Power Electronics Education
Electronic Book

Welcome to PEEEB

Lecture 6: Non-isolated DC-DC Converters with Real Components

Presenter: Dr. Firuz Zare

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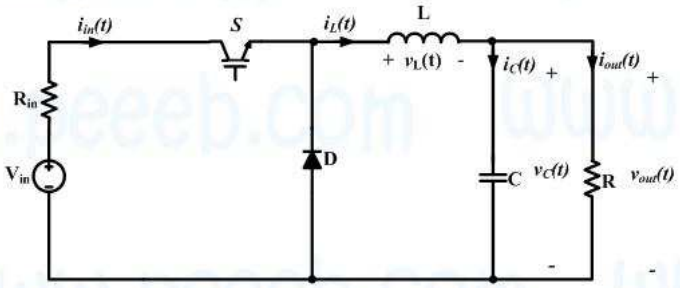
Buck Converter



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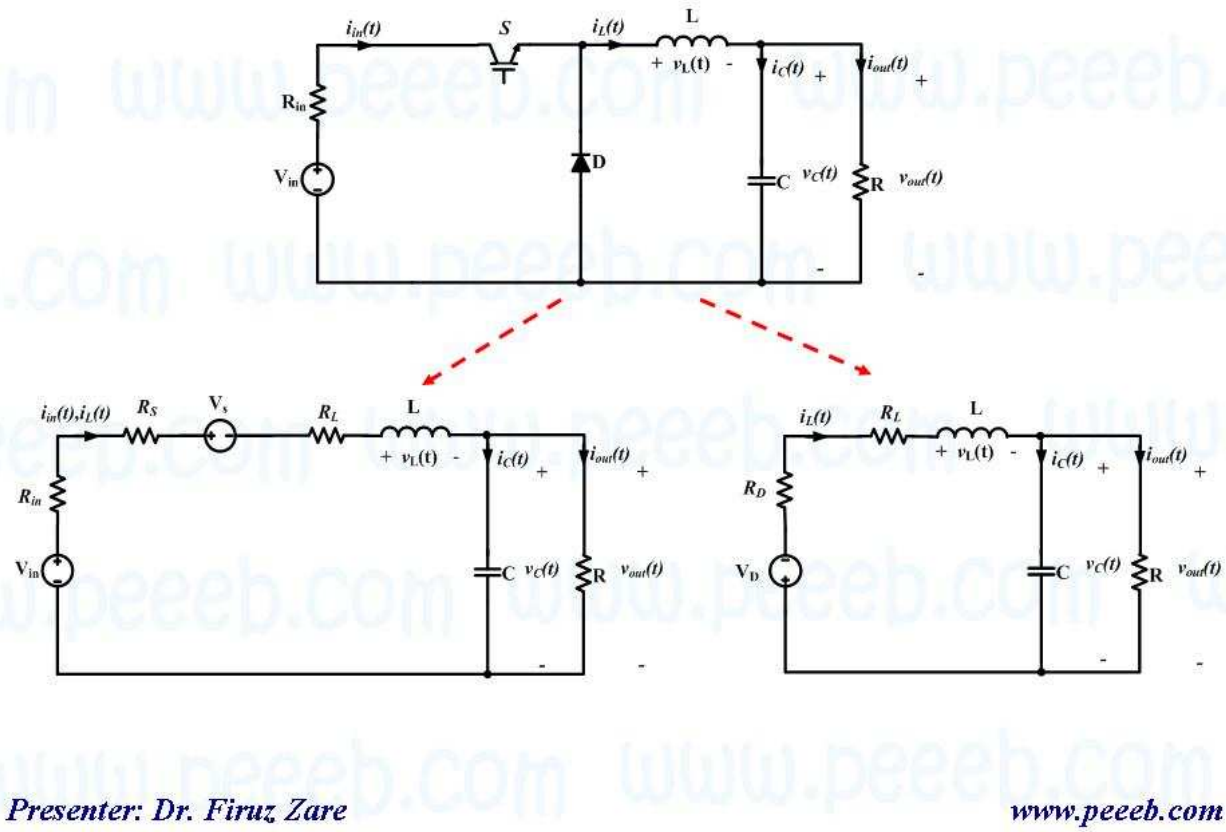
Buck Converter



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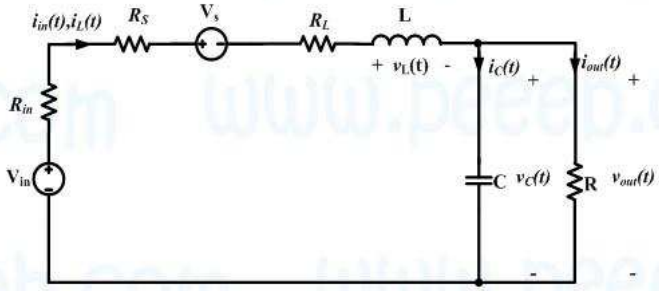
Buck Converter

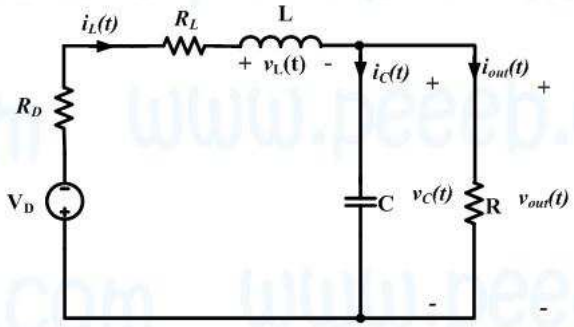


$$V_{in} = R_{in} i_L(t) + R_S i_L(t) + V_S + R_L i_L(t) + v_L(t) + v_{out}(t)$$

$$i_L(t) = i_C(t) + i_{out}(t)$$

$$\begin{cases} v_L(t) = V_{in} - V_S - V_{out} - I_L(R_{in} + R_S + R_L) \\ i_C(t) = I_L - \dfrac{V_{out}}{R} \end{cases}$$

Buck Converter



$$V_D + R_D i_L(t) + R_L i_L(t) + v_L(t) + v_{out}(t) = 0$$

$$i_L(t) = i_C(t) + i_{out}(t)$$

$$\begin{cases} v_L(t) = -V_{out} - V_D - I_L(R_D + R_L) \\ i_C(t) = I_L - \dfrac{V_{out}}{R} \end{cases}$$

