UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

ECE 445 - Senior Design Project Proposal

Electric Bicycle with Fully Electric Architecture

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Team 15

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1 Introduction

1.1 Our Problem:

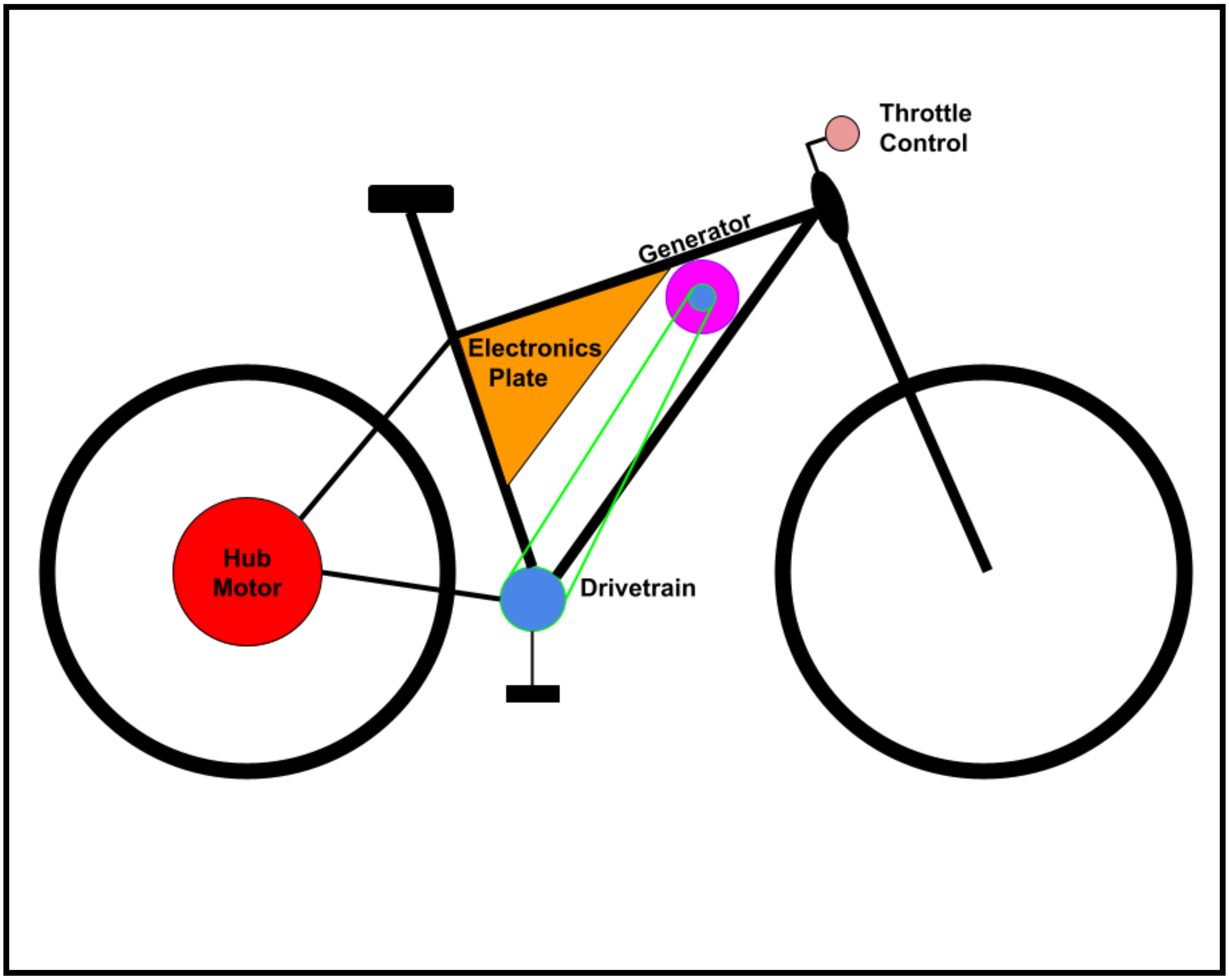
Most current electric bikes use a combination of chain and motor to provide pedal assistance. The issue with these systems is the complexity of dealing with a chain and motor simultaneously. The complexity of these systems that are constantly exposed to the elements means that durability is a concern. This problem is especially prevalent with bike sharing programs, where easy maintenance and care is essential to keeping costs down.

