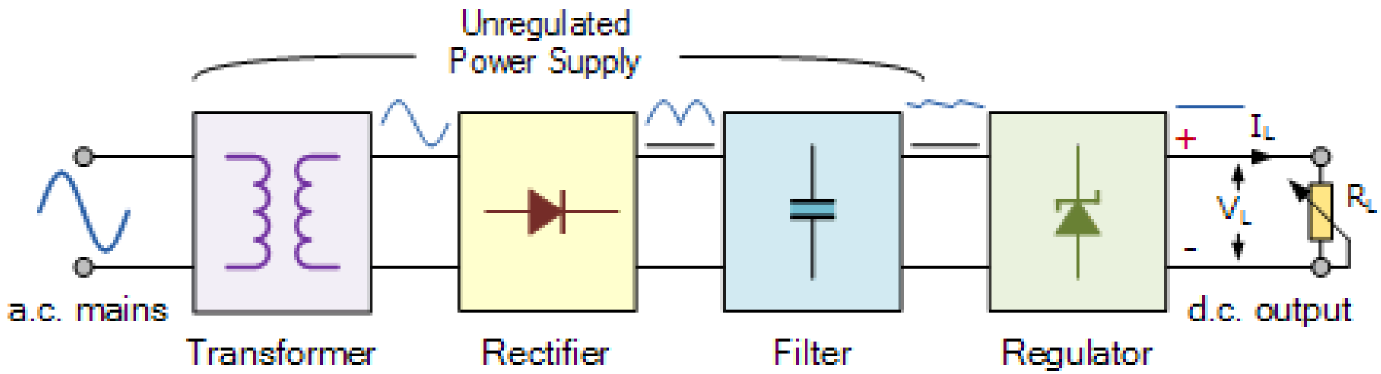
Switched Mode Power Supply (SMPS)

Control, Modeling, and Simulation

Why Use a Switching Regulator?

SMPS



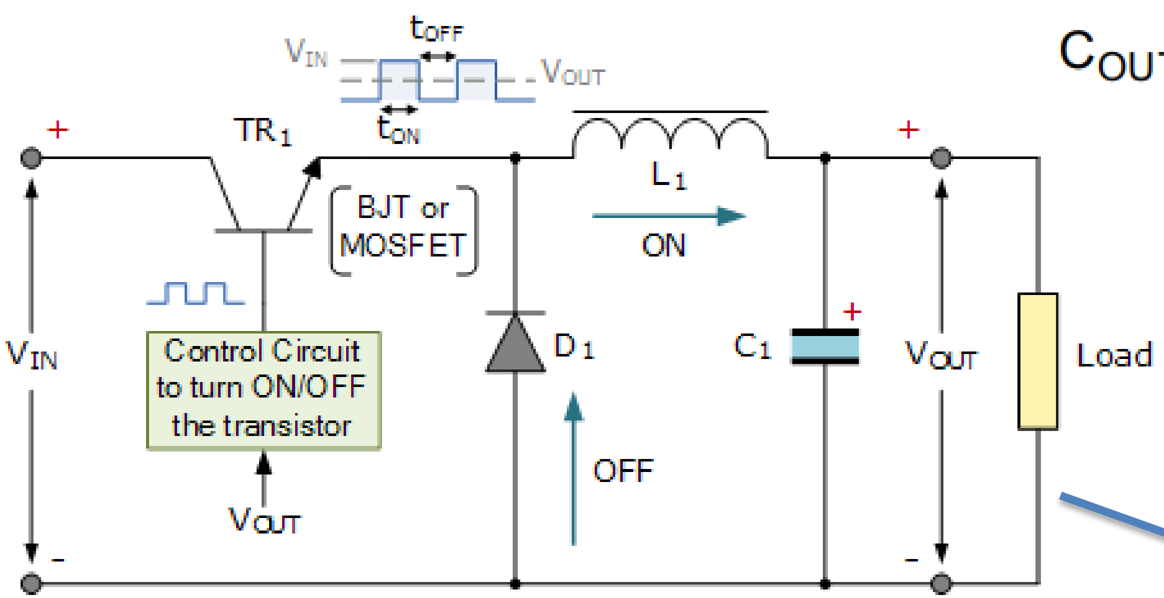
- Various types of voltage regulators, used in Linear Power Supplies (LPS), are dissipative regulator, as they have a voltage control element usually transistor or zener diode which dissipates power equal to the voltage difference between an unregulated input voltage and a fixed supply voltage multiplied by the current flowing through it.
- The switching regulator acts as a continuously variable power converter and hence its efficiency is negligibly. Hence the switching regulator is ‘non-dissipative regulator’.
- In a SMPS, the active device that provides regulation is always operated in cut-off or in saturation mode.

