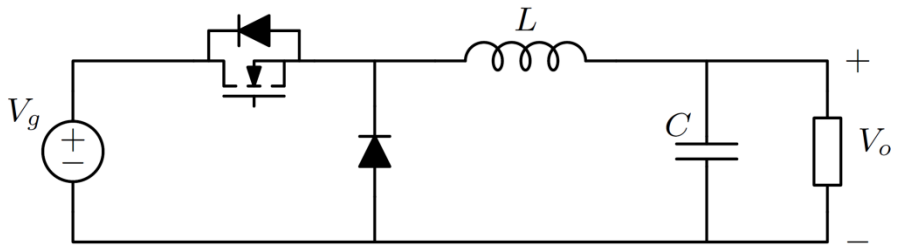
Summary of Steady-State Equations of Basic dc-dc Converters

Luca Corradini

Power Electronics Group
http://pelgroup.dei.unipd.it

University of Padova
Department of Information Engineering – DEI

Buck Converter

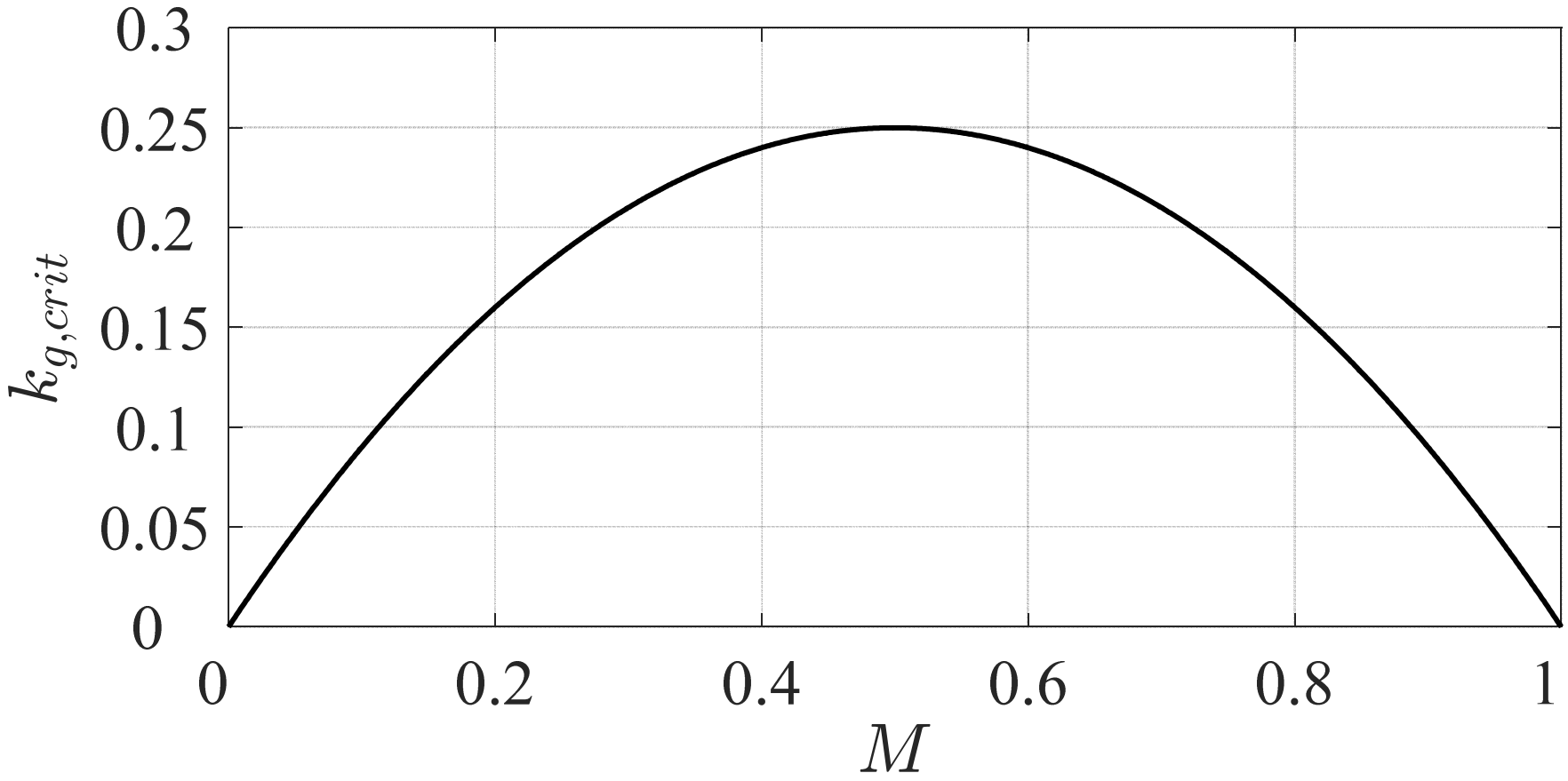


Buck converter with constant current load: voltage conversion ratio $M(D,k_g)$

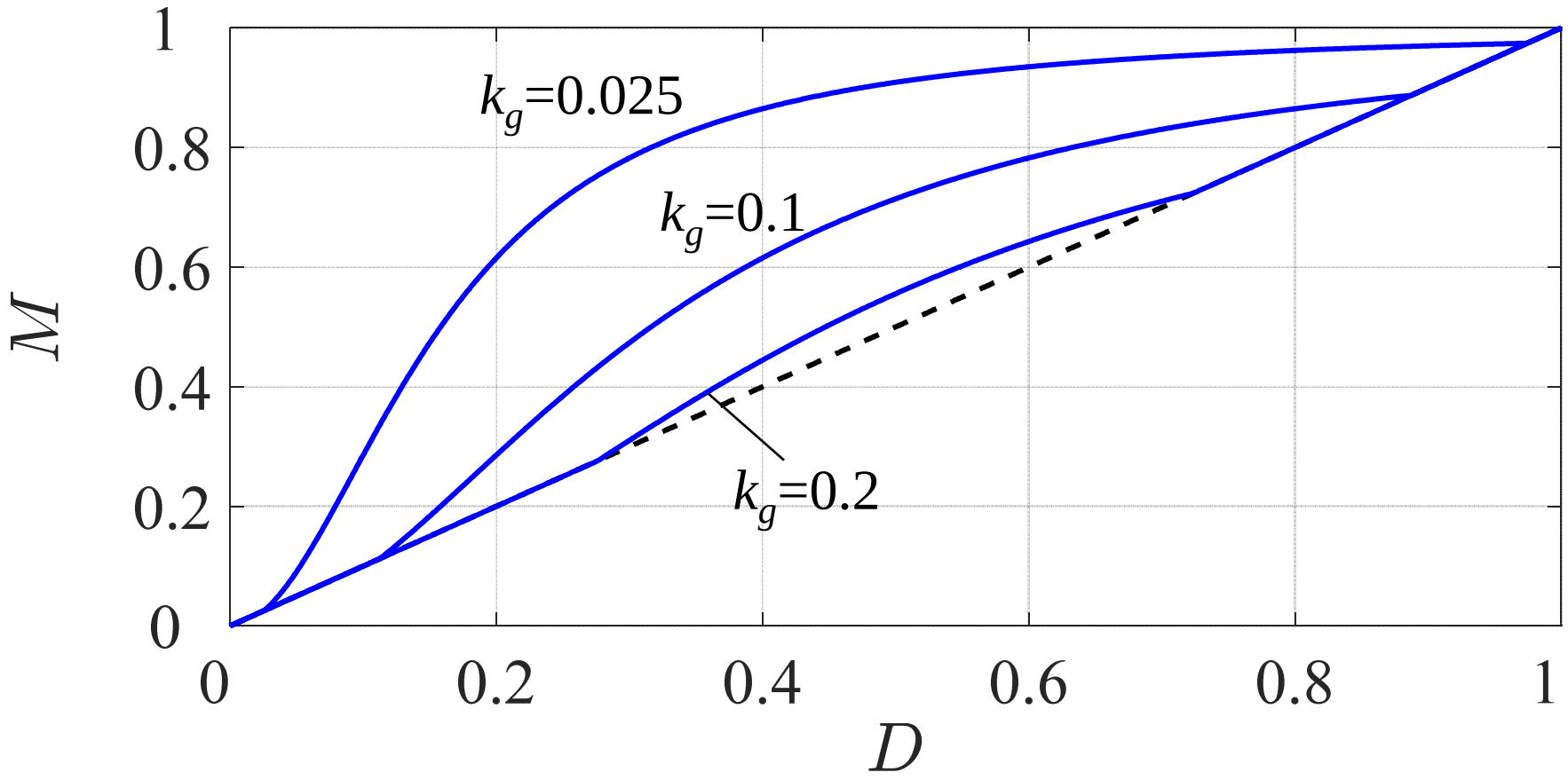
$$M(D,k_g)=\begin{cases} D, & k_g > k_{g,crit} \quad \text{(CCM)} \\ \dfrac{1}{1+\dfrac{k_g}{D^2}}, & k_g < k_{g,crit} \quad \text{(DCM)} \end{cases}$$

$$k_g \triangleq \frac{2f_s L I_o}{V_g}, \qquad k_{g,crit}(D) \triangleq D(1-D) \quad \text{or} \quad k_{g,crit}(M) \triangleq M(1-M)$$

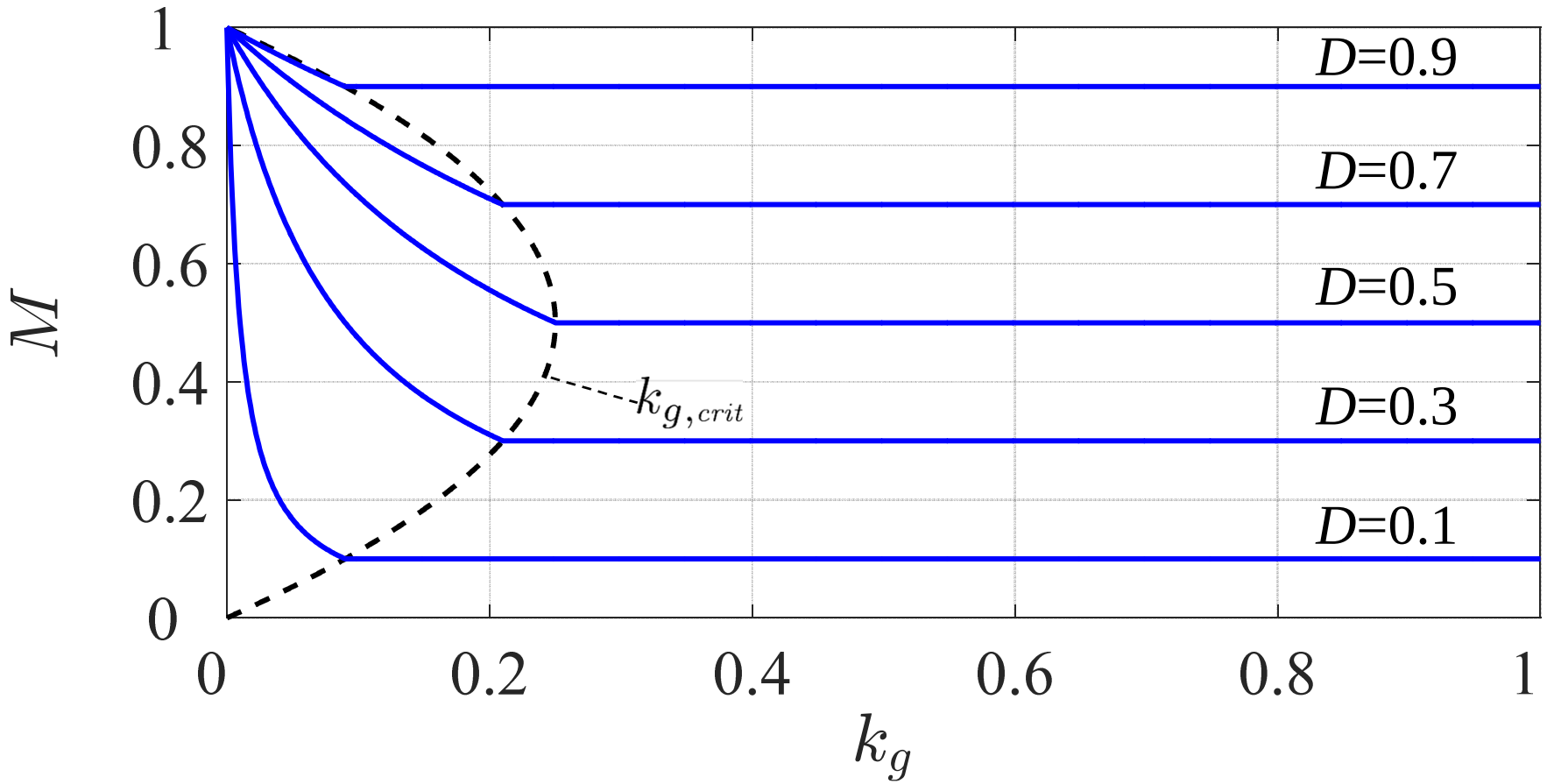
Buck converter with constant current load: critical k_g vs. M



