BikeBike Revolution: Energy Efficient E-Bike

ECE 445 Project Proposal

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1. Introduction

1.1 Background

Biking is a longtime hobby and top choice of exercise with a broad audience and many components that can be improved upon. Indoor cycling has been a great form of activity that is currently on the rise of popularity in both cases of public and private use [1]. While the energy that is being burned is for the purpose of staying fit, there can be an even more optimal application for this mechanical power: to convert it back into electrical energy and use it to power the bike, thus turning it into an electrically-assisted E-bike. Many advantages can come out of this situation as the energy put in and coming out of the system is largely efficient and has multiple benefits. This also doubles as an indoor and outdoor bike, which can help users save financially and enjoy the hobby and exercise in multiple environments - whether stationary or covering real ground.

1.2 Objective

Our solution is to allow a pedal-assist E-bike to convert into an indoor stationary bike, and to use the energy generated from pedaling indoors to power the E-Bike for use outdoors. The amount of energy generated after pedaling for an hour is about 80 Wh including losses, while the average fully-electric E-bike is rated between 300-1000 Wh [2], [3]. This amount of power generated can then be feasible in an electrically-assisted bike, which can be rated as low as 144 Wh. We would also want to implement a multi-input system to allow the battery to be adapted to the grid to ensure a reliable energy source if needed. There will be an indoor stand to support the bike for safe use indoors, while the hub motor-generator, battery, and power electronics will be included on the bike frame itself. A system of power electronics includes DC-DC and AC-DC power conversion, as well as a digital control circuit.

1.3 Physical Design

Our adaptive E-bike will contain almost all of the subsidiary components in our design, including the motor on the rear wheel, and the power electronics and battery attached to the top tube frame of the bike. There will be a protective cover for both of these parts to ensure safety and longevity of the devices. An outlet on the cover will be available for charging the battery using the grid. The cadence sensor will be connected to the chain rings of the pedals and the battery life indicator LED will be attached next to the handlebars of the bike. The bicycle used will be a Schwinn World Tourist Road Bike, with the frame that is drawn in Figure 1. Two stands will also be designed to support the bike while it is being used indoors. All components will be interfaced with robust wires that connect between the motor, cadence sensor, power electronics, battery, and battery life indicator.