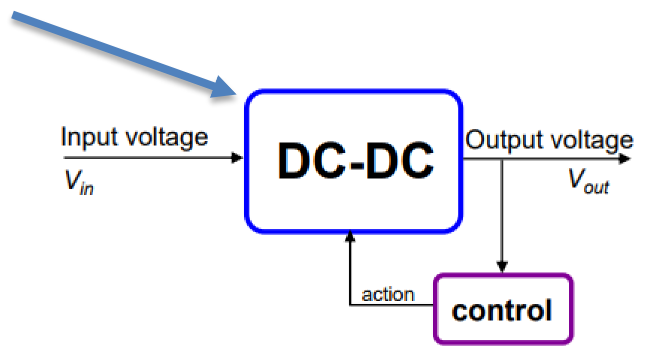
Buck Switching Regulator

Maximum Duty Cycle: $D = \dfrac{V_{OUT}}{V_{IN(max)} \times \eta}$

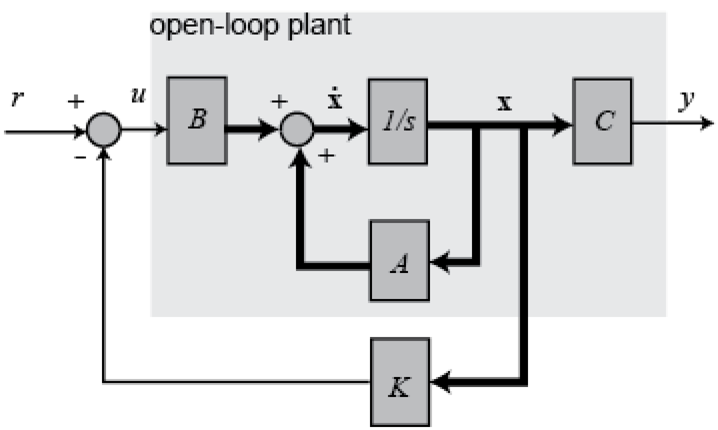
$$L = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{\Delta I_L \times f_S \times V_{IN}}$$

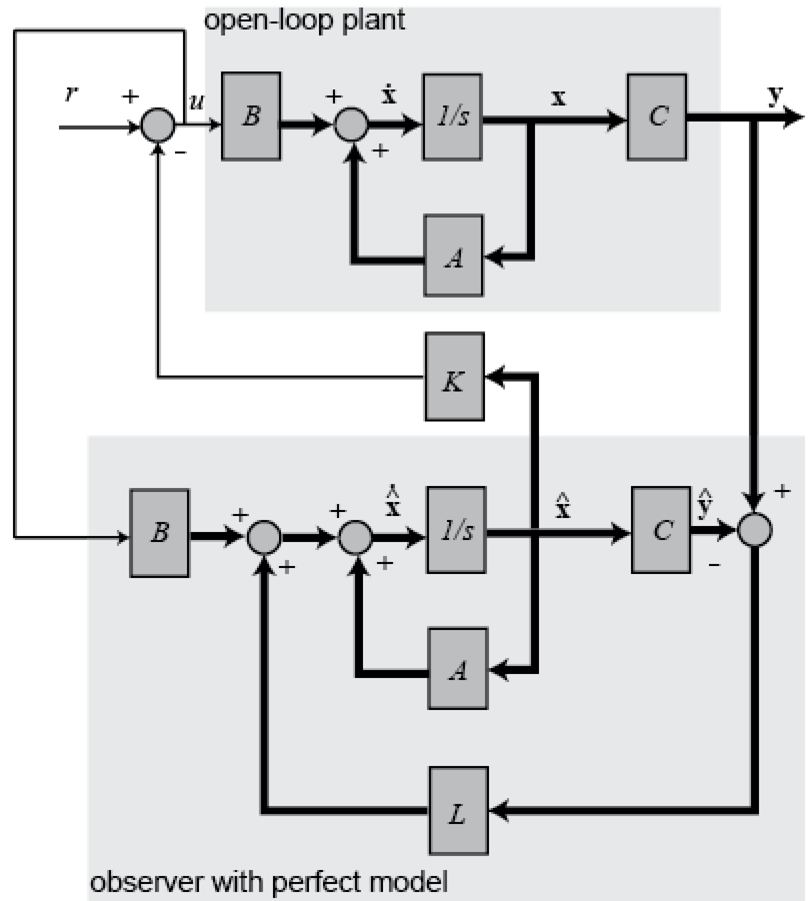
$$C_{OUT(min)} = \frac{\Delta I_L}{8 \times f_S \times \Delta V_{OUT}}$$



