

Iowa State University
Electrical and Computer Engineering
E E 452. Electric Machines and Power Electronic Drives

Laboratory #6
Buck Converter – Hardware Implementation

Summary

This lab will build upon work done in Labs 4 and 5. In Lab 4, you designed and simulated the buck converter using ASMG. In Lab 5, you designed the buck converter embedded control application in MATLAB/Simulink, using the Embedded Coder toolbox. Now, you will run the control application on the F28035 MCU, to control the buck converter. Lab-Volt equipment will realize the load.

Learning objectives

- Implement a buck converter using an embedded controller.
- Analyze the power converter's performance.
- Drive a dc machine with the buck converter.

Background material (should be read before coming to the lab)

- *TMDSHVMTRPFCKIT Hardware Reference Guide (HVMotorCtrl+PFC_HWGuide.pdf)*
- *TMDSHVMTRPFCKIT schematics (HVMotorCtrl+PFC-SCH[R5].pdf)*
 - *Peripheral Mapping and DC-bus Sensing*
- *F28035 ePWM reference guide (ePWM_spruge9e.pdf)*
 - *Peripheral Configuration*
- *F28035 Analog-to-Digital Converter reference guide (ADC_spruge5f.pdf)*
 - *Conversion equation*
- *MATLAB User's Guide*
 - *Sections on using ePWM and ADC blocks for TI C2000 devices*
- *Krause, chapter3*

Exercises and Questions

Instructions: every student should deliver his/her own report at the end of the lab session, even though the experiments are conducted in groups. You may want to answer the questions as you go along the exercises. Time yourselves according to the recommendations below.

1. Model Configuration and Code Generation [30 minutes]

Before continuing with this lab, you should have finished developing the control application in Lab 5. If you did not complete this, you should do so now. Your controller should be similar to that of Figure 1.

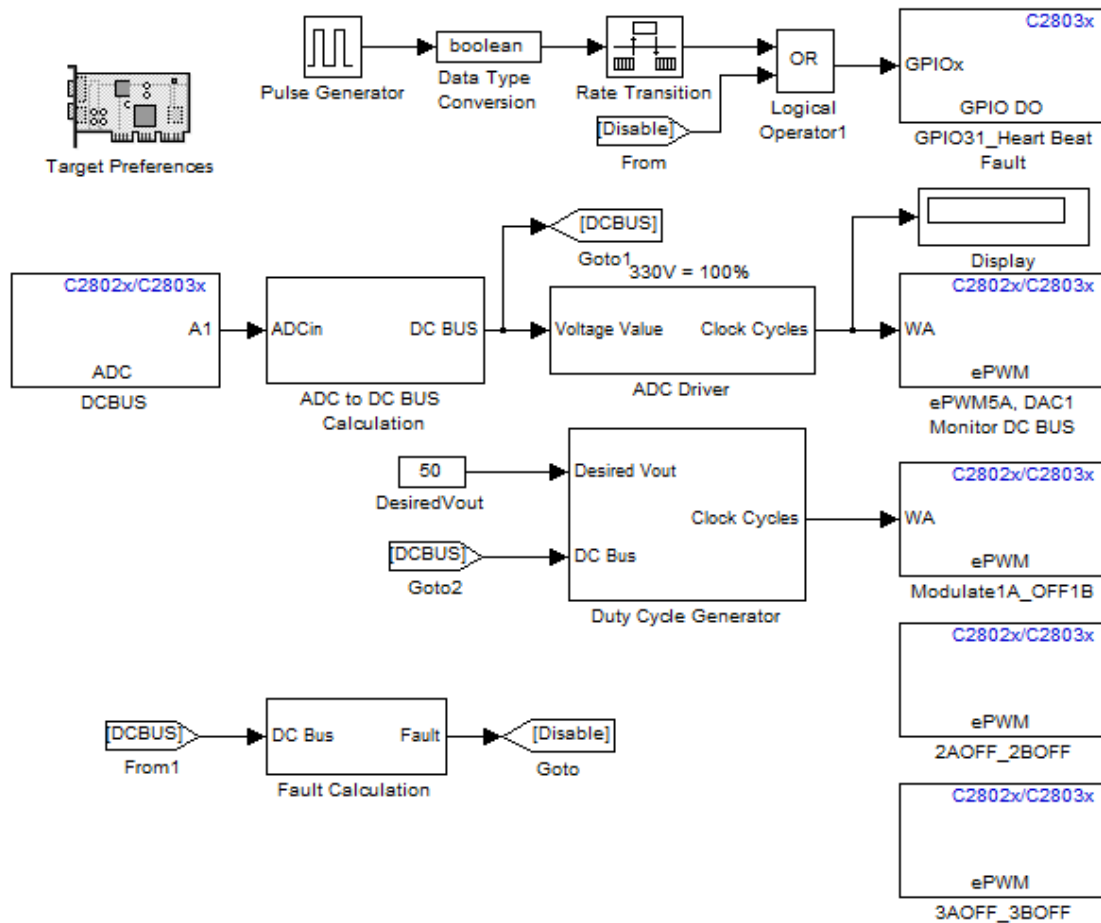


Figure 1. Buck converter control application.