1.2 Our Solution:

Our idea is to construct an electric bike/moped that is fully powered by electricity, which means that instead of using a chain to transfer human power to the wheels, the pedals would instead be connected to an electric generator which would then feed a motor for the wheels.

While this configuration is not as efficient for driving the wheels as a direct chain would in terms of just human power, it allows for a very simple mechanical design with few moving parts. This could allow for very little maintenance, as there is no longer a chain or gears to take care of. Furthermore, most of the components can be sealed away from the elements by mounting them internally to the bike frame or within sealed containers that can be mounted to the bike frame. Additionally, an all electric system would also allow for regenerative braking (a reach goal) to be implemented more elegantly, allowing for energy to be recovered during braking and a better experience on hilly terrain while also reducing wear on the brakes.

1.3 Visual Aid:

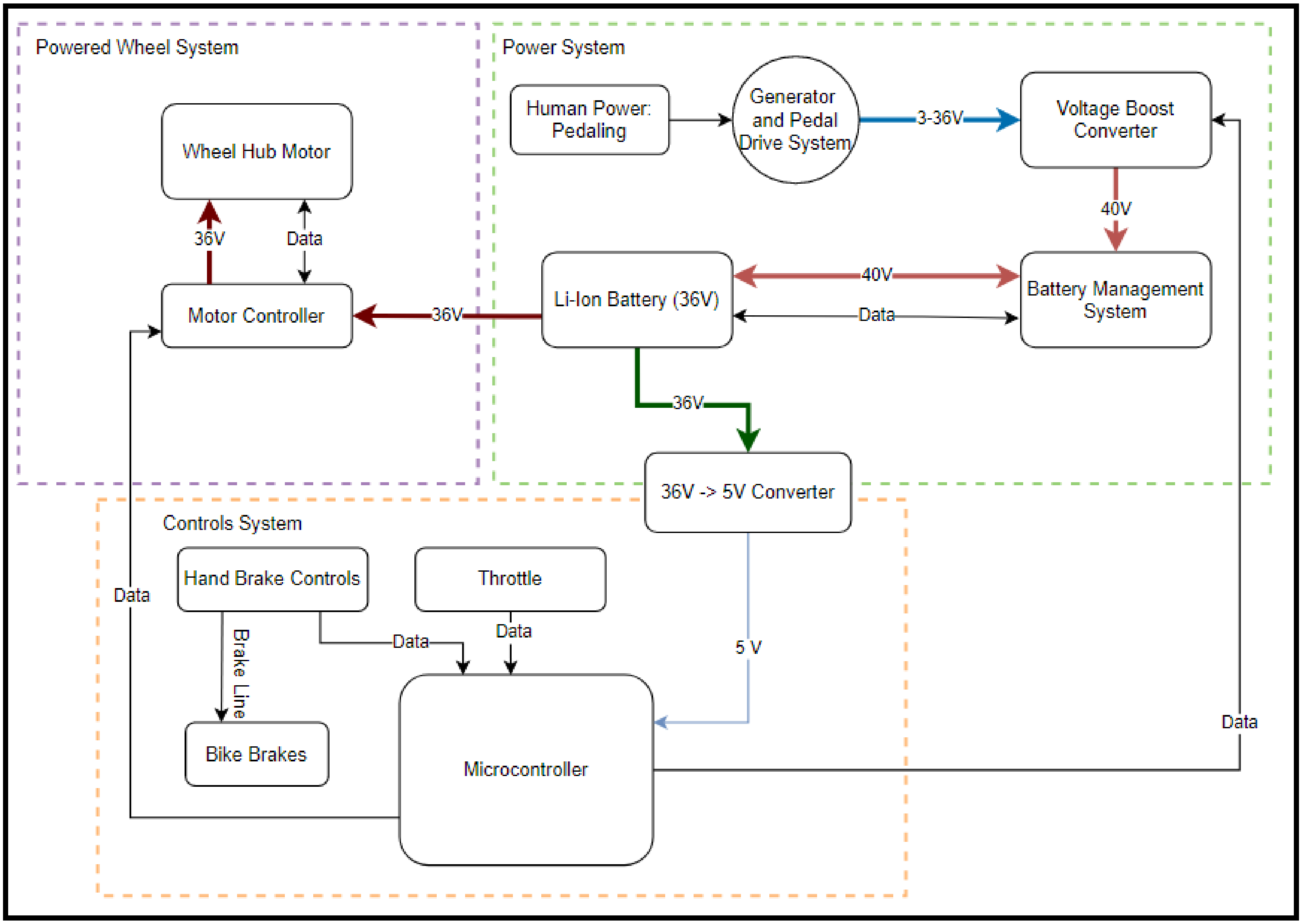


1.4 High-Level Requirements List:

- The Power System will be able to effectively charge the 36V battery with power from the pedal-generator and then route ~36V from the battery to the hub motor. The Power System must also be able to supply the 5V that is required to power the microcontroller.
- Rear wheel motor can propel the vehicle to 5 mph on flat ground with ~180 pounds of load.
    - Note that this is a prototype, ideally this vehicle will be much more capable.
- Motor speed can be controlled through a throttle system by the user.
- Must have at least 40% efficiency of power conversion from pedaling to electricity.

2 Design

2.1 Block Diagram:



2.2 Subsystem Overview:

Subsystem 1 - Power System

The purpose of the generator is to generate electricity from the mechanical rotation of the pedals, aided with a gearbox to achieve a better mechanical advantage. We are using a 36V DC motor as our generator, which is connected with a short chain to the pedals. The generator is connected to a 36V switching boost converter to provide a steady voltage level for the battery charging. The battery is used to power the rear wheel hub motor. It is also used to power the control system at a stepped down 5V.