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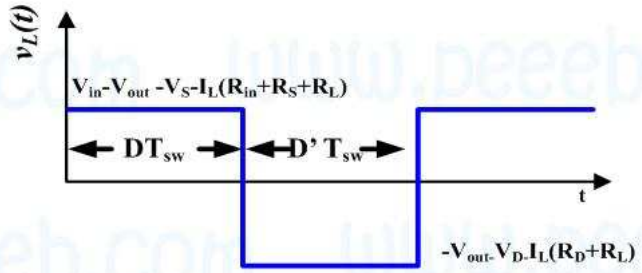
Buck Converter



$$v_L(t)=\begin{cases} V_{in}-V_S-V_{out}-I_L\left(R_{in}+R_S+R_L\right) & 0<t<t_{on} \\ -V_{out}-V_D-I_L\left(R_D+R_L\right) & t_{on}<t<T_{sw} \end{cases}$$

$$i_C(t)=I_L-\frac{V_{out}}{R} \qquad 0<t<T_{sw}$$

Buck Converter

$$\overline{i_C(t)} = 0$$

$$\frac{1}{T_{sw}} \int_0^{T_{sw}} i_C(t)\,dt = 0$$

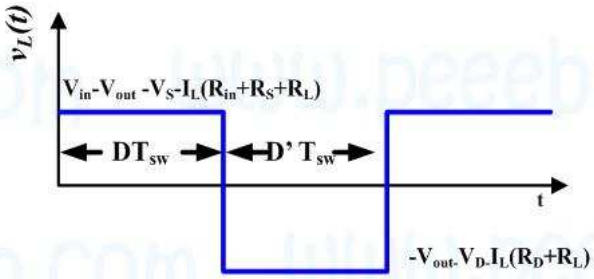
$$i_C(t) = I_L - \frac{V_{out}}{R} \qquad 0 < t < T_{sw}$$

$$I_L = \frac{V_{out}}{R}$$

Buck Converter

$$\overline{v_L(t)} = 0$$

$$\frac{1}{T_{sw}}\int_0^{T_{sw}} v_L(t)\,dt = 0$$



$$(V_{in} - V_S - V_{out} - I_L R_{in} - I_L R_S - I_L R_L)DT_{sw} + (-V_{out} - V_D - I_L R_D - I_L R_L)(T_{sw} - DT_{sw}) = 0$$

$$\begin{cases} DV_{in} - DV_S - DV_{out} - DI_L(R_{in} + R_S + R_L) - D'V_{out} - D'V_D - D'I_L(R_D + R_L) = 0 \\ I_L = \dfrac{V_{out}}{R} \end{cases}$$

Buck Converter

$$DV_{in} - DV_S - V_{out} - D'V_D - D \times \frac{V_{out}}{R}\left(R_{in} + R_S + R_L\right) - D' \times \frac{V_{out}}{R}\left(R_D + R_L\right) = 0$$

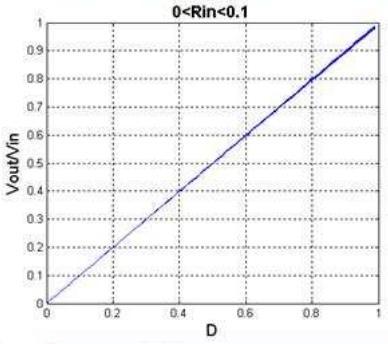
$$DV_{in} - DV_S - D'V_D = V_{out}\left[1 + D\left(\frac{R_{in} + R_S + R_L}{R}\right) + D'\left(\frac{R_D + R_L}{R}\right)\right]$$

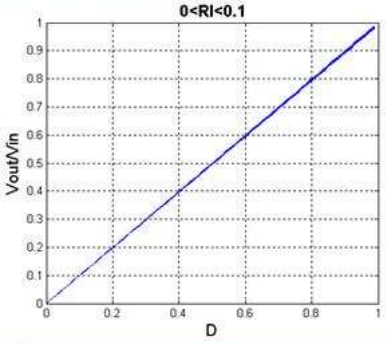
$$K_{Buck} = 1 + D\left(\frac{R_{in} + R_S + R_L}{R}\right) + D'\left(\frac{R_D + R_L}{R}\right)$$

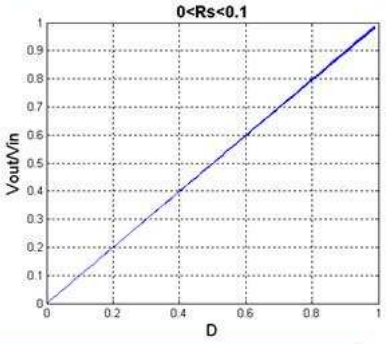
$$\frac{V_{out}}{V_{in}} = \frac{D}{K_{Buck}} - \frac{DV_S}{K_{Buck}V_{in}} - \frac{D'V_D}{K_{Buck}V_{in}}$$

Buck Converter

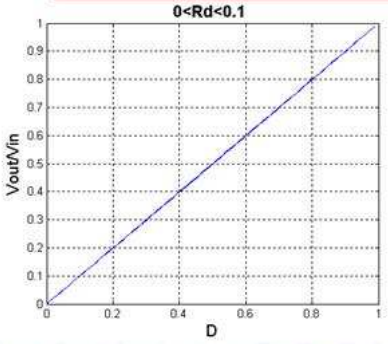
R=10 Ohm, Vin=100 V

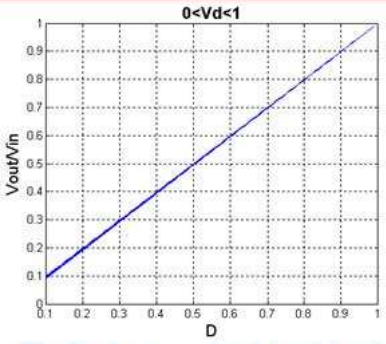


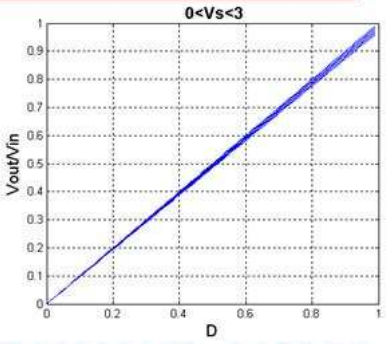




$$\frac{V_{out}}{V_{in}} = \frac{D}{K_{Buck}} - \frac{DV_S}{K_{Buck}V_{in}} - \frac{D'V_D}{K_{Buck}V_{in}} \qquad K_{Buck} = 1 + D\left(\frac{R_{in} + R_S + R_L}{R}\right) + D'\left(\frac{R_D + R_L}{R}\right)$$