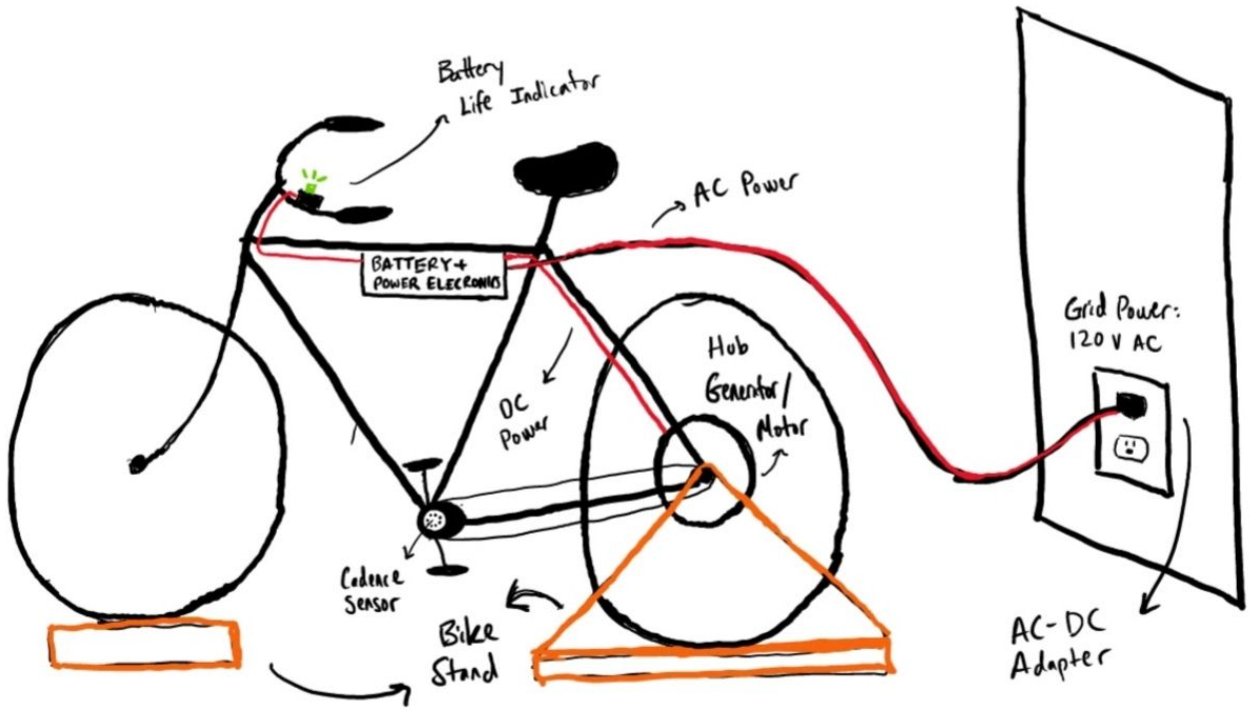

Figure 1. Simple Drawing of Integrated Elements of Our Project

1.4 High-level Requirements List

1. The bike must be able to travel with electric-assisted power for 1 hour.
2. In generator mode at a maximum input, the bike should be able to generate at least 100W of power by the user pedaling the bike. In this mode, the bike must also be able to switch to using power from the grid in order to get charged.
3. The DC-DC converter must be able to exhibit at least 75% efficiency when taking in varying values of voltage output from the generator.

2. Design

2.1 Block Diagram

Our block diagram consists of four interconnected subsystems - the power electronics, hub motor / generator, control module, and sensing module. The major components that drive the system's longevity, effectiveness, and efficiency are within the battery, converters, controls, and the motor. The ratings on these parts will be integral in satisfying our requirements of using the bike with pedal-assist functionality for a certain amount of time, as well as switching to generator mode to charge the bike at a satisfactory pace. The efficiency of power transmission as shown through the diagram is also achieved by these main components but also by direct data transmission between the modules through the digital controls and sensors.

