Designing a DC/DC convertor based on LLC Resonant Half-Bridge Power Convertor

While half-bridge power stages have commonly been used for isolated, medium-power applications, convertors with high-voltage inputs are often designed with resonant switching to achieve higher efficiency, an improvement that comes with added complexity but that offers several performance benefits. This topic provides detailed information on designing a resonant half-bridge convertor that uses two inductors (LL) and a capacitor (C), known as LLC Configuration.

INTRODUCTION

Higher efficiency, higher power density, and higher component density have become common in power-supply designs and their applications. Resonant power converters especially those with an LLC half-bridge configuration—are receiving renewed interest because of this trend and the potential of these converters to achieve both higher switching frequencies and lower switching losses. However, designing such converters presents many challenges, among them the fact that the LLC resonant half-bridge converter performs power conversion with frequency modulation instead of pulse-width modulation, requiring a different design approach.

DESIGNING OF LLC CONVERTOR

- **Specifications of DC/DC CONVERTOR**

	Min.	Nominal.	Max.
Input Voltage	**72 V**	**78 V**	**84 V**
Rated output Power	**-**	**600 W**	**-**
Output Voltage	**10 V**	**12 V**	**15 V**
Rated Output Current	**20 A**	**-**	**50 A**
Output Voltage (Pk-pk Ripple)	**-**	**-**	**200mV**
Efficiency (Vm = 78V; Io = 40A)	**90%**	**-**	**-**
Switching Frequency (Functional region)	**150 kHz**	**-**	**220 kHz**

- **Components used Parameters:**

Components	**Voltage Rating (V)**	**Current Rating (A)**	**Value**
Resonance Inductor (L_r)	**50 V (AC)**	**30 A**	**1.013 µH**
Resonance Capacitor (C_r)	**115 V**	**30A**	**625 nF**
Leakage Inductance (L_m)	**40 V (AC)**	**20 A**	**2.026 µH**
Rectifier Diode	**25 V**	**80 A**	**-**
Filter capacitor	**16 V**	**25 A**	**470 µF**
MOSFET	**100 V**	**25.6 A**	**Low R_{ds_on}**
Transformer	**Values are mentioned Below**		

➢ Calculations:

1. *Determine Transformer Turns Ratio (n)*

$$n = M_g \times \frac{Vin/2}{Vo} = \frac{Vin\_nom/2}{Vo\_nom}|_{Mg=1}$$

$$= \frac{78/2}{12} = 3.25$$

2. *Determine $Mg_{\_min}$ and $Mg_{\_max}$*

$$M_{g\_min} = \frac{n\times(Vo\_\min + Vf)}{Vin_{max}/2}$$; (Vf = fwd. voltage drop in the rectifier)

$$= \frac{3.25\times(10+1.4)}{\frac{84}{2}}$$

$$= 0.8821$$

$$M_{g\_max} = \frac{n\times(Vo\_\max + Vf + V_{loss})}{Vin\_min/2}$$

$$= \frac{3.25\times(14+1.4+1.05)}{\frac{72}{2}}$$

$= 1.485$

Note : For V_loss, we consider 92% efficiency at 600W and 50A current, So the output voltage drop would be

$$\frac{\frac{600W}{92\%}\times 8\%}{50} = 1.05V$$

3. *Select L_n and Q_e*

From the plot of Voltage-gain function with Ln and Qe as variable we can select the best suited value with suitable maximum attainable gain.

- If the values $L_n = 2$ and $Q_e = 0.62$ are selected, the corresponding $Mg_{\_ap} = 1.6$, which is greater than $Mg_{\_max} = 1.485$.