Build the model to generate the .out file. Make sure to verify the settings of the *Target Configuration* and *Simulation Configuration Parameters*. You should use the board named "F28035", not the one named "F28035 FLASH". When the build is finished, you should see a new folder created in the location of your *Current Folder*, named "projectname_ticcs". Verify this folder contains the .out file necessary to program the device.

2. Construct and Run the Buck Converter [100 minutes]

The buck converter with capacitor circuit that you simulated in Lab 5 will be built and tested. Performance of this circuit should closely match your simulation results.

WARNING! ENSURE ALL POWER IS TURNED OFF BEFORE BUILDING THE CIRCUIT. ONLY ENERGIZE THE CIRCUIT AFTER YOU HAVE CONFIRMED YOUR CONFIGURATION AND PROGRAM WITH YOUR GROUP MEMBERS AND T.A.

WARNING! THE DC-BUS CAPACITORS IN THIS KIT WILL STAY CHARGED FOR A VERY LONG TIME. ALWAYS VERIFY THAT THE DC BUS IS DISCHARGED BEFORE DISASSEMBLING YOUR CIRCUIT.

DELIVERABLE 1: Study the schematics. At 100 V, how much energy is stored in the DC-bus capacitors located on this kit? Through a short circuit discharge resistance of 0.005 ohm (ignoring any series inductance), what is the initial discharge current?

Note: The TMDSHVMTRPFCKIT schematics have a typo. The Inverter DC-bus capacitors (*C6, C7, C8, C19, C20*) are shown to be 330 μF each, but actually, they are 220 μF each.

a) TMDSHVMTRPFCKIT Development Kit Configuration

This kit can be used for many applications. It is necessary to make some changes to the configuration to accommodate our application.

CAUTION! MAKE SURE YOU WEAR A GROUNDING STRAP BEFORE TOUCHING THE BOARD. CONNECT THE STRAP TO THE EARTH GROUND PROVIDED ON THE LAB-VOLT POWER SUPPLY.

- Isolate the Three-Phase Inverter by removing any existing jumpers, as described in the *TMDSHVMTRPFC Hardware Reference Guide*.
- Connect a DC-bus (Lab-Volt power supply *pins 7-N*) to the TI TMDSHVMTRPFC Kit (*BS5-BS6*). Ensure the supply is OFF and that the dial is set to the minimum output.
- Move jumper *M3.J4* to *Main.J9*. This will allow for JTAG programming of the ControlCARD.
- Plug in the +15 V DC supply to the Control Power input, *JP1*.
- Move jumpers *Main.J3, 4, 5* to *Main.J6, 7, 8* to provide control power.
- Ensure jumpers *Main.J11, 12, 13* are in the 1-2 position.
- Connect the kit to the computer via the USB cable.
- It is not necessary to use the fan for this experiment.

b) Buck Converter Implementation

Configure the Lab-Volt passive elements to construct the Buck Converter with capacitor that you simulated in Lab 5. Your circuit should be connected to the Phase U output of the TI Kit. Connect voltage and current probes as needed, to measure the input voltage, load voltage and load current. Also measure any DAC outputs to verify program variables.

Check that your embedded application, that you made in MATLAB/ Simulink, is configured to run the buck converter with capacitor (i.e. verify that the switching frequency and desired output voltage match your design).

CAUTION!

Verify your hardware configuration and embedded program with your group members, and then with your T.A.

MAKE SURE YOU CONFIGURE YOUR SCOPES AND PROBES CORRECTLY.

Open Code Composer Studio. Open your *Target Configuration File*, which you made last time, to verify the type of connection (...USB...v1). Go to Run/Debug Configurations. Set the path of your target configuration file. Set the path of the .out file you would like to download.

Debug the project. When the debugger launches, your program will be loaded onto the device. The program will initially be in the *Suspended* state.

BEFORE RUNNING THE APPLICATION, ENSURE YOUR HARDWARE IS CONFIGURED PROPERLY, INCLUDING MEASUREMENT TOOLS.

WARNING! If you need to stop the program execution, use the “Reset” button, not the “Pause” button; pause will lock the switching state output.

Observe the circuit’s behavior using your oscilloscope.

