VAO and Power-Limit variations with qVff in the UCC28070

Jan 16, 2008
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$\mu := 10^{-6}$ $\quad$ $\text{Vrms} := 1, 1.2 .. 300$

Vout = global definition: $\text{Vout} \equiv 400$

$$k_{R1} \equiv \left(\frac{1}{132.33}\right)\cdot\left(\frac{\text{Vout}}{3} - 1\right) \qquad k_{R1} = 1$$

Vout =	when R1=
414V	137.00
408V	135.00
400V	132.33
392V	129.67
386V	127.67

$R_1 \equiv k_{R1}\cdot 132.33$

$R_1 = 132.333$

$R_2 \equiv 1$

$$k_r \equiv \frac{R_2}{R_1 + R_2}$$

$k_r = 7.5 \times 10^{-3}$

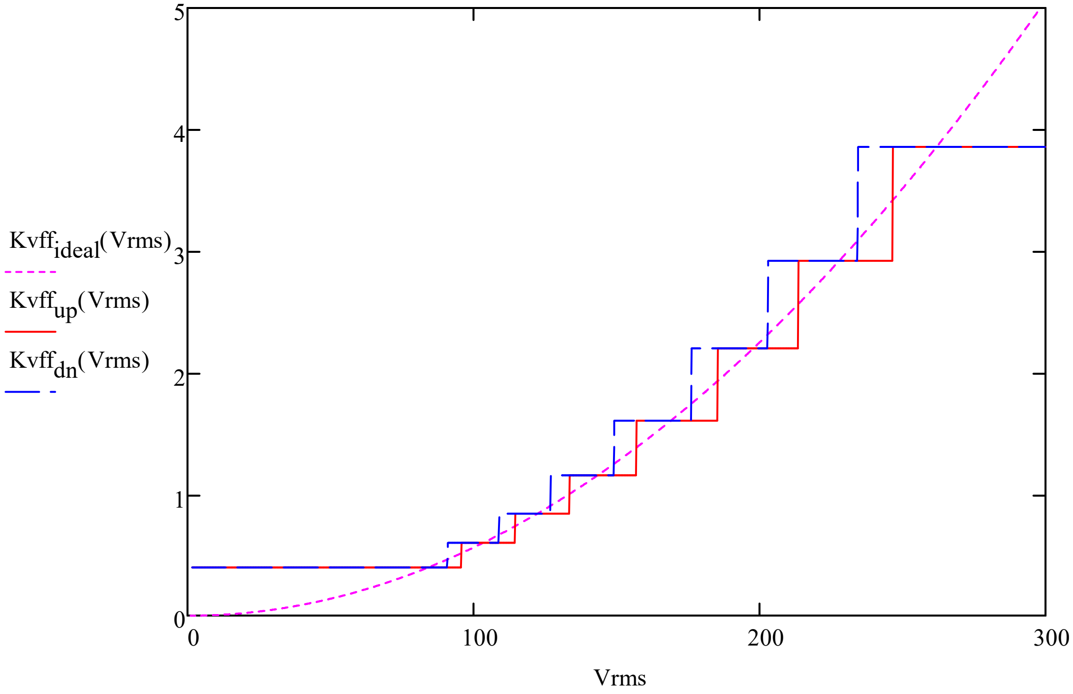
Select standard component values for R1 and R2, scaled per the factors above, for the desired average Vout voltage.

$\frac{3V}{k_r} = 400\text{ V}$ $\qquad$ $\frac{1}{k_r} = 133.333$

$$\text{Vvinac}_{pk}(\text{Vrms}) \equiv \left(\sqrt{2}\cdot\text{Vrms} - 2\right)\cdot k_r$$

The following graph demonstrates the quantized feed-forward levels of the scaled-Vrms, with the continuous ideal scaled-Vff curve for comparison. The scale is based on a nominal 400Vdc output with respect to the 3V regulation reference. The level thresholds are roughly centered on the ideal curve, and deviate from ideal for output voltages other than 400V. Down-going thresholds are 95% of the up-going thresholds. In other words, to drop from a higher quantized-Vrms feed-forward level to a lower one, the peak voltage of the input Vrms must drop below 95% of the threshold of the higher level.

Graph of Kvff vs Vrms, for $\mathrm{Vout} = 400$



For a 1200W design, allow 10% extra power to recover from line drop-outs at full load. Set maximum Pout = 1320W.

$\mathrm{Pout} := 1320 \qquad \mathrm{Vvao}_{max} := 5$

$R_S := 23.7 \qquad R_{IMO} := 24300$

$\eta := 0.95 \qquad N_{CT} := 100$

(η is really a function of line and load.
A constant factor will be used until a suitable function can be developed.)
VAO error voltage varies with Vrms to maintain Vout in regulation at any Pout.