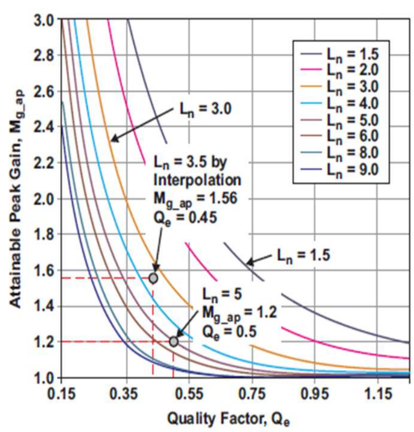


Fig. 1. Plot to determine Qe and Ln with peak gain (Mg_ap)

4. *Determine the Equivalent Load Resistance (R_e)*

$$R_e = \frac{8\times n^2}{\pi^2} \times \frac{Vo}{Io} = 2.054\ \Omega$$

5. *Design Resonant Circuit's Parameters*

A switching frequency of 200 kHz may be selected initially for the series resonant frequency, and then the resonant circuit's parameters can be calculated at full load:

$$C_r = \frac{1}{2\pi \times Qe \times f0 \times Re} = 625\ nF; \qquad \text{(fo is the resonance frequency = 200kHz)}$$

$$L_r = \frac{1}{(2\pi \times f0)^2 Cr} = 1.013\ \mu H;$$

$$L_m = L_r \times L_n = 2 \times 1.013\ \mu H = 2.026 \mu H$$

6. *Dead time between switching of S1 and S2*

$$t_{dead} \geq 16 \times C_{eq} \times f_{SW} \times L_m > 100\text{ns}$$

7. *Determine the Primary-Side Currents*

$$I_{OE} = \frac{\pi}{2\sqrt{2}} \times \frac{I_O}{n} = 1.11 \times \frac{50\ A \times 110\%}{3.25} = 18.78\ ; \quad f_{SW\_min} = 160\ kHz$$

$$I_m = 0.901 \times \frac{nVo}{\omega L_m} = 17.29\ A;$$

$$I_r = \sqrt{Im^2 + Ir^2} = 25.6\ A;$$

8. *Determine the Secondary-Side Currents*

$$I_{\mathbf{oe.s}} = n \times I_{OE} = 3.25 \times 17.29 = 56.1925\ A$$

$$I_{s.av} = \frac{2}{\pi}\sqrt{2} \times I_{\mathbf{oe.s}} = 50.59\ A;$$

9. *Select the Transformer*

- Turns ratio (n): 3.25
- Primary terminal Voltage: 90 – 100 VAC
- Primary winding's rated Current, $I_{wp:}$ 28 – 30 A
- Secondary terminal voltage: 20 VAC
- Secondary winding's rated Current, I_{ws}: 60 A
- Frequency at no load: 220 kHz
- Frequency at full load: 160 kHz
- Insulation between primary and secondary sides: IEC60950 reinforced insulation

10. *Select the Resonant Inductor*

- Series Resonant Inductance, L_r: 1.013 µH
- Rated current, I_{Lr}: 25.6 A
- Terminal AC voltage, V_{Lr}: 50 V
- Frequency Range: 160 to 220 kHz

11. *Select the Resonant Capacitor*

- Series Resonant Capacitance, C_r: 625 nF
- Rated current, I_{Cr}: 25.6 A
- AC voltage, V_{Cr}: $X_{Cr} \times I_r = 40.743\ V \simeq 50\ V$
- RMS voltage: 65.3 V

- Corresponding peak Voltage: 112.71 V $\simeq$ 115 V

12. Select the Primary-Side MOSFETs

- $V_{Q1\_peak} = V_{Q2\_peak} = V_{in} = 84$ V $\Rightarrow$ 100 V
- Low R_{ds_on}
- $I_{Q1\_RMS} = I_{Q2\_RMS} = I_r = 25.6$ A

13. Select the Rectifier Diodes

- Voltage rating of Diode, V_d: 20 – 25 V
- Current Rating of diode: 60 – 90 A

- **From the above parameters we can run an open-loop MATLAB simulation**
- **All Simulation Results is Documented below.**