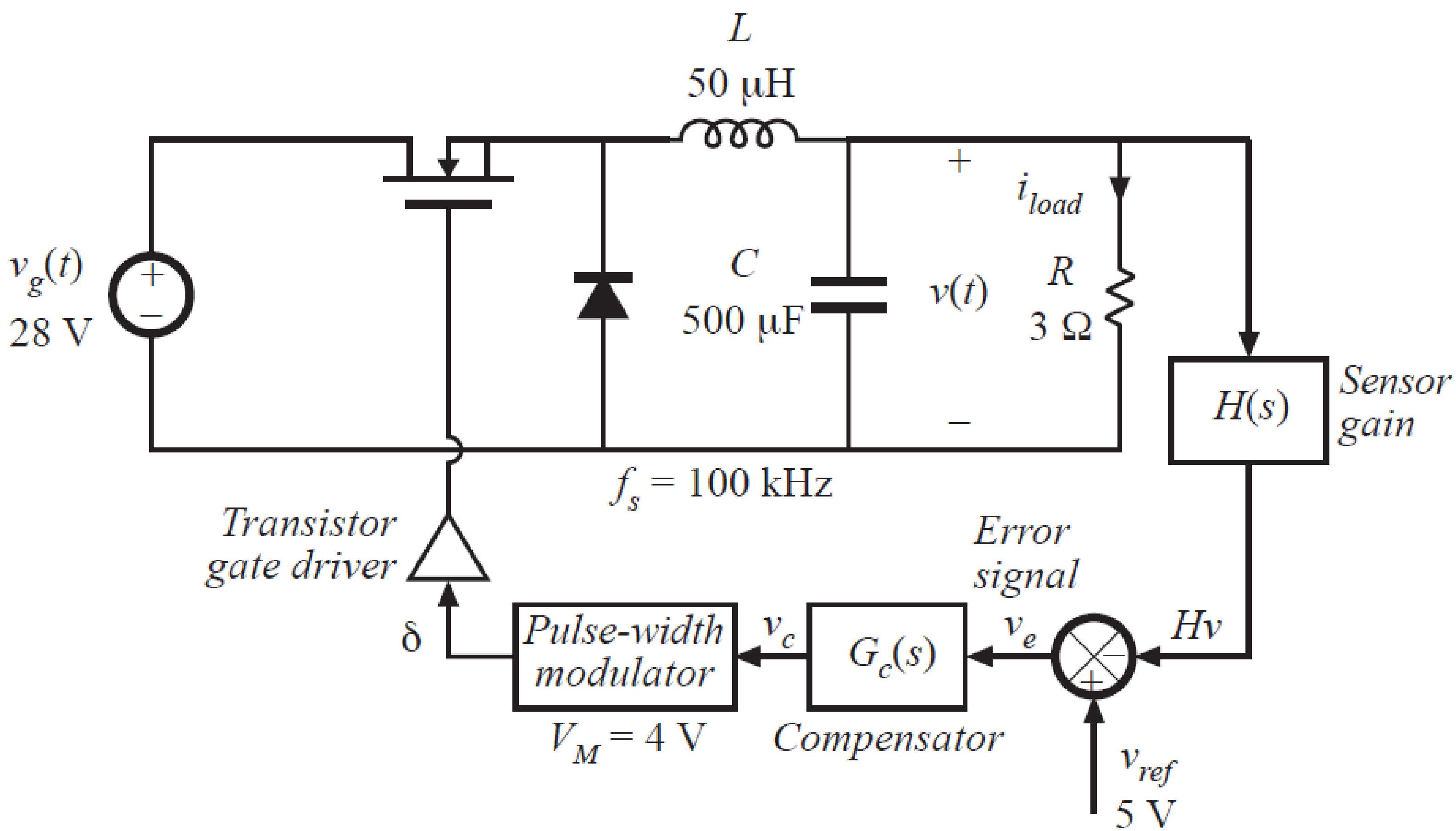


Control Design Using Pole Placement