V_{VAO} clamps at 5V to limit the maximum Pout available.

$$\mathrm{Vvao}_{up}(\mathrm{Vrms}) := \frac{\mathrm{Pout}}{\eta\cdot N_{CT}\cdot\left(\frac{1}{k_r}\right)\cdot\left(\frac{R_{IMO}}{R_S}\right)\cdot 17\mu\cdot\left(\frac{\mathrm{Vvinac}_{pk}(\mathrm{Vrms})^2}{\mathrm{Kvff}_{up}(\mathrm{Vrms})}\right)} + 1$$

$$\mathrm{Vvao}_{dn}(\mathrm{Vrms}) := \frac{\mathrm{Pout}}{\eta\cdot N_{CT}\cdot\left(\frac{1}{k_r}\right)\cdot\left(\frac{R_{IMO}}{R_S}\right)\cdot 17\mu\cdot\left(\frac{\mathrm{Vvinac}_{pk}(\mathrm{Vrms})^2}{\mathrm{Kvff}_{dn}(\mathrm{Vrms})}\right)} + 1$$

$$\mathrm{Vclamp}(\mathrm{Vrms}) := \mathrm{Vvao}_{max}$$

$$\mathrm{Vvao\_up}(\mathrm{Vrms}) := \left|\begin{array}{ll} \mathrm{Vclamp}(\mathrm{Vrms}) & \text{if } \mathrm{Vvao}_{up}(\mathrm{Vrms}) > \mathrm{Vvao}_{max} \\ \mathrm{Vvao}_{up}(\mathrm{Vrms}) & \text{if } \mathrm{Vvao}_{up}(\mathrm{Vrms}) \le \mathrm{Vvao}_{max} \end{array}\right.$$

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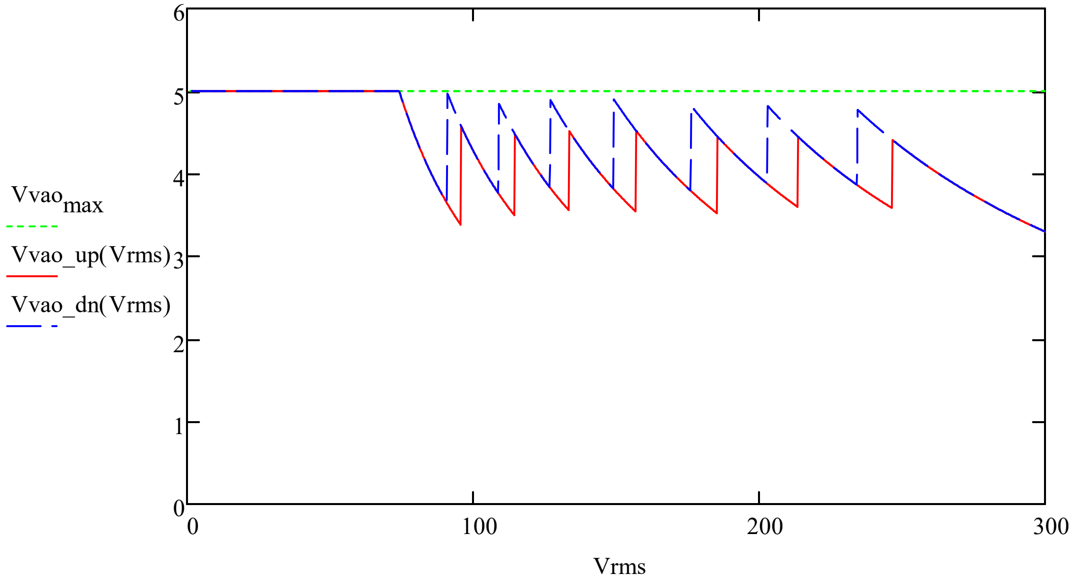

$k_{tpz} := 1.15$ (Trapezoidal equivalency factor due to PKLMT flattening the sine wave.)

$\mathrm{Irms}_{pklmt} := 7.40$ (RMS current limit per phase due to PKLMT. See note below.)

$P_{PKLMT}(Vrms) := 2 \cdot k_{tpz} \cdot Irms_{pklmt} \cdot Vrms$ (Total input power limit due to PKLMT.)

$$P_{LIMup}(Vrms) := \left(\frac{R_{IMO}}{R_S}\right) \cdot \left(Vvao_{max} - 1\right) \cdot \left(\frac{Vvinac_{pk}(Vrms)^2}{Kvff_{up}(Vrms)}\right) \cdot \eta \cdot N_{CT} \cdot \left(\frac{1}{k_r}\right) \cdot 17\mu$$