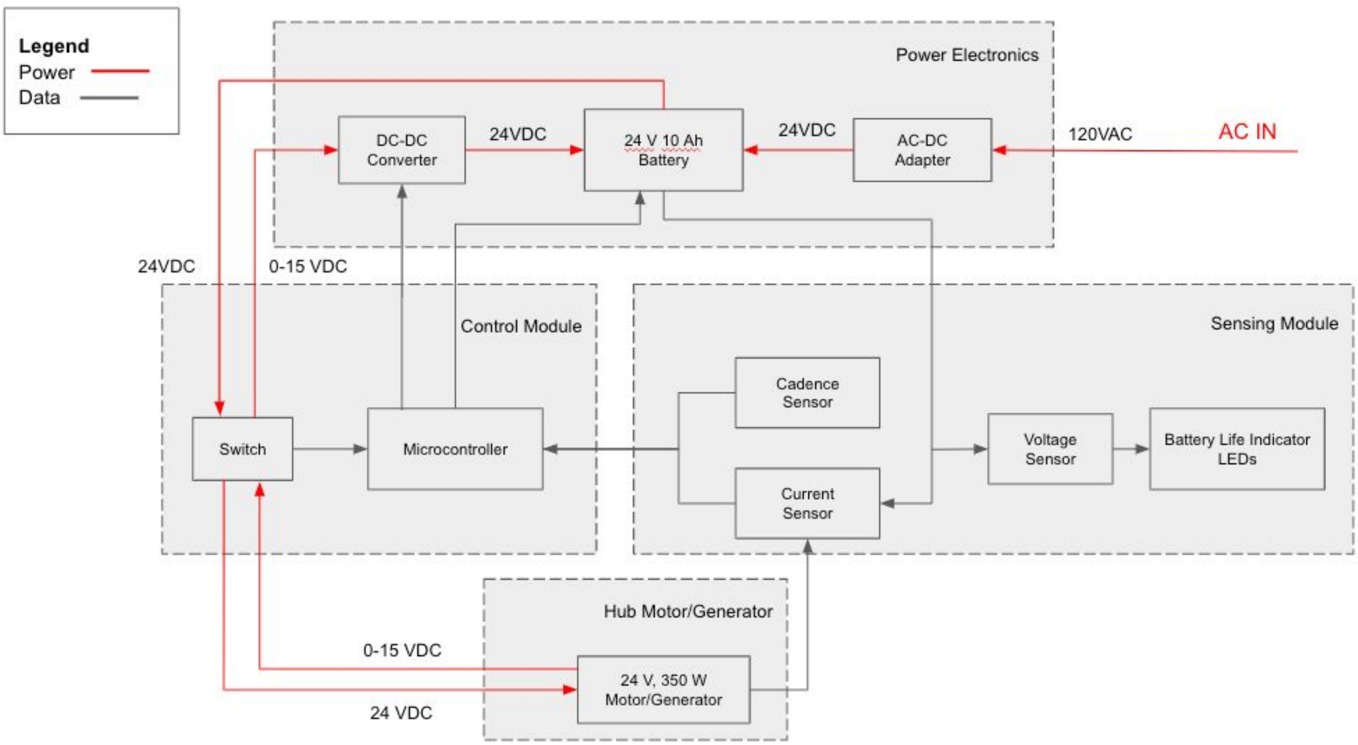

Figure 2. Block Diagram

2.2 Functional Overview

2.2.1 Power Electronics

- **Battery:** The 24 V, 10 Ah battery is where the power used in the system is stored. Depending on the signal from the microcontroller, it can either discharge current to the switch and to the motor or take in current from the AC-DC adapter or the DC-DC converter, which charges the battery at a rated voltage.
- **Grid Power:** The 120 V AC power supply coming from the standard American outlet will be also utilized in this system as a way of providing a powerful and reliable energy source to the E-Bike if necessary. This source will be indirectly charging the DC battery on the bike.

- **AC-DC Adapter:** An AC to DC power conversion needs to be made in order to connect the 120 V AC grid power to the 24 V battery. We decided to use a 100-240 V AC to 24 V DC adapter for this step as it is the simplest and has easy accessibility for implementation to the rest of the system.
- **DC-DC Converter:** DC to DC power conversion will be integral to safely and successfully transfer different voltage ratings between the motor, generator, and battery. A boost converter will most likely be used in order to step up the varying input voltage from the generator to the 24 V that is needed for the battery. We chose a converter over a transformer as it is lighter and more cost effective.

2.2.2 Hub Motor/Generator

- **Motor/Generator:** The motor/generator is a single component determined by the switch to run as a motor or as a generator. We decided to use a 24 V 350 W Permanent Magnet Electric Motor for this project. In the motor mode, the motor draws power from the battery to drive the rear wheel of the bike. In the generator mode, current is generated as the user pedals and spins the generator. This current is sent out to the DC-DC converter to be stored in the battery.

2.2.3 Control Module

- **Microcontroller:** The microcontroller takes in data from the switch, cadence sensor, and current sensor to determine how much power should be supplied to and from the battery. If the switch is in motor mode, the microcontroller allows the battery to supply power to the motor and depending on the cadence sensor, the microcontroller allows more or less power to be supplied. When the switch is in the generator mode, the microcontroller allows the DC-DC converter to supply power to the battery. The microcontroller also takes in data from the current sensor to check if the correct amount of current is traveling between the components, and corrects it if it is not at a rated value.
- **Switch:** The switch will control whether the motor-generator should be functioning as a motor, a generator, or in the off position. In the motor mode, the switch connects the battery to the motor. While in the generator mode, the switch connects the generator to the battery through the DC-DC converter. In the off position, it does not connect anything and the user can charge the battery directly from the grid.

2.2.4 Sensing Module

- **Cadence Sensor:** The cadence sensor we will be using is to measure how fast the user is pedaling the bike. This sensor will be mounted on the pedals of the bike. The data from the sensor will be input to our microcontroller to direct the motor in pedal-assist mode, specifically to supply more power when pedaling speed decreases and less power when pedaling speed increases.

- **Current Sensor:** The current sensor regulates how much current is going in and out of the battery and the motor to make sure the correct amount is being transferred. If the amount of current is incorrect, the current sensor will notify the microcontroller to adjust the current so that the system does not break. The current sensor is also a safety measure to ensure that too much current is not going into the battery.
- **Voltage Sensor:** The voltage sensor is used to check the voltage of the battery through a voltage divider so that the battery indicator will know how much charge the battery has left through the microcontroller. As the battery life decreases, the voltage would also decrease following the battery's voltage curve.
- **Battery Life Indicator LEDs:** The battery life indicator LEDs are used to show the user how much charge is left in the battery. There will be three LEDs, a green LED to indicate 66%-100% charge, a yellow LED to indicate 33%-65% charge, and a red LED to indicate 0%-32% charge. The voltage sensor will be used to indicate how much charge is left in the battery.