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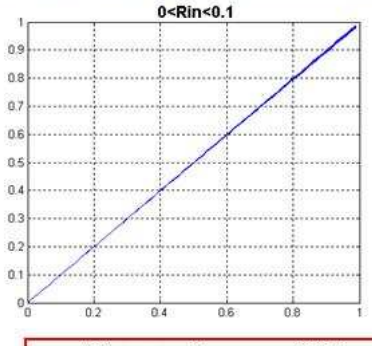
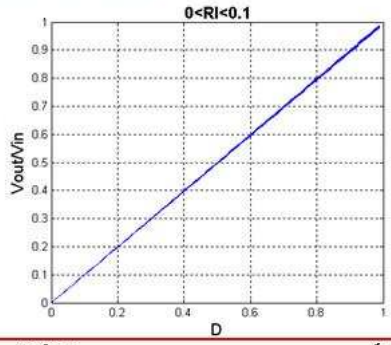
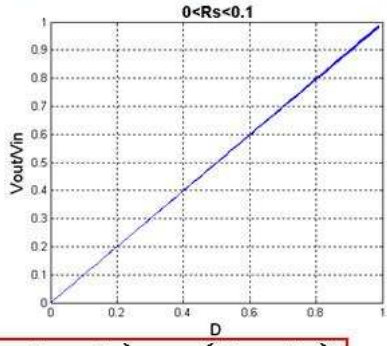
Buck Converter

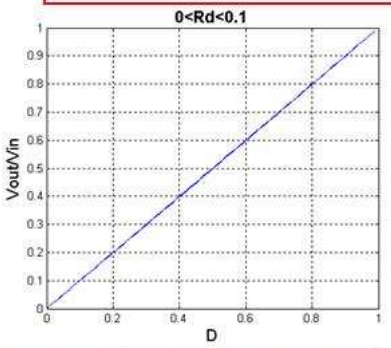
R=10 Ohm, Vin=10 V

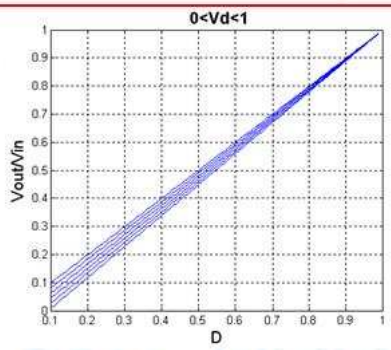


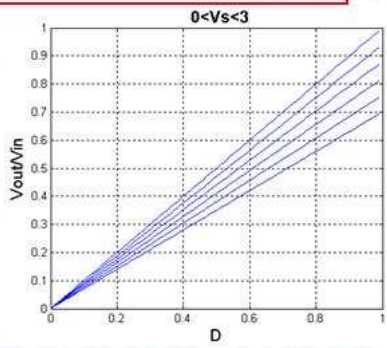




$$\frac{V_{out}}{V_{in}} = \frac{D}{K_{Buck}} - \frac{DV_S}{K_{Buck}V_{in}} - \frac{D'V_D}{K_{Buck}V_{in}} \qquad K_{Buck} = 1 + D\left(\frac{R_{in} + R_S + R_L}{R}\right) + D'\left(\frac{R_D + R_L}{R}\right)$$







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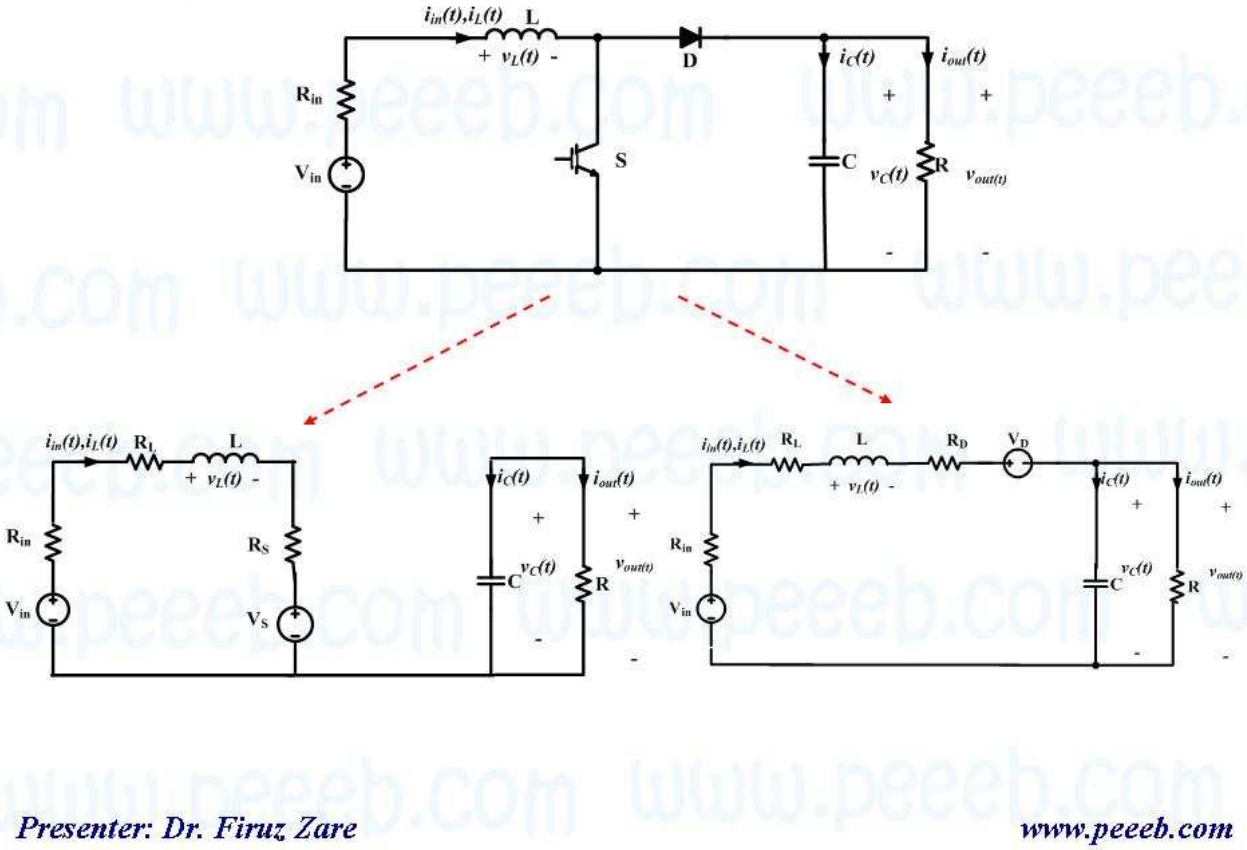
Boost Converter



