ECE 445

Spring 2020

Project Proposal

Hip Hop Xpress: Power Management System for Converted School Bus

Anabel Rivera (anabelr2), Antonio Rivera (amr2),

Eros Garcia (egarci90)

TA: Ruhao Xia

February 13, 2020

1. Introduction

Objective

The School of Architecture and the School of Music at the University of Illinois at Urbana-Champaign converted a school bus that will serve as a mobile educational platform to teach children about STEM through hip hop and music [1]. This bus will contain musical equipment, such as stereos and mixing tables, various LEDs and educational mediums. For this bus to run all of these electronics while the bus engineer is off, a battery reserve must be implemented. This bus must attract people with music and lights, while also being environmentally friendly. In order to accomplish this the electronics on the bus must be battery-driven and work for an extended period of time without running the engine.

Dr. William Paterson, who is taking lead on this project, approached the ECE department of the University of Illinois for expertise to help build the power system for this bus.
Our goal is to develop a working model of a power system that can be scalable to power the school bus. We will be focusing on creating a custom battery management system and data management subsystem. Due to the electronics on the bus having a large power load we will be using lithium ion batteries. These battery packs will be managed using our custom battery management system (BMS) PCB. This BMS will have the ability to charge the batteries from either a solar array or via the AC outlet. The BMS will also be monitoring voltage, current and temperatures from the battery packs. This data will be sent a RaspberryPi where the data will be displayed through a monitor. Further analysis will also be displayed here.

Background

The Hip Hop Xpress Bus will be driving to neighborhoods that consist primarily of low-income homes [1]. Children of these neighborhoods may not have access to musical equipment nor do schools in these neighborhoods have enough resources to provide an enriching musical education. This school bus will host numerous activities and classes to teach students how to produce and create music through STEM activities, fostering a sense of community and creativity in the neighborhood.

Although many teams on this project are creating activities and visuals, they do not have access to power such electronics. Our senior design team will be tackling the issue of power management through our power system design.

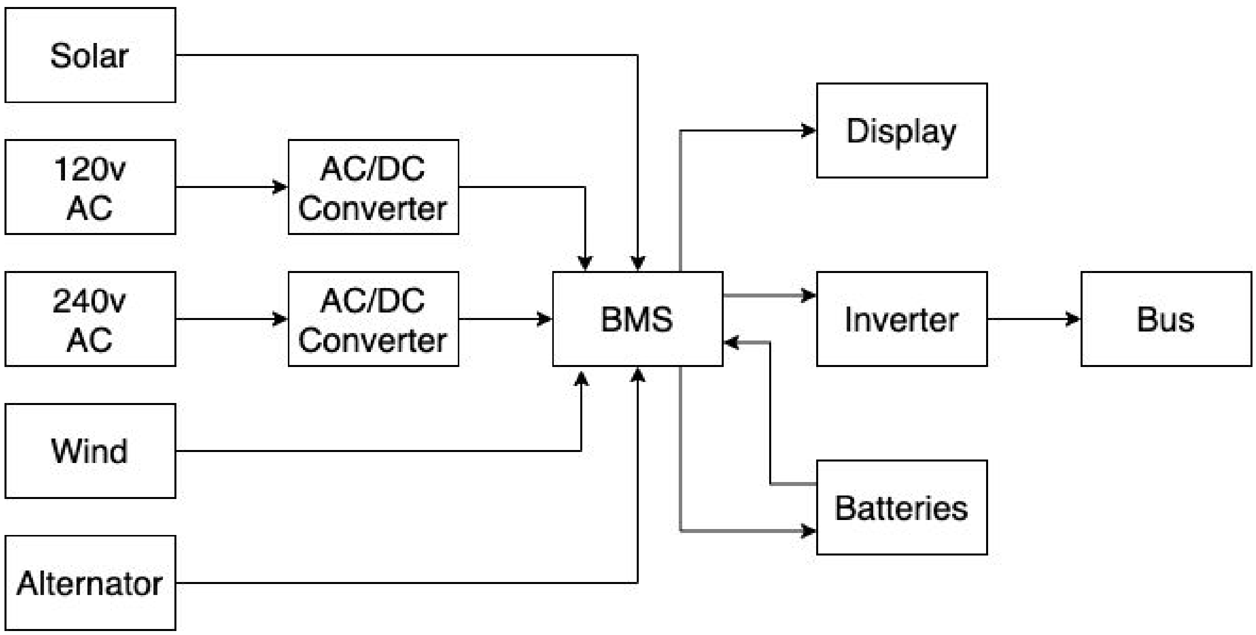
A power system that will take in solar and possibly wind energy and AC power is essential to make the equipment on the bus work and also be environmentally friendly. We will also be including a display where data from the system will be charted and presented professionally. These visuals will also serve as an educational outlet to anyone on the bus.

