APPENDIX

This worksheet calculates the relevant currents and voltages as well as losses in PFC boost topologies. Constant output voltage and continuos conduction mode (CCM) and critical conduction mode (CRM) operation is assumed.

Constants:

$p := 10^{-12}$ $nano := 10^{-9}$ $u := 10^{-6}$ $m := 10^{-3}$ $k := 10^{3}$ $MEG := 10^{6}$ $j := \sqrt{-1}$

$i := 0..200$ $y := 1..5$ $x := 0..4$ $Fs := 100 \cdot k$

$Vout := 385$ $VAC\_min := 85$ $VAC := 120$

$Pout := 200$ $\eta := 0.95$ $Pin := \frac{Pout}{\eta}$ $Iload := \frac{Pout}{Vout}$

Pin_var allows input power to be varied over a range to compare losses.

$$Pin\_var_x := Pin \cdot (x + 1)$$

$$j := 0..5$$

$$VAC2 := \begin{pmatrix} 85 \\ 120 \\ 132 \\ 215 \\ 240 \\ 265 \end{pmatrix}$$

$$Vin_i := \sqrt{2} \cdot VAC \cdot \left| \sin\left(i \cdot \frac{\pi}{200} \right) \right|$$

Boost converter duty cycle

$$D_i := \frac{Vout - Vin_i}{Vout}$$

Average boost inductor current in CCM.

$$IAC_i := \frac{Vin_i \cdot Pin}{VAC^2}$$

A. Calculate currents in the CCM boost

RMS switch current

$$Iq\_rms\_ccm := \frac{Pin}{VAC} \cdot \sqrt{1 - \frac{8}{3 \cdot \pi} \cdot \frac{\sqrt{2} \cdot VAC}{Vout}}$$

$$Iq\_rms\_ccm = 1.388$$

RMS switch current varying as a function of input power.

$$Iq\_rms\_ccm\_var_x := \frac{Pin\_var_x}{VAC} \cdot \sqrt{1 - \frac{8}{3 \cdot \pi} \cdot \frac{\sqrt{2} \cdot VAC}{Vout}}$$

Peak inductor current

$$IL\_pk\_ccm := \frac{\sqrt{2} \cdot Pin}{VAC} + 0.1 \cdot \frac{\sqrt{2} \cdot Pin}{VAC}$$

Let delta i in CCM inductor be 20% of peak current at low line.

$$IL\_ripple := 0.2 \cdot \frac{\sqrt{2} \cdot Pin}{VAC}$$

Pk current is Iin avg + 1/2 delta i

Peak inductor current as a function of input power

$$IL\_pk\_ccm\_var_x := \frac{\sqrt{2} \cdot Pin\_var_x}{VAC} + 0.1 \cdot \frac{\sqrt{2} \cdot Pin\_var_x}{VAC}$$

Inductor current valley

$$IL\_valley\_ccm := \frac{\sqrt{2} \cdot Pin}{VAC} - \left(0.1 \cdot \frac{\sqrt{2} \cdot Pin}{VAC}\right)$$

$$IL\_valley\_ccm = 2.233$$

$$IL\_valley\_ccm\_var_x := \frac{\sqrt{2} \cdot Pin\_var_x}{VAC} - \left(0.1 \cdot \frac{\sqrt{2} \cdot Pin\_var_x}{VAC}\right)$$

Peak diode current is equal to the peak inductor current.

$$Idiode\_pk\_ccm := IL\_pk\_ccm$$

B. Calculate currents in the CRM boost converter:

$$IL\_pk\_crm := 2\sqrt{2}\cdot\frac{Pin}{VAC}$$

$$IL\_pk\_crm = 4.962$$

Peak current in CRM is twice the CCM current, neglecting the ripple current for CCM.