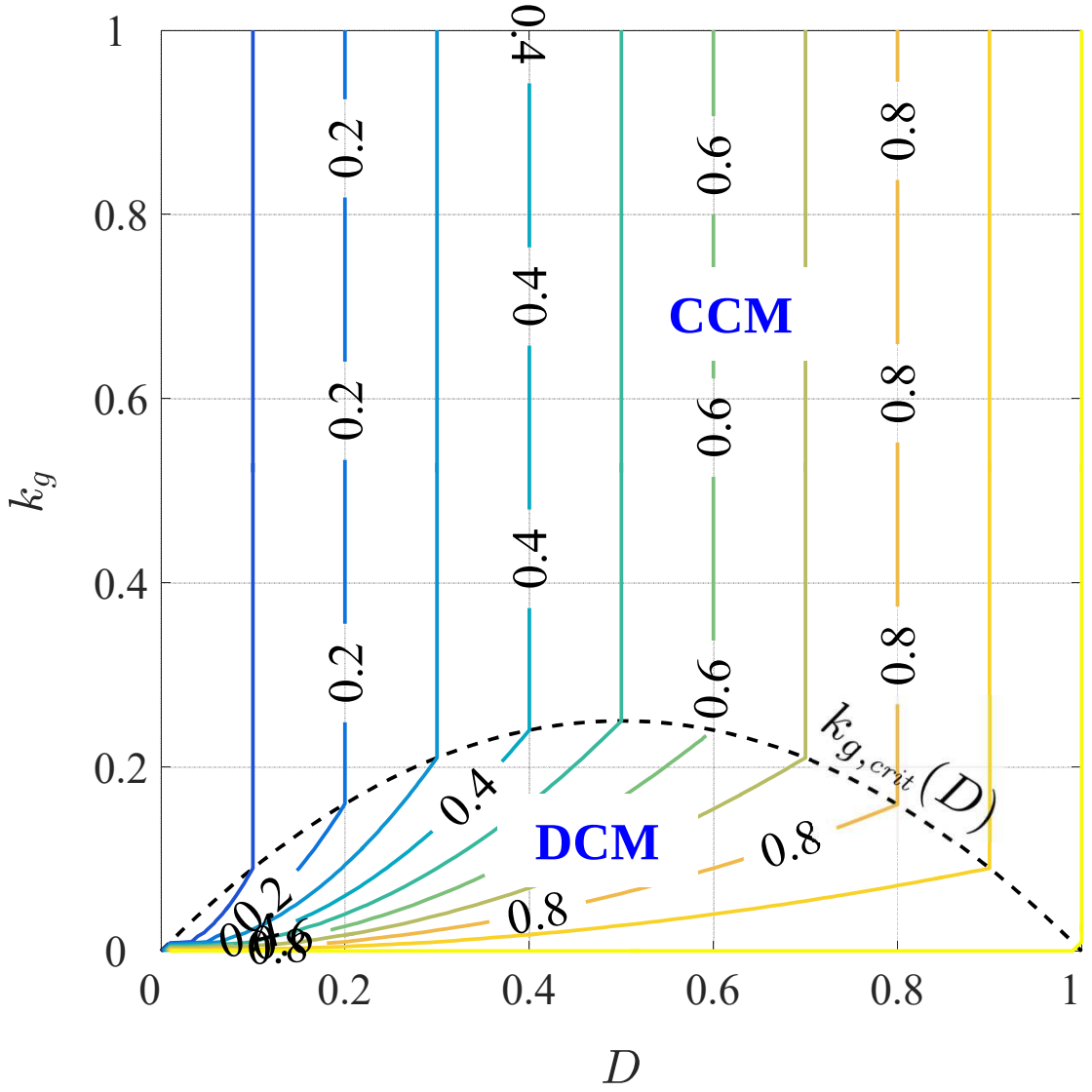
Buck converter with constant current load: control characteristics



Buck converter with constant current load: output characteristics



Buck converter with constant current load: voltage conversion ratio $M(D,k_g)$

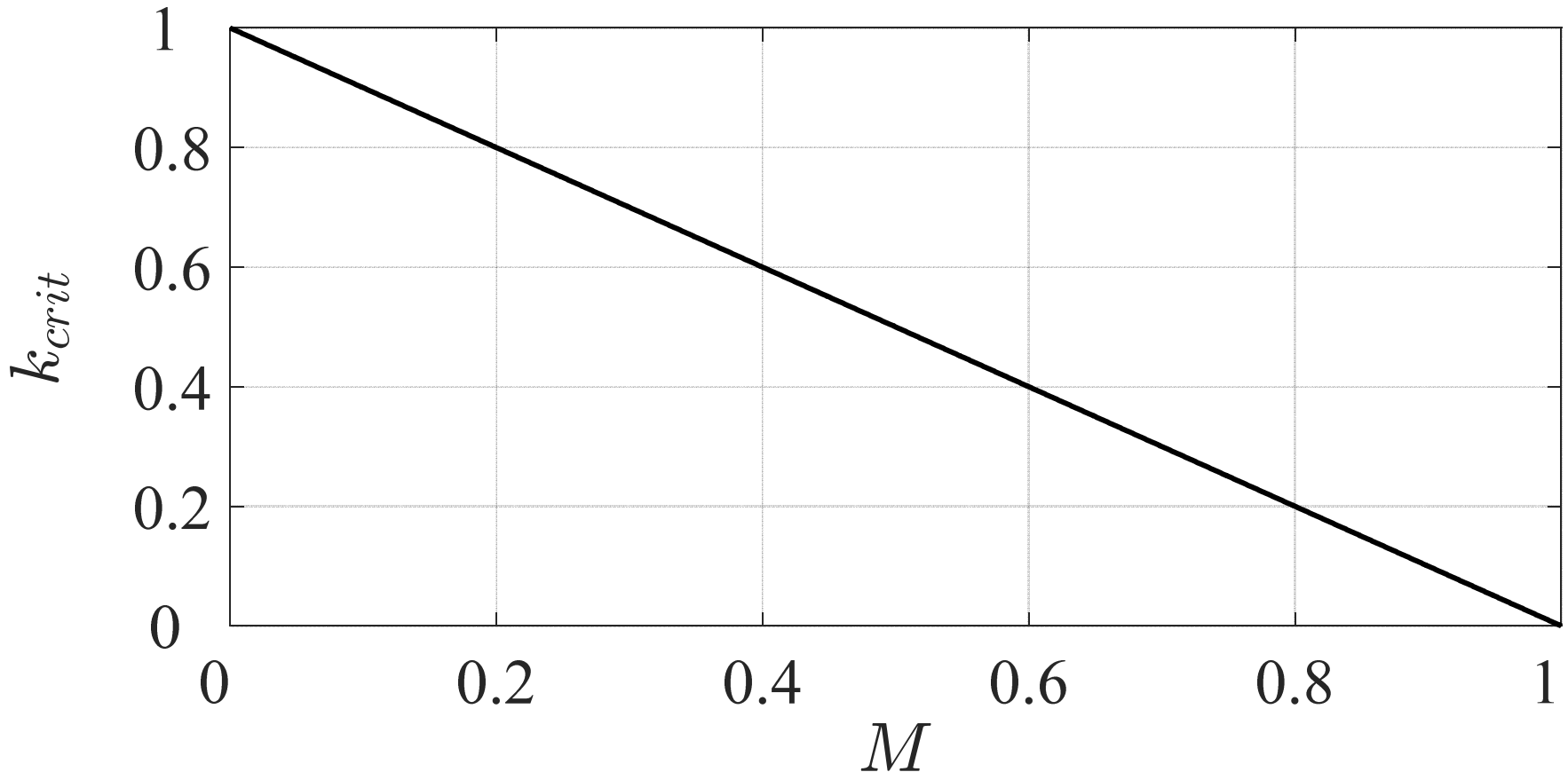


Buck converter with resistive load: voltage conversion ratio $M(D,k)$

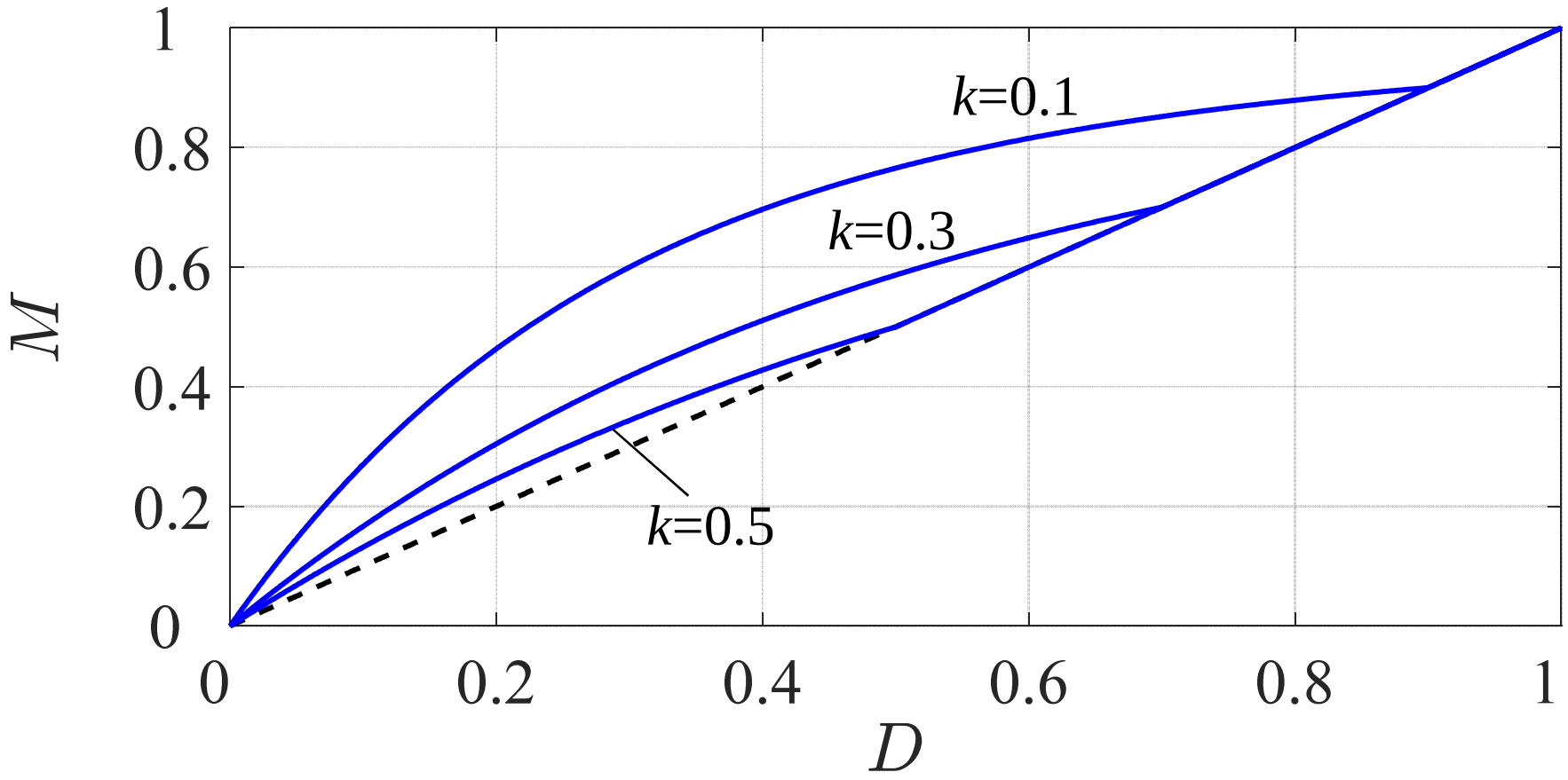
$$M(D,k) = \begin{cases} D, & k > k_{crit} \quad \text{(CCM)} \\ \dfrac{2}{1+\sqrt{1+\dfrac{4k}{D^2}}}, & k < k_{crit} \quad \text{(DCM)} \end{cases}$$

$$k \triangleq \frac{2 f_s L I_o}{V_o}, \qquad k_{crit}(D) \triangleq 1 - D \quad \text{or} \quad k_{crit}(M) \triangleq 1 - M$$

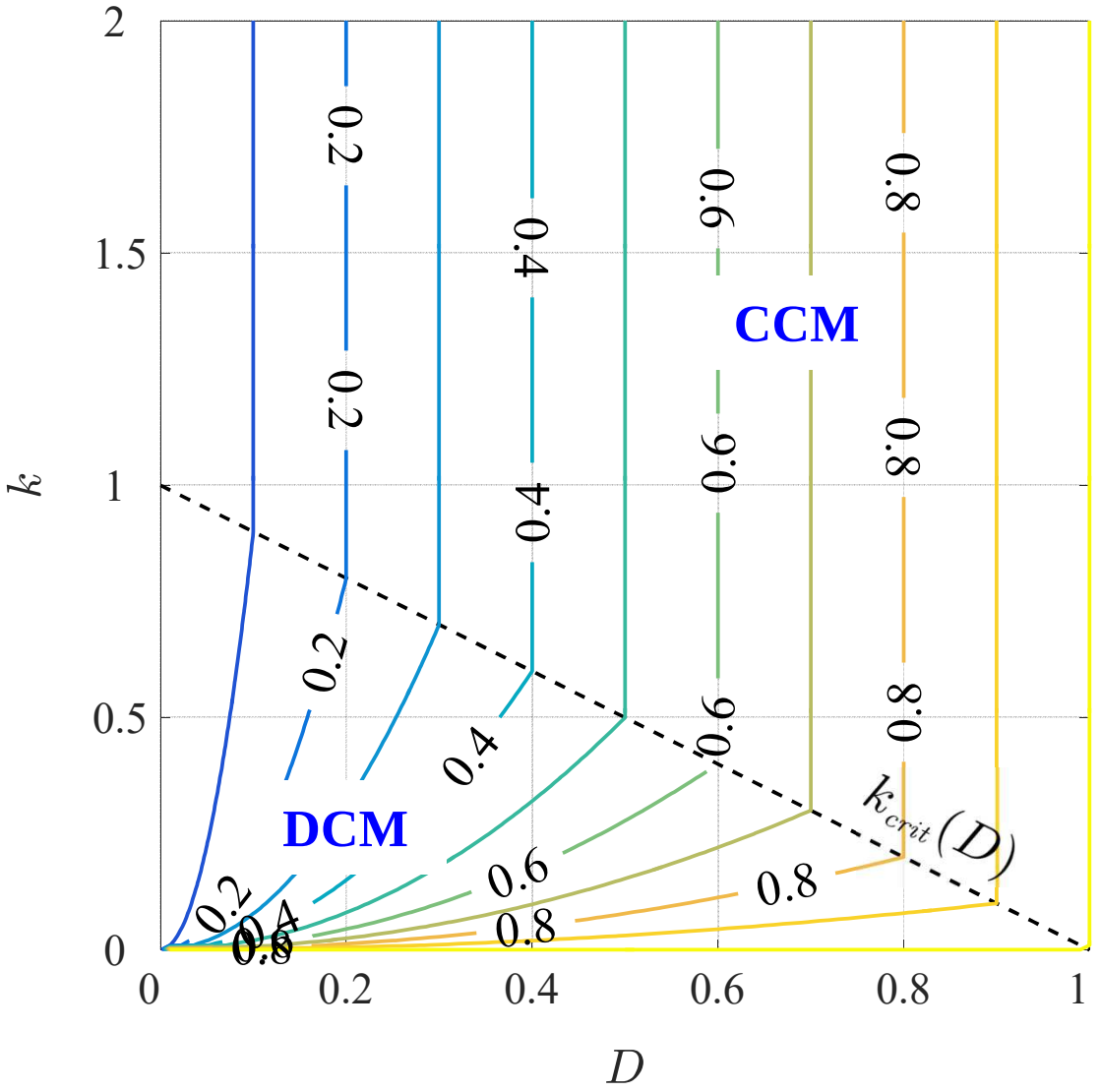
Buck converter with resistive load: critical k vs. M



