Boost Converter Operated in CCM

Christophe Basso - Switch Mode Power Supplies: SPICE Simulations and Practical Designs
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1) Input data

$V_{in} := 2.7\ V$ $L_1 := 5\ \mu H$ $T_{sw} := 1\ \mu s$ $R_{load} := 5\ \Omega$ $V_{out} := 5\ V$ $\eta := 100\%$

2) Calculations

$$F_{sw} := \frac{1}{T_{sw}} = 1\ MHz$$

Beyond this load value, the converter operates in DCM: $$R_{crit} := \frac{2 \cdot L_1 \cdot F_{sw} \cdot V_{out}^{\ 2}}{\left(1 - \frac{V_{in}}{V_{out}}\right) \cdot V_{in}^{\ 2}} = 74.551\ \Omega$$

$$P_{out} := \frac{V_{out}^{\ 2}}{\eta \cdot R_{load}} = 5\ W \qquad D_{boost} := \frac{V_{out} - V_{in}}{V_{out}} = 0.46$$

$$I_{outboost} := \frac{P_{out}}{V_{out}} = 1\ A \qquad R_{loadboost} := \frac{V_{out}^{\ 2}}{P_{out}} = 5\ \Omega \qquad M_{boost} := \frac{V_{out}}{V_{in}} = 1.852$$

$$I_{pboost} := \frac{P_{out}}{V_{in}} + \frac{V_{in}}{2 \cdot L_1} \cdot D_{boost} \cdot T_{sw} = 1.976\ A$$

$$I_{vpboost} := \frac{P_{out}}{V_{in}} - \frac{V_{in}}{2 \cdot L_1} \cdot D_{boost} \cdot T_{sw} = 1.728\ A$$

$$\Delta I_{Lboost} := \frac{V_{in}}{L_1} \cdot D_{boost} \cdot T_{sw} = 0.248\ A$$

$$\tau_L := \frac{L_1}{R_{loadboost} \cdot T_{sw}} = 1$$

2.1) Inductor rms current

$$I_{LCCM} := \sqrt{\frac{P_{out}^{\ 2}}{V_{in}^{\ 2}} + \frac{\Delta I_{Lboost}^{\ 2}}{12}} = 1.853\ A$$

$$\sqrt{\frac{P_{out}^{\ 2}}{V_{in}^{\ 2}} + \left(\frac{D_{boost} \cdot T_{sw} \cdot V_{in}}{L_1}\right)^2 \cdot \frac{1}{12}} = 1.853\ A$$

$$I_{outboost} \cdot \sqrt{\frac{1}{\left(1-D_{boost}\right)^2} + \frac{{D_{boost}}^2 \cdot \left(1-D_{boost}\right)^2 \cdot {R_{loadboost}}^2}{12 \cdot {F_{sw}}^2 \cdot {L_1}^2}} = 1.853\ A$$

$$\frac{V_{out}}{R_{loadboost}} \cdot \sqrt{\frac{1}{\left(1-D_{boost}\right)^2} + \frac{1}{3} \cdot \left(\frac{1}{2 \cdot \tau_L}\right)^2 \cdot \left({D_{boost}}^2 \cdot \left(1-D_{boost}\right)^3\right)} = 1.853\ A$$

2.2) Switch rms current

$$I_{SWCCM} := \sqrt{D_{boost} \cdot \left(\frac{{P_{out}}^2}{{V_{in}}^2} + \frac{{\Delta I_{Lboost}}^2}{12}\right)} = 1.257\ A$$

$$\frac{\sqrt{\frac{{D_{boost}}^3 \cdot {T_{sw}}^2 \cdot {V_{in}}^4 + 12 \cdot D_{boost} \cdot {L_1}^2 \cdot {P_{out}}^2}{{L_1}^2 \cdot {V_{in}}^2}}}{2 \cdot \sqrt{3}} = 1.257\ A$$

