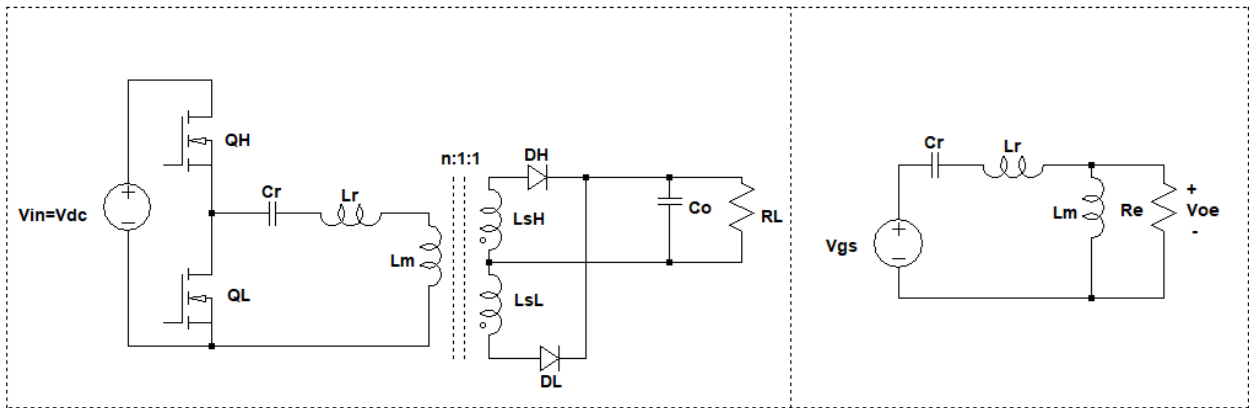


LLC tank pre-design calculations

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Voltage Gain – Theoretical Overview



The voltage gain function (normalized) expression is:

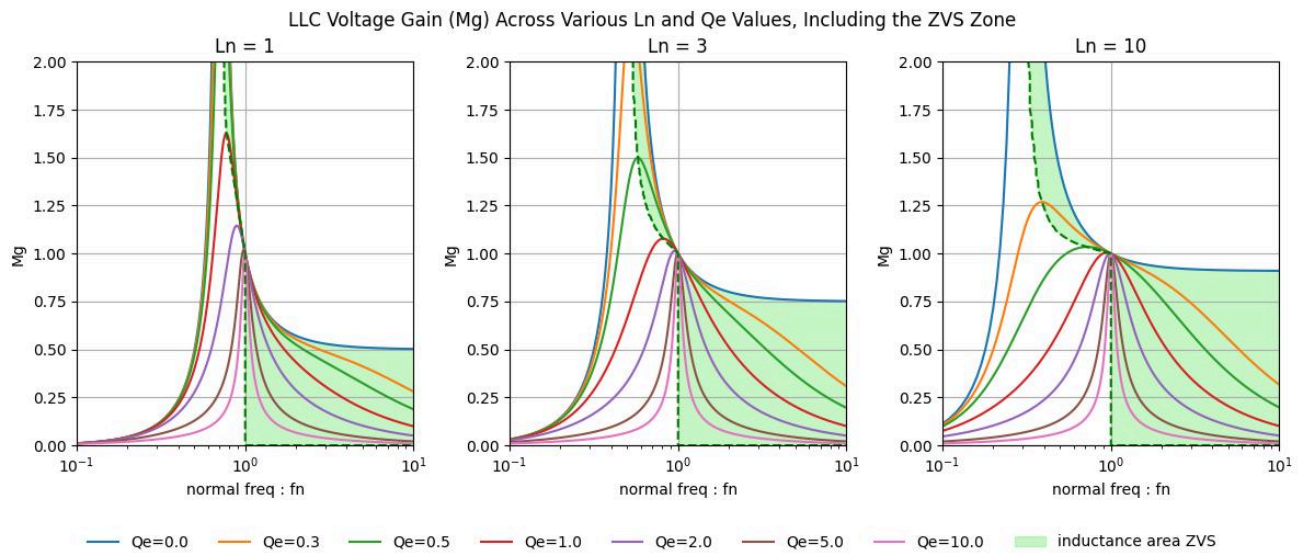
$$M_g = \left| \frac{L_n \cdot f_n^2}{[(L_n + 1) \cdot f_n^2 - 1] + j[(f_n^2 - 1) \cdot f_n \cdot Q_e \cdot L_n]} \right|$$