$$IL\_pk\_crm\_var_x := 2\sqrt{2}\cdot\frac{Pin\_var_x}{VAC}$$

$$IL\_pk\_crm\_var_x := 2\sqrt{2}\cdot\frac{Pin\_var_x}{VAC}$$

$$Iq\_rms\_crm := \sqrt{\frac{1}{6} - 4\cdot\sqrt{2}\frac{VAC}{9\cdot\pi\cdot Vout}}\cdot IL\_pk\_crm$$

$$Iq\_rms\_crm = 1.603$$

$$Iq\_rms\_crm\_var_x := \sqrt{\frac{1}{6} - 4\cdot\sqrt{2}\frac{VAC}{9\cdot\pi\cdot Vout}}\cdot IL\_pk\_crm\_var_x$$

$$Idiode\_pk\_crm := IL\_pk\_crm$$

C. Calculate loss components.

Calculate diode related losses:

Assume di/dt at turn off is 100A/us.

For the purpose of calculation use the 8ETH06 IR diode as reference. Also assume IRF840 for MOSFET

$$VFF := 0.6$$

$$trr := 50\cdot nano \qquad Qrr := 120\cdot nano \qquad Irrm := 4.8 \qquad didf := 100\cdot\frac{1}{u} \qquad Rdson := 0.85$$

$$transistor\_rise := 75\cdot nano$$

$$transistor\_fall := 75\cdot nano$$

$$Irrm\_pfc_i := Irrm\cdot\left|\sin\left(i\cdot\frac{\pi}{200}\right)\right|$$

Loss in MOSFET due to reverse recovery current from boost diode. Only valid for CCM operation.

$$Prr\_ccm\_var := \begin{bmatrix} \dfrac{\sum_{i=0}^{200} Vout \cdot \left[\left(\dfrac{Irrm\_pfc_i}{2} \cdot \dfrac{Irrm\_pfc_i}{didf}\right) + \dfrac{Irrm\_pfc_i}{4} \cdot \left(trr - \dfrac{Irrm\_pfc_i}{didf}\right)\right]}{201} \cdot Fs \\ \dfrac{\sum_{i=0}^{200} Vout \cdot \left[\left(\dfrac{1.5 Irrm\_pfc_i}{2} \cdot \dfrac{Irrm\_pfc_i}{didf}\right) + \dfrac{(1.5 Irrm\_pfc)_i}{4} \cdot \left(trr - \dfrac{Irrm\_pfc_i}{didf}\right)\right]}{201} \cdot Fs \\ \dfrac{\sum_{i=0}^{200} Vout \cdot \left[\left[\dfrac{(2 Irrm\_pfc)_i}{2} \cdot \dfrac{Irrm\_pfc_i}{didf}\right] + \dfrac{(2 Irrm\_pfc)_i}{4} \cdot \left(trr - \dfrac{Irrm\_pfc_i}{didf}\right)\right]}{201} \cdot Fs \\ \dfrac{\sum_{i=0}^{200} Vout \cdot \left[\left[\dfrac{(2.5 Irrm\_pfc)_i}{2} \cdot \dfrac{Irrm\_pfc_i}{didf}\right] + \dfrac{2.5 Irrm\_pfc_i}{4} \cdot \left(trr - \dfrac{Irrm\_pfc_i}{didf}\right)\right]}{201} \cdot Fs \\ \dfrac{\sum_{i=0}^{200} Vout \cdot \left[\left[\dfrac{(3 Irrm\_pfc)_i}{2} \cdot \dfrac{Irrm\_pfc_i}{didf}\right] + \dfrac{(3 Irrm\_pfc)_i}{4} \cdot \left(trr - \dfrac{Irrm\_pfc_i}{didf}\right)\right]}{201} \cdot Fs \end{bmatrix}$$

$$Prr\_ccm\_var = \begin{pmatrix} 2.567 \\ 3.85 \\ 5.133 \\ 6.416 \\ 7.7 \end{pmatrix}$$

