dSPACE Based Implementation of PID Controller for Buck Converter

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ABSTRACT

In this paper output voltage of chosen buck DC – DC converter is regulated at nominal output voltage of 13 volts under [1] under supply disturbance of 20 to 25 volt and vice versa [2] under load disturbance of 28 to 50 ohms and vice versa. The performance indices considered are overshoot and undershoot in the output voltage under these disturbances and the corresponding settling times. These indices are found to be within the permissible limits validating the control strategy developed using the available DS1103 dSPACE board. The output voltage of the buck converter after suitable scaling is fed to the on board ADC of DS1103. Based on the error between the desired output voltage and the actual output voltage under the disturbances, the PID control strategy developed appropriately manipulates the duty cycle of the buck converter and such PWM pulses generated by DS1103 board are given to the gate of the MOSFET through suitable drivers to regulate the output voltage at the desired value. CLP1103 panel is used for ease of operation. Work is being extended to regulate output voltage and provide equal current sharing among two paralleled buck converters.

1. INTRODUCTION

Power electronics, a discipline rich in non-linear dynamics, has real life applications in industrial, commercial, residential and aerospace environments. Advances in electronic systems used in such environments demand corresponding advances in power supply technology. Such power supplies must be made increasingly reliable and efficient. A better method of meeting these demand is to employ several individual converters that share the load and supply requirements. In this work the control objective is to maintain the output voltage close to the reference of a single PWM based DC-DC power supply. Usually the output voltage of PWM based DC-DC converter can be varied by varying the duty cycle and hence such PWM pulses are generated in this work by available DS1103 board for PID control of chosen buck converter under supply and load disturbances. The results are presented and analyzed.

2 DC-DC CONVERTER

DC-DC converter is a high speed on/off semiconductor switch. It connects source to load and disconnects the load from source at a fast speed. In Figure 1 chopper is represented by a switch SW which may be turned-on or turned-off as desired.

![Figure 1 DC – DC converter](image)

During the period Ton, chopper is on and load voltage is equal to source voltage Vs. During the interval T_off, chopper is off. Load current flows through the freewheeling diode FD. As a result, load terminals are short circuited by FD and load voltage is therefore zero during T_off. In this manner, a chopped DC voltage is produced at the load terminals.
2.1 BUCK CONVERTER

A step-down converter produces an average output voltage, which is lower than the DC input voltage $V_{in}$. The basic circuit of a step-down converter is shown in Figure 2.

In continuous-conduction mode of operation, assuming an ideal switch, when the switch is on for the time duration $T_{on}$, the inductor current passes through the switch and the diode becomes reverse biased. This results in a positive voltage ($V_{in} - V_o$) across the inductor, which, in turn, causes a linear increase in the inductor current $i_{in}$. When the switch is turned off, because of the inductive energy storage, $i_{in}$ continues to flow. This current flows through the diode and decreases. Average output voltage can be calculated in terms of the switch duty ratio as

$$V_{o\,avg} = \frac{T_{on}}{T} V_{in}$$

The average output voltage varies linearly in buck converter with $T_{on}$ or $V_{in}$

2.2 DESIGN OF CONVENTIONAL CONTROLLERS FOR DC-DC BUCK CONVERTER

Classical control theory uses a mathematical model to define a relationship that transforms the desired state and measured state of a system into an input or inputs that will alter the future state of the system. The purpose of control is to influence the behavior of a system by adjusting input values according to a rule or set of rules that model how the system operates. The conventional Proportional Integral Derivative (PID) controller is commonly used to achieve this objective. It produces an output $m(t)$ based on the difference $e(t)$ between the desired and measured values according to the following general equation

$$m(t) = K_p e(t) + K_i \int e(t) \, dt + K_d \frac{de(t)}{dt}$$

where $K_p$, $K_i$, and $K_d$ are constants (PID controller settings), $e(t)$ is the error term, $\int e(t) \, dt$ is the integral of the error over time and $de(t)/dt$ is the change in the error term. The major drawback of this system is that it usually assumes that the system being modeled is linear or at least behaves in some fashion that is monotonic.

The chosen buck converter is modeled in on-mode and off-mode using the small signal approach and the corresponding state matrices are obtained. Using the average of these matrices and the circuit parameters of the chosen converter, the corresponding PI controller settings i.e. proportional gain $K_p$, integral time $T_i$ (i.e. $K_p/K_i$) and derivative gain $K_d$ are designed using Ziegler-Nichols tuning technique based on the converter’s open loop step response. Table 1 Provides the
transfer function model of chosen buck DC – DC converter and next Table 2 shows the corresponding PI/PID controller settings employed in this work.