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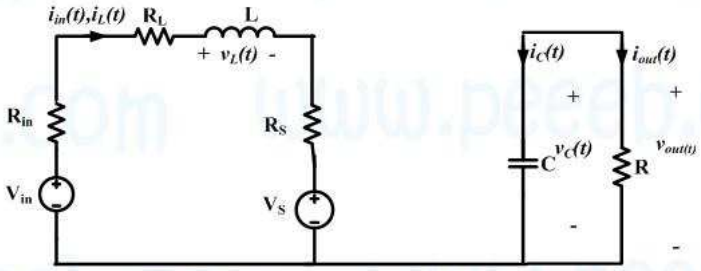
Boost Converter

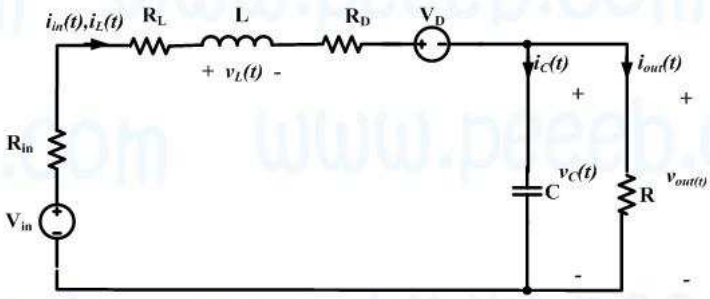


$$V_{in} = R_{in} i_L(t) + R_L i_L(t) + v_L(t) + R_S i_L(t) + V_S$$

$$i_C = -\frac{v_{out}(t)}{R}$$

$$\begin{cases} v_L(t) = V_{in} - V_s - R_{in} I_L - R_L I_L - R_S I_L \\ i_C(t) = -\dfrac{V_{out}}{R} \end{cases}$$

Boost Converter

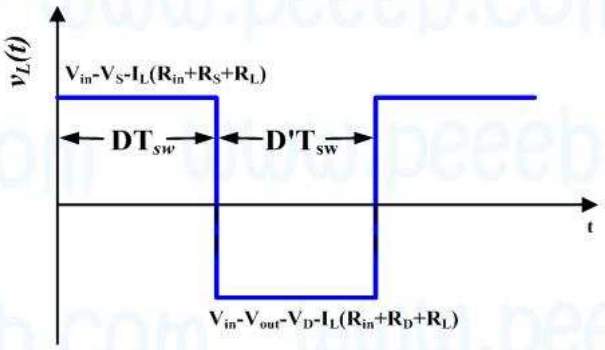


$$V_{in} = R_{in} i_L(t) + R_L i_L(t) + v_L(t) + R_D i_L(t) + V_D + v_{out}(t)$$

$$i_C = i_L(t) - \frac{v_{out}(t)}{R}$$

$$\begin{cases} v_L(t) = V_{in} - V_{out} - V_D - R_{in} I_L - R_L I_L - R_D I_L \\ i_C(t) = I_L - \frac{V_{out}}{R} \end{cases}$$

Boost Converter



$$v_L(t)=\begin{cases} V_{in}-V_S-I_L\left(R_{in}+R_S+R_L\right) & 0<t<t_{on} \\ V_{in}-V_{out}-V_D-I_L\left(R_{in}+R_D+R_L\right) & t_{on}<t<T_{sw} \end{cases}$$

$$i_C(t)=\begin{cases} -\dfrac{V_{out}}{R} & 0<t<t_{on} \\ I_L-\dfrac{V_{out}}{R} & t_{on}<t<T_{sw} \end{cases}$$

Boost Converter

$$\overline{i_C(t)} = 0$$

$$\frac{1}{T_{sw}}\int_0^{T_{sw}} i_C(t)\,dt = 0$$

$$i_C(t) = \begin{cases} -\dfrac{V_{out}}{R} & 0 < t < t_{on} \\ \\ I_L - \dfrac{V_{out}}{R} & t_{on} < t < T_{sw} \end{cases}$$

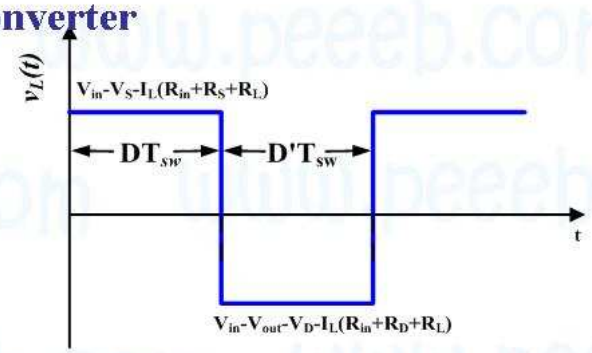
$$\int_0^{DT_{sw}} \left(-\frac{V_{out}}{R}\right) dt + \int_{DT_{sw}}^{T_{sw}} \left(I_L - \frac{V_{out}}{R}\right) dt = 0$$

$$\left(-\frac{V_{out}}{R}\right) DT_{sw} + \left(I_L - \frac{V_{out}}{R}\right)(T_{sw} - DT_{sw}) = 0$$

$$-D\frac{V_{out}}{R} + D'I_L - D'\frac{V_{out}}{R} = 0$$

$$\Rightarrow \frac{V_{out}}{R} = D'I_L \;, I_L = \frac{V_{out}}{D'R}$$

Boost Converter



$$\overline{v_L(t)} = 0$$

$$\frac{1}{T_{sw}}\int_0^{T_{sw}} v_L(t)\,dt = 0$$

$$v_L(t) = \begin{cases} V_{in} - V_S - I_L(R_{in} + R_S + R_L) & 0 < t < t_{on} \\ V_{in} - V_{out} - V_D - I_L(R_{in} + R_D + R_L) & t_{on} < t < T_{sw} \end{cases}$$

$$(V_{in} - V_S - I_L R_{in} - I_L R_S - I_L R_L)DT_{sw} + (V_{in} - V_{out} - V_D - I_L R_D - I_L R_L - I_L R_{in})(T_{sw} - DT_{sw}) = 0$$

$$DV_{in} - DV_S - DI_L(R_{in} + R_S + R_L) - D'V_{in} - D'V_{out} - D'V_D - D' \times I_L(R_{in} + R_D + R_L) = 0$$