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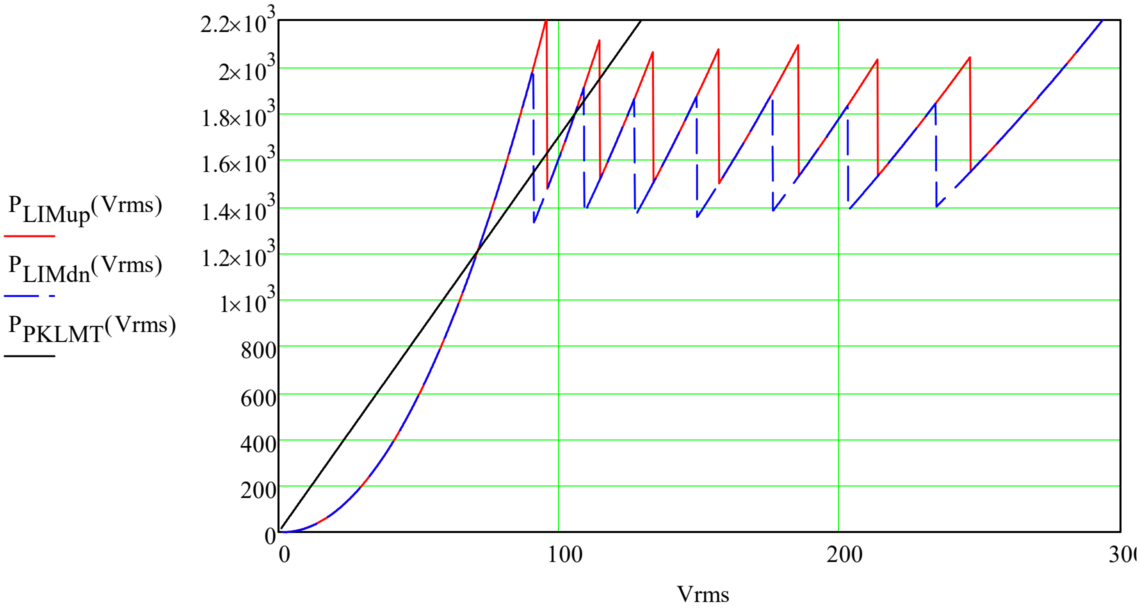

At the lower input voltages, if the per-phase ripple current peaks reach the PKLMT set-point, the PKLMT function will dominate and limit input power. At higher voltages, the power limit dominates. Although the overload input power may be much higher than the normal maximum load power, the line currents are always lower than the peak current limit.

PKLMT should be chosen to allow enough current/power margin at the lowest desired input voltage.

For a 1200W design, allow 10% extra power to recover from line drop-outs at full load. Set maximum Pout = 1320W.

$$Pout1 := 660$$

$$Vvao1_{max} := 3$$

(η is really a function of line and
load.
A constant factor will be used until a
suitable function can be developed.)
VAO error voltage varies with Vrms to maintain Vout in regulation at any Pout.

V_{VAO} clamps at 5V to limit the maximum Pout available.

$$\mathrm{Vvao1}_{up}(\mathrm{Vrms}) := \frac{\mathrm{Pout1}}{\eta \cdot N_{CT} \cdot \left(\frac{1}{k_r}\right) \cdot \left(\frac{R_{IMO}}{R_S}\right) \cdot 17\mu \cdot \left(\frac{\mathrm{Vvinac}_{pk}(\mathrm{Vrms})^2}{\mathrm{Kvff}_{up}(\mathrm{Vrms})}\right)} + 1$$

$$\mathrm{Vvao1}_{dn}(\mathrm{Vrms}) := \frac{\mathrm{Pout1}}{\eta \cdot N_{CT} \cdot \left(\frac{1}{k_r}\right) \cdot \left(\frac{R_{IMO}}{R_S}\right) \cdot 17\mu \cdot \left(\frac{\mathrm{Vvinac}_{pk}(\mathrm{Vrms})^2}{\mathrm{Kvff}_{dn}(\mathrm{Vrms})}\right)} + 1$$

$$\mathrm{Vclamp1}(\mathrm{Vrms}) := \mathrm{Vvao1}_{max}$$

$$\mathrm{Vvao\_up1}(\mathrm{Vrms}) := \left| \begin{array}{ll} \mathrm{Vclamp1}(\mathrm{Vrms}) & \text{if } \mathrm{Vvao1}_{up}(\mathrm{Vrms}) > \mathrm{Vvao1}_{max} \\ \mathrm{Vvao1}_{up}(\mathrm{Vrms}) & \text{if } \mathrm{Vvao1}_{up}(\mathrm{Vrms}) \le \mathrm{Vvao1}_{max} \end{array} \right.$$