Table 1 Transfer function model for voltage and current controller

<table>
<thead>
<tr>
<th>Voltage Transfer Function Model</th>
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</thead>
<tbody>
<tr>
<td>( \frac{v_0(s)}{d_0(s)} = \frac{9.8 + 1.2936 \times 10^{-3}s}{39 \times 10^{-3}s^2 + 0.2651s + 1} )</td>
</tr>
</tbody>
</table>

Table 2 PI and PID controller parameters for the single buck DC-DC converters

<table>
<thead>
<tr>
<th>Controller parameters</th>
<th>Voltage controller</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>PI</td>
</tr>
<tr>
<td>( K_p )</td>
<td>0.2277</td>
</tr>
<tr>
<td>( T_i )</td>
<td>0.0205</td>
</tr>
<tr>
<td>( T_d )</td>
<td>--</td>
</tr>
</tbody>
</table>

2.3 HARDWARE IMPLEMENTATION OF BUCK DC-DC CONVERTER USING DSPACE

The dSPACE DS1102 was first used at Bradley University in the year 2000 when a users manual and a workstation based on this board were developed. Since then, a newer dSpace DS1103 board has become available. The controller is designed and simulated using the SIMULINK and the dSPACE blocksets, the Matlab-to-DSP interface libraries, Real-Time Interface to SIMULINK, and Real-Time Workshop on a PC. Output from the DS1103 includes the PWM signal for the gate of MOSFET of buck DC-DC converter. Inputs to and outputs from the DS1103 pass through the CLP1103 connector panel for the DS1103 board or through the cables connected to the computer.

The control system has been implemented in this work in the dSPACE DS1103 PPC system; it is a mixed RISC/DSP digital controller providing a powerful processor for floating point calculations. The DS1103 PPC card is plugged in one of the ISA slots of the mother-board of the host computer. The control system has been developed using MATLAB/Simulink and then automatically processed and run in the DS1103 PPC card.

A Graphical User Interface (GUI) has been built using the software control desk of dSPACE. It allows the real-time evaluation of the control system. “control desk” serves multiple uses. It provides the interface for downloading controller models designed in SIMULINK onto the DSP. The instrument panel feature of control desk is used to display various measurements such as the duty cycle of the PWM signal, regulated output (voltage and current) and error to the controller. Signals must be sent through the “CLP1103” and “DS1103” before the measurements can be displayed in control desk on the computer.
The “CLP1103” serves as an interface between the “DS1103” and the external hardware portion of the overall system. The CLP1103 contains connectors for twenty (20) Analog-to-Digital inputs, eight (8) Digital-to-Analog outputs, several other connectors that can be used for Digital I/O, slave/DSP I/O, incremental encoder interfaces, CAN interface and serial interfaces.

![Block diagram of hardware setup](image)

Figure 3 Block diagram of hardware setup

This work uses the slave I/O connector to output the PWM signal from the DS1103 to the power converter sub system. The control of the buck DC-DC converter has been implemented in dSPACE platform as in Figure 3.

### 2.4 EXPERIMENTAL RESULTS

In this paper output voltage of chosen buck DC – DC converter is regulated at nominal output voltage of 13volts under [1] under supply disturbance of 20 to 25 volt and vice versa [2] under load disturbance of 28 to 50 ohms and vice versa. The performance indices considered are overshoot and undershoot in the output voltage under these disturbances and the corresponding settling times. These indices are found to be within the permissible limits validating the control strategy developed using the available DS1103 dSPACE board. The output voltage of the buck converter after suitable scaling is fed to the on board ADC of DS1103. Based on the error between the desired output voltage and the actual output voltage under the disturbances, the PID control strategy developed appropriately manipulates the duty cycle of the buck converter and such PWM pulses generated by DS1103 board are given to the gate of the MOSFET through suitable drivers to regulate the output voltage at the desired value. CLP1103 panel is used for ease of operation Figure 4 shows the PWM signal obtained using DS1103 board for 0.9 duty cycle Figure 5 & 6 displays regulated output voltage under line and load disturbances. Table 3 provides details of performance evaluation of PID controller.

#### Table 3 performances indices
<table>
<thead>
<tr>
<th>Supplier disturbance 20 -25 V</th>
<th>Settling time</th>
<th>Over shoot</th>
<th>Under shoot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply disturbance 25 -20 V</td>
<td>400ms</td>
<td>-</td>
<td>25%</td>
</tr>
<tr>
<td>Load disturbance 50 – 28 Ω</td>
<td>150ms</td>
<td>-</td>
<td>4%</td>
</tr>
<tr>
<td>Load disturbance 28 – 50 Ω</td>
<td>200ms</td>
<td>4%</td>
<td>-</td>
</tr>
</tbody>
</table>

Figure 4 PWM signal generated from DS1103 dSPACE for 0.9 duty-cycle
Figure 5 Regulated output voltage with line disturbance from 20V to 25V and 25V to 20V

Figure 6 Regulated output voltage with load disturbance from 50Ω to 28Ω and 28Ω to 50 Ω
3 CONCLUSION

The PID controller is implemented in real time using dSPACE and the performance of the chosen buck DC-DC converter is found to be satisfactory under line and load disturbances.

REFERENCES