Boost Converter

$$\begin{cases} V_{in} - DV_S - D'V_D = \left[D\left(R_{in} + R_S + R_L\right) + D'\left(R_{in} + R_D + R_L\right)\right]I_L + D'V_{out} \\ I_L = \dfrac{V_{out}}{D'R} \end{cases}$$

$$V_{in} - DV_S - D'V_D = \left[R_{in} + R_L + \left(DR_S + D'R_D\right)\right] \times \frac{V_{out}}{D'R} + D'V_{out}$$

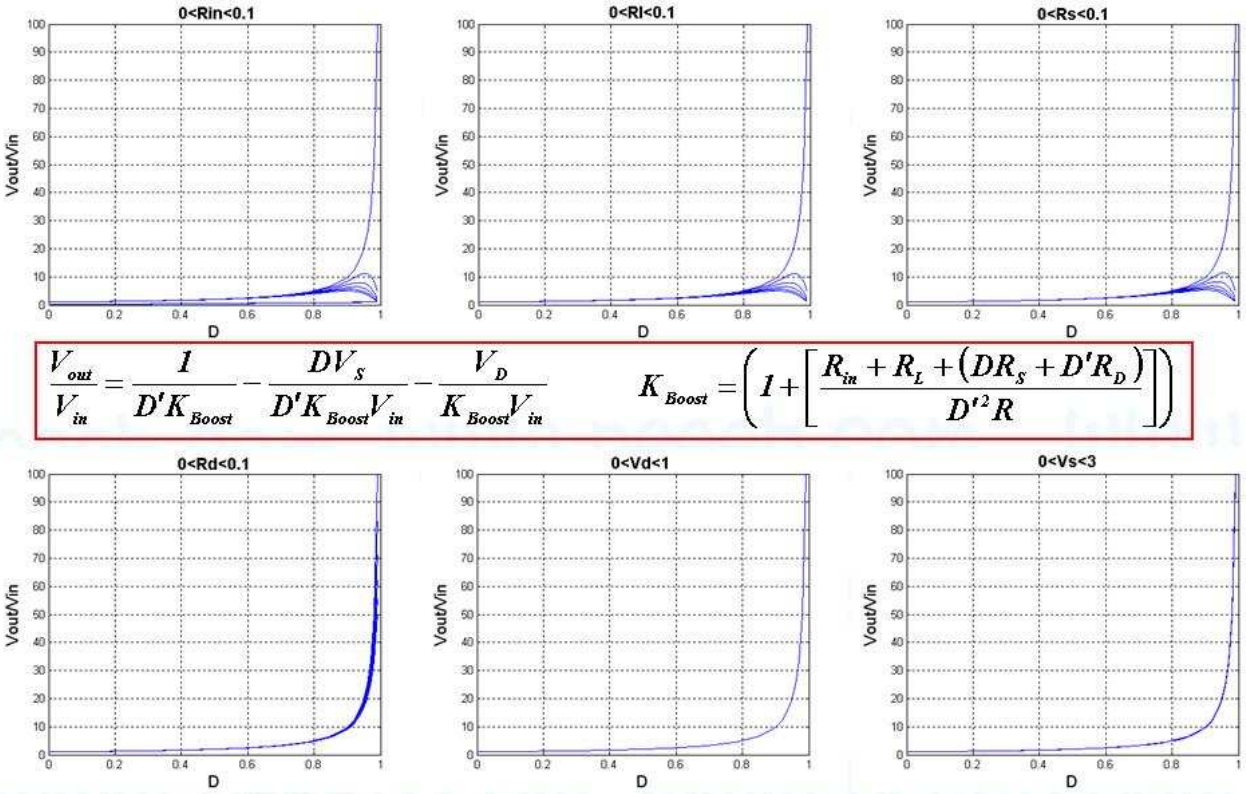
$$\frac{V_{in}}{D'} - \frac{D}{D'}V_S - V_D = \left(1 + \left[\frac{R_{in} + R_L + \left(DR_S + D'R_D\right)}{D'^2R}\right]\right)V_{out}$$

$$K_{Boost} = \left(1 + \left[\frac{R_{in} + R_L + \left(DR_S + D'R_D\right)}{D'^2R}\right]\right)$$

$$\frac{V_{out}}{V_{in}} = \frac{1}{D'K_{Boost}} - \frac{DV_S}{D'K_{Boost}V_{in}} - \frac{V_D}{K_{Boost}V_{in}}$$

Boost Converter

R=10 Ohm, Vin=100 V



$$\frac{V_{out}}{V_{in}} = \frac{1}{D'K_{Boost}} - \frac{DV_S}{D'K_{Boost}V_{in}} - \frac{V_D}{K_{Boost}V_{in}} \qquad K_{Boost} = \left(1 + \left[\frac{R_{in} + R_L + (DR_S + D'R_D)}{D'^2 R}\right]\right)$$