With:

$$L_n = \frac{L_m}{L_r}, \quad Q_e = \frac{\sqrt{\frac{L_r}{C_r}}}{R_e}, \quad f_n = \frac{f_{sw}}{f_0}, \quad f_0 = \frac{1}{2\pi\sqrt{L_r C_r}}$$

See page 3 formula (23) [\[1\]](#).

You can found all formula of this chapter in the same ref



Inputs and Specifications

$$V_{In_{min}} = 360 \text{ (v)}$$

$$V_{In_{nom}} = 380 \text{ (v)}$$

$$V_{In_{max}} = 400 \text{ (v)}$$

$$V_{O_{min}} = 42 \text{ (v)}$$

$$V_{O_{nom}} = 48 \text{ (v)}$$

$$V_{O_{max}} = 54 \text{ (v)}$$

$$\text{Power} = 1200 \text{ (w)}$$

$$f_{nom} = 100000.000 \text{ (Hz)}$$

Inputs data

```
{'V_In_min': 360.0,
'V_In_nom': 380.0,
'V_In_max': 400.0,
'Vo_min': 42.0,
'Vo_nom': 48.0,
'Vo_max': 54.0,
'Power': 1200.0,
'f_nom': 100000.0}
```

Transfo ratio and Voltage Gain

$$n = \frac{V_{In_{nom}}}{V_{O_{nom}} \cdot 2} = \frac{380}{48 \cdot 2} = 3.958$$

Choose an integer value to simplify the transformer design.

$$n = \text{round}(n) = \text{round}(4) = 4$$

$$V_f = 0.200 \text{ (drop voltage in the mos)}$$

$$\text{efficiency} = 0.950 \text{ (hypothesis)}$$

$$\text{loss} = 1 - \text{efficiency} = 1 - 0.950 = 0.050$$

$$I_{o_{nom}} = \frac{\text{Power}}{V_{o_{nom}}} = \frac{1200}{48} = 25.000 \text{ (A)}$$

$$V_{loss} = \frac{\frac{\text{Power} \cdot \text{loss}}{\text{efficiency}}}{I_{o_{nom}}} = \frac{\frac{1200 \cdot 0.050}{0.950}}{25.000} = 2.526 \text{ (v)}$$

$$\text{margin} = 0.010$$

$$\begin{aligned} Mg_{min} &= n \cdot \frac{V_{o_{min}} \cdot (1 - \text{margin}) + V_f}{\frac{V_{In_{max}}}{2}} \\ &= 4 \cdot \frac{42 \cdot (1 - 0.010) + 0.200}{\frac{400}{2}} \\ &= 0.836 \end{aligned}$$

$$\begin{aligned} Mg_{max} &= n \cdot \frac{V_{o_{max}} \cdot (1 + \text{margin}) + V_f + V_{loss}}{\frac{V_{In_{min}}}{2}} \\ &= 4 \cdot \frac{54 \cdot (1 + 0.010) + 0.200 + 2.526}{\frac{360}{2}} \\ &= 1.273 \end{aligned}$$

$$\begin{aligned} Mg_{max110} &= Mg_{max} \cdot \left(\frac{110}{100} \right) \\ &= 1.273 \cdot \left(\frac{110}{100} \right) \\ &= 1.400 \end{aligned}$$

Lm, Lr, Cr tank

Below we will use grid search to find the best values for **Ln** and **Qe**.

The idea:

- Change **Ln** in the range: start = 1, stop = 10, step = 0.01 (around 100 points)
- Change **Qe** in the range: start = 0.1, stop = 1, step = 0.01 (around 10 points)

We will select the **Ln** and **Qe** values that give an **Mg** value closest to **Mg_max110**.