The main responsibility of the power system is to facilitate the charging of the battery with the pedal generator. This generator can produce voltage levels from 10-30V depending on the speed, so we require a switching boost converter to produce a constant 36V for the battery charger. The power system gets input from the controls system for this process. The generator will only be allowed to charge the battery when it is producing enough voltage that the converter can achieve 36V, this can be monitored with a pin on the converter that outputs whether it is producing the desired voltage.

The power system is also in charge of distributing the power from the battery. To the rear motor, it provides 36V to the motor controller. To the controls system it provides 5V, which is achieved with a linear regulator.

Requirement	Verification
Supply 36V +/- 1V to the Powered Wheel System at up to 7A	Set throttle to full speed, insert voltage and current probes between battery and motor
Supply 5V +/- 0.1V to the Controls System at up to 500mA	Measure voltage and current from battery to PCB header
Regulate input from generator to charge battery: supply constant 36V from switching converter to battery charger	Measure voltage output from the switching converter while pedals are turning, ensuring that it is a steady 36V. Bring the generator to a stop, and ensure that the switching converter turns off when the generator is no longer producing enough voltage.

Subsystem 2 - Powered Wheel System

The rear wheel is powered by a 36V hub motor that is built into the center of the wheel. This motor takes power from the power subsystem, and receives speed control signals from and sends encoder data to the microcontroller. The rear motor's speed is controlled by a twist throttle on the handlebars, and the wheels can be brought to a stop with standard bike hand brakes. We use a software PID controller on the MCU to regulate the speed of the rear wheel.

The internal hub motor is connected to a motor controller, which handles power and speed signals. This allows us to abstract motor control to a speed and direction, instead of having to drive the actual motor leads.