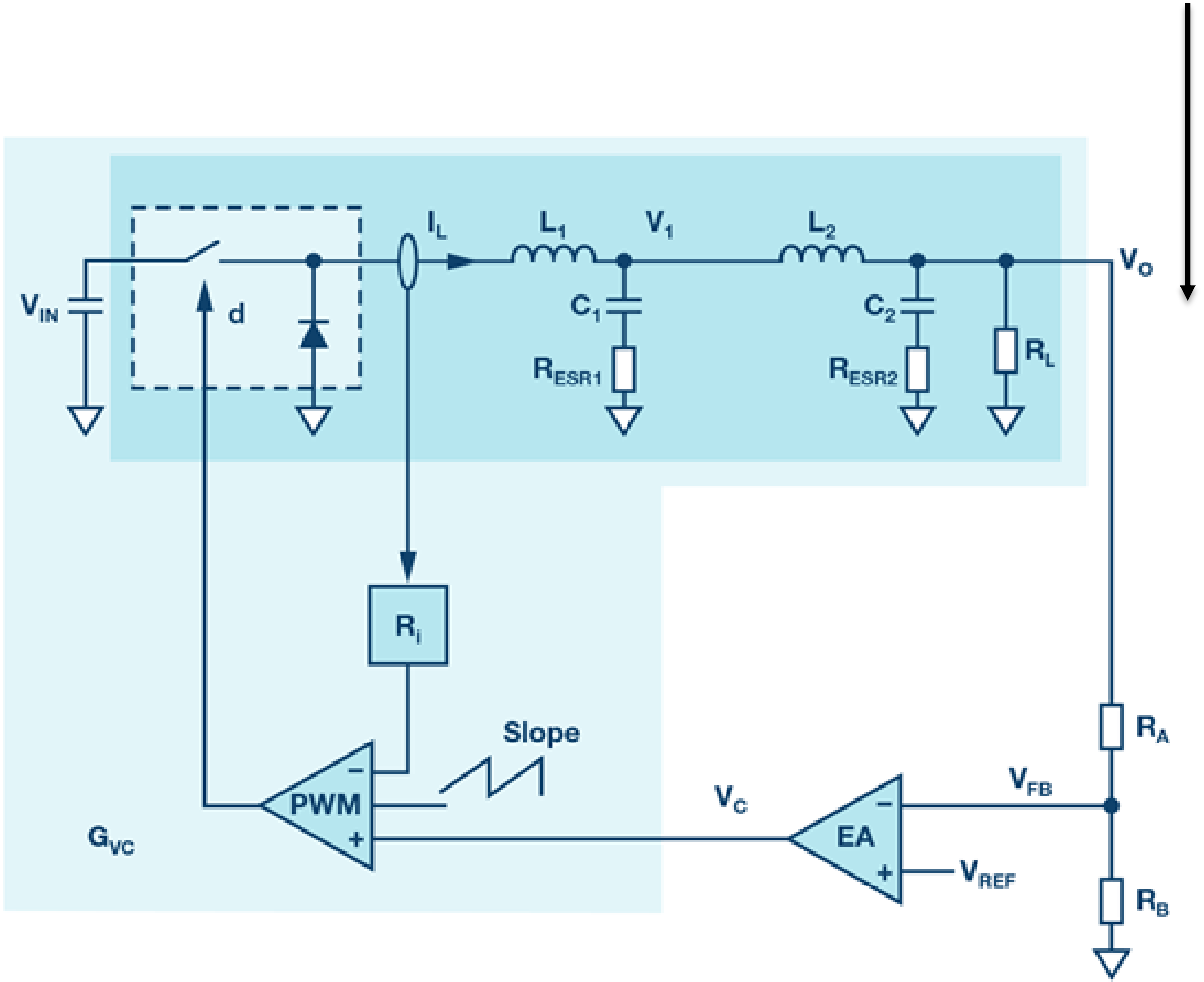




Voltage Mode Control of Buck Converter