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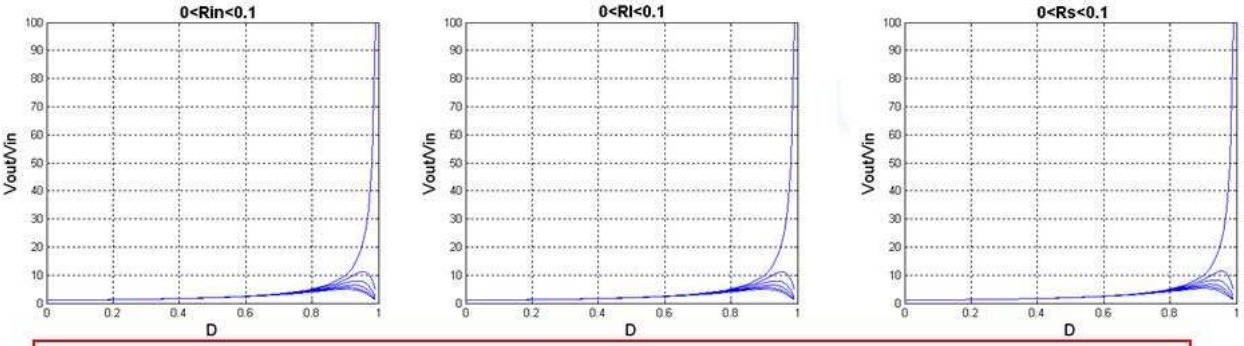
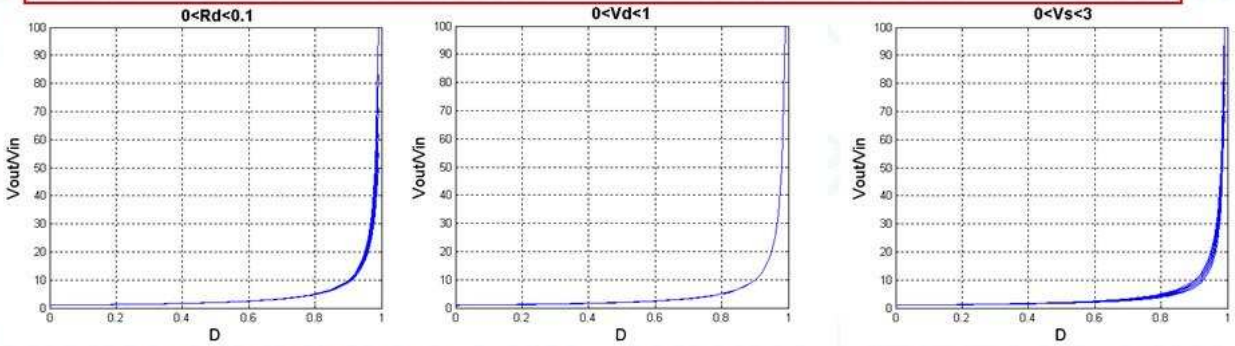
Boost Converter

R=10 Ohm, Vin=10 V



$$\frac{V_{out}}{V_{in}} = \frac{1}{D'K_{Boost}} - \frac{DV_S}{D'K_{Boost}V_{in}} - \frac{V_D}{K_{Boost}V_{in}} \qquad K_{Boost} = \left(1 + \left[\frac{R_{in} + R_L + (DR_S + D'R_D)}{D'^2 R}\right]\right)$$



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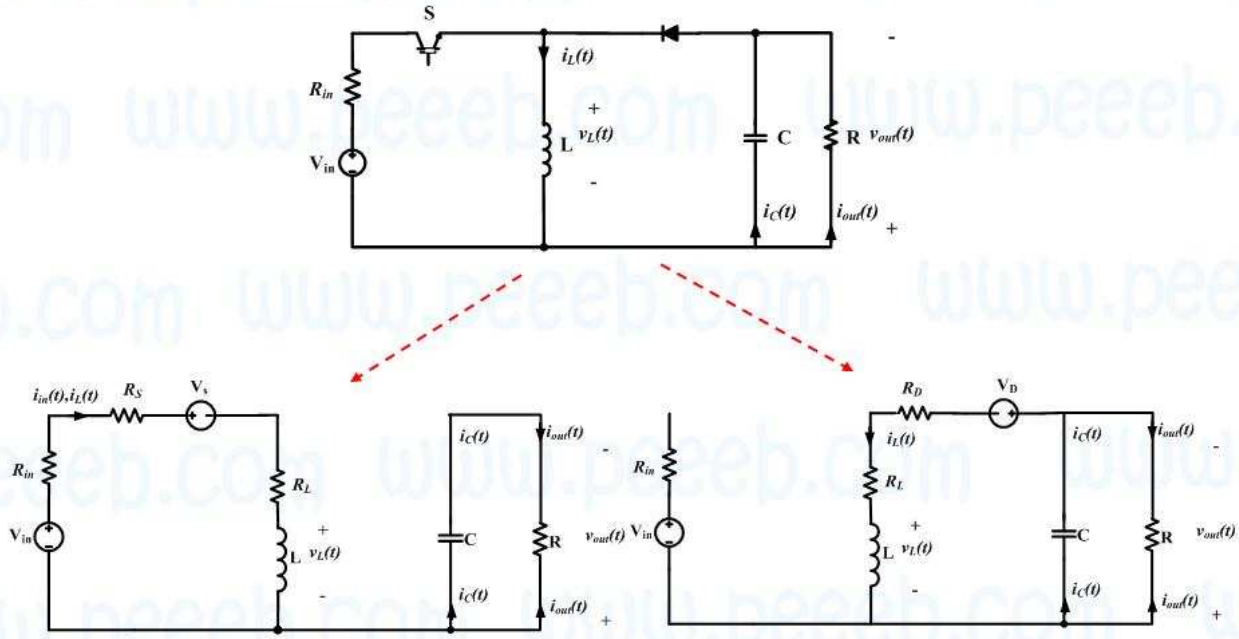
Buck Boost Converter



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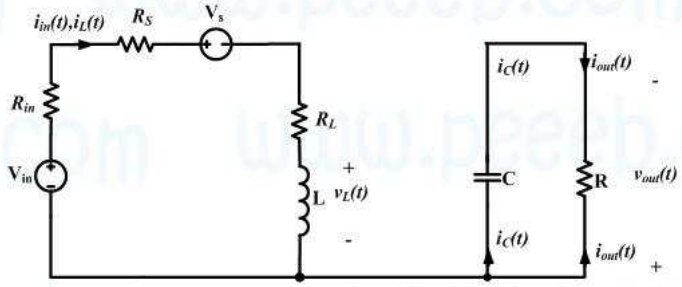
Buck Boost Converter