Buck converter with resistive load: control characteristics



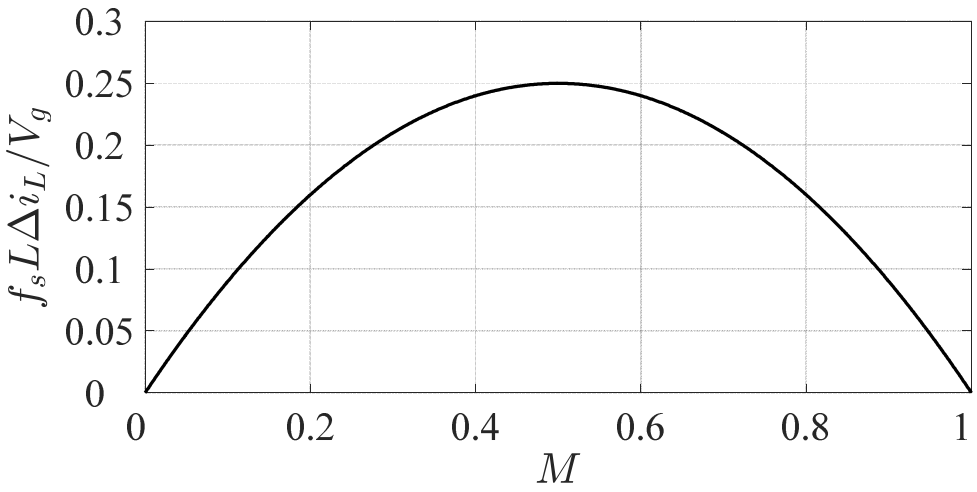
Buck converter with resistive load: voltage conversion ratio $M(D,k)$



Buck converter: inductor current ripple in CCM

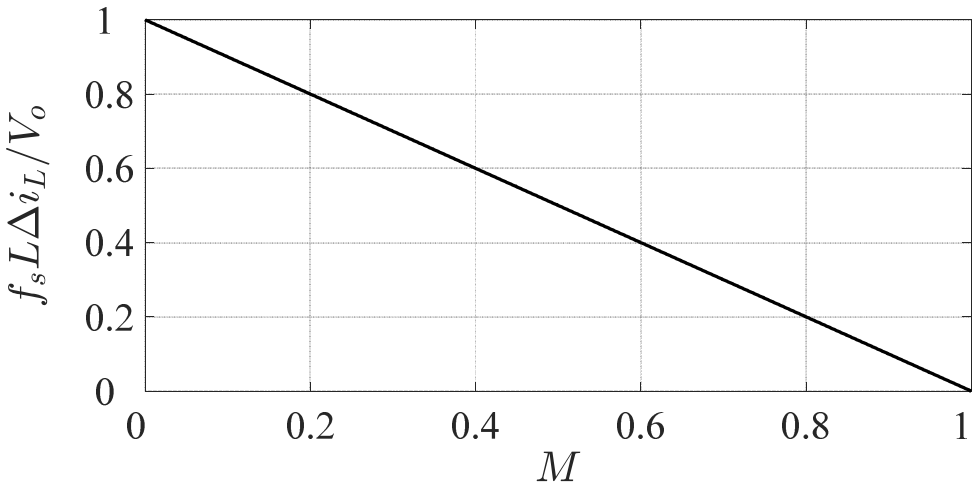
- Constant V_g:

$$\Delta i_L = \frac{V_g}{f_s L} D(1-D)$$
$$= \frac{V_g}{f_s L} M(1-M)$$



- Constant V_o:

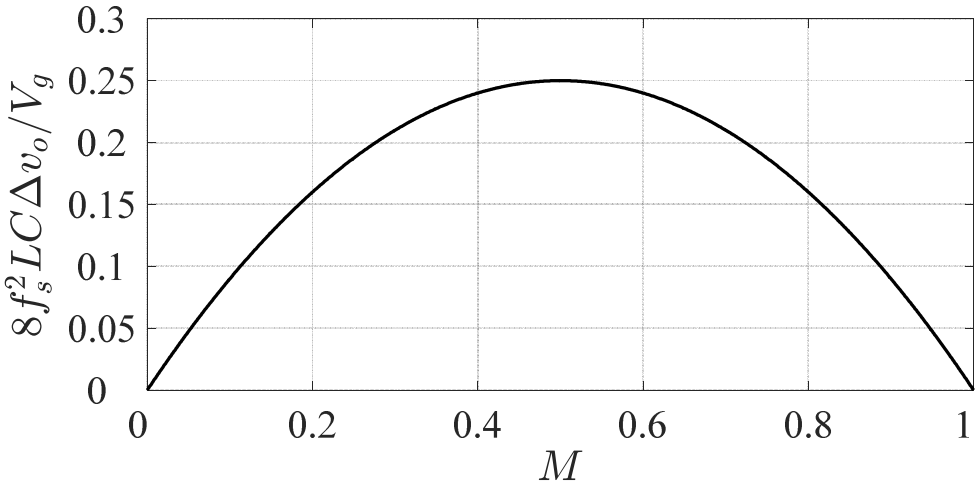
$$\Delta i_L = \frac{V_o}{f_s L}(1-D)$$
$$= \frac{V_o}{f_s L}(1-M)$$



Buck converter: output voltage ripple in CCM

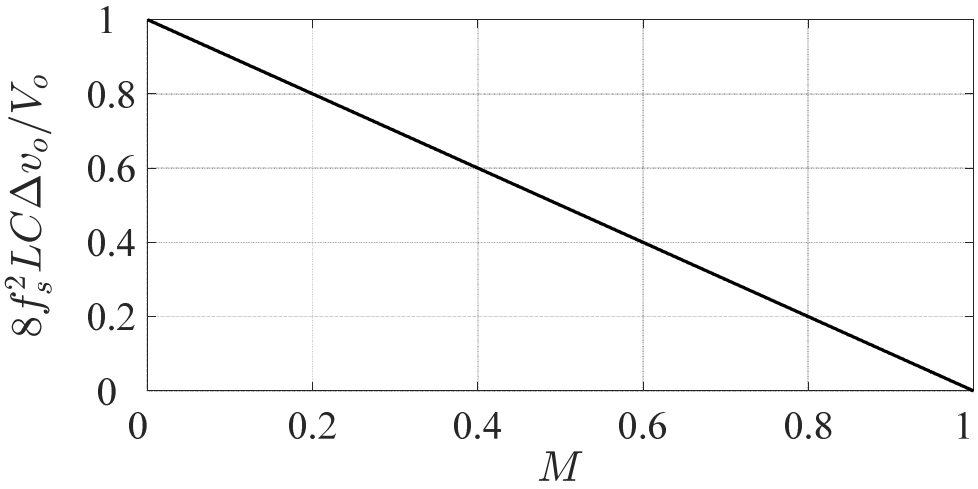
- Constant V_g:

$$\Delta v_o = \frac{\Delta i_L}{8 f_s C} = \frac{V_g}{8 f_s^2 LC} M(1-M)$$



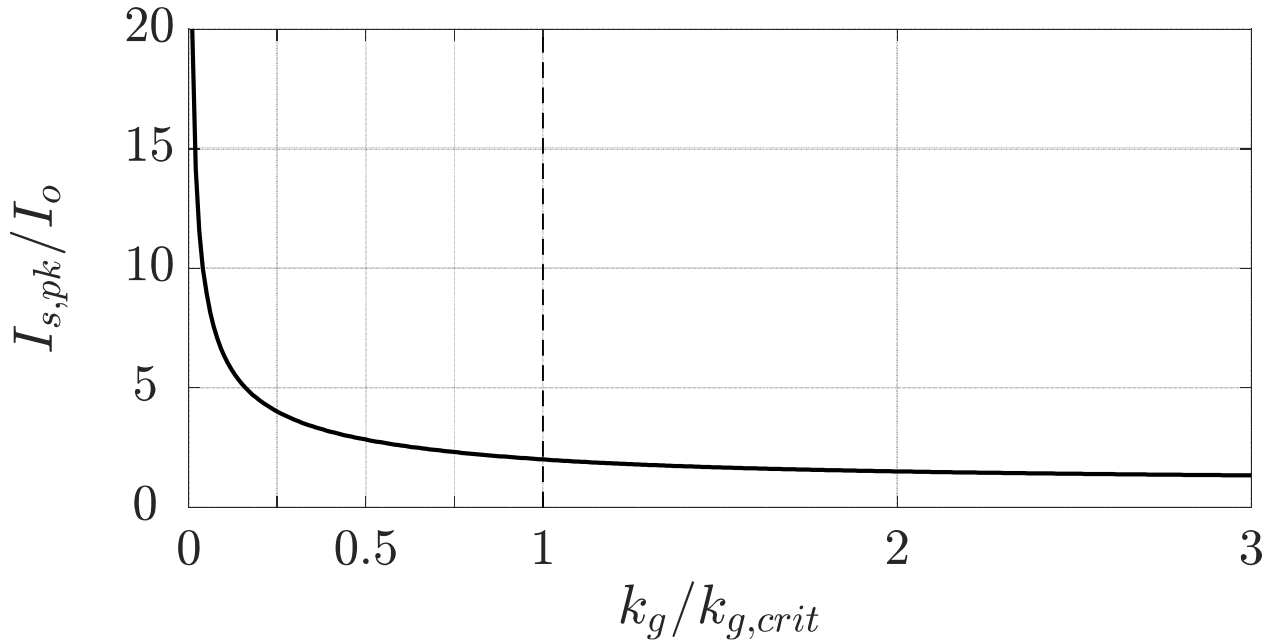
- Constant V_o:

$$\Delta v_o = \frac{\Delta i_L}{8 f_s C} = \frac{V_o}{8 f_s^2 LC}(1-M)$$

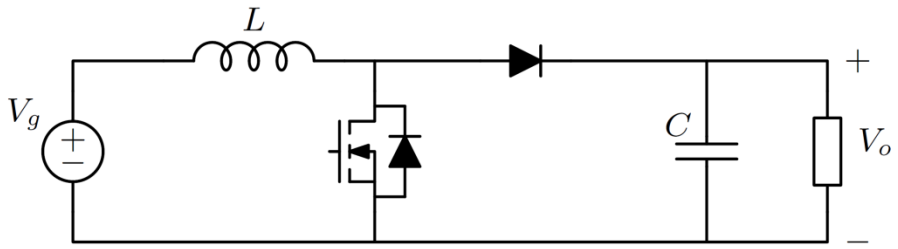


Buck converter: current stress

$$\frac{I_{s,pk}}{I_o} = \begin{cases} 1 + \dfrac{1}{k_g/k_{g,crit}} & \text{(CCM)} \\ \dfrac{2}{\sqrt{k_g/k_{g,crit}}} & \text{(DCM)} \end{cases}$$