Requirement	Verification
Drive hub motor with 36V	Connect to battery, ensure wheel turns
Accept a 0-5V speed control signal from the MCU	Turn throttle from off to full, ensure wheel ramps up in speed and remains steady when throttle is held a fixed setpoint

Transmit encoder signal to MCU	Spin the rear wheel at a fixed speed and measure this speed with a tachometer. Output encoder reading from MCU, and ensure that the values match up

Subsystem 3 - Controls System

The controls system is housed on a custom PCB. It contains two soldered-on chips: a microcontroller and a switching boost converter. It is connected to the battery, the generator, the rear motor, and the throttle. The software on the MCU has several functions. It determines the rear motor setpoint from the throttle, and regulates its speed. It monitors the status of the generator, and enables the boost converter to begin charging the battery if the generator is producing enough power. It also monitors the battery's charge level, and disables the power to the rear wheel if the battery drops too low.

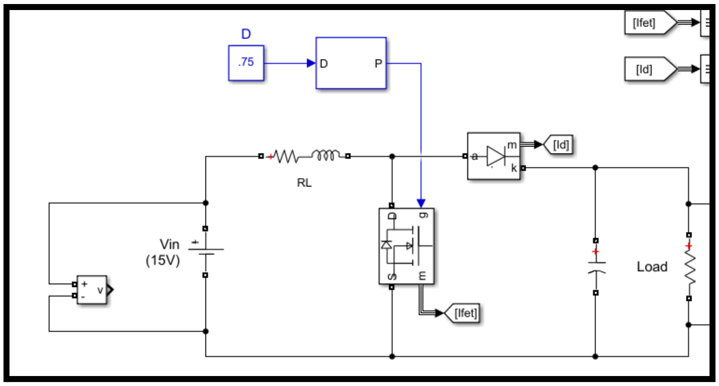
The throttle is implemented with a potentiometer, which acts as a voltage divider. Reading the voltage across the throttle with the MCU will allow us to determine the desired speed. Given our setpoint, we use a software PID loop to adjust the input to the motor controller based on the measured speed from the encoder. This allows us to drive the rear wheel at a desired speed, rather than controlling the power we send to it.

The controls system provides signals to the power system to control battery charging. When the pedal generator is turning, it can generate a varying voltage, and may sometimes drop too low. This causes the switching converter to be unable to produce a steady 36V, which is indicated to the MCU through an output pin. If this happens, we disable the switching converter and the battery charger. We also wish to disable charging if the battery reaches 90% capacity. On the other side, we also disable the entire rear wheel system if the battery drops to 20% capacity or below; if it drops below this capacity, its voltage can drop to an unusable level under load.

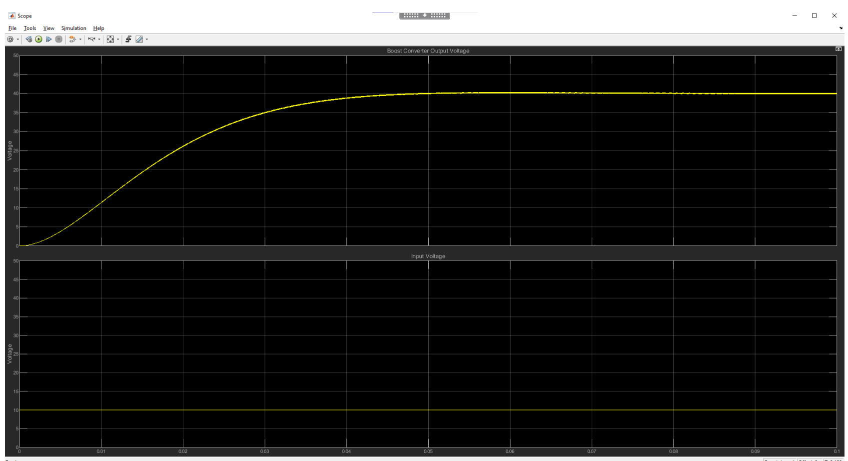
Requirement	Verification
Read desired speed from throttle, as 0-5V signal	Turn throttle back and forth, ensure reading on MCU is accurate
Regulate speed of rear motor and correct for error with encoder signal	Set the rear wheel to a specific speed, measure with a tachometer. Ensure that the wheel maintains setpoint when resistance is applied to the wheel with the handbrake.
Control charging/discharging of the battery	Ensure that the MCU can read the current charge status of the battery. Pedal the wheels until the generator is up to speed, ensure that the battery begins charging. Let the battery charge level drop to 20%, and ensure that the system stops sending power to the rear wheel.

