

Experiment 7

Complete System Implementation

ECE 482

The objectives of this experiment are:

- To aggregate the designs produced throughout the semester and design a coordinated control of each circuit
- To construct and demonstrate a functioning electric bicycle

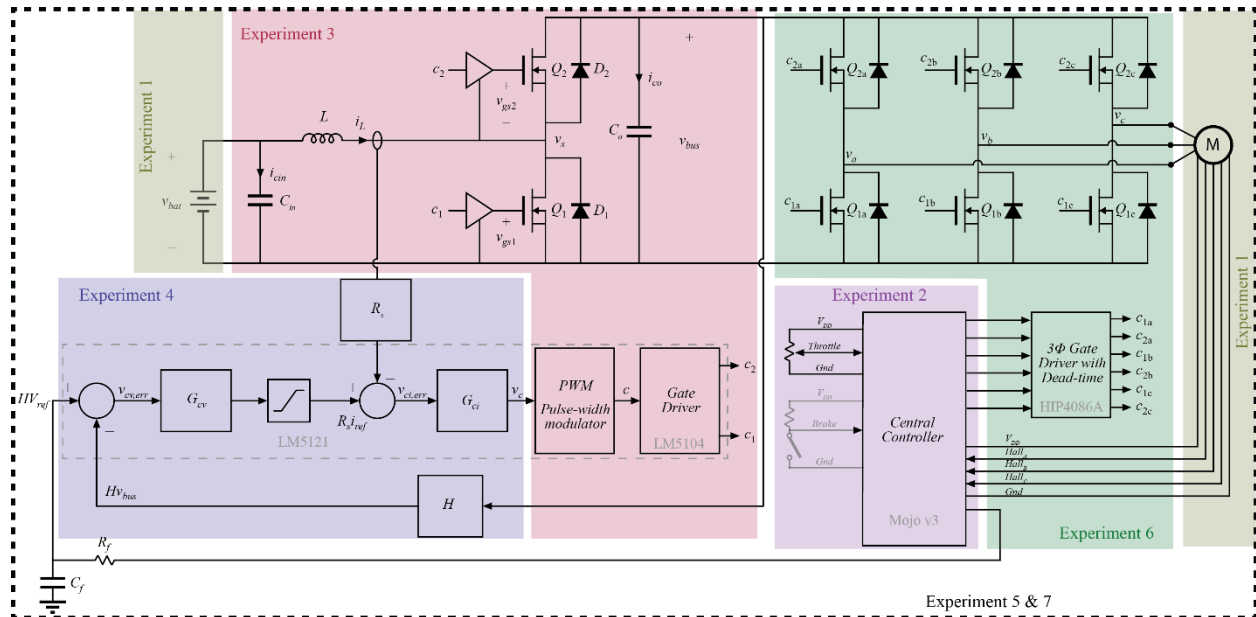


Figure 1: Motor drive power stage and control circuit schematic

In this final lab of the semester, you will complete the system you have designed and test ride the electric bicycle. You are *not* required to actually ride the bicycle, and should not do so if you are not entirely confident in the safety and reliability of the system you have constructed. It is sufficient to test the fully assembled bicycle on the stand only.

I. Boost Converter Population and Verification

Populate the boost converter and its control circuit on the PCB you designed. Using the same testing procedures developed so far in the course, populate one step at a time, testing as you go to ensure proper operation. Verify that the boost converter is able to regulate V_{bus} in the presence of a time-varying control signal, V_{ref} still supplied from a benchtop power supply.

Once you have confirmed that your circuit layout is correct and the boost converter is stable and functions correctly in closed loop, add the R-C filter in Fig. 1 composed of R_f and C_f . These two components will be used to low-pass filter a high frequency PWM output from the Mojo controller to generate an analog voltage from a digital output pin. You should design filter values and PWM frequency such that:

1. The filter cutoff frequency is at least two decades below the PWM switching frequency of the digital signal (this frequency does not need to match any other switching frequency in your circuit). This will help to ensure a low-ripple analog output.
2. The PWM switching frequency of the signal is at least two decades below the Mojo clock frequency. This ensures that you have a resolution of at least 1% in adjusting the analog reference voltage.

Beyond these tips, you can select the analog reference implementation as you see fit.

Once implemented verify that you are able to, adjust the duty cycle of the mojo digital output to control the boost converter voltage from V_{bat} to 50 V, when $V_{bat} = 26$ V. Make a measurement of the converter efficiency at $V_{bus} = 50$ V, $P_{out} = 100$ W, and compare to your results from Experiments 3 and 4. Discuss any discrepancies.

In order to test on the benchtop, temporarily fix the motor drive duty cycle at a low value so that the boost converter reference voltage can be increased without supply excessive power to the motor, resulting in unsafe speeds. Verify and demonstrate that you can control the motor speed with the throttle setting the boost reference voltage alone.