Boost Converter

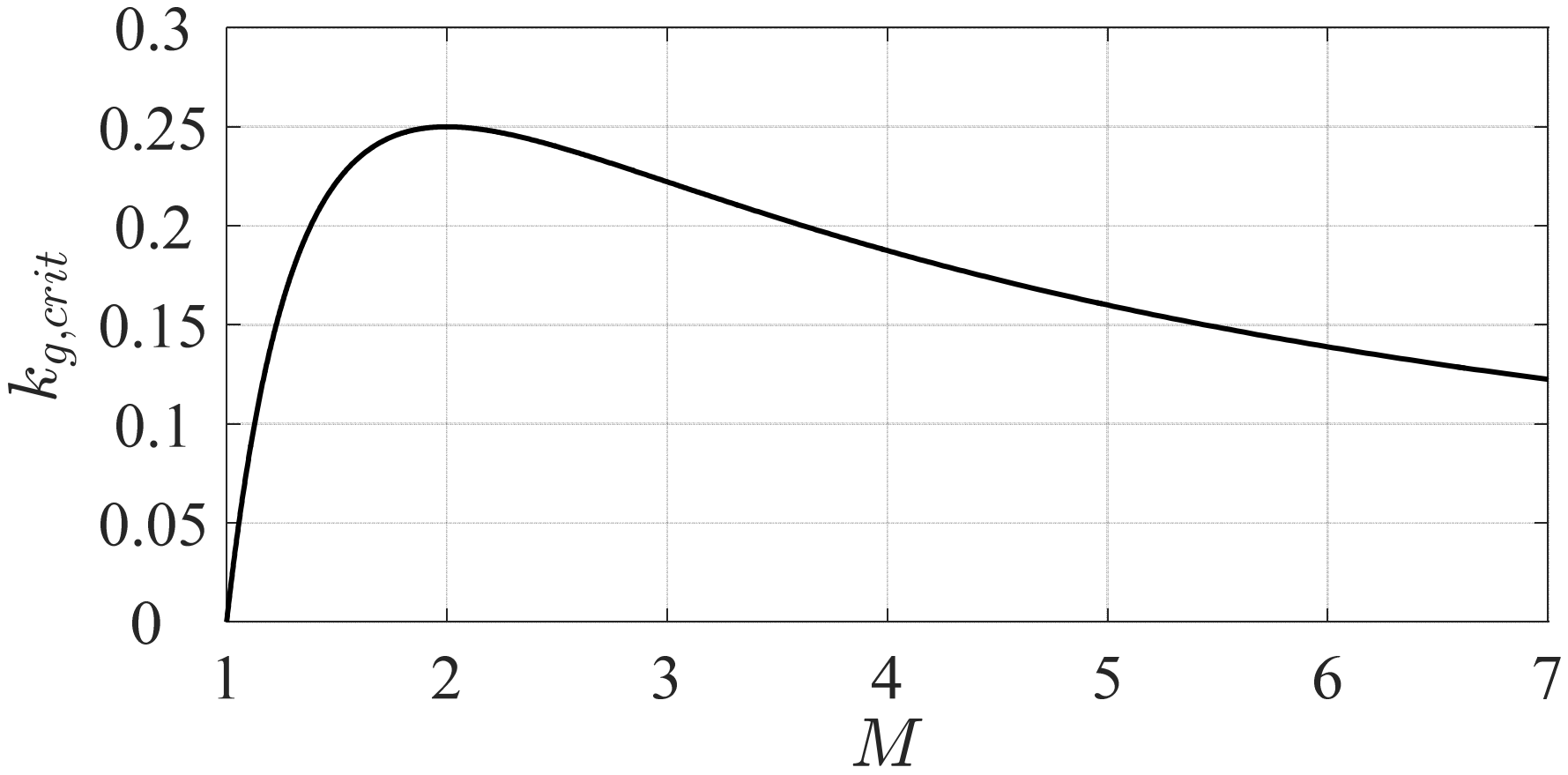


Boost converter with constant current load: voltage conversion ratio $M(D,k_g)$

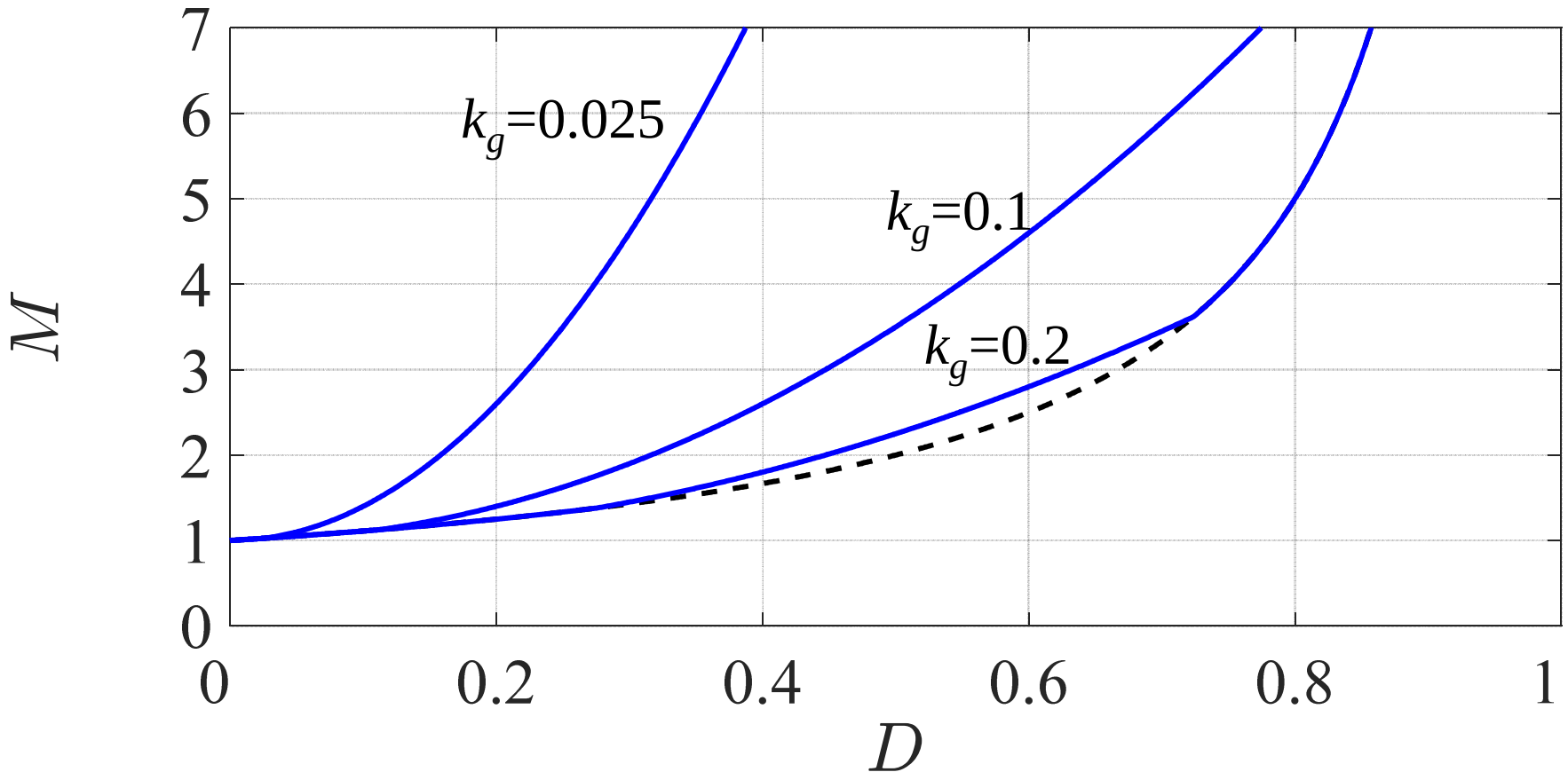
$$M(D,k_g)=\begin{cases}\dfrac{1}{1-D}, & k_g > k_{g,crit} \quad \text{(CCM)}\\[2ex] 1+\dfrac{D^2}{k_g}, & k_g < k_{g,crit} \quad \text{(DCM)}\end{cases}$$

$$k_g \triangleq \frac{2f_sLI_o}{V_g}, \qquad k_{g,crit}(D) \triangleq D(1-D) \quad \text{or} \quad k_{g,crit}(M) \triangleq \frac{M-1}{M^2}$$

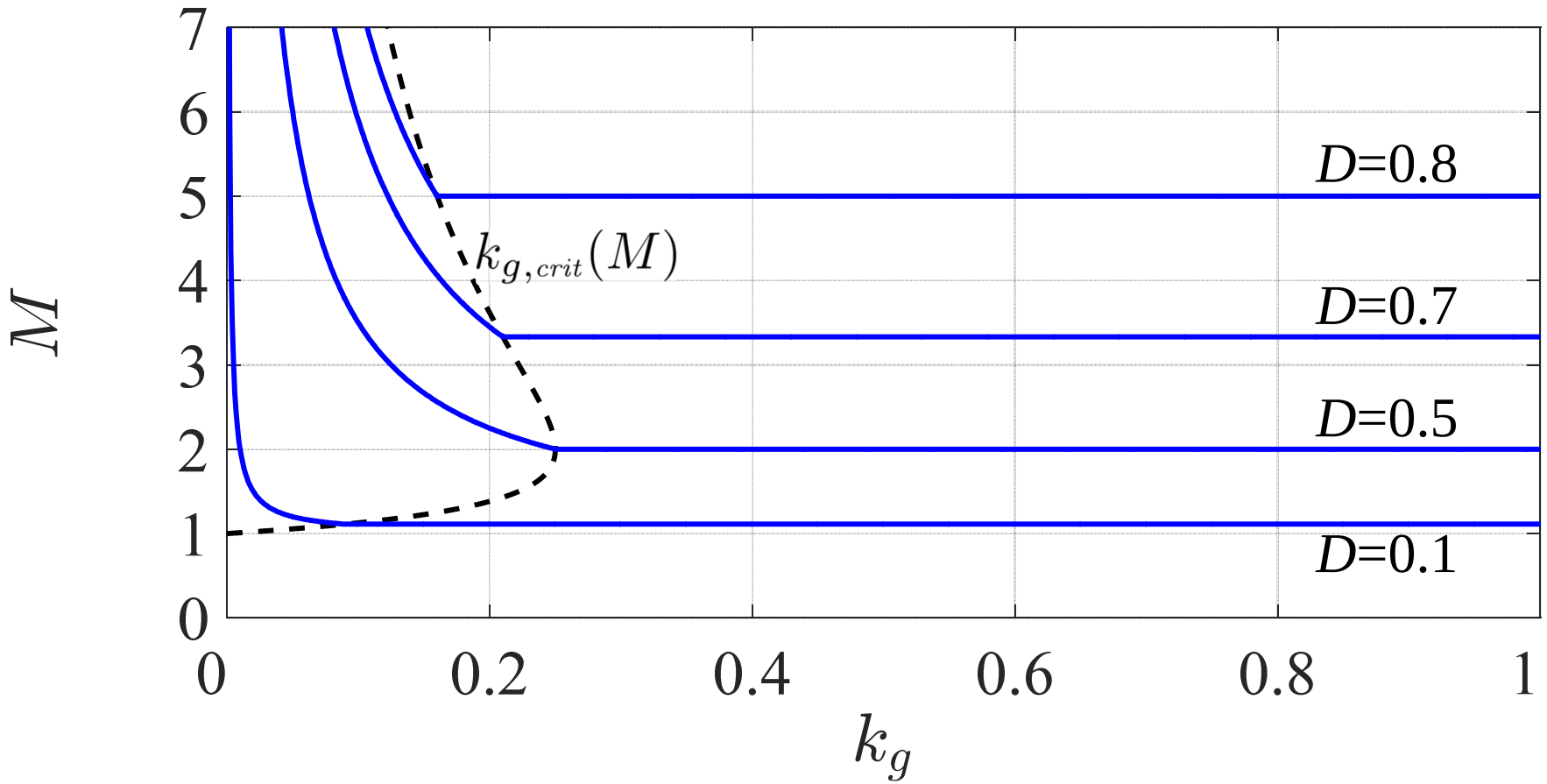
Boost converter with constant current load: critical k_g vs. M



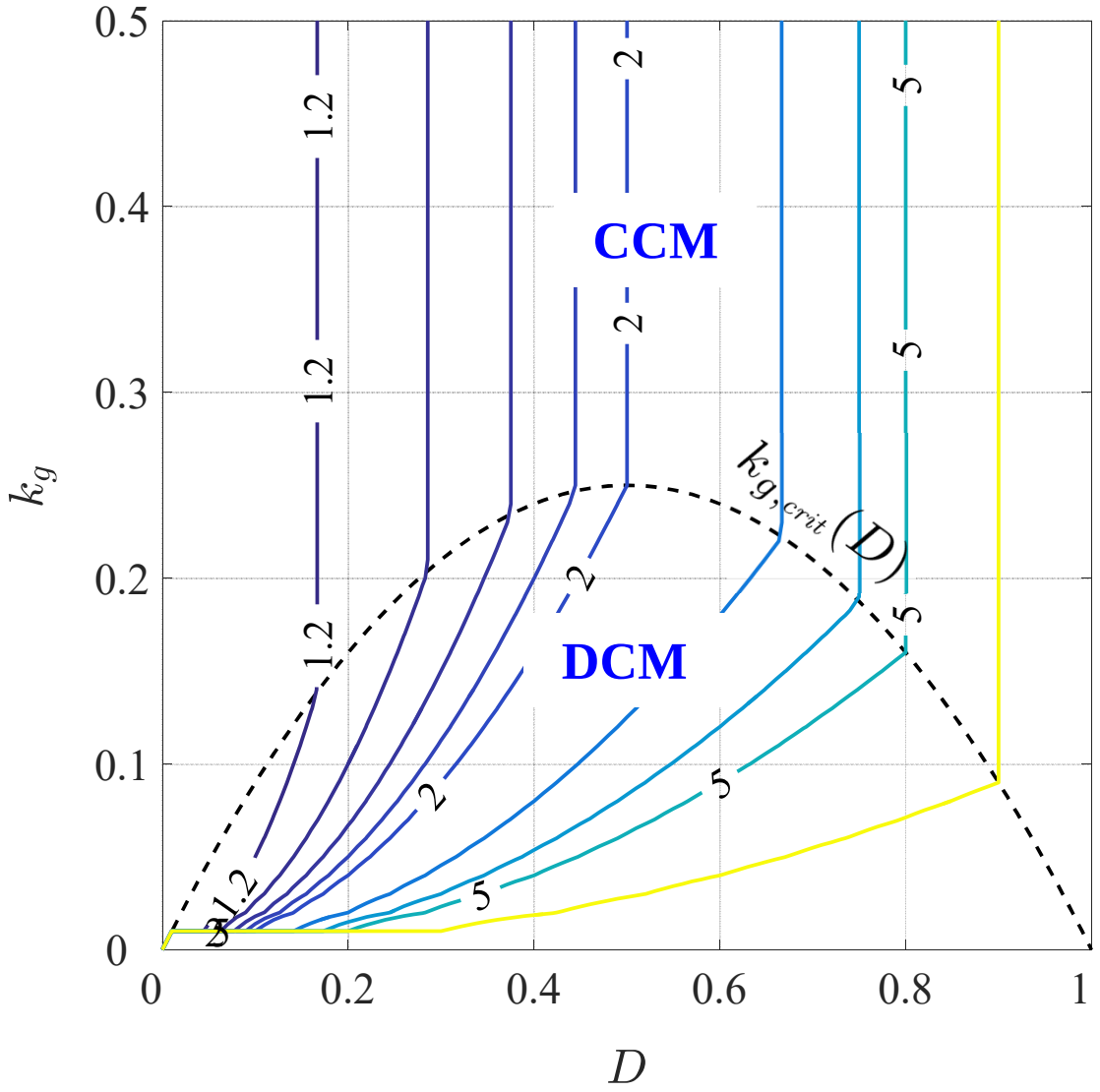
Boost converter with constant current load: control characteristics