Current Mode Control of Buck Converter

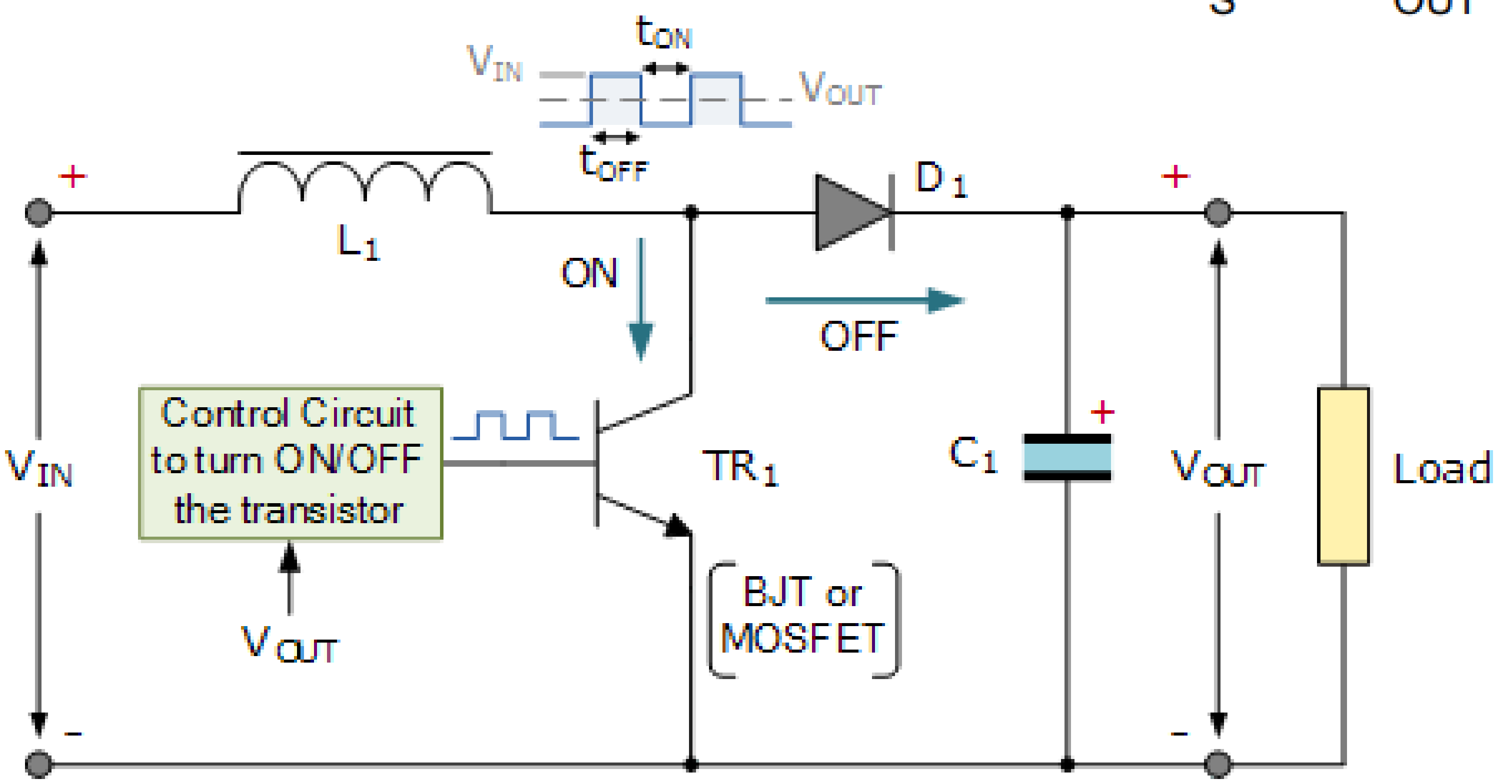


Boost SMPS