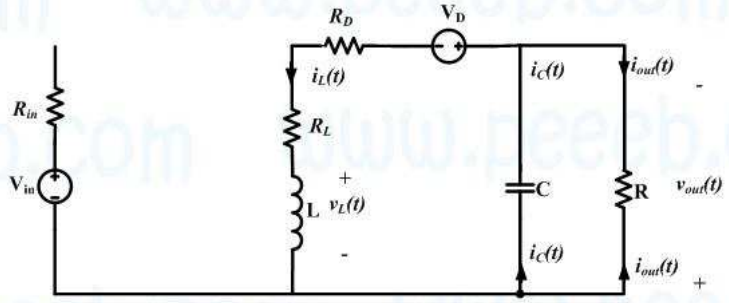


$$V_{in} = R_{in} i_L(t) + R_S i_L(t) + V_S + R_L i_L(t) + v_L(t)$$

$$i_C(t) = -i_{out}(t)$$

$$\begin{cases} v_L(t) = V_{in} - V_S - R_{in} I_L - R_L I_L - R_S I_L \\ i_C(t) = -\dfrac{V_{out}}{R} \end{cases}$$

Buck Boost Converter



$$v_{out}(t)+V_D+R_D i_L(t)+R_L i_L(t)+v_L(t)=0$$

$$i_L(t)=i_C(t)+i_{out}(t)$$

$$\begin{cases} v_L(t)=-V_{out}-V_D-R_L I_L-R_D I_L \\ i_C(t)=I_L-\dfrac{V_{out}}{R} \end{cases}$$

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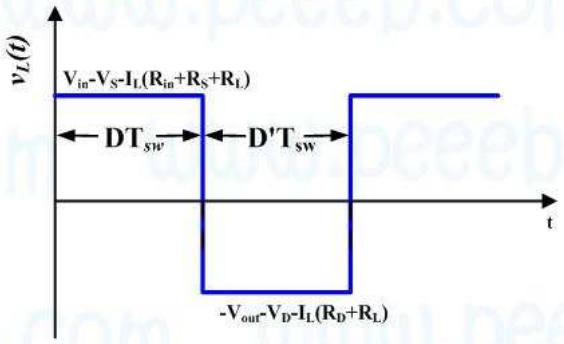
Buck Boost Converter



$$v_L(t)=\begin{cases} V_{in}-V_S-I_L\left(R_{in}+R_S+R_L\right) & 0<t<t_{on} \\ -V_{out}-V_D-I_L\left(R_D+R_L\right) & t_{on}<t<T_{sw} \end{cases}$$

$$i_C(t)=\begin{cases} -\dfrac{V_{out}}{R} & 0<t<t_{on} \\ I_L-\dfrac{V_{out}}{R} & t_{on}<t<T_{sw} \end{cases}$$

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Buck Boost Converter

$$\overline{i_C(t)} = 0$$

$$\frac{1}{T_{sw}}\int_{\theta}^{T_{sw}} i_C(t)\,dt = 0$$

$$i_C(t) = \begin{cases} -\dfrac{V_{out}}{R} & 0 < t < t_{on} \\ I_L - \dfrac{V_{out}}{R} & t_{on} < t < T_{sw} \end{cases}$$

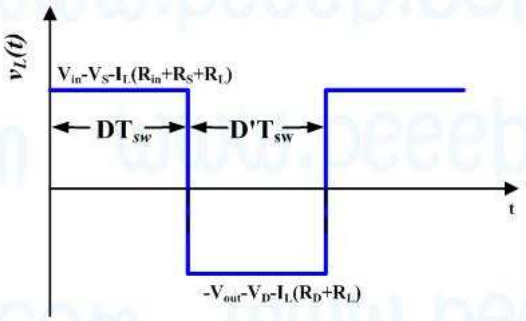
$$\int_{\theta}^{DT_{sw}} \left(-\frac{V_{out}}{R}\right)dt + \int_{DT_{sw}}^{T_{sw}} \left(I_L - \frac{V_{out}}{R}\right)dt = 0$$

$$\left(-\frac{V_{out}}{R}\right)DT_{sw} + \left(I_L - \frac{V_{out}}{R}\right)(T_{sw} - DT_{sw}) = 0$$

$$-D\frac{V_{out}}{R} + D'I_L - D'\frac{V_{out}}{R} = 0$$

$$\frac{V_{out}}{R} = D'I_L \;,\; I_L = \frac{V_{out}}{D'R}$$

Buck Boost Converter



$$\overline{v_L(t)} = 0$$

$$\frac{1}{T_{sw}}\int_0^{T_{sw}} v_L(t)\,dt = 0$$

$$\int_0^{DT_{sw}} (V_{in} - V_S - I_L R_{in} - I_L R_S - I_L R_L\ )dt + \int_{DT_{sw}}^{T_{sw}} (-V_{out}(t) - V_D - I_L R_D - I_L R_L\ )dt = 0$$

$$(V_{in} - V_S - I_L R_{in} - I_L R_S - I_L R_L\ )DT_{sw} + (-V_{out}(t) - V_D - I_L R_D - I_L R_L\ )(T_{sw} - DT_{sw}\ ) = 0$$

$$DV_{in} - DV_S - DI_L(R_{in} + R_S + R_L) - D'V_{out} - D'V_D - D' \times I_L(R_D + R_L) = 0$$

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Buck Boost Converter

$$\begin{cases} DV_{in} - DV_S - D'V_D = D'V_{out} + DI_L(R_{in} + R_S + R_L) + D' \times I_L(R_D + R_L) \\ I_L = \dfrac{V_{out}}{D'R} \end{cases}$$

$$DV_{in} - DV_S - D'V_D = D'V_{out} + \frac{V_{out}}{D'R}\left[D(R_{in} + R_S + R_L) + D'(R_D + R_L)\right]$$

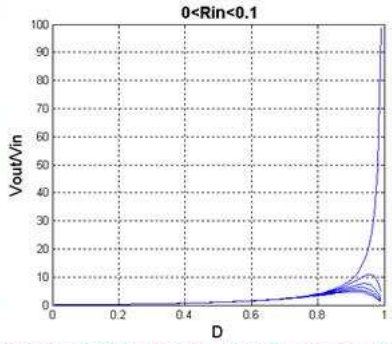
$$DV_{in} - DV_S - D'V_D = D'V_{out}\left[1 + \frac{1}{D'^2R}\left(D(R_{in} + R_S + R_L) + D'(R_D + R_L)\right)\right]$$