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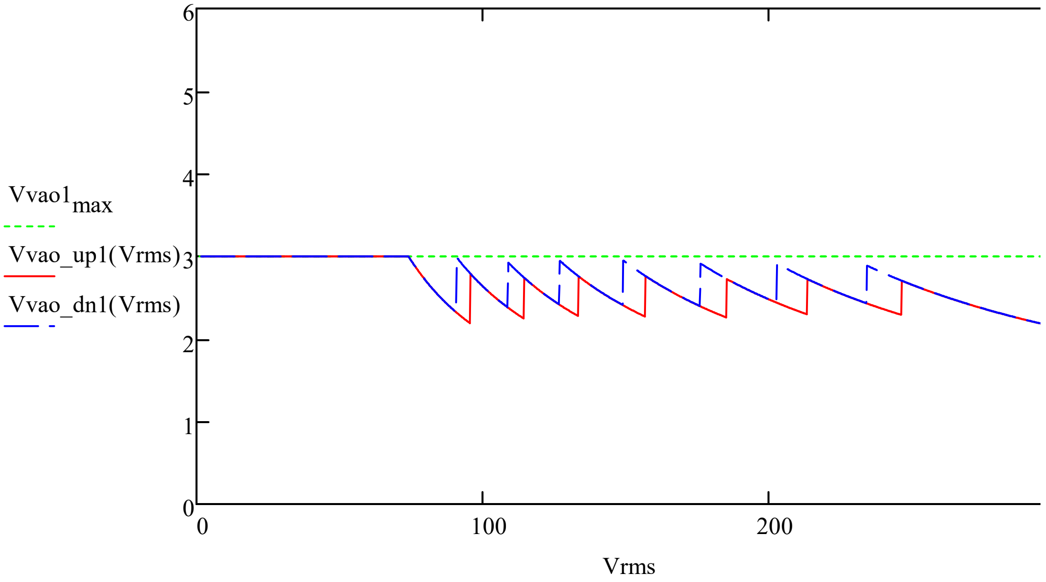


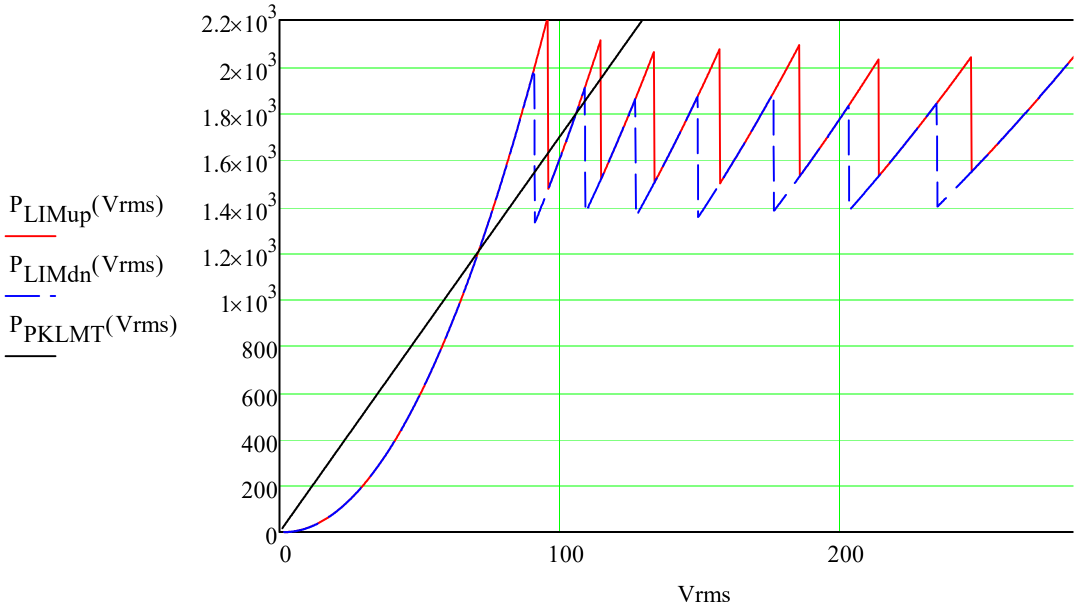
$k_{tpz} := 1.15$ (Trapezoidal equivalency factor due to PKLMT flattening the sine wave.)

$\mathrm{Irms}_{pklmt} := 7.40$ (RMS current limit per phase due to PKLMT. See note below.)

$$P_{PKLMT}(Vrms) := 2\cdot k_{tpz}\cdot Irms_{pklmt}\cdot Vrms$$ (Total input power limit due to PKLMT.)

$$P_{LIMup}(Vrms) := \left(\frac{R_{IMO}}{R_S}\right)\cdot\left(Vvao_{max} - 1\right)\cdot\left(\frac{Vvinac_{pk}(Vrms)^2}{Kvff_{up}(Vrms)}\right)\cdot\eta\cdot N_{CT}\cdot\left(\frac{1}{k_r}\right)\cdot 17\mu$$

$$P_{LIMdn}(Vrms) := \left(\frac{R_{IMO}}{R_S}\right)\cdot\left(Vvao_{max} - 1\right)\cdot\left(\frac{Vvinac_{pk}(Vrms)^2}{Kvff_{dn}(Vrms)}\right)\cdot\eta\cdot N_{CT}\cdot\left(\frac{1}{k_r}\right)\cdot 17\mu$$



At the lower input voltages, if the per-phase ripple current peaks reach the PKLMT set-point, the PKLMT function will dominate and limit input power. At higher voltages, the power limit dominates. Although the overload input power may be much higher than the normal maximum load power, the line currents are always lower than the peak current limit.