$$I_{outboost} \cdot \sqrt{\frac{D_{boost}}{\left(1-D_{boost}\right)^2} + \frac{{D_{boost}}^3 \cdot \left(1-D_{boost}\right)^2 \cdot {R_{loadboost}}^2}{12 \cdot {F_{sw}}^2 \cdot {L_1}^2}} = 1.257\ A$$

$$\frac{V_{out}}{R_{loadboost}} \cdot \sqrt{\frac{D_{boost}}{\left(1-D_{boost}\right)^2} + \frac{1}{3} \cdot \left(\frac{1}{2 \cdot \tau_L}\right)^2 \cdot \left({D_{boost}}^2 \cdot \left(1-D_{boost}\right)^3\right)} = 1.257\ A$$

2.3) Diode rms current

$$I_{DCCM} := \sqrt{\left(1-D_{boost}\right) \cdot \left(\frac{{P_{out}}^2}{{V_{in}}^2} + \frac{{\Delta I_{Lboost}}^2}{12}\right)} = 1.362\ A$$

$$\frac{\sqrt{\frac{\left(1-D_{boost}\right) \cdot \left({D_{boost}}^2 \cdot {T_{sw}}^2 \cdot {V_{in}}^4 + 12 \cdot {L_1}^2 \cdot {P_{out}}^2\right)}{{L_1}^2 \cdot {V_{in}}^2}}}{2 \cdot \sqrt{3}} = 1.362\ A$$

$$I_{outboost} \cdot \sqrt{\frac{1}{\left(1-D_{boost}\right)} + \frac{{D_{boost}}^2 \cdot \left(1-D_{boost}\right)^3 \cdot {R_{loadboost}}^2}{12 \cdot {F_{sw}}^2 \cdot {L_1}^2}} = 1.362\ A$$

$$\frac{V_{out}}{R_{loadboost}} \cdot \sqrt{\frac{1}{\left(1-D_{boost}\right)} + \frac{1}{3} \cdot \left(\frac{1}{2 \cdot \tau_L}\right)^2 \cdot \left({D_{boost}}^2 \cdot \left(1-D_{boost}\right)^3\right)} = 1.362\ A$$

2.4) Output capacitor rms current

$$I_{CCCM} := \sqrt{(1-D_{boost}) \cdot \left(\frac{P_{out}^{2}}{V_{in}^{2}} + \frac{\Delta I_{Lboost}^{2}}{12}\right) - I_{outboost}^{2}} = 0.924\ A$$

$$\sqrt{\frac{(1-D_{boost}) \cdot \left(D_{boost}^{2} \cdot T_{sw}^{2} \cdot V_{in}^{4} + 12 \cdot L_1^{2} \cdot P_{out}^{2}\right)}{12 \cdot L_1^{2} \cdot V_{in}^{2}} - I_{outboost}^{2}} = 0.924\ A$$

$$I_{outboost} \cdot \sqrt{\frac{D_{boost}}{1-D_{boost}} + \frac{D_{boost}^{2} \cdot (1-D_{boost})^{3} \cdot R_{loadboost}^{2}}{12 \cdot F_{sw}^{2} \cdot L_1^{2}}} = 0.924\ A$$

$$\frac{V_{out}}{R_{loadboost}} \cdot \sqrt{\frac{D_{boost}}{1-D_{boost}} + \frac{D_{boost}^{2} \cdot (1-D_{boost})}{12} \cdot \left(\frac{1-D_{boost}}{\tau_L}\right)^{2}} = 0.924\ A$$

2.5) Input capacitor rms current

$$I_{CinRMS} := \sqrt{I_{LCCM}^{2} - (M_{boost} \cdot I_{outboost})^{2}} = 71.707\ mA$$

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3) Input data

$V_{in} := 10\ V$ $L_1 := 2.8\ \mu H$ $T_{sw} := 10\ \mu s$ $R_{loadboostDCM} := 6\ \Omega$ $V_{outbDCM} := 12\ V$ $\eta := 100\%$