Boost converter with constant current load: output characteristics



Boost converter with constant current load: voltage conversion ratio $M(D,k_g)$

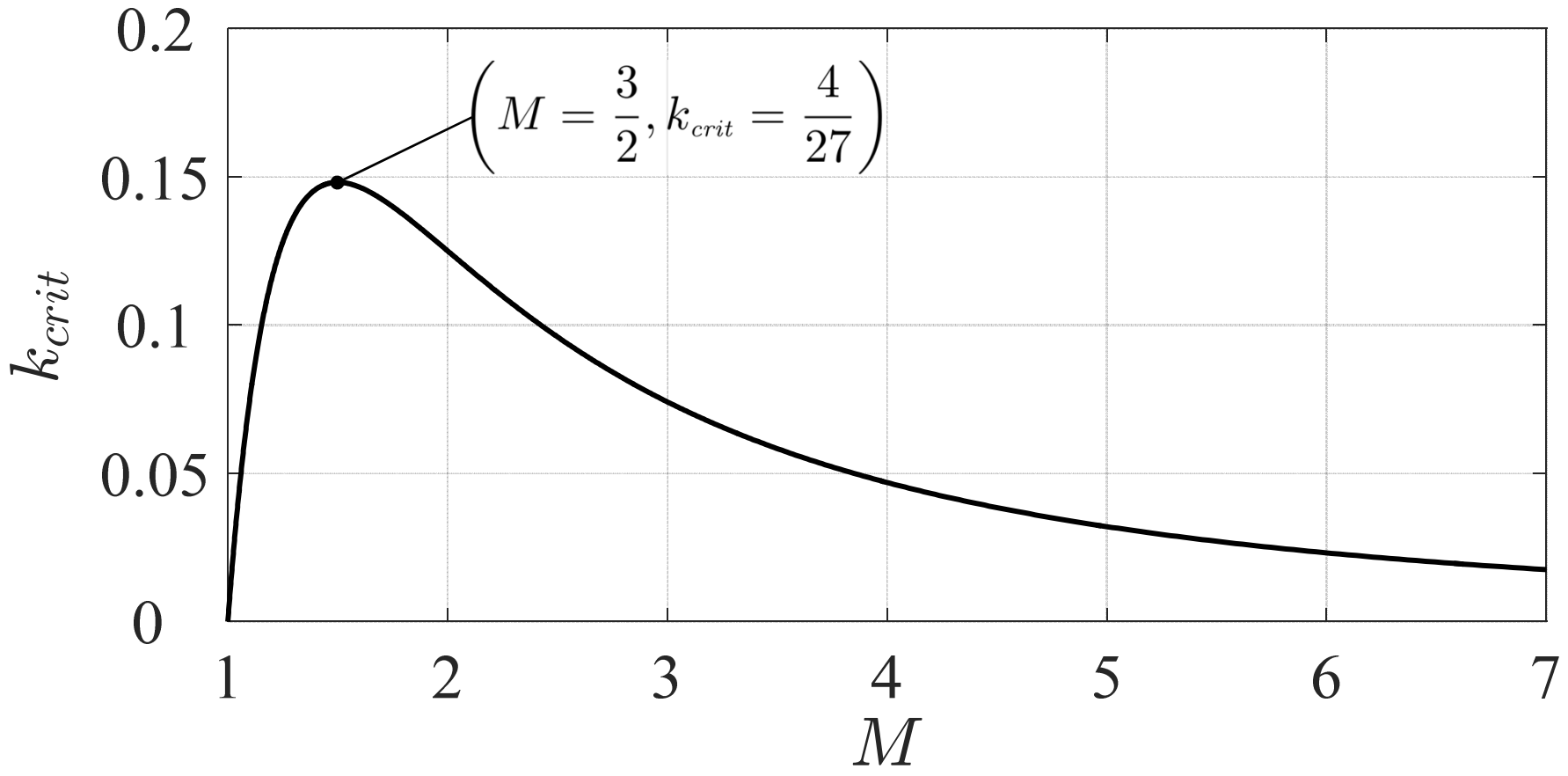


Boost converter with resistive load: voltage conversion ratio $M(D,k)$

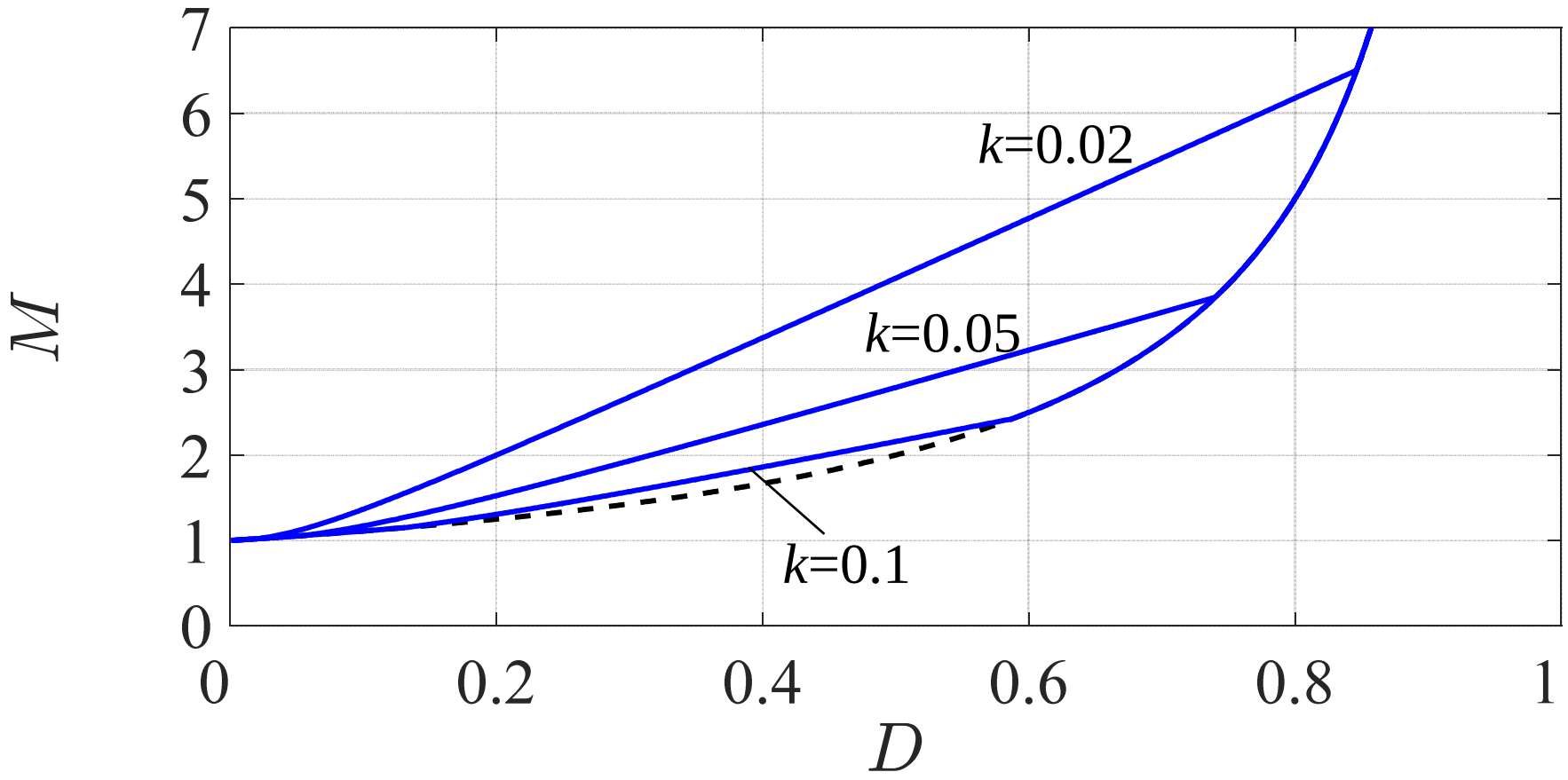
$$M(D,k) = \begin{cases} \dfrac{1}{1-D}, & k > k_{crit} \quad \text{(CCM)} \\ \dfrac{1+\sqrt{1+\dfrac{4D^2}{k}}}{2}, & k < k_{crit} \quad \text{(DCM)} \end{cases}$$

$$k \triangleq \frac{2f_s L I_o}{V_o}, \qquad k_{crit}(D) \triangleq D(1-D)^2 \quad \text{or} \quad k_{crit}(M) \triangleq \frac{M-1}{M^3}$$

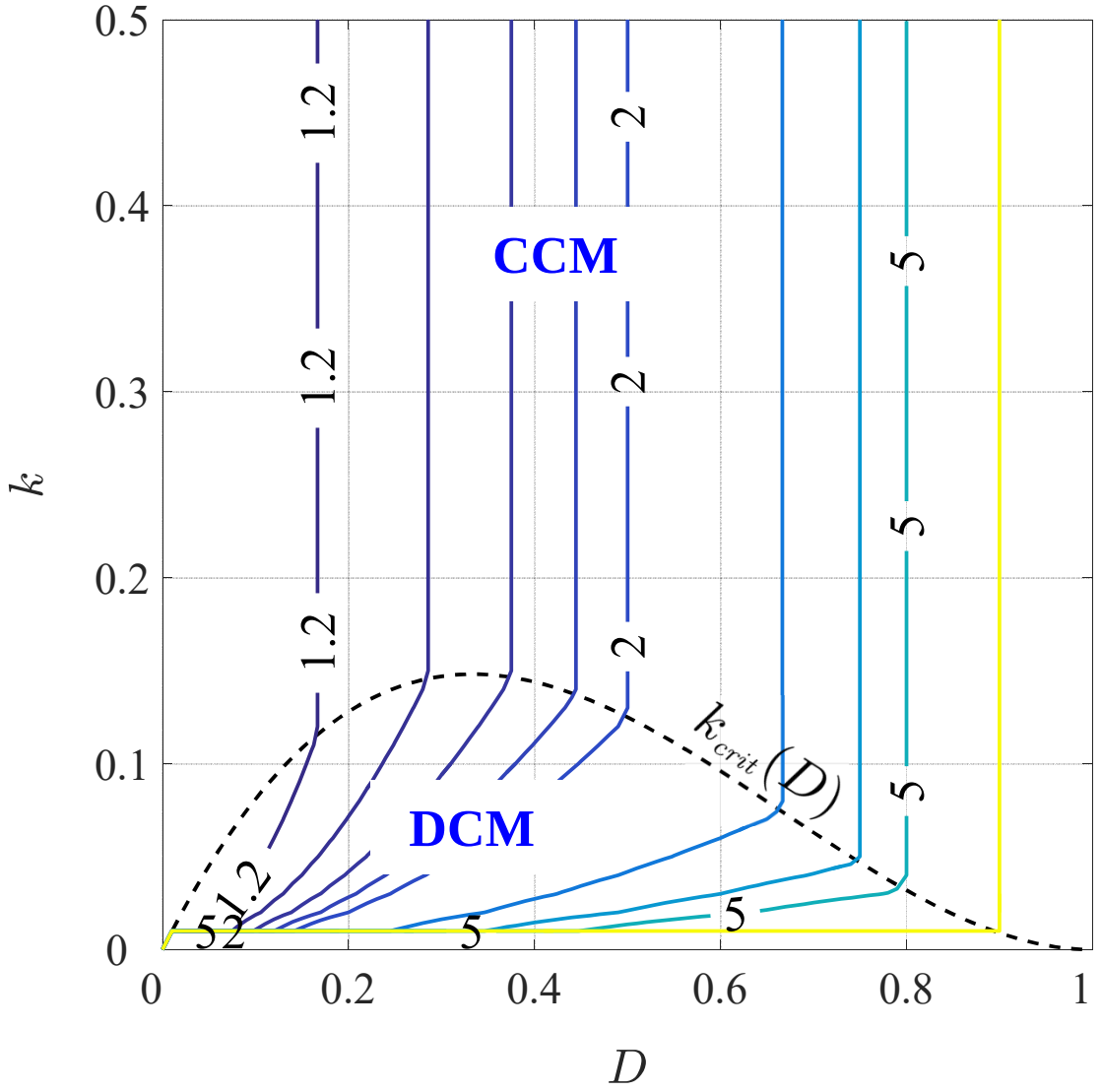
Boost converter with resistive load: critical k vs. M



Boost converter with resistive load: control characteristics



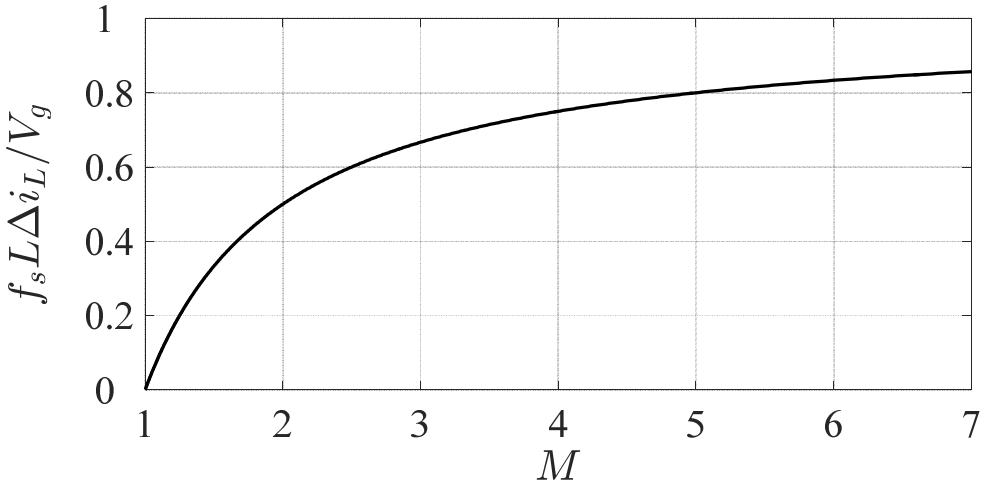
Boost converter with resistive load: voltage conversion ratio $M(D,k)$