PKLMT should be chosen to allow enough current/power margin at the lowest desired input voltage.

$$\mathrm{Kvff}_{\mathrm{ideal}}(\mathrm{Vrms}) := \left(\mathrm{Vrms}\cdot\frac{3}{400}\right)^{2}$$ for the UCC28070

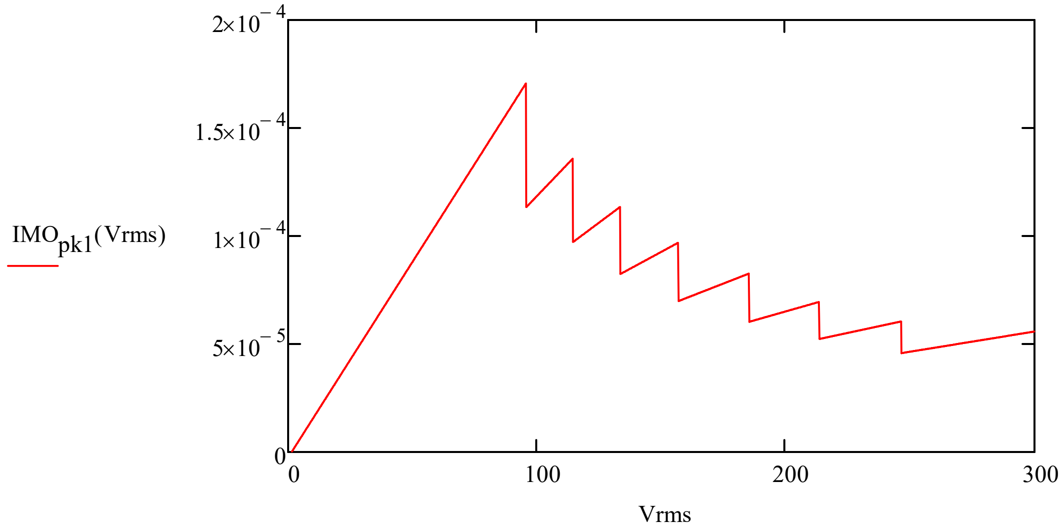
$$\mathrm{Kvff}_{\mathrm{up}}(\mathrm{Vrms}) := \left|\begin{array}{l} 0.398 \ \text{ if } \ 0.00 \le \mathrm{Vvinac}_{\mathrm{pk}}(\mathrm{Vrms}) < 1.00 \\ 0.600 \ \text{ if } \ 1.00 \le \mathrm{Vvinac}_{\mathrm{pk}}(\mathrm{Vrms}) < 1.20 \\ 0.839 \ \text{ if } \ 1.20 \le \mathrm{Vvinac}_{\mathrm{pk}}(\mathrm{Vrms}) < 1.40 \\ 1.156 \ \text{ if } \ 1.40 \le \mathrm{Vvinac}_{\mathrm{pk}}(\mathrm{Vrms}) < 1.65 \\ 1.604 \ \text{ if } \ 1.65 \le \mathrm{Vvinac}_{\mathrm{pk}}(\mathrm{Vrms}) < 1.95 \\ 2.199 \ \text{ if } \ 1.95 \le \mathrm{Vvinac}_{\mathrm{pk}}(\mathrm{Vrms}) < 2.25 \\ 2.922 \ \text{ if } \ 2.25 \le \mathrm{Vvinac}_{\mathrm{pk}}(\mathrm{Vrms}) < 2.60 \\ 3.857 \ \text{ if } \ 2.60 \le \mathrm{Vvinac}_{\mathrm{pk}}(\mathrm{Vrms}) \end{array}\right.$$

$$\mathrm{Kvff}_{dn}(\mathrm{Vrms}) := \left| \begin{array}{l} 0.398 \text{ if } 0.00 \le \mathrm{Vvinac}_{pk}(\mathrm{Vrms}) < 0.95 \\ 0.600 \text{ if } 0.95 \le \mathrm{Vvinac}_{pk}(\mathrm{Vrms}) < 1.14 \\ 0.839 \text{ if } 1.14 \le \mathrm{Vvinac}_{pk}(\mathrm{Vrms}) < 1.33 \\ 1.156 \text{ if } 1.33 \le \mathrm{Vvinac}_{pk}(\mathrm{Vrms}) < 1.5675 \\ 1.604 \text{ if } 1.5675 \le \mathrm{Vvinac}_{pk}(\mathrm{Vrms}) < 1.8525 \\ 2.199 \text{ if } 1.8525 \le \mathrm{Vvinac}_{pk}(\mathrm{Vrms}) < 2.1375 \\ 2.922 \text{ if } 2.1375 \le \mathrm{Vvinac}_{pk}(\mathrm{Vrms}) < 2.470 \\ 3.857 \text{ if } 2.470 \le \mathrm{Vvinac}_{pk}(\mathrm{Vrms}) \end{array} \right.$$