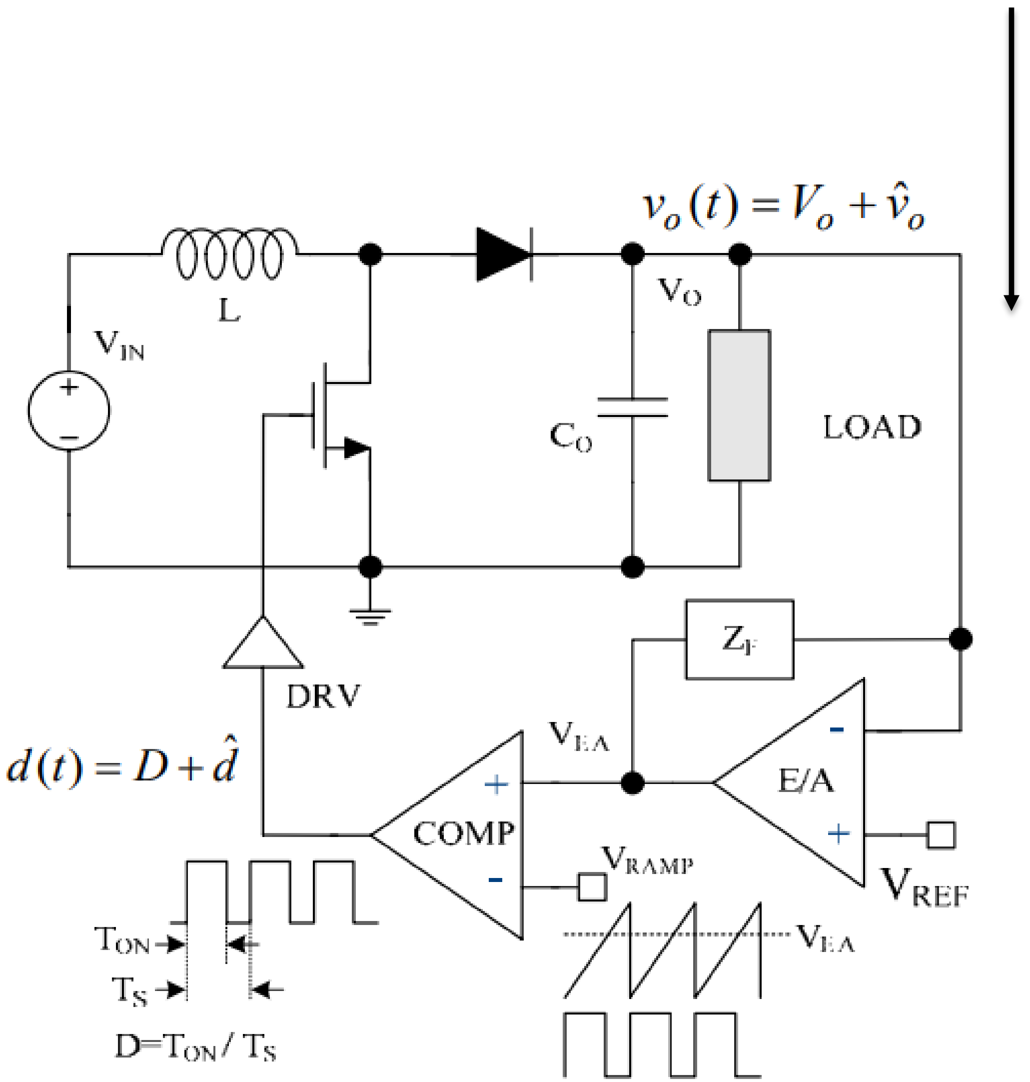
$$D = 1 - \frac{V_{IN(min)} \times \eta}{V_{OUT}}$$

