Experiment 6
Motor Drive Control
ECE 482

The objectives of this experiment are:

- To implement a central control system and rider interface
- To populate and test the motor drive on your PCB
- To implement six-step (trapezoidal) motor control
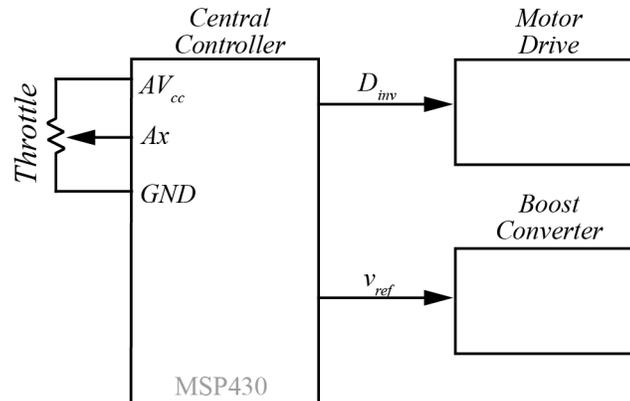- To successfully test an electrical to mechanical energy conversion system

Figure 1: Communication Diagram of central control

In this lab, you will use the MSP430 controller code designed in Experiment 2 to test a throttle-controlled motor drive. You will use the PCB designed in Experiment 5 for the power stage.

I.   Central Controller Coding

Fig. 1 shows the general communication diagram of the system. Depending on your chosen motor drive realization, the number and nature of signals communicated between the different blocks will vary. At a high level, the MSP430 provides an analog v_{ref} to control the output voltage V_{bus} of the boost converter, and an analog/PWM signal to the motor driver to control its duty cycle. Both are determined from a single rider input – an analog voltage coming from the throttle.

At this point, we have two methods of controlling the power flow to the motor. First, it is possible to PWM the legs of the motor drive with a variable duty cycle 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 (50 V in our baseline design), and the motor drive then does all of the "step-down" at low powers. However, this approach can be inefficient. The switching devices in both converters exhibit switching loss according to the bus voltage, so stepping up this voltage when it is not required leads to greater-than-necessary switching 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.
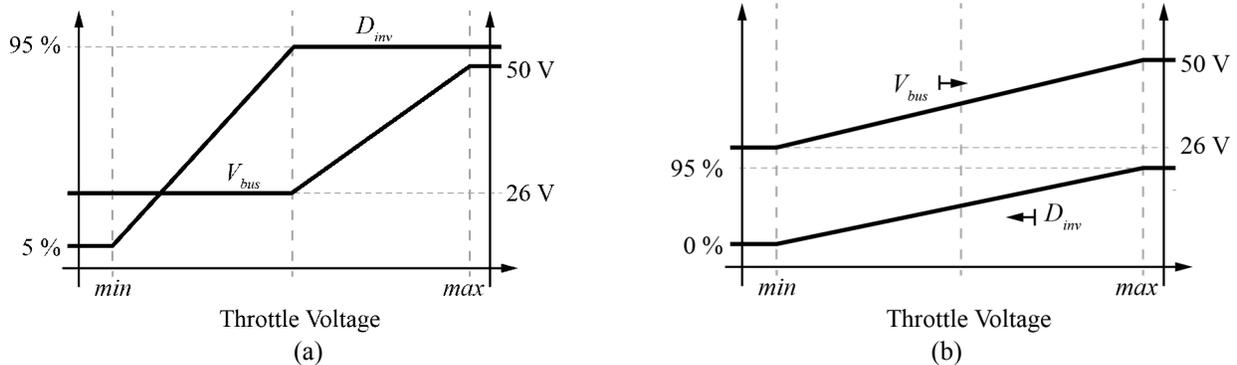
Figure 2: Steady-state diagram of two example implementations of dual throttle control

Before the PCBs return from manufacture, develop your MSP code to implement the central control functionality. Demonstrate working MSP430 code, using the correct pin assignments from your layout and handling any other communication (e.g. enable pins, etc.) that responds to throttle input by varying the signals which control both inverter duty cycle and bus voltage from minimum to maximum values.

Note: The throttle for the e-bike is solid state. The internal implementation uses a hall sensor, rather than a physical potentiometer. As such, the throttle will not function without an applied voltage. For the full range of throttle twist, the output voltage from Fig. 1 will vary monotonically from approximately 0.8 V to $A_{vcc}-0.8$ V.

II. PCB Population and Testing

When your PCBs from Experiment 5 arrive, populate the motor drive stage. At this point, you do not need to populate any of the boost converter, but can use the benchtop power supplies to establish a voltage on V_{bus}. Using the same testing approaches developed so far in the course, populate one step at a time, testing as you go to ensure proper operation. Make sure each component is working properly before any power flow through the converter is attempted.

Before connecting your circuit, make sure that you properly configure every pin connection as input or output. Programming a pin as an output which is connected to a low impedance signal may cause damage to the circuit. In this experiment, make sure that all of the pins which connected to the hall sensor buffer are designated as inputs.

III. Six-Step Trapezoidal PWM

The details of your motor connection and control will vary for each group, depending on the implementation chosen in the previous experiment. Consult with the instructor as you are populating to determine an appropriate test schedule. In all cases, once you have confirmed that your circuit layout is correct and the motor driver will function correctly, do not connect to the three motor windings before you have verified that the outputs from the motor drive are consistent with expectations when the hall-effect signals are used.

IV. Testing with the Motor

Once all half-bridge outputs are verified, connect your motor drive and hub motor, with protection fuses in between. Leave the hub motor in the stand on the floor at all times (i.e. do not put the stand on the benchtop). Beginning with just 5V and a 1A current-limited supply on V_{bus}, and increasing steadily, test your motor drive by steadily applying throttle. Demonstrate to the instructor that you are able to control the speed of the hub motor using the throttle. Only test the hub motor at low speeds, as excessive speed will cause the motor to become unstable on the provided stands. Once this is verified, increase the V_{bus} supply to 26 V and test, again only at throttle values small enough to correspond to low speed operation.

V. Deliverables

Submit the following to receive credit for this experiment:

A half-page (max) writeup detailing any problems faced in the experiment, how you solved them, and any modifications you would like to make to the system in retrospect.