Buck Converter Modeling in Simulink:

Switched and Averaged Models

Modeling, simulation, and validation for control-oriented design

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1 Overview

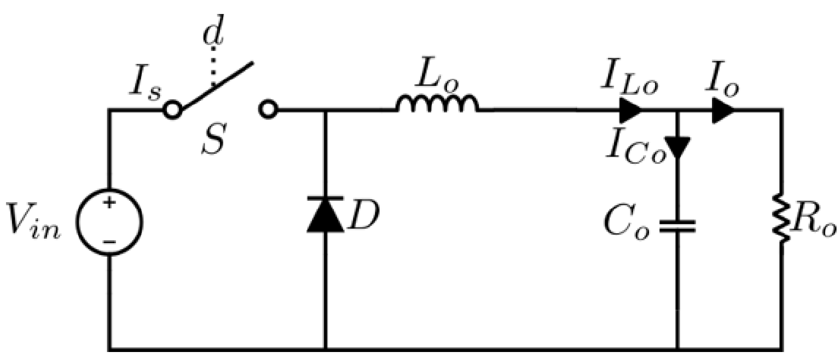
markdown

This live script presents the modeling and simulation of a DC-DC Buck converter using both switched and averaged representations in Simulink. The averaged model is intended for control design and fast simulation, while the switched model captures high-frequency switching behavior and is used for validation of the averaged dynamics. The objective is to compare both models in terms of output voltage, inductor current, and computational efficiency.

2. System Description

2.1 Buck Converter Topology

The Buck converter consists of a controlled switch (MOSFET), a diode, an inductor, an output capacitor, and a resistive load. Energy is transferred from the input source to the load by controlling the duty cycle of the switching device.



2.2 Modeling Assumptions

- Continuous Conduction Mode (CCM)
- Ideal switch and diode
- Constant input voltage
- Negligible parasitics
- Ideal output capacitor

3. Mathematical Model

3.1 State Variables

The system is described using the following state variables:

Variable	Description
i_L	Inductor current [A]
v_C	Output capacitor voltage [V]
D	Duty cycle (0 <= D <= 1)

3.2 Switched Model Equations

The switched model alternates between two linear subsystems depending on the switching state.

On state

$$\dot{i_L} = \frac{V_{in} - v_C}{L}$$

$$\dot{v_C} = \frac{i_L - \frac{v_C}{R}}{C}$$

Off state

$$\dot{i_L} = \frac{-v_C}{L}$$

$$\dot{v_C} = \frac{i_L - \frac{v_C}{R}}{C}$$

This representation captures switching ripple and high-frequency dynamics.

3.3 Averaged Model

The averaged model replaces the switching behavior by its duty-cycle weighted average.

$$\dot{i_L} = \frac{DV_{in} - v_C}{L}$$

$$\dot{v_C} = \frac{i_L - \frac{v_C}{R}}{C}$$

Under steady-state CCM operation:

$$V_o = D * V_{in}$$

4. Simulink Implementation

4.1 Switched Model

The switched model is implemented in Simulink using:

- A PWM generator operating at fixed switching frequency
- Conditional logic to select ON and OFF state equations

- Fixed-step discrete solver

Model file:

```
thisFile = matlab.desktop.editor.getActiveFilename;
projectRoot = fileparts(thisFile);

modelsDir = fullfile(projectRoot, '..', 'models');

assert(isfolder(modelsDir), 'Models folder not found: %s', modelsDir)

open_system(fullfile(modelsDir, 'buck_switched.slx'))
```

4.2 Averaged Model Implementation

The averaged model is implemented without explicit switching. This allows larger simulation time steps and faster execution.