Losses in MOSFET due to turn-off overlap of voltage and current:

$$Pq\_ccm\_turnoff\_var := \begin{bmatrix} \dfrac{\displaystyle\sum_{i=0}^{200} Vout \cdot \left[\dfrac{\left(IL\_pk\_ccm\_var_0 \cdot \left| \sin\left(i \cdot \dfrac{\pi}{200} \right) \right| \right) \cdot (transistor\_fall)}{2} \right]}{201} \cdot Fs \\ \dfrac{\displaystyle\sum_{i=0}^{200} Vout \cdot \left[\dfrac{\left(IL\_pk\_ccm\_var_1 \cdot \left| \sin\left(i \cdot \dfrac{\pi}{200} \right) \right| \right) \cdot (transistor\_fall)}{2} \right]}{201} \cdot Fs \\ \dfrac{\displaystyle\sum_{i=0}^{200} Vout \cdot \left[\dfrac{\left(IL\_pk\_ccm\_var_2 \cdot \left| \sin\left(i \cdot \dfrac{\pi}{200} \right) \right| \right) \cdot (transistor\_fall)}{2} \right]}{201} \cdot Fs \\ \dfrac{\displaystyle\sum_{i=0}^{200} Vout \cdot \left[\dfrac{\left(IL\_pk\_ccm\_var_3 \cdot \left| \sin\left(i \cdot \dfrac{\pi}{200} \right) \right| \right) \cdot (transistor\_fall)}{2} \right]}{201} \cdot Fs \\ \dfrac{\displaystyle\sum_{i=0}^{200} Vout \cdot \left[\dfrac{\left(IL\_pk\_ccm\_var_4 \cdot \left| \sin\left(i \cdot \dfrac{\pi}{200} \right) \right| \right) \cdot (transistor\_fall)}{2} \right]}{201} \cdot Fs \end{bmatrix}$$

Losses in MOSFET due to turn-on overlap of voltage and current:

$$Pq\_ccm\_turnon\_var := \begin{bmatrix} \dfrac{\sum_{i=0}^{200} Vout \cdot \left[\left[\dfrac{\left(IL\_valley\_ccm\_var_0 \cdot \left|\sin\left(i \cdot \frac{\pi}{200}\right)\right|\right) \cdot (transistor\_rise)}{2}\right]\right]}{201} \cdot Fs \\ \dfrac{\sum_{i=0}^{200} Vout \cdot \left[\dfrac{\left(IL\_valley\_ccm\_var_1 \cdot \left|\sin\left(i \cdot \frac{\pi}{200}\right)\right|\right) \cdot (transistor\_rise)}{2}\right]}{201} \cdot Fs \\ \dfrac{\sum_{i=0}^{200} Vout \cdot \left[\dfrac{\left(IL\_valley\_ccm\_var_2 \cdot \left|\sin\left(i \cdot \frac{\pi}{200}\right)\right|\right) \cdot (transistor\_rise)}{2}\right]}{201} \cdot Fs \\ \dfrac{\sum_{i=0}^{200} Vout \cdot \left[\dfrac{\left(IL\_valley\_ccm\_var_3 \cdot \left|\sin\left(i \cdot \frac{\pi}{200}\right)\right|\right) \cdot (transistor\_rise)}{2}\right]}{201} \cdot Fs \\ \dfrac{\sum_{i=0}^{200} Vout \cdot \left[\dfrac{\left(IL\_valley\_ccm\_var_4 \cdot \left|\sin\left(i \cdot \frac{\pi}{200}\right)\right|\right) \cdot (transistor\_rise)}{2}\right]}{201} \cdot Fs \end{bmatrix}$$

Conduction losses in the MOSFET:

$$Pq\_ccm\_rms\_var := \begin{bmatrix} \left(Iq\_rms\_ccm\_var_0\right)^2 \cdot Rdson \\ \left(Iq\_rms\_ccm\_var_1\right)^2 \cdot Rdson \\ \left(Iq\_rms\_ccm\_var_2\right)^2 \cdot Rdson \\ \left(Iq\_rms\_ccm\_var_3\right)^2 \cdot Rdson \\ \left(Iq\_rms\_ccm\_var_4\right)^2 \cdot Rdson \end{bmatrix}$$