High-Level Requirements

- The battery management system will have the ability to charge the batteries through solar power and via AC outlet with safety being a priority.
- Our system will be able to store and track data for current and future use.
- Since the load of all the electronics is demanding, we will be focusing our effort to creating a working model that can be scalable. Our goal is to power a 2kw load with a 1kwh capacity. (The fully scalable system will contain many of our models in parallel.)

2. Design

Block Diagram



The high-level, power flow block diagram. Most of these components will be bought off-the-shelf. The primary exception will be the central BMS system. We will be constructing that as our PCB.

Solar - This section provides a 12v output from the solar panels that will be mounted on the bus. This will be an easy connection from the panels to the input of our BMS as both input and output voltage will be the same. If losses become a problem, we can attach a boost converter to slightly boost up the voltage to 12v +/- 1%. Expected to provide 5-6 kW of power optimal. Our proof of concept will have one 1m^2 solar panel array and is expected to provide about 300W of power.

120v AC - This is the standard for line-to-neutral voltage for AC systems. We will purchase a rectifier to convert this into a steady 12v +/-1% DC line. This line would then be connected to the input of the BMS. This line is meant for slower but more reliable charging due to the availability of these outlets. Expecting a max load of around 1.4 kW.

240v AC - This is the standard for line-to-line voltage for AC systems. We will purchase a rectifier to convert this into a steady 12v +/-1% DC line. This line would then be connected to the input of the BMS. This line is meant for faster charging due to the higher power rating of these outlets. Expecting a max load of around 3.8 kW.

Wind - This will be used in conjunction with solar power to both charge the batteries and to offset load during events. These would be deployable turbines, which would be planted around the bus after it is parked. The turbines have a unique advantage in that their capacity has potential to be expanded by adding more turbines. Solar is limited to the roof of the bus, while wind is limited by the capacity of the input interface of the BMS.