$$L = \frac{V_{IN} \times (V_{OUT} - V_{IN})}{\Delta I_L \times f_S \times V_{OUT}}$$

$$C_{OUT(min)} = \frac{I_{OUT(max)} \times D}{f_S \times \Delta V_{OUT}}$$

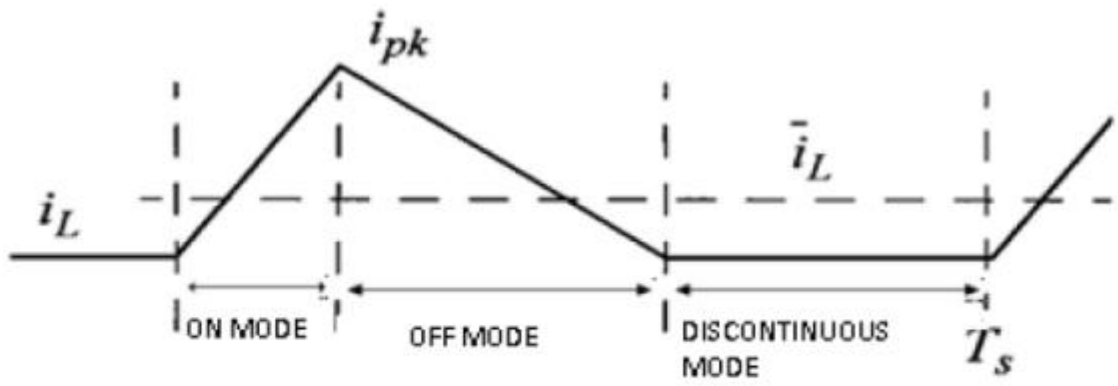


Feedback Control of Boost Converter



Buck Modes of Operation

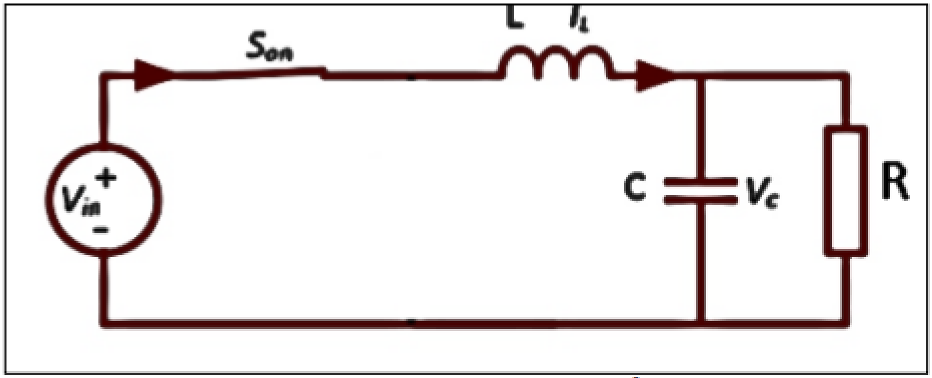
$d_1 T_S = ON\ Period\ time$
$d_2 T_S = OFF\ Period\ time$
$T_S = Total\ time\ period\ for\ one\ cycle$
$i_{pk} = peak\ value\ of\ inductor\ current\ after\ ON\ period$
$\overline{i_L} = Average\ value\ of\ current$
$V_{in} = input\ voltage$



State Space Modeling

- If the system is linear, then the derivatives of the state variables are expressed as linear combinations of the system independent inputs and state variables themselves.
- The physical state variables of a system are usually associated with the storage of energy.
- For a typical converter circuit, the physical state variables are the inductor currents and capacitor voltages.