Diode conduction losses:

$$\text{Pdiode\_ccm\_var} := \begin{bmatrix} \dfrac{\displaystyle\sum_{i=0}^{200}\left[\left(\text{IL\_pk\_ccm\_var}_0\cdot\left|\sin\left(i\cdot\frac{\pi}{200}\right)\right|\right)\cdot \text{VFF}\cdot\left(1-D_i\right)\right]}{201} \\ \dfrac{\displaystyle\sum_{i=0}^{200}\left[\left(\text{IL\_pk\_ccm\_var}_1\cdot\left|\sin\left(i\cdot\frac{\pi}{200}\right)\right|\right)\cdot \text{VFF}\cdot\left(1-D_i\right)\right]}{201} \\ \dfrac{\displaystyle\sum_{i=0}^{200}\left[\left(\text{IL\_pk\_ccm\_var}_2\cdot\left|\sin\left(i\cdot\frac{\pi}{200}\right)\right|\right)\cdot \text{VFF}\cdot\left(1-D_i\right)\right]}{201} \\ \dfrac{\displaystyle\sum_{i=0}^{200}\left[\left(\text{IL\_pk\_ccm\_var}_3\cdot\left|\sin\left(i\cdot\frac{\pi}{200}\right)\right|\right)\cdot \text{VFF}\cdot\left(1-D_i\right)\right]}{201} \\ \dfrac{\displaystyle\sum_{i=0}^{200}\left[\left(\text{IL\_pk\_ccm\_var}_4\cdot\left|\sin\left(i\cdot\frac{\pi}{200}\right)\right|\right)\cdot \text{VFF}\cdot\left(1-D_i\right)\right]}{201} \end{bmatrix}$$

Diode bridge conduction losses:

$$Pdiodebridge\_ccm\_var := \begin{bmatrix} \dfrac{\sum_{i=0}^{200}\left[\left(IL\_pk\_ccm\_var_0\cdot\left|\sin\left(i\cdot\frac{\pi}{200}\right)\right|\right)\cdot VFF\cdot(2)\right]}{201} \\ \dfrac{\sum_{i=0}^{200}\left[\left(IL\_pk\_ccm\_var_1\cdot\left|\sin\left(i\cdot\frac{\pi}{200}\right)\right|\right)\cdot VFF\cdot(2)\right]}{201} \\ \dfrac{\sum_{i=0}^{200}\left[\left(IL\_pk\_ccm\_var_2\cdot\left|\sin\left(i\cdot\frac{\pi}{200}\right)\right|\right)\cdot VFF\cdot(2)\right]}{201} \\ \dfrac{\sum_{i=0}^{200}\left[\left(IL\_pk\_ccm\_var_3\cdot\left|\sin\left(i\cdot\frac{\pi}{200}\right)\right|\right)\cdot VFF\cdot(2)\right]}{201} \\ \dfrac{\sum_{i=0}^{200}\left[\left(IL\_pk\_ccm\_var_4\cdot\left|\sin\left(i\cdot\frac{\pi}{200}\right)\right|\right)\cdot VFF\cdot(2)\right]}{201} \end{bmatrix}$$

$$P1 := Prr\_ccm\_var + Pq\_ccm\_turnoff\_var + Pq\_ccm\_turnon\_var$$

$$P2 := Pq\_ccm\_rms\_var + Pdiode\_ccm\_var + Pdiodebridge\_ccm\_var$$

$$P\_loss\_semi\_ccm\_var := P1 + P2$$

$$P\_loss\_semi\_ccm\_var = \begin{pmatrix} 11.176 \\ 24.342 \\ 40.784 \\ 60.5 \\ 83.491 \end{pmatrix}$$

Calculate losses in the CRM boost.