Boost converter: inductor current ripple in CCM

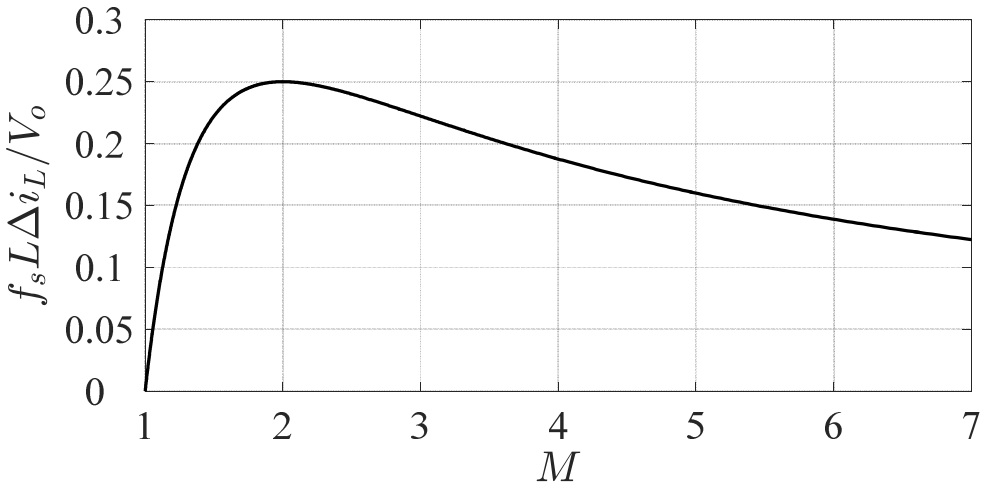
- Constant V_g:

$$\Delta i_L = \frac{V_g}{f_s L} D = \frac{V_g}{f_s L} \frac{M-1}{M}$$



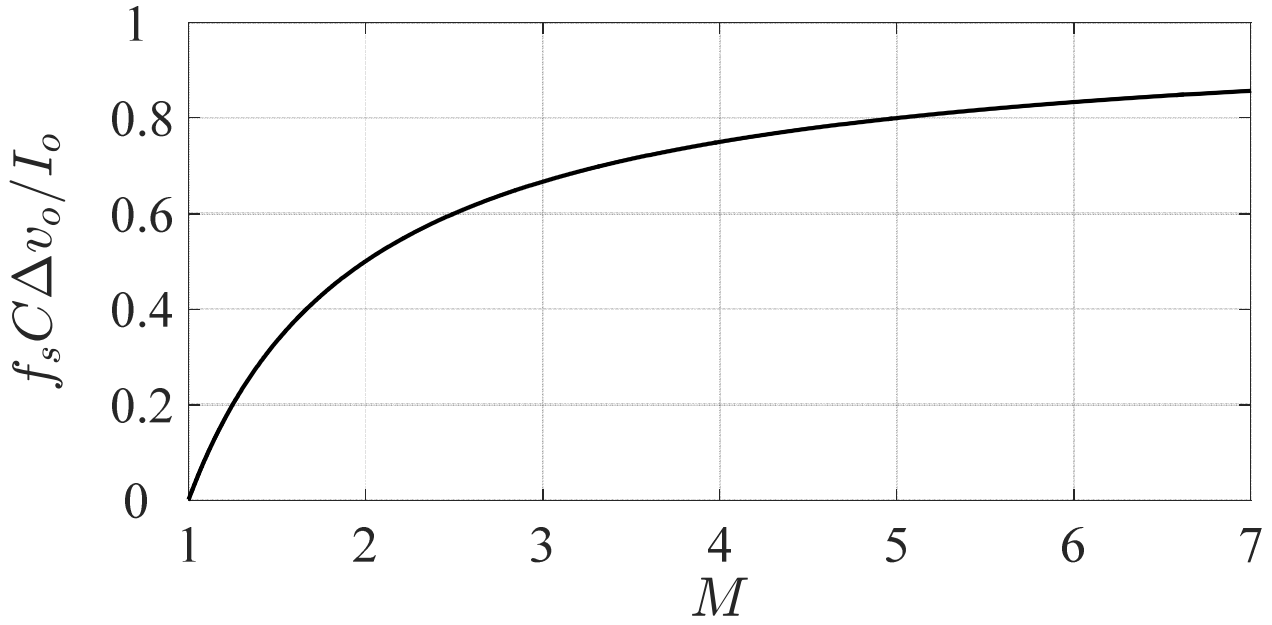
- Constant V_o:

$$\Delta i_L = \frac{V_o}{f_s L} D(1-D) = \frac{V_o}{f_s L} \frac{M-1}{M^2}$$



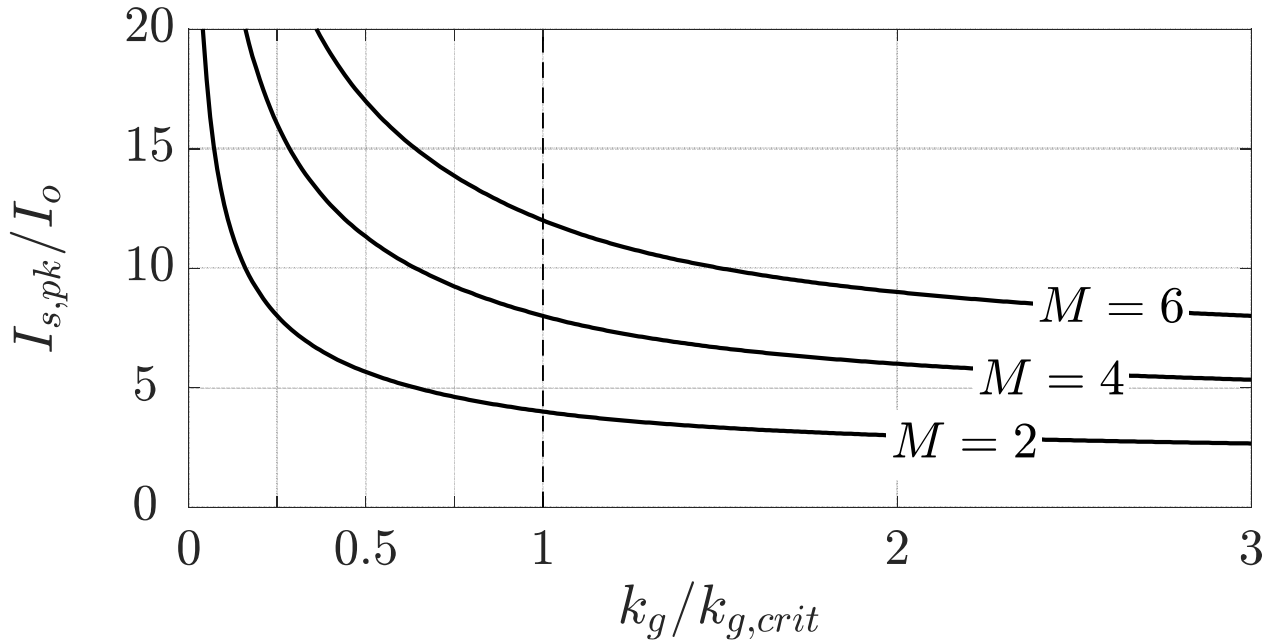
Boost converter: output voltage ripple in CCM

$$\Delta v_o = \frac{DI_o}{f_s C} = \frac{I_o}{f_s C}\frac{M-1}{M}$$

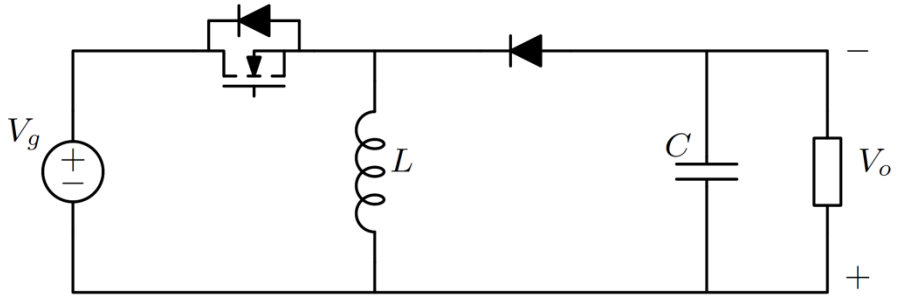


Boost converter: current stress

$$\frac{I_{s,pk}}{I_o} = \begin{cases} M\left(1+\dfrac{1}{k_g/k_{g,crit}}\right) & \text{(CCM)} \\ \dfrac{2M}{\sqrt{k_g/k_{g,crit}}} & \text{(DCM)} \end{cases}$$



Buck-Boost Converter

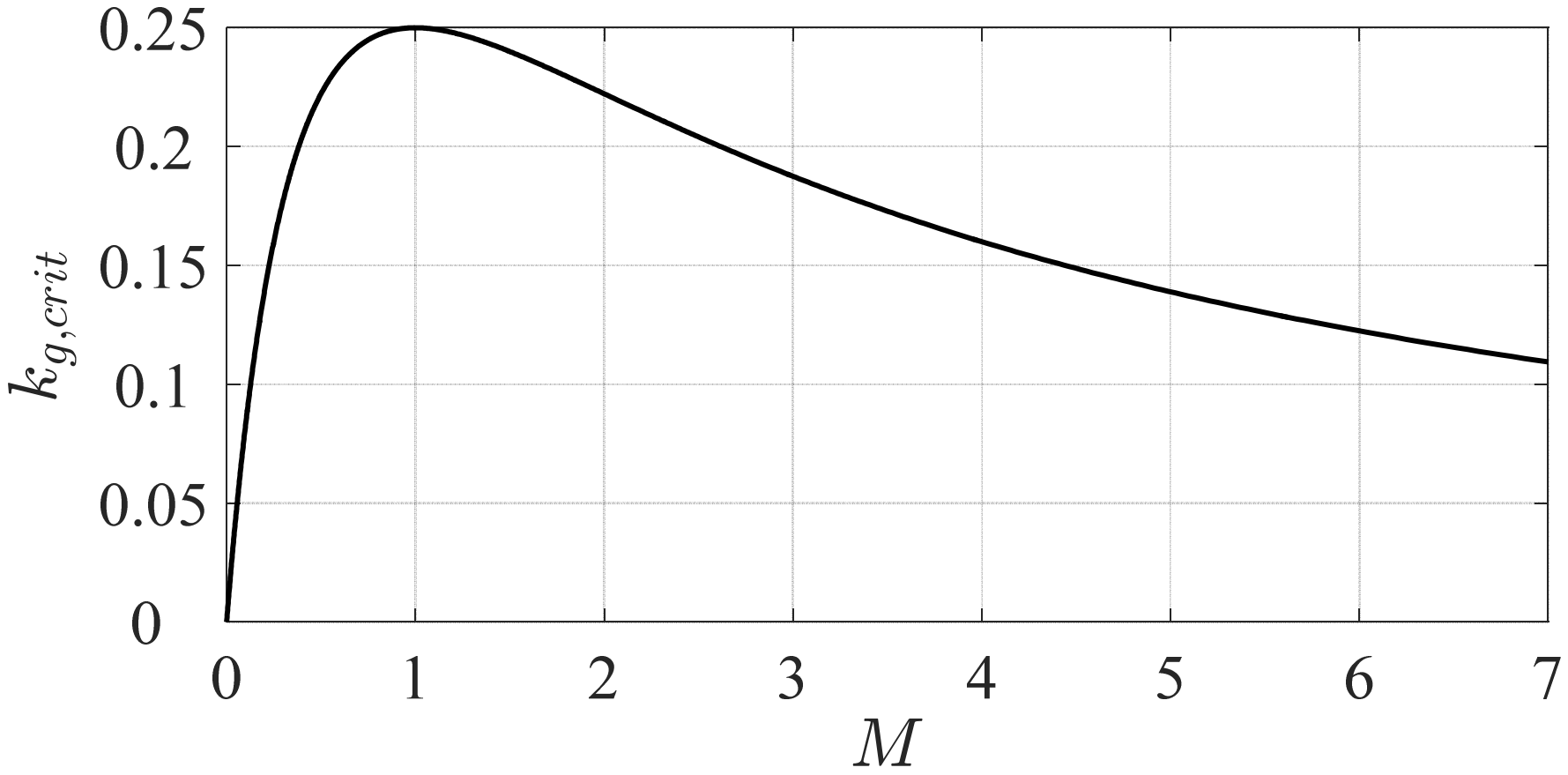


Buck-Boost converter with constant current load: voltage conversion ratio $M(D,k_g)$

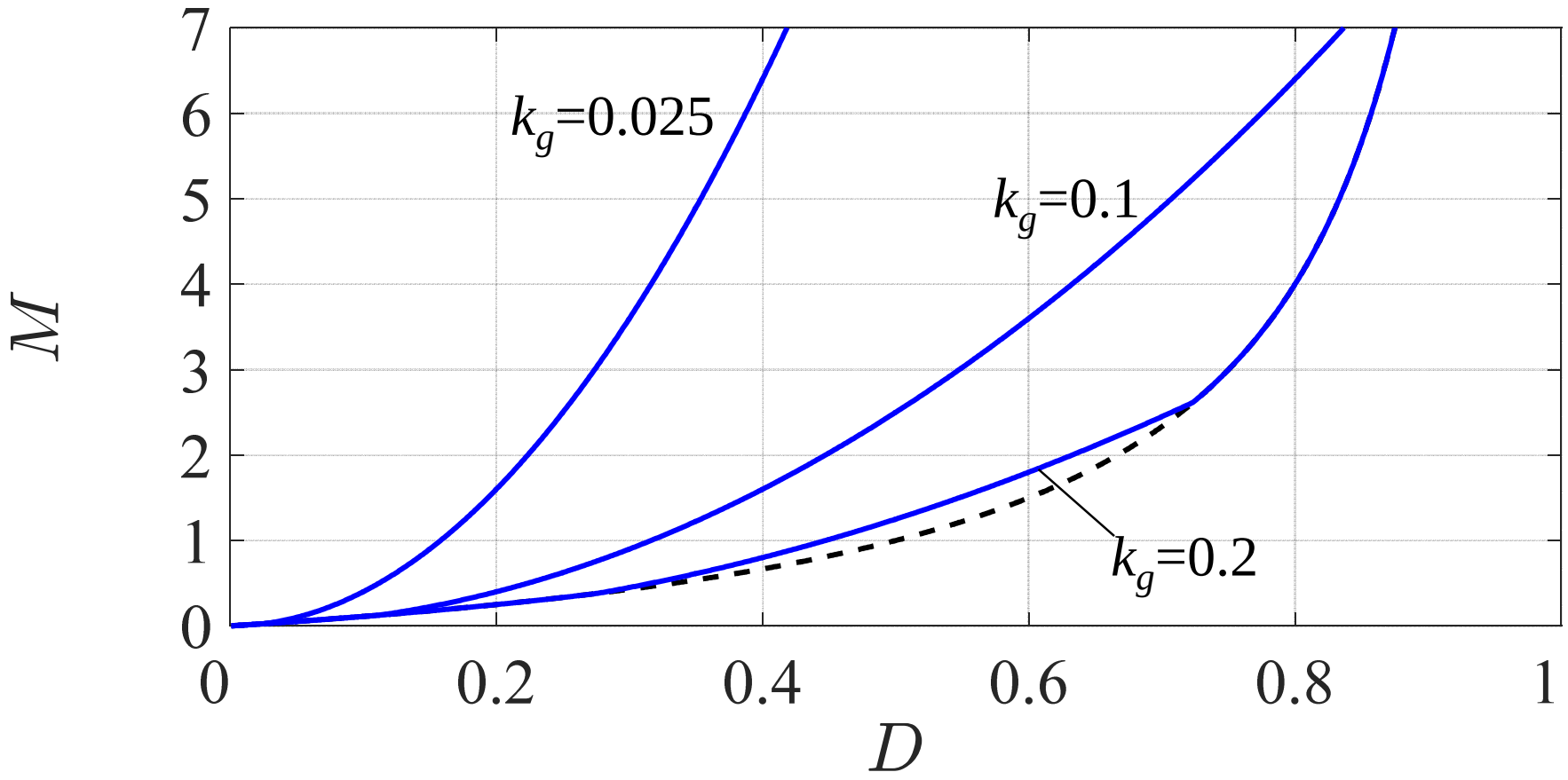
$$M(D,k_g)=\begin{cases}\dfrac{D}{1-D}, & k_g > k_{g,crit} \quad \text{(CCM)}\\ \dfrac{D^2}{k_g}, & k_g < k_{g,crit} \quad \text{(DCM)}\end{cases}$$

$$k_g \triangleq \frac{2f_s L I_o}{V_g}, \qquad k_{g,crit}(D) \triangleq D(1-D) \quad \text{or} \quad k_{g,crit}(M) \triangleq \frac{M}{(1+M)^2}$$