Buck Converter During ON Mode
Write the State Space Model



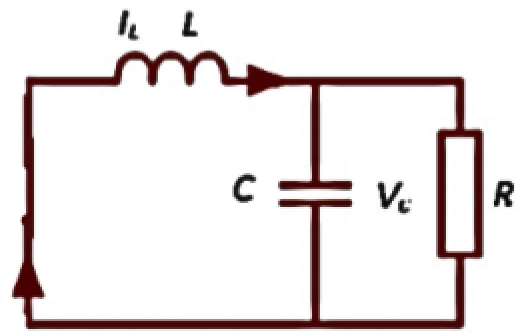
From KVL $v_{in} - L\frac{di_L}{dt} - v_C = 0$

From KCL $\frac{v_c}{R} + C\frac{dv_C}{dt} - i_L = 0$

Write

- $\begin{bmatrix} \frac{di_L}{dt} \\ \frac{dv_C}{dt} \end{bmatrix} = \begin{bmatrix} \quad & \quad \\ \quad & \quad \end{bmatrix} \begin{bmatrix} i_L \\ v_C \end{bmatrix} + \begin{bmatrix} \quad \\ \quad \end{bmatrix} v_{in}$; $V_o = [0 \quad 1] \begin{bmatrix} i_L \\ v_C \end{bmatrix}$

Buck Converter During Off Mode
Write State Space Model



From KVL $\quad v_C + L\frac{di_L}{dt} = 0$

Write

From KCL $\quad i_L - \frac{v_C}{R} - \frac{C\,dv_C}{dt} = 0$

$$\begin{bmatrix} \frac{di_L}{dt} \\ \frac{dv_C}{dt} \end{bmatrix} = \begin{bmatrix} & \\ & \end{bmatrix} \begin{bmatrix} i_L \\ v_C \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} v_{in} \,; V_o = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} i_L \\ v_C \end{bmatrix}$$

During Discontinuous Conduction Mode

From KVL $\dfrac{di_L}{dt} = 0$

From KCL $\dfrac{v_c}{R} + C\dfrac{dv_C}{dt} = 0$

Write

$$\begin{bmatrix} \dfrac{di_L}{dt} \\ \dfrac{dv_C}{dt} \end{bmatrix} = \begin{bmatrix} \quad & \quad \\ \quad & \quad \end{bmatrix} \begin{bmatrix} i_L \\ v_C \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} v_{in} \; ; v_o = \begin{bmatrix} 0 & 0 \end{bmatrix} \begin{bmatrix} i_L \\ v_C \end{bmatrix}$$

Buck Modelling Analysis

- Averaging
- Inductor current analysis
- Duty-ratio constraint.

State space averaging techniques are employed to get a set of equations that describe the system over one switching period.

$$\dot{\bar{X}} = [A_1 d_1 + A_2 d_2 + A_3(1 - d_1 - d_2)]\bar{x} + [B_1 d_1 + B_2 d_2 + B_3(1 - d_1 - d_2)]u$$

$$\bar{i_L} = \frac{i_{pk}}{2} . (d_1 + d_2)$$

The Final Model

The state space averaged model for the above equation is

Write

$$\frac{d}{dt}\begin{bmatrix}\overline{i_L}\\ \overline{v_C}\end{bmatrix} = \begin{bmatrix} & \\ & \end{bmatrix}\begin{bmatrix}\overline{i_L}\\ \overline{v_C}\end{bmatrix} + \begin{bmatrix}\frac{d_1}{L}\\ 0\end{bmatrix}V_{in}$$

$$\frac{d}{dt}\begin{bmatrix}\overline{i_L}\\ \overline{v_C}\end{bmatrix} = \begin{bmatrix} & \\ & \end{bmatrix}K\begin{bmatrix}\overline{i_L}\\ \overline{v_C}\end{bmatrix} + \begin{bmatrix}\frac{d_1}{L}\\ 0\end{bmatrix}V_{in} \qquad K = \begin{bmatrix}\frac{1}{d1+d2} & 0\\ 0 & 1\end{bmatrix}$$

$$\begin{bmatrix} & \\ & \end{bmatrix}\begin{bmatrix}\overline{i_L}\\ \overline{v_C}\end{bmatrix} + \begin{bmatrix}\frac{d1}{L}\\ 0\end{bmatrix}V_{in}$$