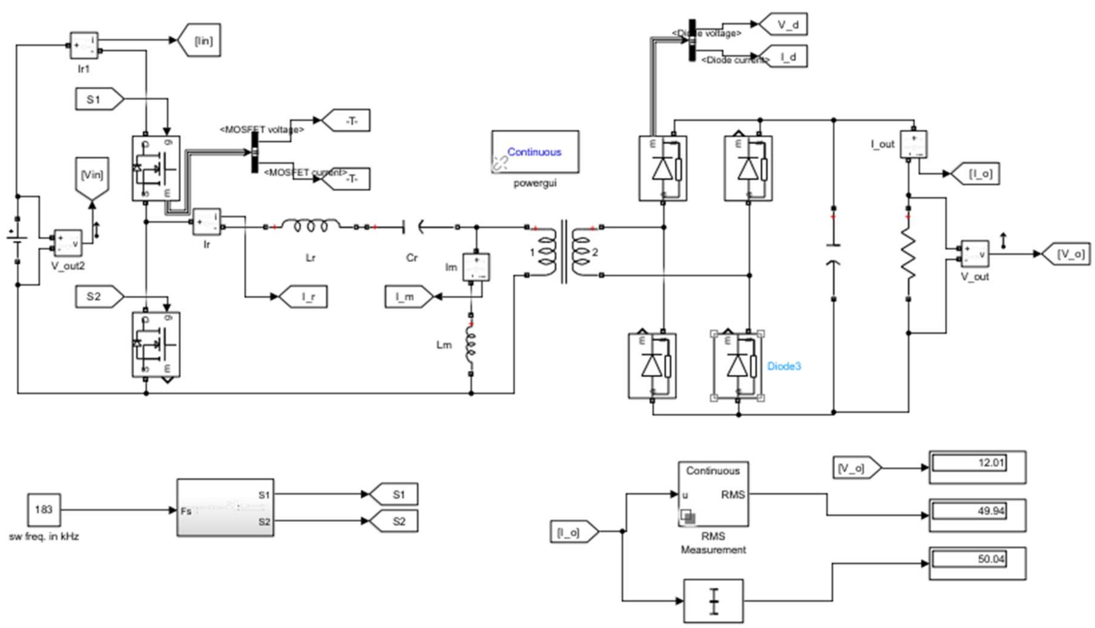
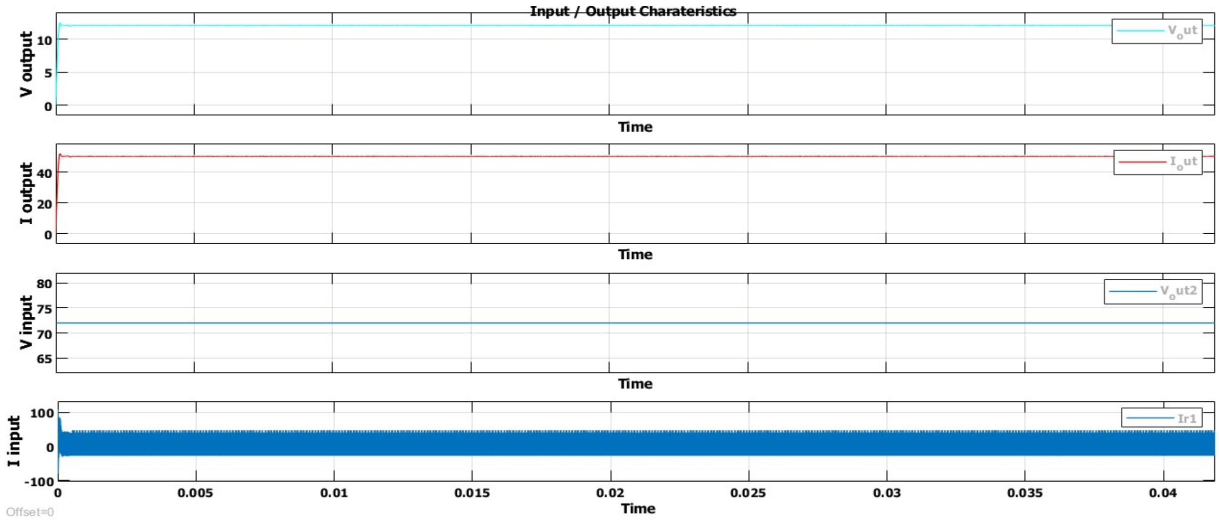
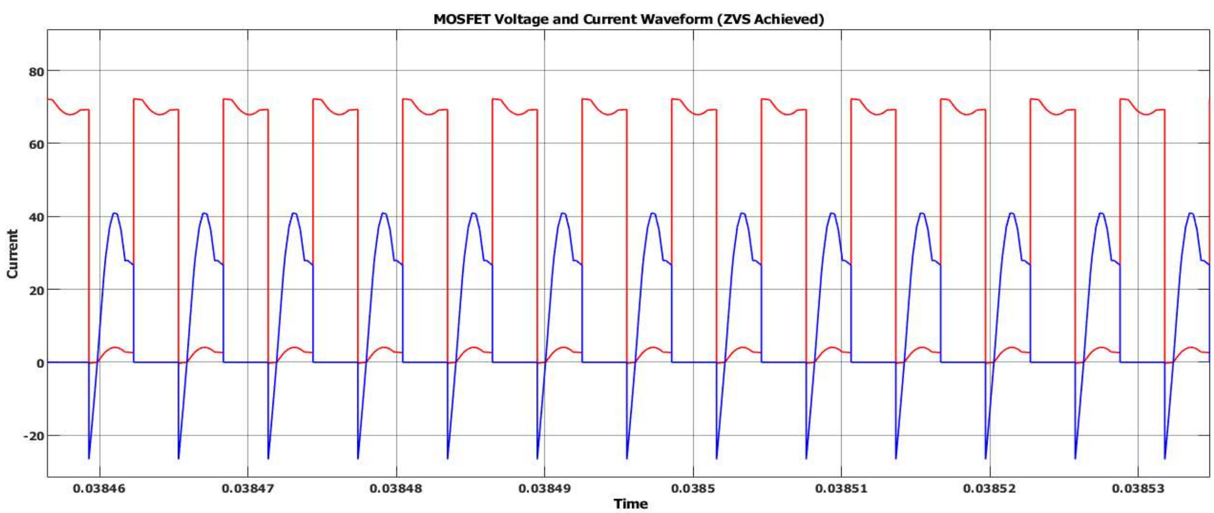