Let the average Fs for CRM operation be 80kHz.

$$Fs\_crm := 80 \cdot k$$

Losses in MOSFET due to turn-off overlap of voltage and current:

$$Pq\_crm\_turnoff\_var := \begin{bmatrix} \dfrac{\sum_{i=0}^{200} Vout \cdot \left[\dfrac{\left(IL\_pk\_crm\_var_0 \cdot \left| \sin\left(i \cdot \frac{\pi}{200} \right) \right| \right) \cdot (transistor\_fall)}{2} \right]}{201} \cdot Fs\_crm \\ \dfrac{\sum_{i=0}^{200} Vout \cdot \left[\dfrac{\left(IL\_pk\_crm\_var_1 \cdot \left| \sin\left(i \cdot \frac{\pi}{200} \right) \right| \right) \cdot (transistor\_fall)}{2} \right]}{201} \cdot Fs\_crm \\ \dfrac{\sum_{i=0}^{200} Vout \cdot \left[\dfrac{\left(IL\_pk\_crm\_var_2 \cdot \left| \sin\left(i \cdot \frac{\pi}{200} \right) \right| \right) \cdot (transistor\_fall)}{2} \right]}{201} \cdot Fs\_crm \\ \dfrac{\sum_{i=0}^{200} Vout \cdot \left[\dfrac{\left(IL\_pk\_crm\_var_3 \cdot \left| \sin\left(i \cdot \frac{\pi}{200} \right) \right| \right) \cdot (transistor\_fall)}{2} \right]}{201} \cdot Fs\_crm \\ \dfrac{\sum_{i=0}^{200} Vout \cdot \left[\dfrac{\left(IL\_pk\_crm\_var_4 \cdot \left| \sin\left(i \cdot \frac{\pi}{200} \right) \right| \right) \cdot (transistor\_fall)}{2} \right]}{201} \cdot Fs\_crm \end{bmatrix}$$

MOSFET conduction losses:

$$Pq\_crm\_rms\_var := \begin{bmatrix} (Iq\_rms\_crm\_var_0)^2 \cdot Rdson \\ (Iq\_rms\_crm\_var_1)^2 \cdot Rdson \\ (Iq\_rms\_crm\_var_2)^2 \cdot Rdson \\ (Iq\_rms\_crm\_var_3)^2 \cdot Rdson \\ (Iq\_rms\_crm\_var_4)^2 \cdot Rdson \end{bmatrix}$$

Diode conduction losses:

$$Pdiode\_crm\_var := \begin{bmatrix} \dfrac{\sum_{i=0}^{200} \left[\left(IL\_pk\_crm\_var_0 \cdot \left| \sin\left(i \cdot \frac{\pi}{200} \right) \right| \right) \cdot VFF \cdot \left(1 - D_i \right) \right]}{201} \\ \dfrac{\sum_{i=0}^{200} \left[\left(IL\_pk\_crm\_var_1 \cdot \left| \sin\left(i \cdot \frac{\pi}{200} \right) \right| \right) \cdot VFF \cdot \left(1 - D_i \right) \right]}{201} \\ \dfrac{\sum_{i=0}^{200} \left[\left(IL\_pk\_crm\_var_2 \cdot \left| \sin\left(i \cdot \frac{\pi}{200} \right) \right| \right) \cdot VFF \cdot \left(1 - D_i \right) \right]}{201} \\ \dfrac{\sum_{i=0}^{200} \left[\left(IL\_pk\_crm\_var_3 \cdot \left| \sin\left(i \cdot \frac{\pi}{200} \right) \right| \right) \cdot VFF \cdot \left(1 - D_i \right) \right]}{201} \\ \dfrac{\sum_{i=0}^{200} \left[\left(IL\_pk\_crm\_var_4 \cdot \left| \sin\left(i \cdot \frac{\pi}{200} \right) \right| \right) \cdot VFF \cdot \left(1 - D_i \right) \right]}{201} \end{bmatrix}$$