Top 6 (Ln, Qe) Combinations Matching Mg_{max110}

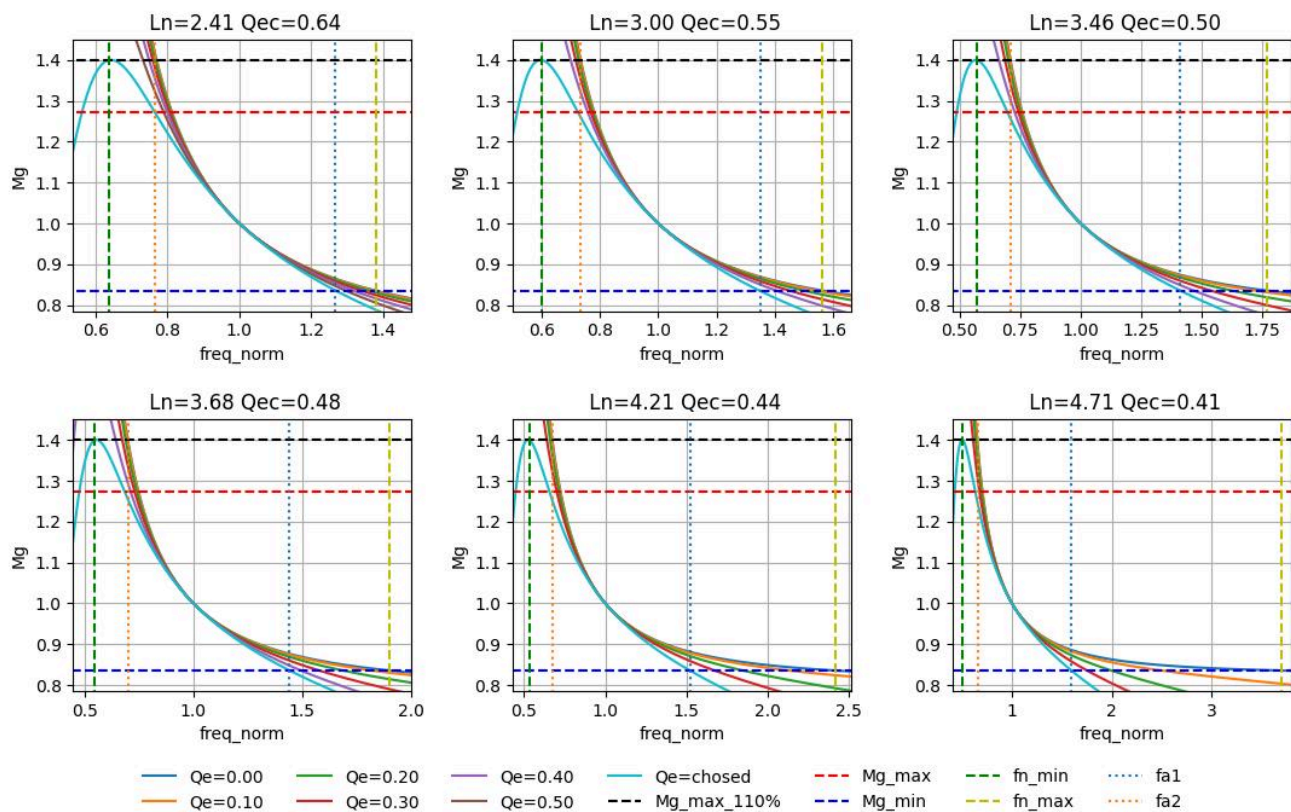
The following 6 values of L_n and Q_e closely match the target voltage gain Mg_{max110} .