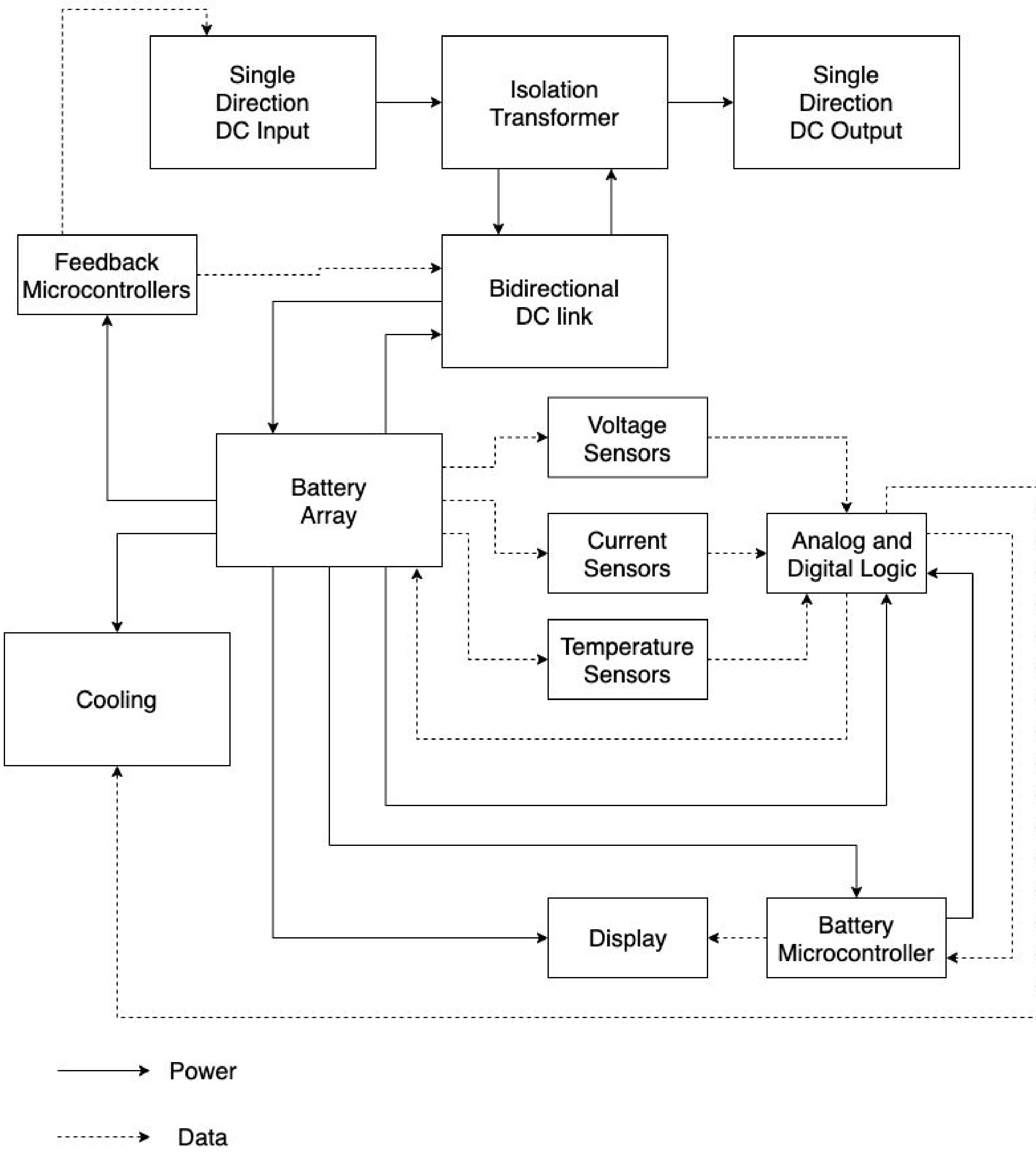
Alternator - This is a minor, but constant, flow of power from the bus. This would piggyback off of the engine to produce energy for the BMS. The power that this would produce is limited by the rating of the alternator (around 1-2 kW) and can be dangerous to use while driving. To get the most out of this, we would need to upgrade the alternator, which may be beyond the scope of our budget and it defeats part of the purpose of this project.

Display - This will show all necessary information that the user would want to know from the BMS, such as current power draw, load voltage and current, state of charge, and estimated time until full charge.

Battery - This is our battery array that will be designing and putting together. We are putting together 12 stacks of lithium ions, which will provide a voltage range from 36v to 50.4v. These batteries will be managed by the BMS. Full pack capacity would be 36 kWh, but our proof-of-concept will have a 1 kWh capacity. More detail in the BMS block diagram below.

Inverter - This will convert the 12v +/-1% output from the BMS to a clean 120v AC line. This line can then be used to power the majority of the devices on the bus and keep them running. We plan on using 2 kW inverters for both the final design and the proof-of-concept.

Bus - All of the equipment that needs to be powered on the bus. Expected load of around 12 kW of 120v AC.



The BMS block diagram. We will be making most of these components on multiple PCBs. Some of these components, such as the cooling and microcontrollers, will be bought but then configured to fit our project.

Single Direction DC Input - This is an AC link converter that allows any DC input to interact with the isolation transformer. There will be multiple of these circuits due to the various input sources such as solar, AC inputs, etc. This circuit will require an AC link due to the large power delivery (<200W). It is a single direction as power will only be flowing towards the transformer from the input sources. This power slow direction will be maintained using diodes. This will take in feedback from the Feedback Microcontroller to enforce a 12v output +/-1% regardless of small variations to the input voltage..