4) Calculations

$$F_{sw} := \frac{1}{T_{sw}} = 100\ kHz$$

Below this load value, the converter operates in DCM: $R_{crit} := \frac{2 \cdot L_1 \cdot F_{sw} \cdot V_{outbDCM}^{2}}{\left(1 - \frac{V_{in}}{V_{outbDCM}}\right) \cdot V_{in}^{2}} = 4.838\ \Omega$

$$P_{outbDCM} := \frac{V_{outbDCM}^{2}}{\eta \cdot R_{loadboostDCM}} = 24\ W \qquad I_{outboostDCM} := \frac{V_{outbDCM}}{R_{loadboostDCM}} = 2\ A$$

$$\tau_L := \frac{L_1}{R_{loadboostDCM} \cdot T_{sw}} = 0.047 \qquad M_{dcm} := \frac{V_{outbDCM}}{V_{in}} = 1.2$$

$$I_{pboostDCM} := \frac{T_{sw} \cdot (V_{outbDCM} - V_{in}) \cdot \sqrt{\frac{2 \cdot L_1 \cdot P_{outbDCM} \cdot V_{outbDCM}}{T_{sw} \cdot (V_{outbDCM} - V_{in})}}}{L_1 \cdot V_{outbDCM}} = 5.345\ A$$

$$D_1 := \frac{(V_{outbDCM} - V_{in}) \cdot \sqrt{\frac{2 \cdot L_1 \cdot P_{outbDCM} \cdot V_{outbDCM}}{T_{sw} \cdot (V_{outbDCM} - V_{in})}}}{V_{in} \cdot V_{outbDCM}} = 0.15 \quad \text{then } t_{on} := D_1 \cdot T_{sw} = 1.497\ \mu s$$

$$D_2 := \frac{\sqrt{\frac{2 \cdot L_1 \cdot P_{outbDCM} \cdot V_{outbDCM}}{T_{sw} \cdot (V_{outbDCM} - V_{in})}}}{V_{outbDCM}} = 0.748 \quad \text{then } t_{off} := D_2 \cdot T_{sw} = 7.483\ \mu s$$

$$D_3 := \frac{V_{in} - \sqrt{\frac{2 \cdot L_1 \cdot P_{outbDCM} \cdot V_{outbDCM}}{T_{sw} \cdot (V_{outbDCM} - V_{in})}}}{V_{in}} = 0.102 \quad \text{then } DT := D_3 \cdot T_{sw} = 1.02\ \mu s$$

We verify $D_1 + D_2 + D_3 = 1$

4.1) Inductor rms current

$$I_{Lrms} := I_{pboostDCM} \cdot \sqrt{\frac{1 - D_3}{3}} = 2.924\ A$$

$$I_{LboostDCMRMS} := \sqrt{\frac{2 \cdot P_{outbDCM} \cdot T_{sw} \cdot (V_{outbDCM} - V_{in}) \cdot \sqrt{\frac{2 \cdot L_1 \cdot P_{outbDCM} \cdot V_{outbDCM}}{T_{sw} \cdot (V_{outbDCM} - V_{in})}}}{3 \cdot L_1 \cdot V_{in} \cdot V_{outbDCM}}} = 2.924\ A$$

$$I_{LboostDCMRMS2} := I_{outboostDCM} \cdot \sqrt{\frac{2 \cdot D_1 \cdot R_{loadboostDCM}}{3 \cdot F_{sw} \cdot L_1}} = 2.924\ A$$

$$\frac{V_{outbDCM}}{R_{loadboostDCM}} \cdot \sqrt{\frac{2}{3} \cdot \frac{D_1}{\tau_L}} = 2.924\ A$$