(The Kvff factors have units of V^2.)

$$\mathrm{IMO}_{pk1}(\mathrm{Vrms}) := \frac{\mathrm{Vvinac}_{pk}(\mathrm{Vrms}) \cdot \left(\mathrm{Vvao}_{max} - 1\right)}{\mathrm{Kvff}_{up}(\mathrm{Vrms})} \cdot 17\mu$$

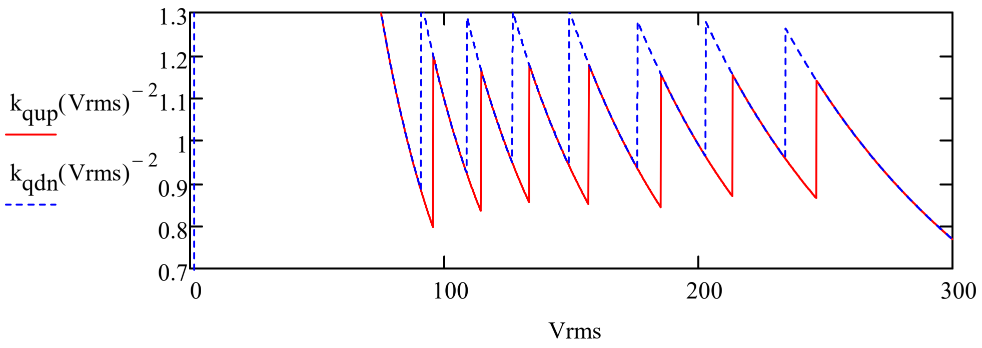
Graph of peak IMO current vs input Vrms with constant Vvao = 5V. This is interesting, but not very useful, since Vvao is not a constant value, but adjusts itself to regulate the output.



Graph of the inverse square of the error factor between the ideal peak VINAC and the quantized values indicates how much the VAO output must change from its ideal level to compensate for the difference.

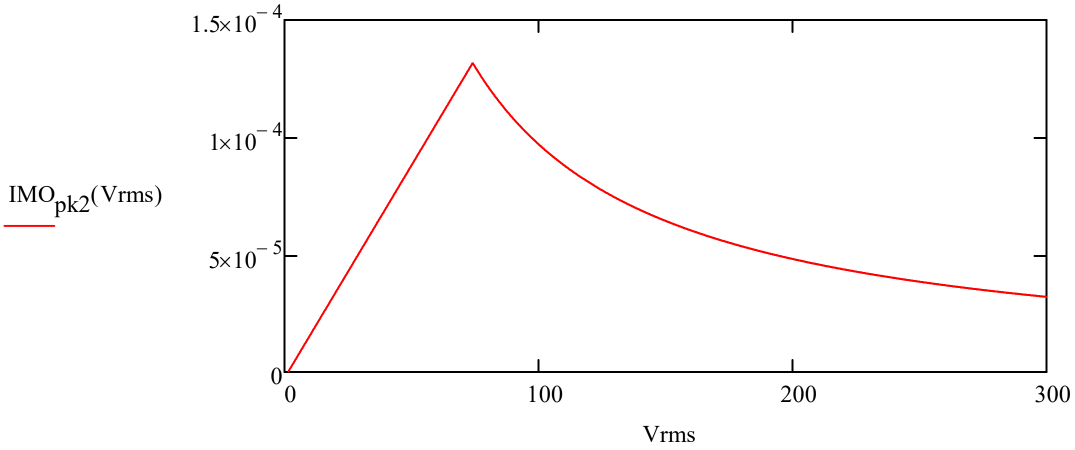
$$Vvinac_{qup}(Vrms) := \sqrt{2 \cdot Kvff_{up}(Vrms)} \qquad Vvinac_{qdn}(Vrms) := \sqrt{2 \cdot Kvff_{dn}(Vrms)}$$

$$k_{qup}(Vrms) := \frac{Vvinac_{pk}(Vrms)}{Vvinac_{qup}(Vrms)} \qquad k_{qdn}(Vrms) := \frac{Vvinac_{pk}(Vrms)}{Vvinac_{qdn}(Vrms)}$$



$$IMO_{pk2}(Vrms) := \frac{Vvinac_{pk}(Vrms)\cdot(Vvao\_up(Vrms) - 1)}{Kvff_{up}(Vrms)}\cdot 17\mu$$

Graph of peak IMO vs Vrms with constant Pout.
This graph is more informative since it shows that the peak IMO current follows a continuous curve in the steady-state.