Model file:

```
open_system(fullfile(modelsDir, 'buck_averaged.slx'))
```

5. Simulation Parameters

5.1 Electrical Parameters

$V_{in} = 28V$	Input voltage [V]
$L = 50\mu^{-6}H$	inductance [H]
$C = 500\mu^{-6}F$	Capacitance [F]
$R = 3\Omega$	Load resistance [Ohm]
$D = 0.536$	Duty cycle

```
Vin = 28;          % Input voltage [V]
L   = 50e-6;      % Inductance [H]
C   = 500e-6;      % Capacitance [F]
R   = 3;          % Load resistance [Ohm]
D   = 0.536;         % Duty cycle

fprintf('Vin = %.1f V, D = %.2f\n', Vin, D)
```

```
Vin = 28.0 V, D = 0.54
```

5.2 Solver Configuration

Switched model:

Fixed-step, Ts = 1e-7 s

Averaged model:

Fixed-step, Ts = 1e-5 s

These configurations ensure numerical stability while balancing accuracy and simulation speed.

6. Simulation Results

6.1 Run Simulations

Run both models and collect results using To Workspace blocks.

```
sim_switched = sim('buck_switched.slx');
sim_averaged = sim('buck_averaged.slx');
```

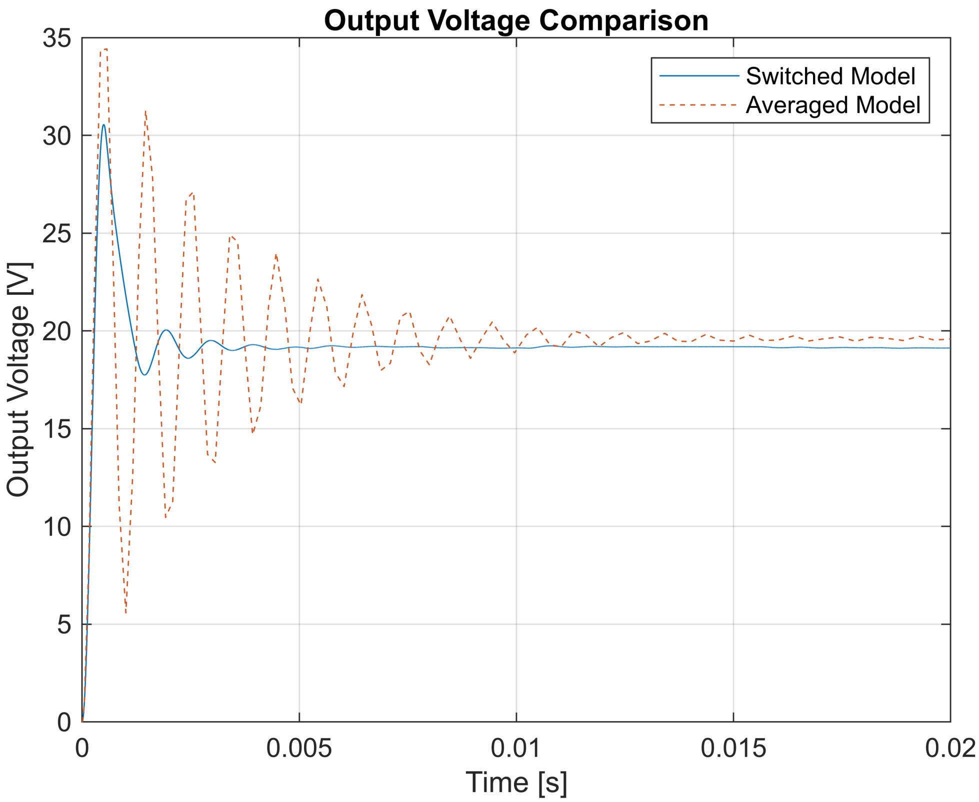
6.2 Output Voltage Comparison

The averaged model should match the mean value of the switched model.

```
t_sw = sim_switched.vout.time;
v_sw = sim_switched.vout.signals.values;

t_av = sim_averaged.vout.time;
v_av = sim_averaged.vout.signals.values;

figure
plot(t_sw, v_sw)
hold on
plot(t_av, v_av, '--')
grid on
xlabel('Time [s]')
ylabel('Output Voltage [V]')
legend('Switched Model','Averaged Model')
title('Output Voltage Comparison')
```