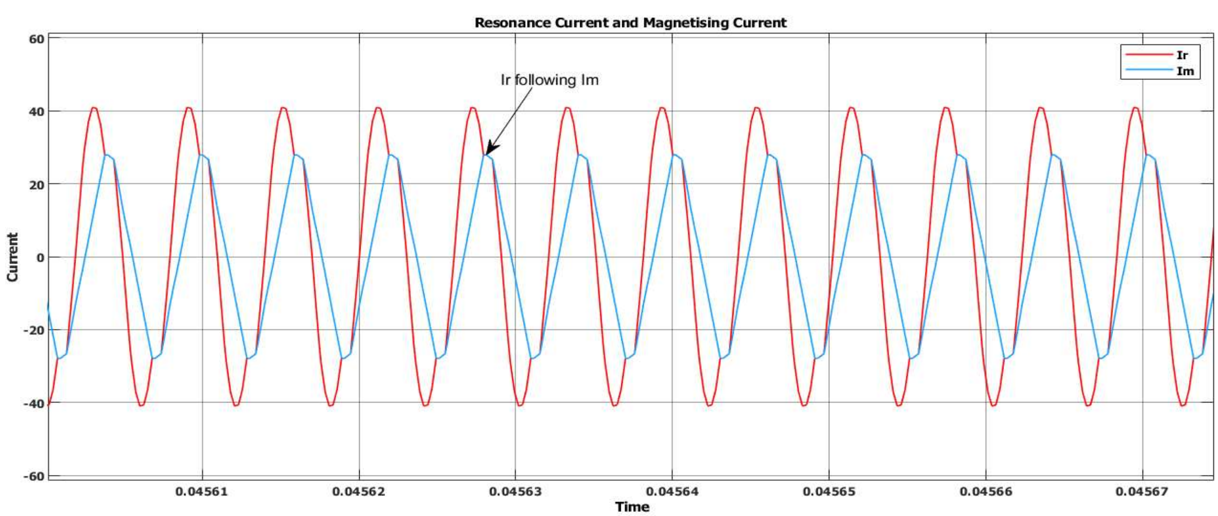
Fig. 2. MATLAB Schematic Diagram of the DC/DC Convertor