II. Throttle Dual Control

At this point, we have two methods of controlling the power flow to the motor. First, as constructed in Experiment 5, it is possible to PWM the legs of the motor drive at high frequency to reduce the current to the motor. In this mode of operation, each leg of the inverter behaves as a buck converter were the output inductance is the motor winding inductance. Additionally, if the duty cycle of the high frequency PWM signal is kept constant, power flow to the motor can be increased by increasing the bus voltage.

In some commercial EVs, the boost converter is controlled to always boost to a maximum voltage (75 V in our baseline design), and the motor drive then does all of the “step-down” at low powers. However, this approach is inefficient. The switching devices exhibit switching loss according to the bus voltage, so stepping up this voltage when it is not required leads to greater-than-necessary power loss. Instead, we would like to keep V_{bus} at 26 V when the motor power is small (i.e. when the throttle command is small).

To implement this, two example control diagrams are given in Fig. 2. In Fig. 2(a), the duty cycle of the inverter is controlled by the throttle initially, until it reaches 95% at which point it saturates and continuing to increase the throttle begins to increase the boost converter voltage. In Fig. 2(b), the inverter duty cycle and boost reference voltage are increased simultaneously. You are free to choose which implementation to pursue, or propose an alternative for approval by the instructor, but your complete system must perform both functions over the range of throttle inputs.

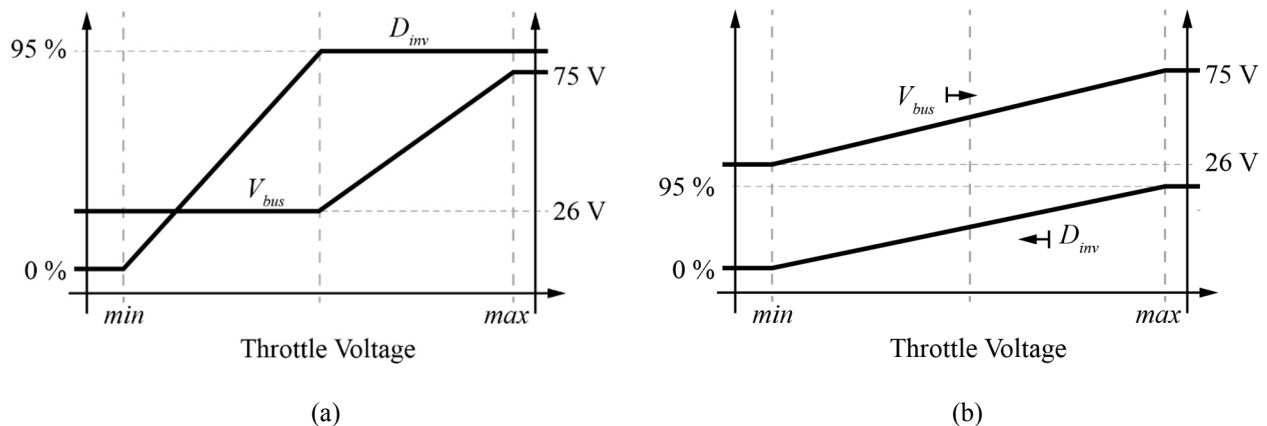


Figure 2: Steady-state diagram of two example implementations of dual throttle control

III. E-Bike Testing

Test your complete system indoors. In the final week of class, bicycles with batteries will be available. Connect, through the required protection, your circuit to the motor and battery. Verify that the motor spins with

speed controlled by the throttle, and can be successfully started, brought to speed, and can coast down without issue. You may use the mechanical brake as necessary to slow the system down.

If you are confident in the system and would like to, you may test the e-bike off the stand, outdoors, with instructor present. Note that all Tennessee state bicycle safety laws still apply, including a speed limit of 20 mph for e-bikes on public streets. You are not required, and will not be penalized, if you choose not to complete this step. For full credit, you must only operate the complete system (with motor and battery) on the stand in the lab.

IV. Deliverables

The deliverables for the final project of the semester are (1) demo of a functioning, complete system on or before April 23rd and (2) a technical reference manual for your completed electric bicycle. The report should include the following:

- General Overview: highlighting the purpose and key features of the system
- System Description: block diagrams & (brief) description of functionality and use of your implementation, capabilities and operating ranges
- Implementation Details: block diagrams and descriptions of their internal operation, including justification of why a system was designed as-is
- Verification: simulations, and experimental results demonstrating the achieved operation of each block and the overall system
- Conclusions: including future steps, as you see them, to improve system performance and any comments on your system's successes, failures, or things you would do differently

Additionally, the following should be included as Appendices as well as additional supplemental files to the report:

- Schematics
- PCB Layout
- Parts List
- FPGA Codes

The technical reference manual and associated files should be sufficient to allow anyone with an appropriate background to reconstruct an exact copy of your system. The depth and comprehensiveness of the reference manual should be comparable to the (better) datasheets and user guides/manuals used in this course.