Bridge diode conduction losses:

$$\text{Pdiodebridge\_crm\_var} := \begin{bmatrix} \dfrac{\sum_{i=0}^{200} \left[\left(\text{IL\_pk\_crm\_var}_0 \cdot \left| \sin\left(i \cdot \frac{\pi}{200} \right) \right| \right) \cdot \text{VFF} \cdot (2) \right]}{201} \\ \dfrac{\sum_{i=0}^{200} \left[\left(\text{IL\_pk\_crm\_var}_1 \cdot \left| \sin\left(i \cdot \frac{\pi}{200} \right) \right| \right) \cdot \text{VFF} \cdot (2) \right]}{201} \\ \dfrac{\sum_{i=0}^{200} \left[\left(\text{IL\_pk\_crm\_var}_2 \cdot \left| \sin\left(i \cdot \frac{\pi}{200} \right) \right| \right) \cdot \text{VFF} \cdot (2) \right]}{201} \\ \dfrac{\sum_{i=0}^{200} \left[\left(\text{IL\_pk\_crm\_var}_3 \cdot \left| \sin\left(i \cdot \frac{\pi}{200} \right) \right| \right) \cdot \text{VFF} \cdot (2) \right]}{201} \\ \dfrac{\sum_{i=0}^{200} \left[\left(\text{IL\_pk\_crm\_var}_4 \cdot \left| \sin\left(i \cdot \frac{\pi}{200} \right) \right| \right) \cdot \text{VFF} \cdot (2) \right]}{201} \end{bmatrix}$$

Total semiconductor losses in CRM:

$$\text{P3} := \text{Pq\_crm\_turnoff\_var} + \text{Pq\_crm\_rms\_var}$$

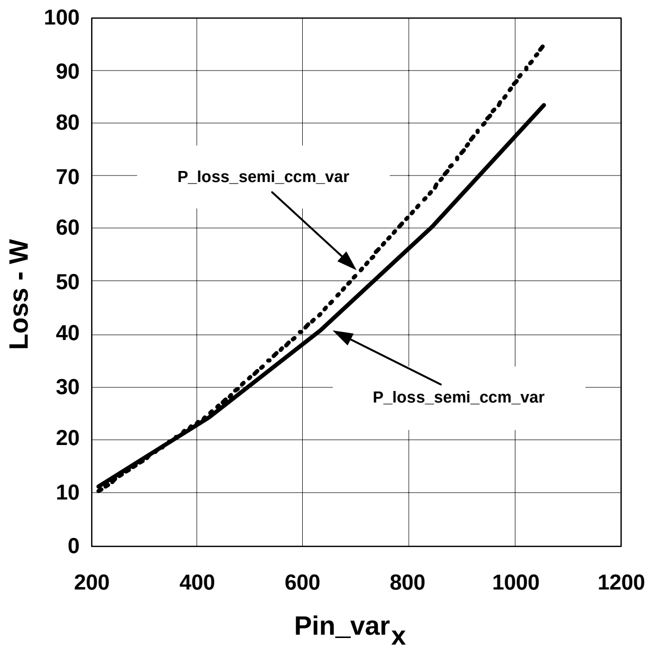
$$\text{P4} := \text{Pdiode\_crm\_var} + \text{Pdiodebridge\_crm\_var}$$

$$\text{P\_loss\_semi\_crm\_var} := \text{P3} + \text{P4}$$

$$\text{P\_loss\_semi\_crm\_var} = \begin{pmatrix} 10.238 \\ 24.843 \\ 43.814 \\ 67.15 \\ 94.853 \end{pmatrix} \qquad \text{P\_loss\_semi\_ccm\_var} = \begin{pmatrix} 11.176 \\ 24.342 \\ 40.784 \\ 60.5 \\ 83.491 \end{pmatrix}$$

for Fs_crm = 80kHz

This plot compares the semiconductor losses for CCM vs. CRM as a function of input power.



Efficiency comparison of CCM vs. CRM as a function of input power.