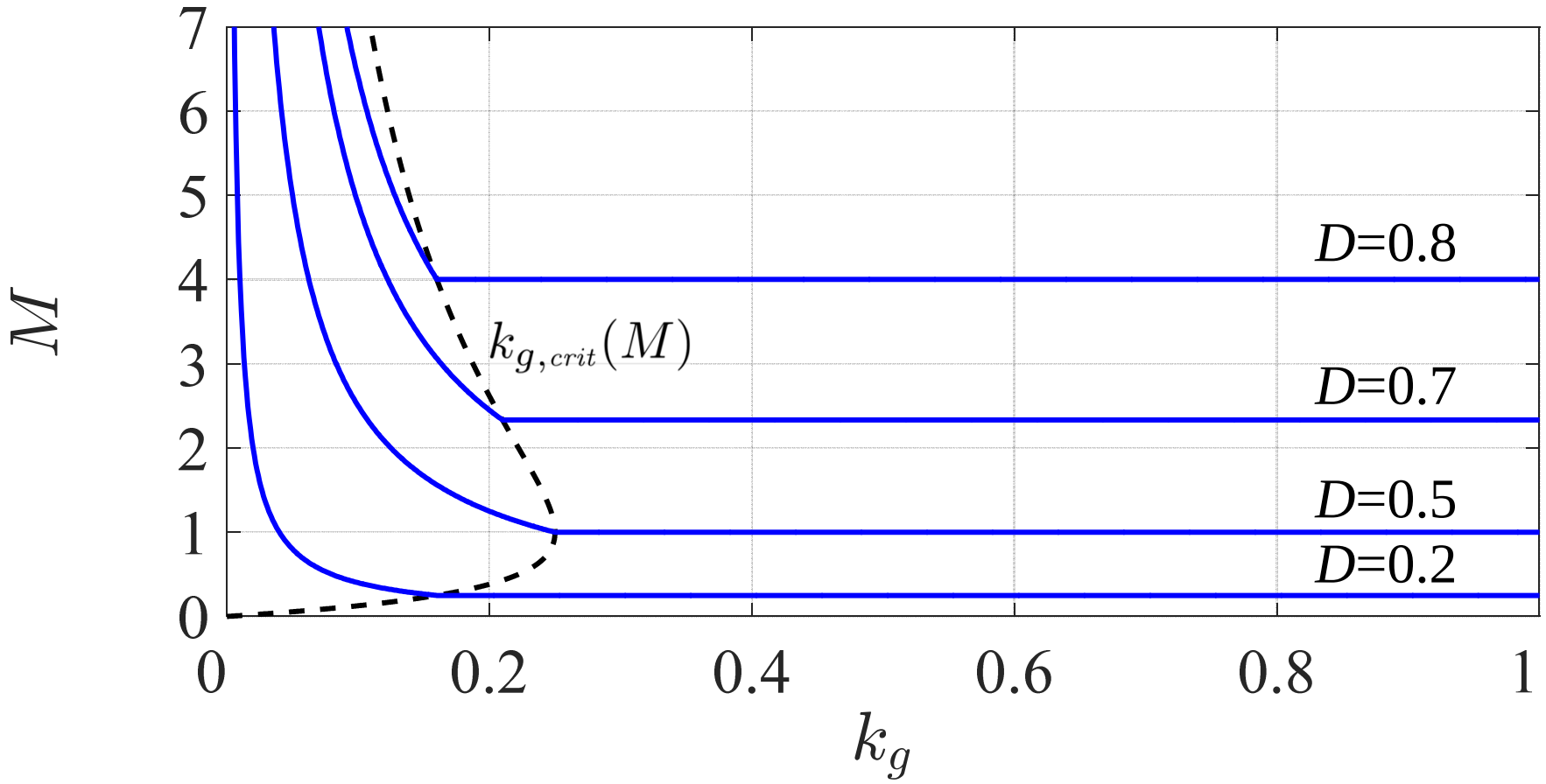
Buck-Boost converter with constant current load: critical k_g vs. M



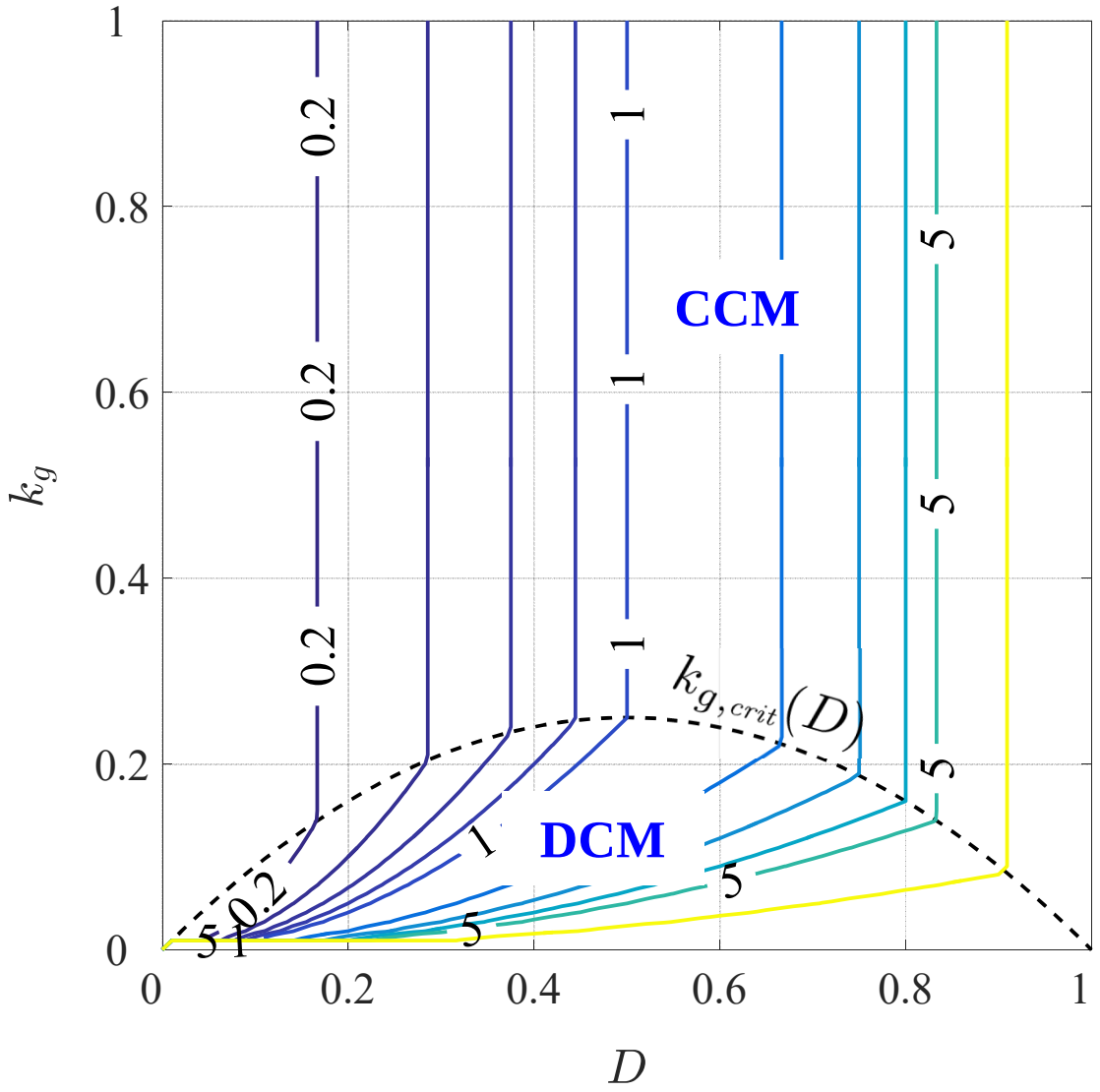
Buck-Boost converter with constant current load: control characteristics



Buck-Boost converter with constant current load: output characteristics



Buck-Boost converter with constant current load: voltage conversion ratio $M(D,k_g)$