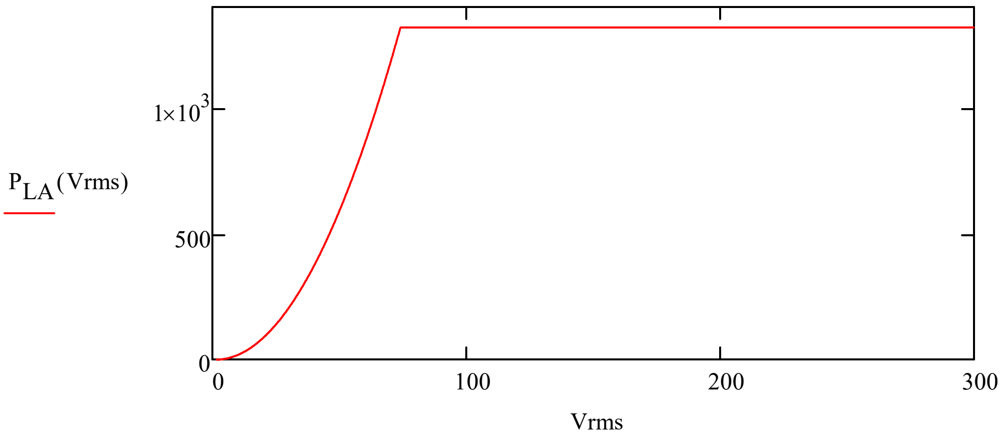
$$P_{LA}(Vrms) := \left(\frac{R_{IMO}}{R_S}\right)\cdot(Vvao\_up(Vrms) - 1)\cdot\left(\frac{Vvinac_{pk}(Vrms)^2}{Kvff_{up}(Vrms)}\right)\cdot\eta\cdot N_{CT}\cdot\left(\frac{1}{k_r}\right)\cdot 17\mu$$

)

For a normal maximum load Pin = 1300W:

$P_{LIMdn}(85) = 1744.068$ Too much margin (+34%) at 85Vac.

$P_{PKLMT}(85) = 1446.7$ +11% power margin at 85Vac, with $Irms_{pklmt}$ target = 7.40A per phase.



$$IMO_{pk3}(Vrms) := \frac{Vvinac_{pk}(Vrms)\cdot\left(Vvao1_{max} - 1\right)}{Kvff_{up}(Vrms)}\cdot 17\mu$$

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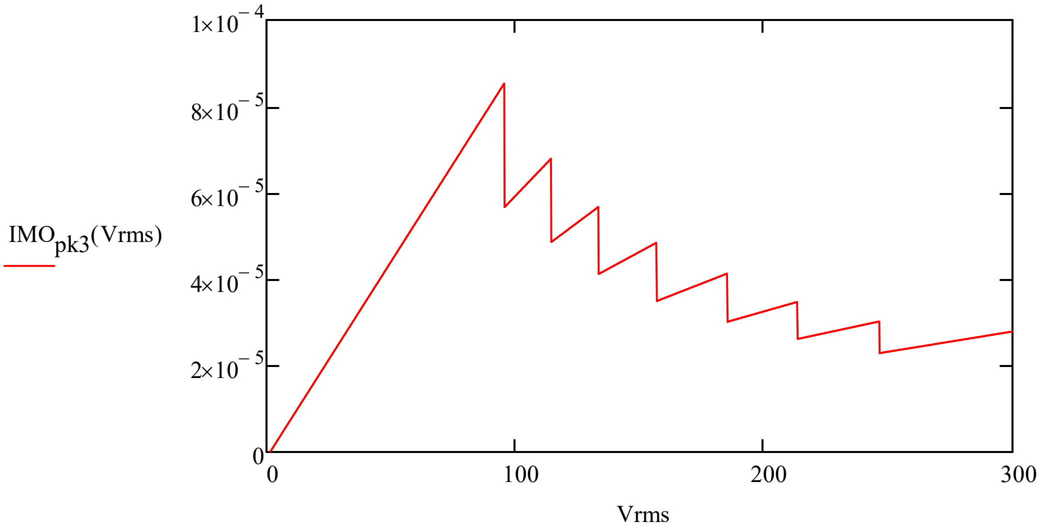

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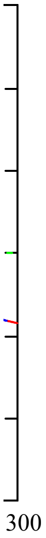
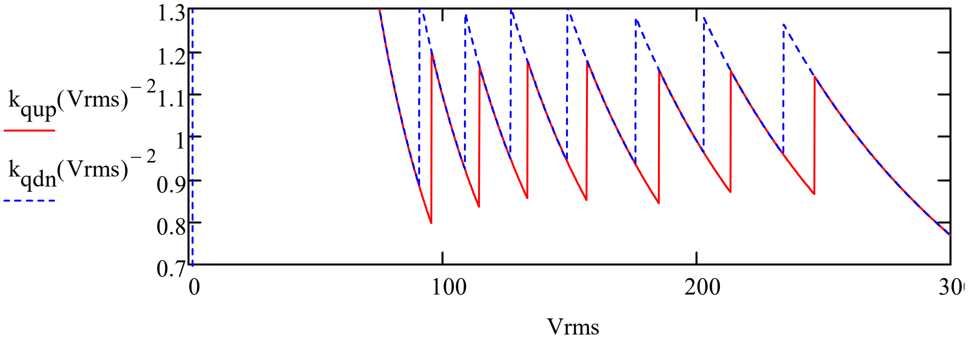