2.3 Block Requirements

2.3.1 Power Electronics: Voltage conversion between the multiple components of this project will be necessary to ensure that the correct amount of power is delivered to each part, thus ensuring the safety and reliability of the system. This subsystem will be taking in 120 V AC power from the grid, taking in varying levels of power from the generator to the battery during generator mode, and also supplying steady 24 V of DC power from the battery to the hub motor when the bike is used outdoors.

2.3.2 Hub Motor/Generator: The motor will require enough power to assist pedaling, so at least 350 W of power must be supplied to the motor. The generator must be able to generate at least 100 W of power to charge the battery.

2.3.3 Control Module: The microcontroller takes inputs from the switch, cadence sensor, and current sensor to determine how the DC-DC converter will function and outputs signals to the battery LED indicators. From the cadence sensor information, the microcontroller will be programmed to calculate how quickly the user is pedaling and how much power should be delivered to the motor. To determine if the hub is acting as a motor or a generator, a switch is required so that the user can easily flip between motor mode and generator mode. Using data from the current sensor, the microcontroller must be able to regulate the current traveling to and from the battery.

2.3.4 Sensing Module: The cadence sensor must output accurate signals back to the control module; as in correctly reading the user's pedaling speed. This module is also connected to the switch module of the hub motor / generator subsystem since the sensor will need to turn off when the system is in generator mode. The voltage and current sensor will need to accurately measure the voltage and current of the battery, within +/- 0.1 V and +/- 0.1 A.

2.4 Risk Analysis

The hub generator and motor is most likely the biggest risk in our project because of the different ways we are trying to implement this component. Losses and efficiency are huge factors in determining the success of this project and that is largely based on how efficient the generator can be as well as how much the motor will effectively use the energy from the battery.

3. Ethics and Safety

3.1 Ethics

When designing this project, many factors went into the safety precautions that would be needed in order to finalize a secure product. Elements such as speed and power from the pedal-assist mode and even hazards that could be formed when using the bike in the generation mode can pose as harmful and dangerous to the user when not operated correctly. Overheating, electrical, and physical are potential risks exposed to the user, while there are also possibilities of exposing harm to the general public while using this product. The following sections follow the different hazards that our project may have and discuss the actions that we will take in order to adhere to IEEE ethical standards [4].

3.2 Public Safety Hazards

We must ensure that the safety of the public is protected and users of our e-bike are aware of any potential dangers associated with it. This is acknowledged in the IEEE Code of Ethics, #1: "to hold paramount the safety, health, and welfare of the public… and to disclose promptly factors that might endanger the public or the environment" [4].

The main concern regarding public safety would be misuse of the e-bike, which could result in accidents or violation of traffic laws. Following the Illinois Vehicle Code under Sections 1-140.10, 1-140.15, and 11-1516, our e-bike would fall under the "low-speed electric bicycle" category, meaning that the motor must be less than 750W [5]. Additional restrictions on using the e-bike include that the bike cannot be used on a sidewalk, may not be operated at a speed greater than 20 mph, and can only be used by people aged 16 years or older [5]. We are using a motor that is less than 750W, meeting the requirement set by Illinois law. Informing users on how to properly use the bike and the limitations of the components can help mitigate actions that could endanger the user and others. However, we would not be responsible for users explicitly deciding to violate traffic laws.

3.3 Overheating Hazards

Some potential safety issues that could arise with our project include the components of our e-bike breaking or overheating, specifically our battery and motor-generator. If excessive voltage is supplied to the motor, this could cause overheating and motor failure. We will avoid this situation by controlling the amount of voltage supplied to the motor.

3.4 Electrical Safety Hazards

We are operating with a high voltage battery and motor, and if both components are not used properly, then a risk can occur with electric shock in the case of exposed wires or improper insulation and connection. Additionally, since our e-bike is meant to be used outdoors, harsh weather conditions could damage the electronics, wiring, sensors, and motor if they are not properly protected against inclement weather. Our end product will ensure that all necessary components are covered with the appropriate material to combat against these kinds of scenarios.

4. References

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[5] U.S. Senate. 111th Congress, 1st session. (2009, Aug. 4). *Public Act 096-0125.* [Online]. Available: https://ilga.gov/legislation/publicacts/96/PDF/096-0125.pdf