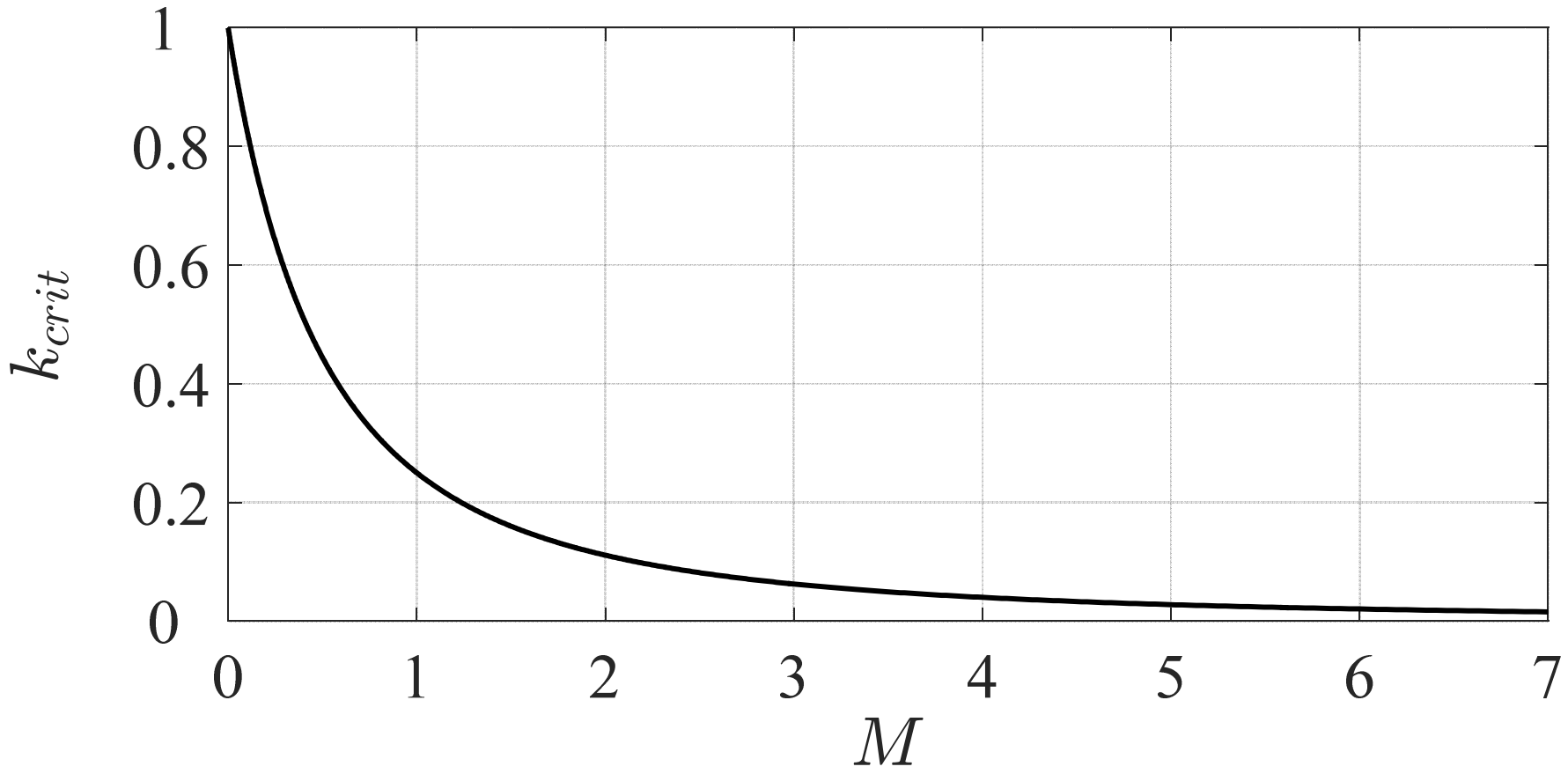


Buck-Boost converter with resistive load: voltage conversion ratio $M(D,k)$

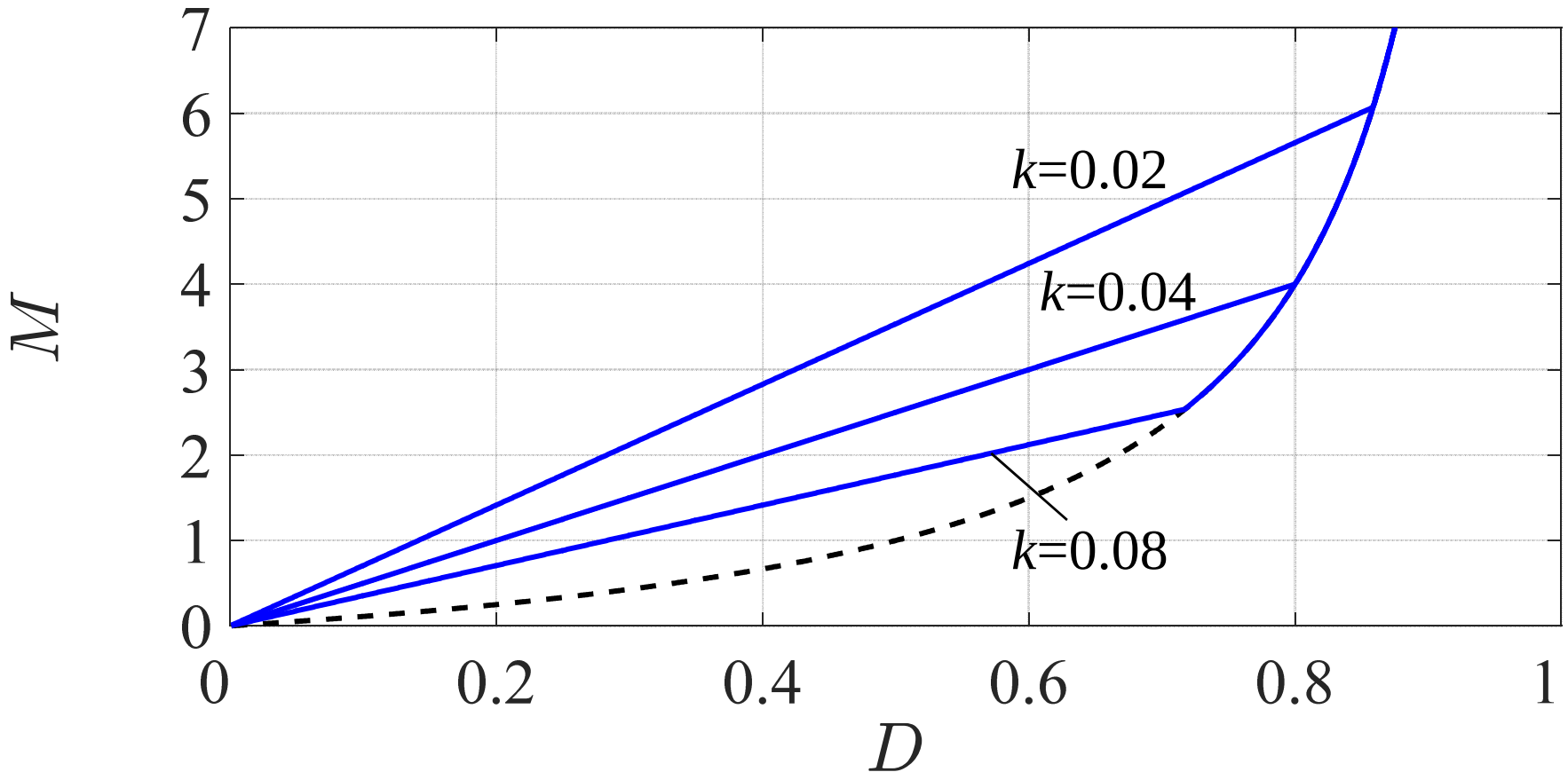
$$M(D,k) = \begin{cases} \dfrac{D}{1-D}, & k > k_{crit} \quad \text{(CCM)} \\ \dfrac{D}{\sqrt{k}}, & k < k_{crit} \quad \text{(DCM)} \end{cases}$$

$$k \triangleq \frac{2 f_s L I_o}{V_o}, \qquad k_{crit}(D) \triangleq (1-D)^2 \quad \text{or} \quad k_{crit}(M) \triangleq \frac{1}{(1+M)^2}$$

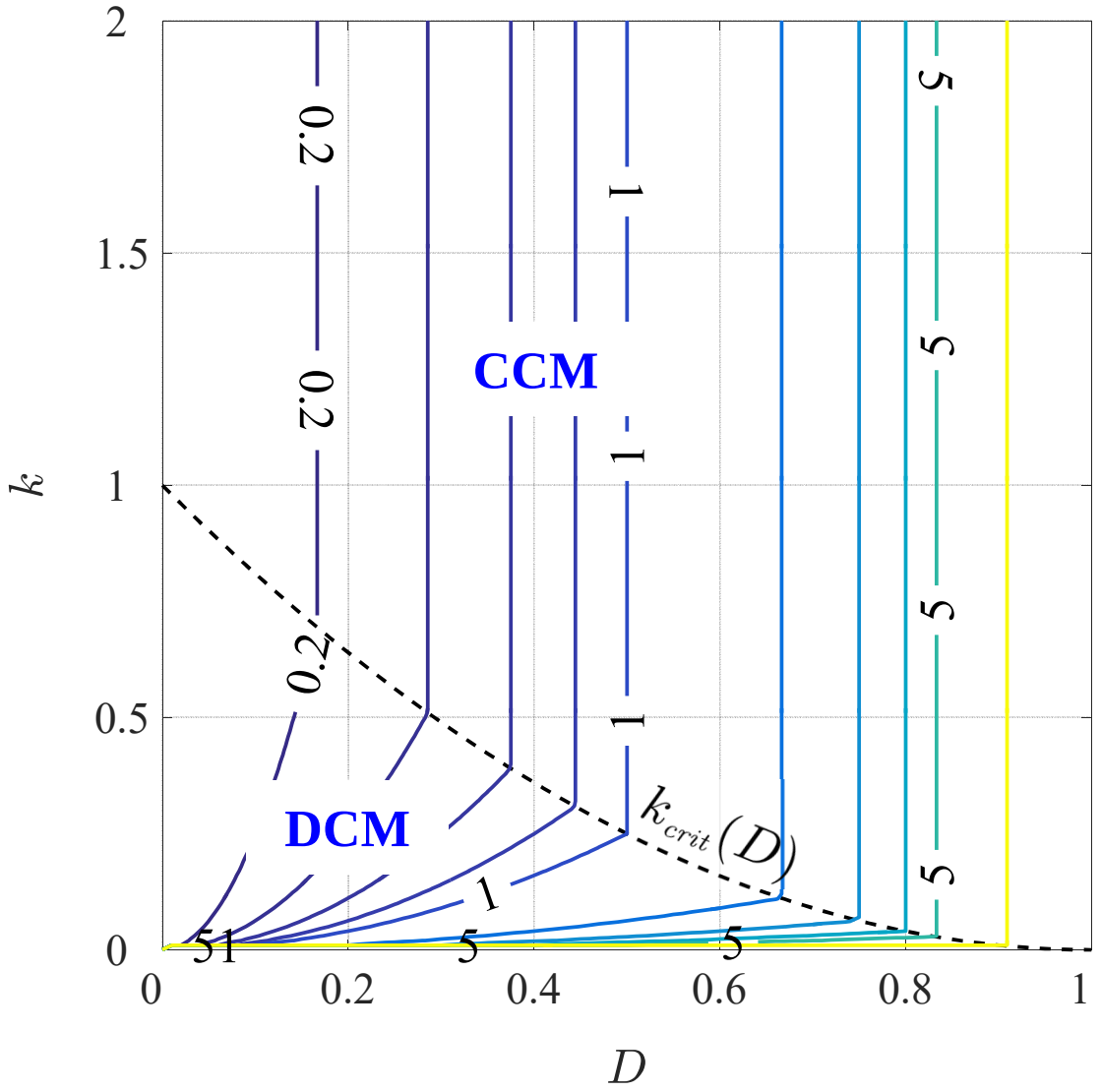
Buck-Boost converter with resistive load: critical k vs. M



Buck-Boost converter with resistive load: control characteristics



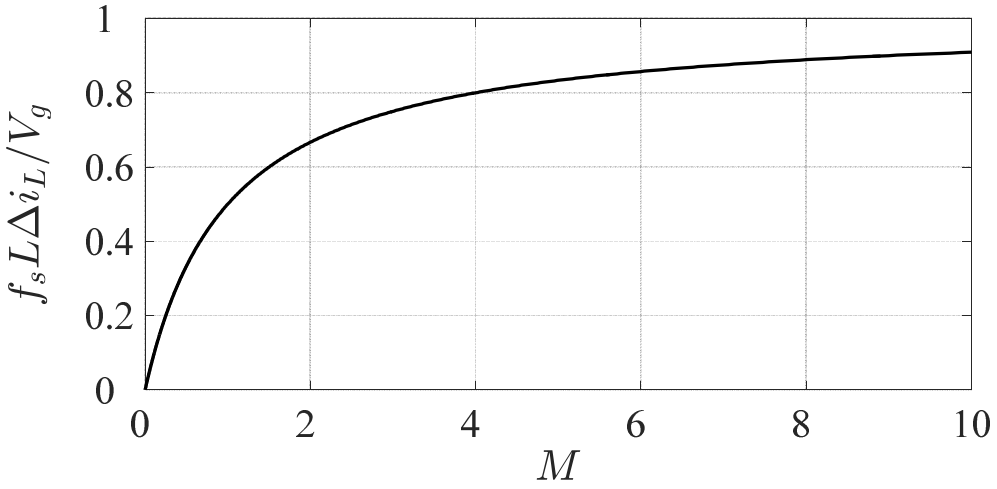
Buck-Boost converter with resistive load: voltage conversion ratio $M(D,k)$



Buck-Boost converter: inductor current ripple in CCM

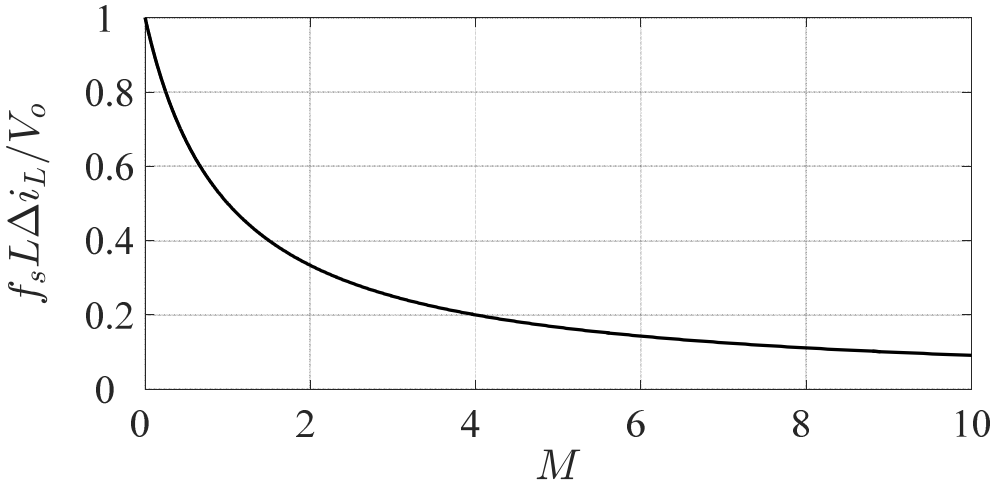
- Constant V_g:

$$\Delta i_L = \frac{V_g}{f_s L} D = \frac{V_g}{f_s L} \frac{M}{1+M}$$



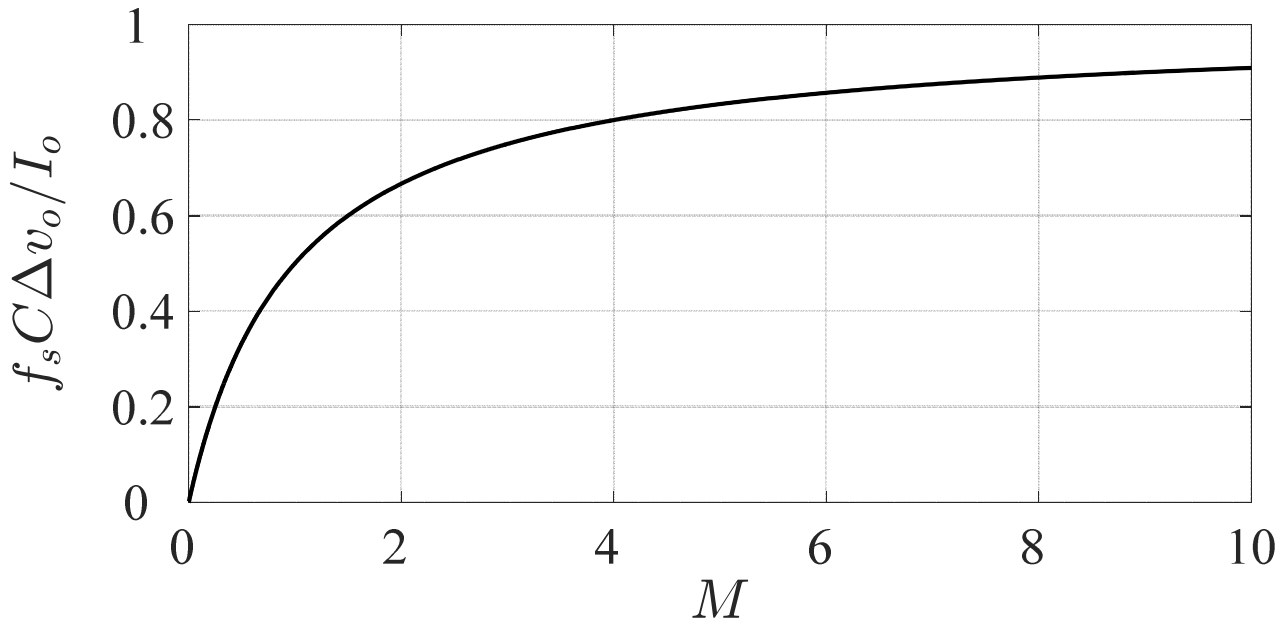
- Constant V_o:

$$\Delta i_L = \frac{V_o}{f_s L}(1-D) = \frac{V_o}{f_s L} \frac{1}{1+M}$$



Buck-Boost converter: output voltage ripple in CCM

$$\Delta v_o = \frac{DI_o}{f_s C} = \frac{I_o}{f_s C}\frac{M}{1+M}$$



Buck-Boost converter: current stress

$$\frac{I_{s,pk}}{I_o} = \begin{cases} (1+M)\left(1+\dfrac{1}{k_g/k_{g,crit}}\right) & \text{(CCM)} \\ \dfrac{2\,(1+M)}{\sqrt{k_g/k_{g,crit}}} & \text{(DCM)} \end{cases}$$