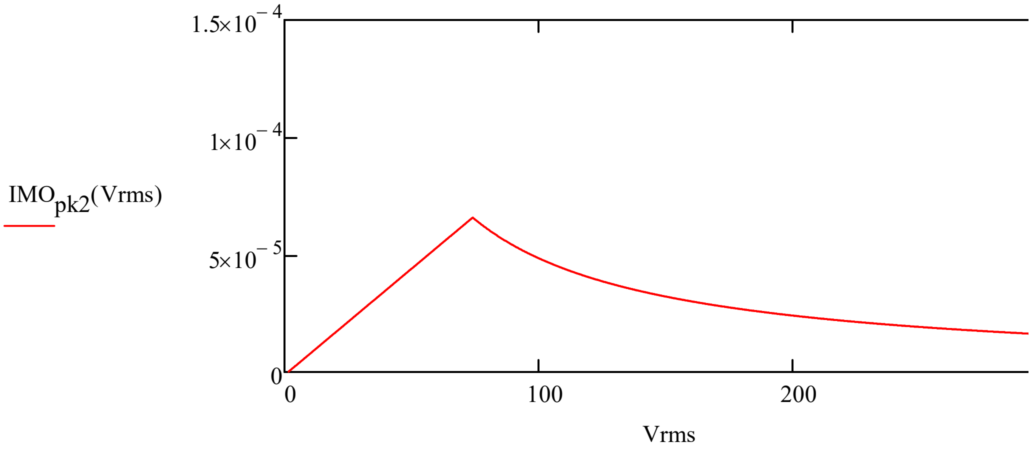
$$Vvinac_{qup}(Vrms) := \sqrt{2 \cdot Kvff_{up}(Vrms)} \qquad Vvinac_{qdn}(Vrms) := \sqrt{2 \cdot Kvff_{dn}(Vrms)}$$

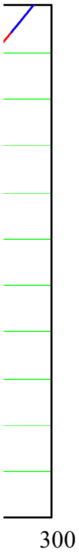
$$k_{qup}(Vrms) := \frac{Vvinac_{pk}(Vrms)}{Vvinac_{qup}(Vrms)} \qquad k_{qdn}(Vrms) := \frac{Vvinac_{pk}(Vrms)}{Vvinac_{qdn}(Vrms)}$$



$$IMO_{pk2}(Vrms) := \frac{Vvinac_{pk}(Vrms)\cdot(Vvao\_up1(Vrms)-1)}{Kvff_{up}(Vrms)}\cdot 17\mu$$

Graph of peak IMO vs Vrms with constant Pout.
This graph is more informative since it shows that the peak IMO current follows a continuous curve in the steady-state.





$$P_{LA1}(Vrms) := \left(\frac{R_{IMO}}{R_S}\right)\cdot(Vvao\_up1(Vrms)-1)\cdot\left(\frac{Vvinac_{pk}(Vrms)^2}{Kvff_{up}(Vrms)}\right)\cdot\eta\cdot N_{CT}\cdot\left(\frac{1}{k_r}\right)\cdot$$

For a normal maximum load Pin = 1300W:

$P_{LIMdn}(85) = 1744.068$ Too much margin (+34%) at 85Vac.

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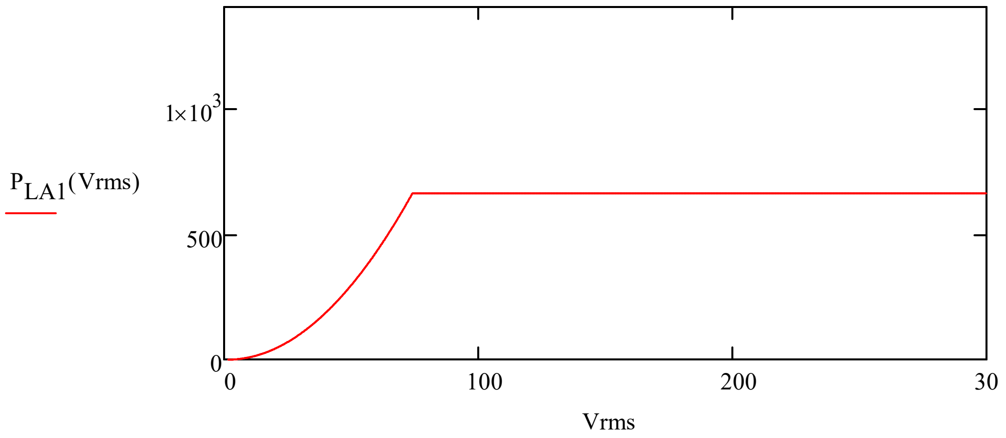
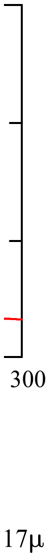

$P_{LA1}(Vrms)$
1×10^3
500
0
0
100
200
30
Vrms

0


300
17μ

0