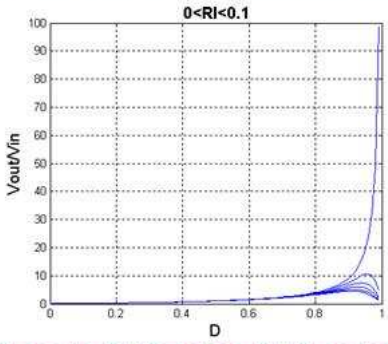
$$K_{Buck-Boost} = 1 + \frac{1}{D'^2R}\left(D(R_{in} + R_S + R_L) + D'(R_D + R_L)\right)$$

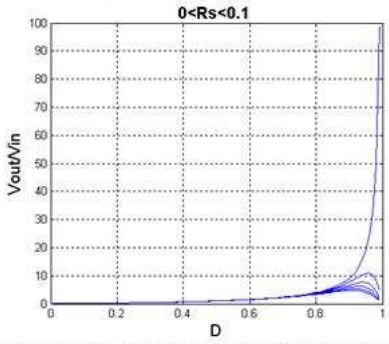
$$\frac{V_{out}}{V_{in}} = \frac{D}{D'K_{Buck-Boost}} - \frac{DV_S}{D'K_{Buck-Boost}V_{in}} - \frac{V_D}{K_{Buck-Boost}V_{in}}$$

Buck Boost Converter

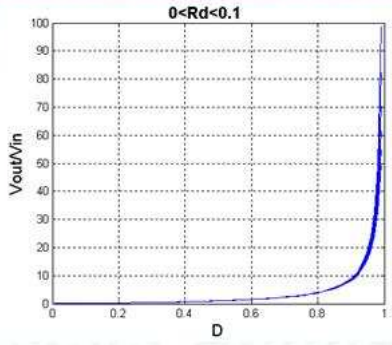
R=10 Ohm, Vin=100 V

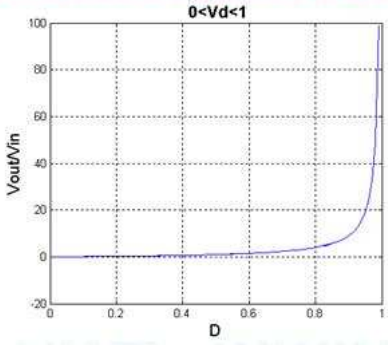


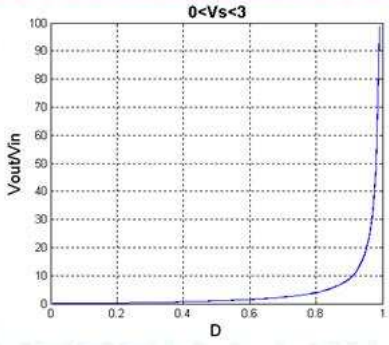




$$\frac{V_{out}}{V_{in}} = \frac{D}{D'K_{Buck-Boost}} - \frac{DV_S}{D'K_{Buck-Boost}V_{in}} - \frac{V_D}{K_{Buck-Boost}V_{in}} \qquad K_{Buck-Boost} = 1 + \frac{1}{D'^2 R}\left(D(R_{in} + R_S + R_L) + D'(R_D + R_L)\right)$$







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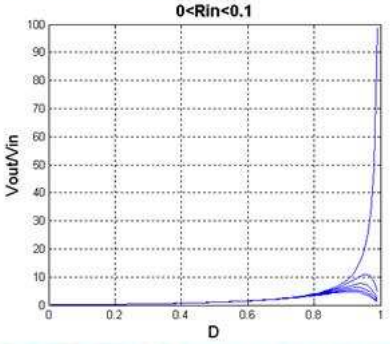
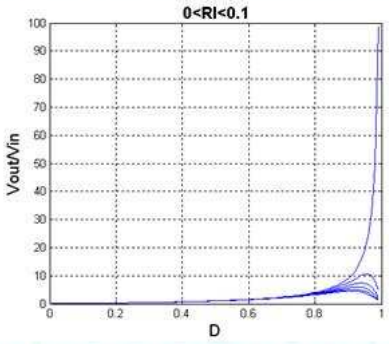
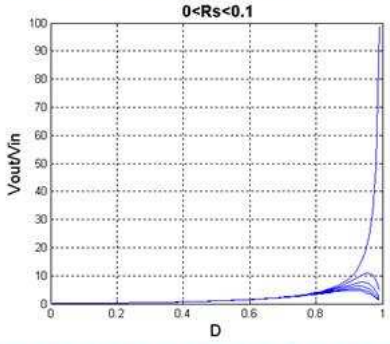
Buck Boost Converter

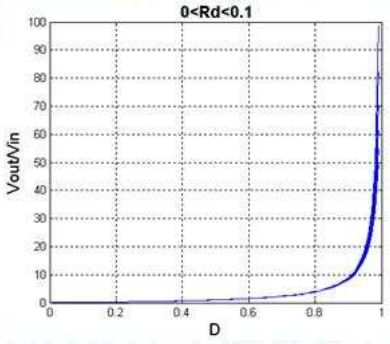
R=10 Ohm, Vin=10 V

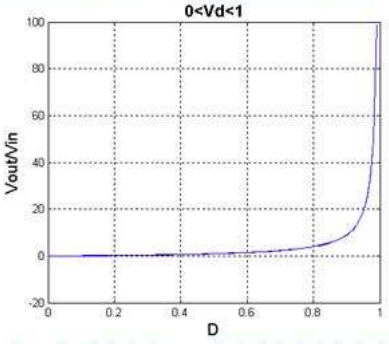


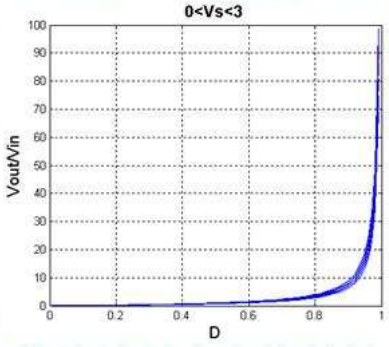




$$\frac{V_{out}}{V_{in}} = \frac{D}{D'K_{Buck-Boost}} - \frac{DV_S}{D'K_{Buck-Boost}V_{in}} - \frac{V_D}{K_{Buck-Boost}V_{in}} \qquad K_{Buck-Boost} = 1 + \frac{1}{D'^2 R}\left(D(R_{in} + R_S + R_L) + D'(R_D + R_L)\right)$$







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