Isolation Transformer - This transformer is in charge of isolating the various sources and loads from each other. Isolation adds a large degree of safety to overall design by limiting any short-circuit current. This when combined with fuses, adds a very large degree of fault protection. This transformer also allows for easy voltage conversions between the different blocks. This final transformer should be rated for 15kW due to the large amount of power. This smaller-scale proof-of-concept will be rated for 2kW.

Single Direction DC Output - This is an AC link converter that allows the isolation transformer to interact with the inverters. This AC link will take the alternating DC voltage from the isolation transformer and rectify it to a 12v +/- 1% DC output. This voltage output is needed to drive the inverters, which will be supplying 120v AC to the bus.

Bidirectional DC Link - This is the third and final AC link, which is bidirectional to allow power to flow both to and from the battery array. This will be operating within an input range of 36v to 50.4v and we will use feedback to provide a stable voltage to the isolation transformer. This block will adjust the voltage range by adjusting switching delays for our link. This is also responsible for providing the charging voltage to the rest of the array during the charging cycle.

Battery Array - This is the battery pack that we will be designing. We will have a 12-cell stack that will bring our operating voltage range from 36v to 50.4v. This higher voltage range allows us to draw less current from the batteries and reduce losses. It also has the side benefit of reducing the negative effects of voltage drops in the converter.

Feedback Microcontroller - These are responsible for adjusting the “dead time” delay of both the bidirectional link and the single directional output link. These let us drop down the voltage to required levels as the input changes.

Voltage Sensors - This is used to directly monitor the voltage level of each cell in a stack. This ensures that the voltage of every cell is within the correct range that it needs to be at (3-4.2v per cell). If any cell falls outside that range or has a disproportionate voltage compared to the other cells in the stack, then the analog logic attached to this will send a disconnect signal to the digital logic.

Current Sensors - This is used to read the current flowing through the stack. This will allow us to monitor the current and send a shutoff signal of the current exceeding upper limits.

This would then link to the rest of the digital logic. For the purposes of our test model, we will have the attached logic send the cutoff signal at 6 A per stack.

Temperature sensors - This is used to read the temperature of each stack. Each stack will have a heatsink metal link between all of the batteries which will share thermals between all of them. These thermals will then be monitored by analog logic that will send a cutoff signal to the digital logic if the temperature rises beyond the maximum threshold of 45 C or 113 F.

Analog and Digital Logic - This component is responsible for monitoring sensor data from each stack and sending an all-clear/danger signal to the battery microcontroller and digital logic. This block is intended to cut down on microcontroller costs by allowing for a large number of analog measurements from the sensors. The analog comparisons will be made using a Schmitt trigger that will be fed into other digital logic. This digital logic will be able to disconnect the battery stack from the rest of the array. This will draw power from the array to function but due to the small power requirements and hundreds of stacks in the final design, the chance of all stacks failing at the same time should be vanishingly small. To help with safety, we will add double redundancy to each stack, and if a component fails then the entire stack will be disconnected.

Battery Microcontroller - This component takes in data from the Analog and Digital circuits to build models based off of it. These models will then be sent to a display for the end user to see them. These models will include data such as power draw, remaining battery capacity, remaining run time, etc. This component should be able to scale all models based on how many stacks are plugged in along with being able to point to faulty stacks.

Display - This component takes in the information from the Battery Microcontroller and displays it. It will run off of the Battery Array.

Cooling - This will be some sort of cooling system. This system will likely cover all of the converters and the Battery Array. This will be implemented as necessary, but will likely be needed due to the large loads that will be delivered by the system. We are looking at both air and water cooled systems. This system should keep most of the converters below 110° C and the battery pack below 45° C.