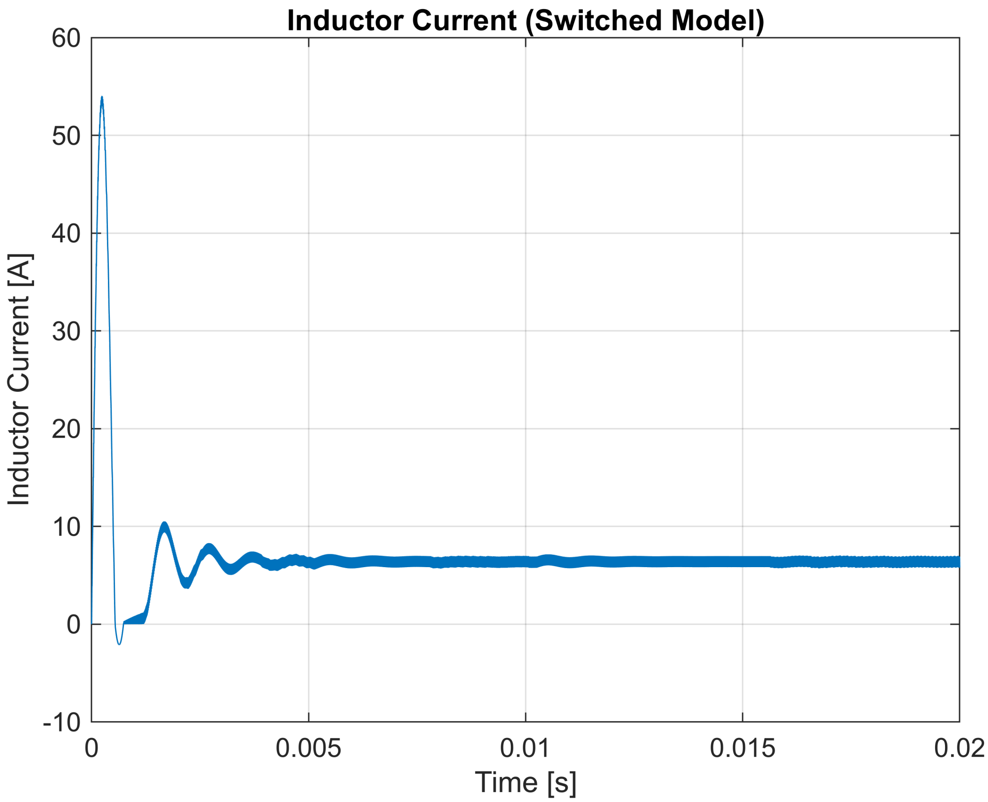


6.3 Inductor Current

The switched model exhibits ripple, while the averaged model represents the mean inductor current.

```
t_iL = sim_switched.iL.time;
iL   = sim_switched.iL.signals.values;

figure
plot(t_iL, iL)
grid on
xlabel('Time [s]')
ylabel('Inductor Current [A]')
title('Inductor Current (Switched Model)')
```



7. Reproducibility

To reproduce these results:

- Open buck_switched.slx
- Open buck_averaged.slx
- Run this live script
- Modify duty cycle D and rerun the simulations

8. Limitations

- Valid only under CCM operation
- Switching losses are not modeled
- Not suitable for EMI or thermal analysis
- Averaged model does not capture ripple dynamics

9. Conclusion

This live script demonstrates a structured workflow for modeling, simulating, and validating a Buck converter in Simulink.

The averaged model enables efficient control design, while the switched model provides accurate validation of converter dynamics.

10. References

[1] R. Erickson and D. Maksimovic, Fundamentals of Power Electronics

[2] MathWorks Documentation: DC-DC Converter Modeling