, depending on how much the source can supply and other respective loads will be drawing. To avoid heating, and unexpected fires from electrical accidents.

Since this project aims to power DC lightbulbs as loads, the focus will be mostly on circuitry that will provide opportunity for illumination of bathroom, living rooms, and kitchen. For safety purposes, the voltage and current draw across the system must be stable to provide steady current/voltage for emitting diodes utilized in the DC light bulbs. With regards to health purposes, the lighting should not flicker or be too bright. Also, to be too hot or energized to shatter glass. Protection diodes must be implemented in all circuitry involved as necessary to omit the risk of damaging the health/safety of the users.
Social and Political:

From a social and political standpoint, the stakeholders for the AC/DC Hybrid Electrical System are intertwined within the two groups. The stakeholders include the project team members, advisor, utility companies, Polytechnic State University, Electrical Engineering Department, IEEE, consumers/users, political members in society that have influence in proximity of power and energy distribution, as well as social activist groups that promote the growth of renewable energy.

The development and implementation of AC/DC hybrid systems promotes renewable by default vs Coal or Nuclear Energy power generation. Solar is currently the affordable method of power generation for residential homes as well as energy storage for DC source applications. Couple negative aspects to the project are that it is geographically limited to locations with prime access to solar rays. Environmentally and socially, communities with less access will not be able to enjoy the comfort this product will provide to its full potential of utilizing free energy provided from the sun.

If this project does become mass produced, it has the potential of creating lots of electronic waste in that it will be sub-level installation in each house of a community rather than one source of reliable power being supplied from a power plant for instance. Environmentally, this is not effective, as the demand and production will exceed the rate of recyclability. With respect to equality, the development of this system is a fair one. The hybrid system provides reliable power for all, and everyone has the opportunity to install it or utilize government incentives for going green to install it.
Equity wise, as mentioned previously, this will be a bit more challenging to achieve. Power generation for DC using solar panels requires Real Estate and also needs to be localized since DC is not efficient for long distance power distribution. Thus, a balance and consensus will be needed to be discussed similar to those in climate conferences among countries in COP26. For instance, regions with better opportune environments for renewable energy run off of wind and solar, while other regions run on nuclear or other clean forms power generation with less carbon emission.

To avoid pseudo conflicts and superficial confrontation of NIMBY type behavior, where parties with similar long term goals in mind become defensive over common shared spaces. An example unintentional consequence of the project if it is mass produced would be installing wind farms in the Midwest region of the United States that have more real estate, to provide power for neighboring regions that lack the necessary land and are more metropolitan in nature.

**Development:**

Although I have completed analysis and calculations for power in circuits previously, designing a power circuit and converters will be a new concept to learn. There are few software applications, that I expect to learn or further familiarize myself in as well which will aid me in the research and simulation of the AC/DC hybrid project development. The software includes OrCAD and Mathcad. Furthermore, I expect to further delve into line and load regulation for DC to DC converters in order to improve efficiency deliverables of the overall system.