Risk Analysis

The building of the battery array will bring a significant liability risk, as there is a risk of explosion. Many pieces of our project revolve around keeping the battery array operating safely. Our battery array will consist of putting together 12 stacks of lithium ions, which will provide a voltage range from 36v to 50.4v. The actual system that will be going on the bus will be 36kWh, but our model will only have a 1kWh capacity. Since this is a large battery bank, we need to make sure nothing fails when it comes to each individual battery. We will be consistently checking the voltage of each battery, and the temperature and current of each stack consistently using logic components and microcontrollers. If any of these values pass a certain threshold we will shut the whole battery pack off. To ensure that our battery array is safe, we will double the sensors at each battery (2 sensors are checking each lithium ion battery voltage, etc.) to avoid issues with sensor failure.

Due to the large capacity of these batteries, thermals become an issue. Our design must have enough space between each stack of batteries. This will allow the batteries to be liquid cooled to reduce thermal heat radiating off the battery array. Our model may or may not include the actual water cooling but we will document how to include it for the scaled system. Since this is a moving vehicle, we will also provide guidance for possible impact protection for the system that is being installed into the bus.

3. Ethics and Safety

Lithium ion batteries have a large energy density and their mode of failure, when physically impacted or operated improperly, can be fire or an explosion [2]. Because the bus will need large amounts of energy to be stored, we must ensure that the power is always safely managed. Although we are only building a small-scale model, while designing our project we need to keep in mind the effects of scaling it up to a large scale capable of storing up to a few dozen kWh. To protect the safety of those who will use and operate the bus in the future, we have recommended to those who proposed the idea to take our design to a professional engineering firm to build the full power-management system. We will also actively seek feedback for our work as the project is progressing.

As stated in the IEEE Code of Ethics [3], we must hold the health and safety of the general public in the highest regard. Multiple layers of monitoring and redundant emergency shut-off mechanisms help us achieve safe use of the system. We must ensure that proper education is given to those who will be operating the bus to understand the dangers of lithium ion batteries to deter reckless behavior or operation of the system, and, as ethical engineers, give our best estimates of the dangers that could arise given the data we have been presented.

Since this bus will be driven on highways with the lithium-ion batteries, a hazardous material, we must comply with the Electronic Code of Federal Regulations § 173.185 Lithium cells and batteries [4]. In order to transport the amount of power ultimately needed, each battery cell and pack will need to be properly insulated, away from metal or conductive surfaces, and secured with an inner packaging. We must ensure that the surrounding material has a resistance of at least 500 ohms/V. Then, each pack must be completely encased in an outer packaging that is drop-proof (up to 1.2 m), impact-resistant, and protects the batteries from debris, while ensuring vibrations due to movements of the bus do not cause the batteries to impact each other. The BMS must ensure the system does not inadvertently turn on during transport. Each outer packaging should be secured to the floor of the bus. The outer packing must have markings declaring its contents, and have proper ventilation for thermal regulation.

Before using our system for the first time we must perform some tests and record reference data for our system. As stated in [2], we must record the internal resistance across each cell and ensure no more than a 15% variation between cells. The open-circuit voltage across cells should have no more than a 2% variation between cells at all times. Maintenance, including cleaning any chemical leaks, verifying secure connections of batteries and checking for deformities, should be performed regularly. The system should also be checked for energy leakage. Our battery management system will record and transmit data about the state of charge and state of health of each group of cells, voltage, and current. The information will be presented in a user-friendly manner, as suggested in the above Guide.

References

[1] *The Hip Hop Xpress*. [Online]. Available: https://publish.illinois.edu/hiphopxpress/. [Accessed: 13-Feb-2020].

[2] IEEE Guide for Design, Operation, and Maintenance of Battery Energy Storage Systems, both Stationary and Mobile, and Applications Integrated with Electric Power Systems," in *IEEE Std 2030.2.1-2019* , vol., no., pp.1-45, 13 Dec. 2019

[3] “IEEE Code of Ethics,” *IEEE*. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 14-Feb-2020].

[4] “§173.185 Lithium cells and batteries.,” *Electronic Code of Federal Regulations (eCFR)*. [Online]. Available: https://www.ecfr.gov/cgi-bin/text-idx?SID=c9068f6400017f54b47e59b9d4e5d486&mc=true&node=se49.2.173_1185&rgn=div8. [Accessed: 13-Feb-2020].