DELIVERABLE 2: Sketch the output voltage and load current waveforms. What is the ripple factor, mean, and rms values for each waveform? How does this compare with your simulated results? Explain any differences you observe.

Before turning off your controller or power supply, reduce the DC-bus voltage until the dial is at the minimum. Turn off the power supply only after you observe on the oscilloscope that the DC-bus is fully discharged. Stop the embedded application, and turn off the controller.

WARNING! TURN OFF POWER BEFORE DISASSEMBLING YOUR CIRCUIT.

3. DC Motor Drive [35 minutes]

For the purpose of introducing machines and drives, we will consider the Lab-volt DC Machine, which can be configured for *series*, *shunt*, or *separate* excitation. A model of the separately excited dc machine is shown in Figure 2. See Krause, chapter 3, for more details. Your buck converter will be used to drive the machine.

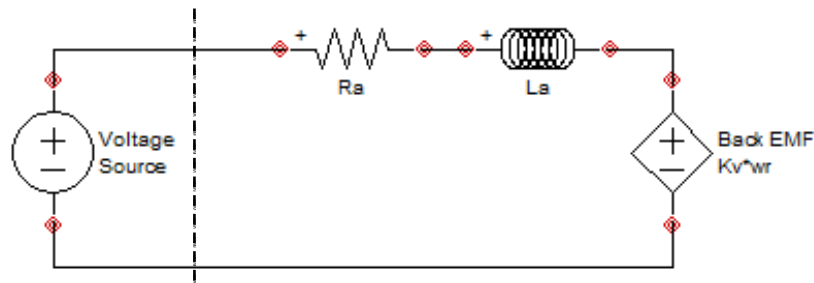


Figure 2. Model of a dc motor with a separately excited, constant magnetic field.

Connect the field labeled “shunt” of the machine to the Lab-Volt constant 120 V dc source (*pins 8-N*). This provides the “separately excited” magnetic field.

Couple the dc motor to the four-quadrant dynamometer, using the belt provided. Set the dynamometer function to operate in *Neg CT Primemover/Brake*. The torque will be controlled after pushing the *Start* button. Applying a torque without the DC machine running will result in the dynamometer accelerating until it reaches a steady-state condition. Caution must be taken when operating in torque control mode.

Before turning the motor with your converter, turn it with the Lab-Volt supply. Connect the variable dc output (*pins 7-N*) to the armature terminals. Turn on the supply and slowly raise the terminal voltage. Observe the motor’s behavior. Turn off the supply when finished, and before adjusting connections.

Connect the output of your buck converter to the Lab-Volt smoothing inductor, and the inductor to the dc machine. Because the output of the buck converter is a positive voltage only, your motor will only spin in one direction.

DELIVERABLE 4: What is the machine’s rated speed and rated voltage?

Ensure that the fan of your TMDSHVMTRPFC is connected to the 15 V fan supply on the kit.

Set the voltage of your controller to 100 V, and the over-voltage protection to 170 V. Load your new code, and slowly turn on the power supply, until the supply is larger than 100 V.

After the motor reaches a steady-state speed, increase the dynamometer torque to apply a load to the motor.

Measure the load current using your oscilloscope. Step change the load, and observe the change in the current.

DELIVERABLE 5: How does the current change when you adjust the load? Sketch the current waveform. How long does it take to reach steady state after the change? How does this new steady-state value compare to the old one?

4. Switching Event Analysis [Optional – time permitting]

While switching the state of power devices, voltages and currents undergo extreme transient conditions. The circuit's dynamic behavior, during the turn-on and turn-off events, depends on the load, power switch, cables, board traces, etc. For high performance power switches, the duration of the transient behavior is on the order of tens of nanoseconds to a few microseconds.

Due to the fast nature of these events, voltage and current waveforms will contain ultra-high frequency components. Therefore, parasitic inductance and capacitance can have a significant effect on performance. The following portion of the lab will show the effect that hard-switching has on the circuit.

With the dc motor still connected and loaded, observe the converter output voltage, not the load voltage, and load current waveforms during switching events. These events have very fast dynamics, on the order of nanoseconds; you will need to zoom in very close to both the turn-on and turn-off events.

Adjust the DC-bus voltage, and observe the change in the output voltage and current waveforms during the switching events. Pay particular attention to the magnitude of oscillations during switching events. As the switching voltage is increased, you should see larger oscillations.

DELIVERABLE 6: Draw a sketch of what you observe during each switching event. Explain what you think is causing this behavior, and why you think this is happening. *Hint:* Look for spikes and oscillations in voltage and current waveforms.

DELIVERABLE 7: What audible differences do you observe? Explain why the noise you hear is louder when the DC-bus voltage is larger.

5. Conclusion [15 minutes]

Write about one or two things you learned in this lab that you think are important or interesting, and why.