❖ RESULTS

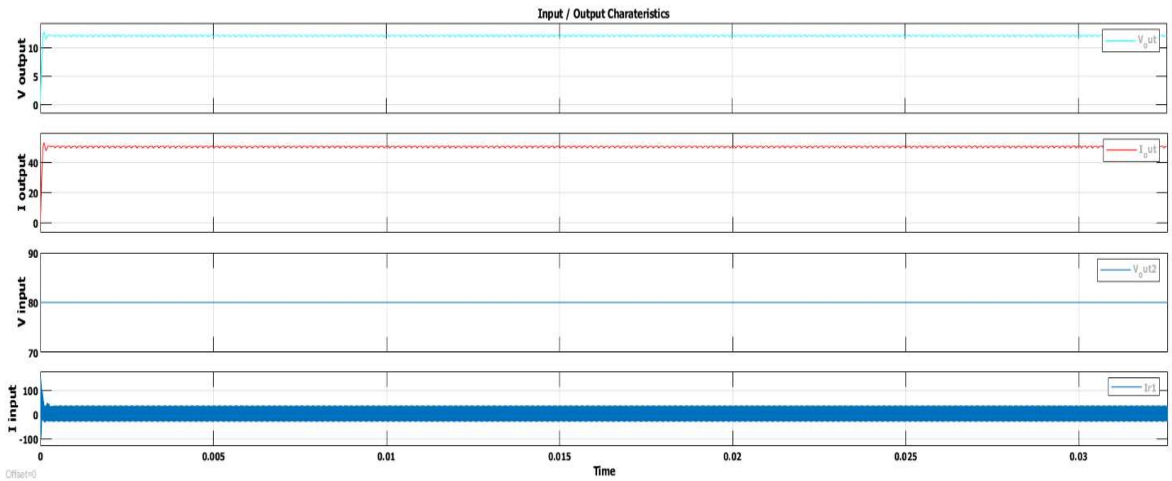
1. **Operating with 72 V input and 165.5 kHz Switching Frequency**

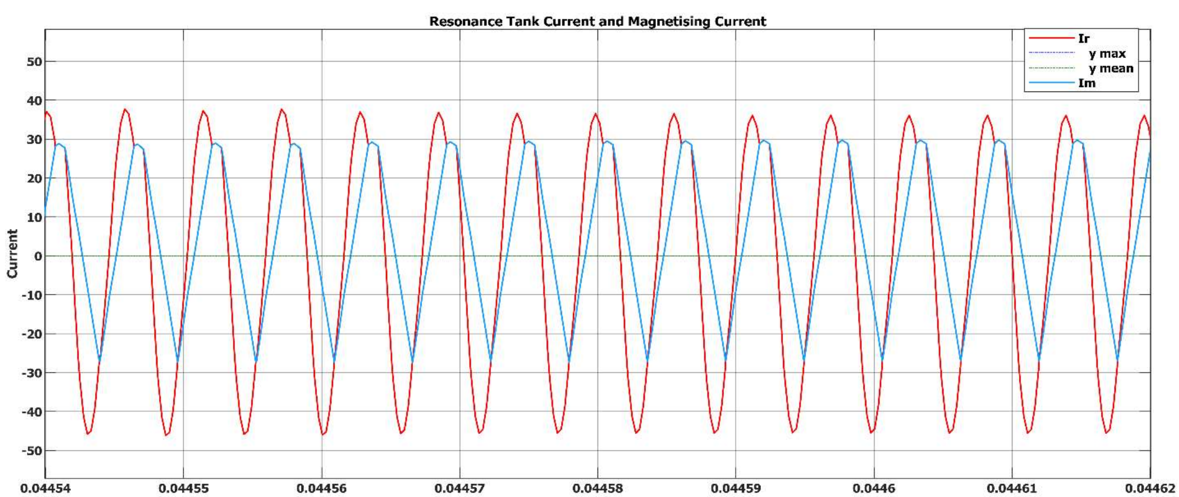






2. **Operating with 80 V input and 176.5 kHz Switching Frequency**





3. **Operating with 84 V input and 183 kHz Switching Frequency**