4.2) Switch rms current

$$I_{SWboostDCMRMS} := I_{pboostDCM} \cdot \sqrt{\frac{D_1}{3}} = 1.194\ A$$

$$I_{SWboostDCMRMS2} := \frac{(V_{outbDCM} - V_{in})}{V_{outbDCM}} \cdot \sqrt{\frac{2 \cdot P_{outbDCM} \cdot T_{sw} \cdot \sqrt{\frac{2 \cdot L_1 \cdot P_{outbDCM} \cdot V_{outbDCM}}{T_{sw} \cdot (V_{outbDCM} - V_{in})}}}{3 \cdot L_1 \cdot V_{in}}} = 1.194\ A$$

$$I_{SWboostDCMRMS3} := I_{outboostDCM} \cdot \frac{1}{\sqrt{3 \cdot D_1}} \cdot \left(\sqrt{1 + \frac{2 \cdot {D_1}^2 \cdot R_{loadboostDCM}}{L_1 \cdot F_{sw}}} - 1 \right) = 1.194\ A$$

$$\frac{V_{outbDCM}}{R_{loadboostDCM}} \cdot \frac{\sqrt{1 + \frac{2 \cdot {D_1}^2}{\tau_L}} - 1}{\sqrt{3 \cdot D_1}} = 1.194\ A$$

$$I_{SWboostDCMRMS4} := I_{Lrms} \cdot \sqrt{\frac{D_1}{1 - D_3}} = 1.194\ A$$

4.3) Diode rms current

$$I_{diodeboostDCMRMS} := I_{pboostDCM} \cdot \sqrt{\frac{D_2}{3}} = 2.67\ A$$

$$I_{diodeboostDCMRMS2} := \frac{1}{V_{outbDCM}} \cdot \sqrt{\frac{2 \cdot P_{outbDCM} \cdot T_{sw} \cdot \left(V_{outbDCM} - V_{in}\right) \cdot \sqrt{\frac{2 \cdot L_1 \cdot P_{outbDCM} \cdot V_{outbDCM}}{T_{sw} \cdot \left(V_{outbDCM} - V_{in}\right)}}}{3 \cdot L_1}} = 2.67\ A$$

$$I_{diodeboostDCMRMS3} := I_{outboostDCM} \cdot \sqrt{\frac{2}{3 \cdot D_1}} \cdot \left(\sqrt{\sqrt{1 + \frac{2 \cdot {D_1}^2 \cdot R_{loadboostDCM}}{L_1 \cdot F_{sw}}} - 1} \right) = 2.67\ A$$

$$I_{diodeboostDCMRMS4} := I_{outboostDCM} \cdot \left(\sqrt{\frac{2}{3} \cdot \frac{\left(\sqrt{1 + \frac{2 \cdot {D_1}^2}{\tau_L}} - 1 \right)}{D_1}} \right) = 2.67\ A$$

$$I_{diodeboostDCMRMS5} := I_{Lrms} \cdot \sqrt{\frac{D_2}{1 - D_3}} = 2.67\ A$$

4.4) Output capacitor rms current

$$I_{CoutRMS1} := \sqrt{\left(\frac{2 \cdot P_{outbDCM} \cdot T_{sw} \cdot \left(V_{outbDCM} - V_{in}\right) \cdot \sqrt{\frac{2 \cdot L_1 \cdot P_{outbDCM} \cdot V_{outbDCM}}{T_{sw} \cdot \left(V_{outbDCM} - V_{in}\right)}}}{3 \cdot L_1 \cdot {V_{outbDCM}}^2} \right) - {I_{outboostDCM}}^2} = 1.768\ A$$

$$I_{CoutRMS2} := I_{outboostDCM} \cdot \sqrt{\frac{2}{3 \cdot D_1} \cdot \left(\sqrt{1 + \frac{2 \cdot {D_1}^2 \cdot R_{loadboostDCM}}{L_1 \cdot F_{sw}}} - 1 \right) - 1} = 1.768\ A$$

$$I_{outboostDCM} \cdot \left(\sqrt{\frac{2}{3} \cdot \frac{\left(\sqrt{1 + \frac{2 \cdot {D_1}^2}{\tau_L}} - 1 \right)}{D_1} - 1} \right) = 1.768\ A$$

4.5) Input capacitor rms current

$$I_{CinRMS} := \sqrt{I_{LboostDCMRMS}{}^2 - \left(M_{dcm} \cdot I_{outboostDCM}\right)^2} = 1.671\ A$$