2.4 Tolerance Analysis:

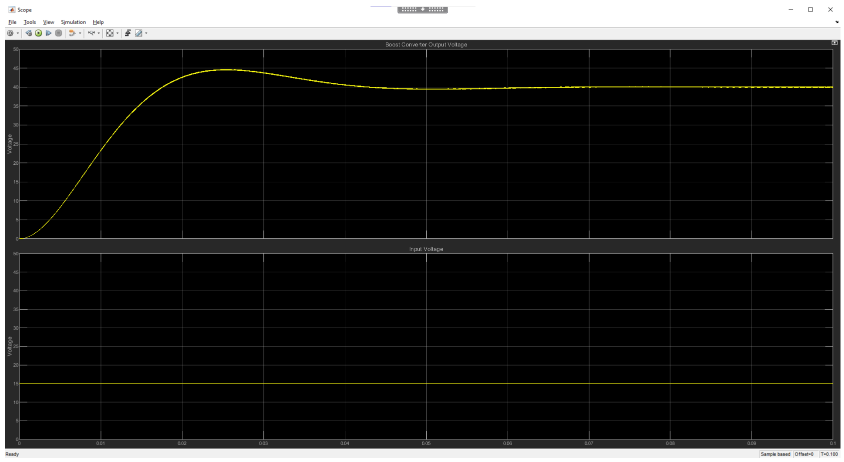
A critical part of our design is the switching boost converter, which regulates the lower input voltage of the pedal generator to a consistent 40V for charging the battery. This ensures that we can harness the unstable input power of the pedals. To show the feasibility of regulating input voltages of 10-20V to 40V, we used Matlab Simulink to simulate the operation of a switching converter, connected to a resistive load that mimics the power requirements of our battery charger. The circuit is shown below, it is a modified version of the Matlab boost converter example, with input and output voltage tweaked to represent our application:



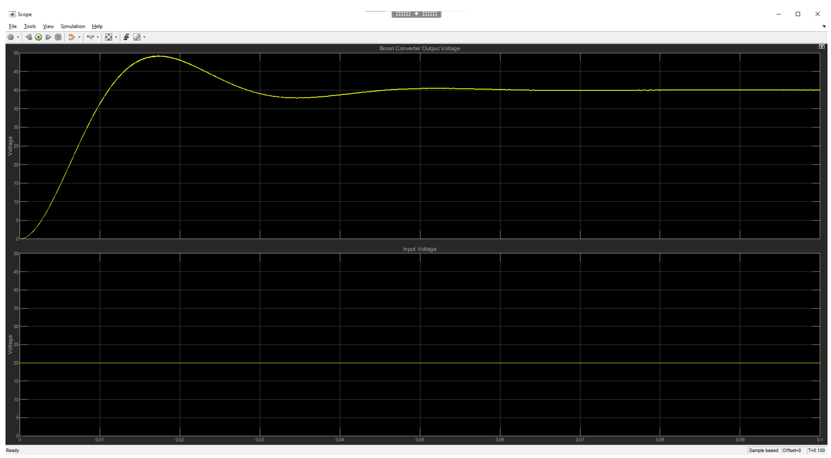
Below we show the performance of the regulator circuit at 10V, 15V, and 20V input voltage, simulated for 100ms:



10V input voltage

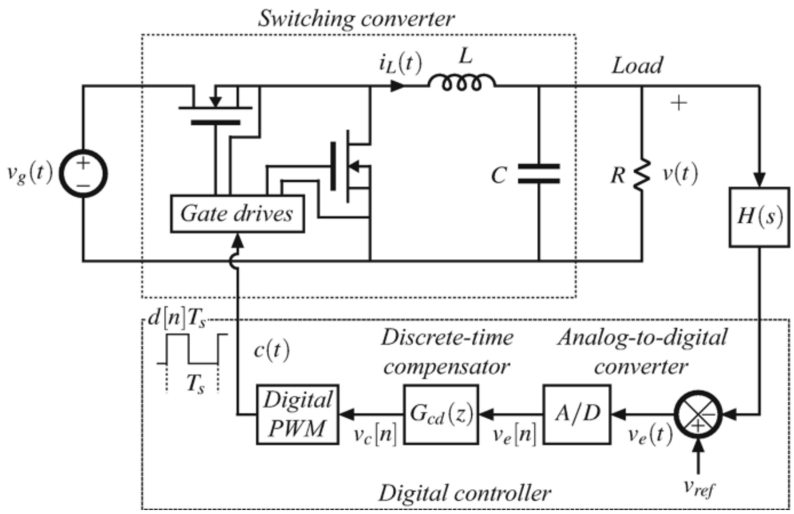


15V input voltage



20V input voltage

As shown in the simulation, this type of converter is capable of stabilizing at our desired output voltage, and holding it within the +-1V range we require. There is a concern about the transients present at higher input voltages; in the case of 20V input, the output voltage spikes to +10V above our desired output voltage. This is because this simulation is effectively open loop control as there is no feedback to the system of the actual output voltage. In our design, we use a TI LM5157 chip which has closed loop control; it receives the output voltage as feedback to the system and can compensate for the error more effectively. An example of this compensation system is shown below, the feedback is fed through a PID controller which controls the duty cycle of the gates.



3 Ethics and Safety

With any transportation device, the user not only assumes various types of risk, but also is able to assume a level of trust with their vehicle. As outlined in Section 1.2 in the ACM Code of Ethics, the statement "ensure that all harm is minimized" [1] stands out to us. To ensure we achieve this, one of our requirements is to keep the three subsystems adequately contained so there is no risk of electrocution. Furthermore, we plan to limit the acceleration and top velocity of the bicycle to discourage reckless use. The main braking system of the bicycle will also be a standard bicycle braking system that is mechanical and separate from the main control system to ensure that the user will always be able to come to a stop safely.

Our product falls into a gray area - it is not necessarily a bicycle, nor is it a Moped. In the State of Illinois, our type of vehicle falls best in the Electric Bicycle category, which is a bicycle that has some sort of assistance by a gas or electric motor. These vehicles, in the state of Illinois, "are legally bicycles, as long as their motors are smaller than 750W (one horsepower) and their pedals are fully functional." [2]. Electric Bicycles are subject to the same laws as bicycles, but also do not require insurance nor registration - to abide by the ACM Code of Ethics, we will encourage users to have some type of liability insurance or make sure they are well versed in the risks of using this type of vehicle, including wearing usual protective equipment such as a bicycle helmet.

Our product requires a 36V Lithium-Ion battery that will be used to power the bicycle, but also will be charged with a pedal-generator, which will output ~40V. While these types of batteries are relatively safe, they can easily become a fire or explosion hazard when proper care is ignored; especially since the battery is on a moving vehicle outdoors, a proper enclosure with a cooling system is required. Furthermore, to prevent other electrical failures, we will follow safety guidelines sent in place by OSHA (Occupational Safety and Health Administration) [3] and by the ECE Department, which include:

- Charging the battery per the manufacturer's instructions and maintaining safe battery charge capacities between ~10% and ~90% and temperatures
- Ensuring our PCB does not short components and designing our PCB in such a way as to minimize shorting risks
- Storing the battery in a safe environment with an insulating cover on the terminal leads.
- Ensuring that fire safety equipment such as a fire extinguisher and battery bag are always present and aware

4 References

1. “The code affirms an obligation of computing professionals to use their skills for the benefit of society.,” Code of Ethics. [Online]. Available: https://www.acm.org/code-of-ethics. [Accessed: 09-Feb-2023].
2. “Illinois laws for moped, scooter, and Electric Bikes,” Horwitz, Horwitz & Associates, Ltd., 16-Sep-2022. [Online]. Available: https://www.horwitzlaw.com/blog/illinois-moped-laws/. [Accessed: 09-Feb-2023].
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