These rows were selected based on the criterion that Mg_{ape} is nearly equal to Mg_{max110} .

$$Mg_{max110} = 1.400$$

	Lnc	Qec	Lm_uH	Lr_uH	Cr_nF	fn_min	fn_max	fsw_min	fsw_max	Mg_ape
0	2.41	0.64	61.127	25.364	99.867314	0.6375	1.3790	63750.0	137900.0	1.400142
1	3.00	0.55	65.392	21.797	116.209238	0.6017	1.5622	60170.0	156220.0	1.400062
2	3.46	0.50	68.562	19.816	127.830162	0.5707	1.7698	57070.0	176980.0	1.399923
3	3.68	0.48	70.005	19.023	133.156419	0.5471	1.9035	54710.0	190350.0	1.400284
4	4.21	0.44	73.413	17.438	145.261548	0.5324	2.4133	53240.0	241330.0	1.400277
5	4.71	0.41	76.532	16.249	155.890441	0.5077	3.6928	50770.0	369280.0	1.400231

Grid search for L_n and Q_e to find the best pair of values.



$$L_{nc} = 3$$

$$Q_{ec} = 0.550$$

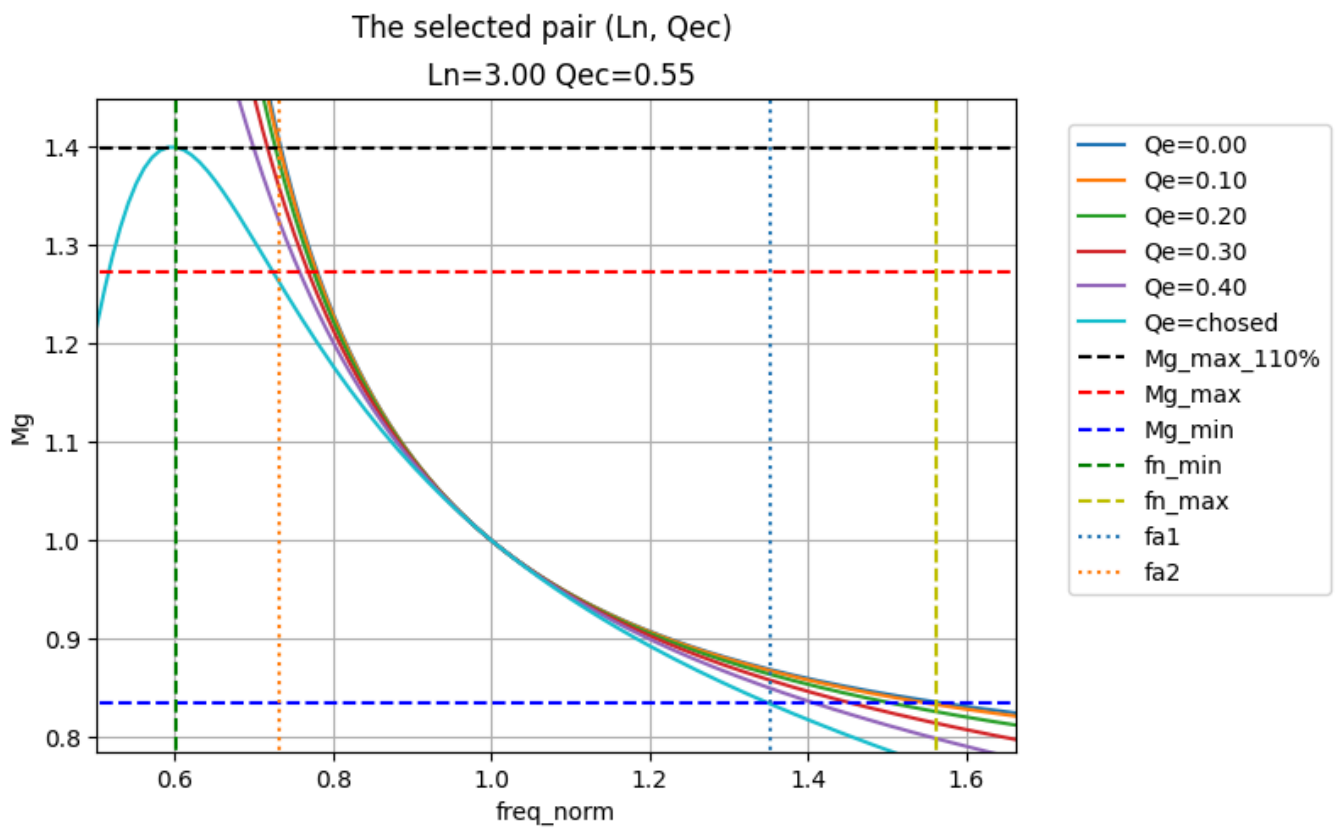
$L_{nc} = 3$ and $Q_{ec} = 0.55$ represent an optimal compromise due to the following:

- Moderate gain slope ($\Delta M/\Delta f$):**

In the inductive region, the gain rises gradually with frequency, enabling stable control without abrupt sensitivity shifts.

- **Limited frequency span (f_{\min} to f_{\max}):**

These parameters restrict the switching frequency range, simplifying component design, controller implementation, and consistent ZVS operation.



Equivalent resistor

$$\begin{aligned}
\text{Re}_{nom} &= 8 \cdot (n)^2 \cdot \frac{V_{o_{nom}}}{(\pi)^2 \cdot I_{o_{nom}}} \\
&= 8 \cdot (4)^2 \cdot \frac{48}{(3.142)^2 \cdot 25.000} \\
&= 24.901
\end{aligned}$$

$$\begin{aligned}
\text{Re}_{nom} &= \text{round}(\text{Re}_{nom}, 3) \\
&= \text{round}(24.901, 3) \\
&= 24.901
\end{aligned}$$

$$\begin{aligned}
\text{Re}_{110} &= 8 \cdot (n)^2 \cdot \frac{V_{o_{nom}}}{(\pi)^2 \cdot I_{o_{nom}} \cdot 1.1} \\
&= 8 \cdot (4)^2 \cdot \frac{48}{(3.142)^2 \cdot 25.000 \cdot 1.1} \\
&= 22.637
\end{aligned}$$

$$\begin{aligned}
P_{re_{110}} &= \frac{\left(\frac{V_{Innom}}{2}\right)^2}{\text{Re}_{nom}} \\
&= \frac{\left(\frac{380}{2}\right)^2}{24.901} \\
&= 1449.741
\end{aligned}$$

Lm, Lr, Cr values

$$\begin{aligned}
\text{Cr}_{nF} &= \frac{1 \times 10^9}{2 \cdot \pi \cdot Q_{ec} \cdot f_{nom} \cdot \text{Re}_{nom}} \\
&= \frac{1 \times 10^9}{2 \cdot 3.142 \cdot 0.550 \cdot 100000.000 \cdot 24.901} \\
&= 116.209 \text{ (nF)}
\end{aligned}$$

$$\text{Cr} = 116.209$$

$$\begin{aligned}
\text{Cr} &= \text{round}(\text{Cr}, 3) \\
&= \text{round}(116.209, 3) \\
&= 116.209
\end{aligned}$$

$$\begin{aligned}
L_r &= \frac{1}{(2 \cdot \pi \cdot f_{nom})^2 \cdot Cr \cdot 1 \times 10^{-9}} \\
&= \frac{1}{(2 \cdot 3.142 \cdot 100000.000)^2 \cdot 116.209 \cdot 1 \times 10^{-9}} \\
&= 0.000
\end{aligned}$$

$$\begin{aligned}
L_{r_{uH}} &= L_r \cdot 1 \times 10^6 \\
&= 0.000 \cdot 1 \times 10^6 \\
&= 21.797 \text{ (uH)}
\end{aligned}$$

$$\begin{aligned}
L_{r_{uH}} &= \text{round}(L_{r_{uH}}, 3) \\
&= \text{round}(21.797, 3) \\
&= 21.797
\end{aligned}$$

$$\begin{aligned}
L_m &= L_r \cdot L_{nc} \\
&= 0.000 \cdot 3.000 \\
&= 0.000
\end{aligned}$$

$$\begin{aligned}
L_{m_{uH}} &= L_m \cdot 1 \times 10^6 \\
&= 0.000 \cdot 1 \times 10^6 \\
&= 65.392 \text{ (uH)}
\end{aligned}$$

$$\begin{aligned}
L_{second_{uH}} &= \frac{L_{m_{uH}}}{(n)^2} \\
&= \frac{65.392}{(4)^2} \\
&= 4.087 \text{ (uH)}
\end{aligned}$$

Verification

$$Q_{cal} = \frac{\sqrt{\frac{L_r}{Cr \cdot 1 \times 10^{-9}}}}{Re_{110} \cdot 1.1} = \frac{\sqrt{\frac{0.000}{116.209 \cdot 1 \times 10^{-9}}}}{22.637 \cdot 1.1} = 0.550$$

$$Q_{ec} = 0.550$$

Fsw limites and primary secondary currents

$$\begin{aligned}
f_{sw_{min}} &= f_{n_{min}} \cdot f_{nom} \\
&= 0.602 \cdot 100000.000 \\
&= 60170.000 \text{ (Hz)}
\end{aligned}$$

$$\begin{aligned}
f_{sw_{max}} &= f_{n_{max}} \cdot f_{nom} \\
&= 1.562 \cdot 100000.000 \\
&= 156220.000 \text{ (Hz)}
\end{aligned}$$

$$\begin{aligned}
w_{min} &= 2 \cdot \pi \cdot f_{sw_{min}} \\
&= 2 \cdot 3.142 \cdot 60170.000 \\
&= 378059.260 \text{ (rad/s)}
\end{aligned}$$

$$\begin{aligned}
w_{max} &= 2 \cdot \pi \cdot f_{sw_{max}} \\
&= 2 \cdot 3.142 \cdot 156220.000 \\
&= 981559.209 \text{ (rad/s)}
\end{aligned}$$

$$\begin{aligned}
I_{m_{rms}} &= 2 \cdot \sqrt{2} \cdot n \cdot \frac{V_{o_{nom}}}{\pi \cdot L_m \cdot w_{min}} \\
&= 2 \cdot \sqrt{2} \cdot 4 \cdot \frac{48}{3.142 \cdot 0.000 \cdot 378059.260} \\
&= 6.992 \text{ (Arms)}
\end{aligned}$$

$$I_o = 25.000 \text{ (Arms)}$$

$$\begin{aligned}
I_{oe_{rms}} &= 1.1 \cdot \pi \cdot \frac{I_o}{n \cdot 2 \cdot \sqrt{2}} \\
&= 1.1 \cdot 3.142 \cdot \frac{25.000}{4 \cdot 2 \cdot \sqrt{2}} \\
&= 7.636 \text{ (Arms @ 110\%)}
\end{aligned}$$

$$\begin{aligned}
I_{os_{rms}} &= I_{oe_{rms}} \cdot n \\
&= 7.636 \cdot 4 \\
&= 30.545 \text{ (Arms)}
\end{aligned}$$

$$\begin{aligned}
I_{r_{rms}} &= \sqrt{(I_{m_{rms}})^2 + (I_{oe})^2} \\
&= \sqrt{(6.992)^2 + (7.636)^2} \\
&= 10.354 \text{ (Arms)}
\end{aligned}$$

Output data


```
{'Lnc': 3.0,  
'Qec': 0.55,  
'Cr_nF': 116.209,  
'n': 4.0,  
'Lr_uH': 21.797,  
'Lm_uH': 65.392,  
'fsw_min': 60170.0,  
'fsw_max': 156220.0,  
'Im_rms': 6.992,  
'Io': 25.0,  
'Ioe_rms': 7.636,  
'Ios_rms': 30.545,  
'Ir_rms': 10.354,  
'L_second_uH': 4.087,  
'Re_nom': 24.901,  
'Re_110': 22.637,  
'Cr': 1.16209e-07,  
'Lr': 2.1796999999999998e-05,  
'Lm': 6.539199999999999e-05}
```

References

[1] Hong Huang, *Designing an LLC Resonant Half-Bridge Power Converter*. Available:
<https://bbs.dianyuan.com/upload/community/2013/12/01/1385867010-65563.pdf> [2]
Code [Python notebook used to make this PDF](#)