A Class D half-bridge series-resonant inverter

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Assignment

Select one of the resonant inverters covered in Chapters 6 through 9.

Using either a textbook example or a homework assignment data, perform time-domain simulations of your selected inverter. Show current and voltage waveforms in resonant components at various values of Q_L. Show how the voltage transfer function varies with the switching frequency and Q_L.

Use any suitable software package. Good candidates are, for example, MATLAB/Simulink, LTSpice, or Simplorer.

Abstract

In this project, a circuit of class D voltage-source half-bridge series-resonant inverter (SRI) is built and data from Chapter 6.8 example 6.2 is simulated in MATLAB/Simulink. And it will show the influence of the loaded quality factor Q_L of current and voltage waveforms in resonant components

Introduction

Class D DC-AC resonant inverters, also called Class D resonant amplifiers, were invented in 1959 by Baxandall and have been widely used in various applications to convert DC energy into AC energy.

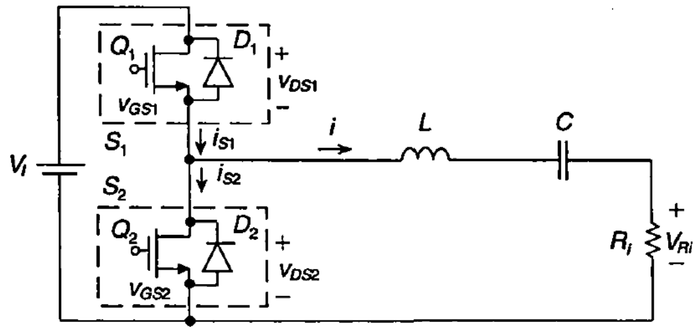
Class D inverters can be classified into two groups:

- Class D voltage-source (or voltage-switching) inverters
- Class D current-source (or current-switching) inverters.

Class D voltage-switching inverters are fed by a DC voltage source. They employ a series-resonant circuit or a resonant circuit that is derived from the series-resonant circuit. If the loaded quality factor is sufficiently high, the current through the resonant circuit is sinusoidal and the currents through the switches are half-wave sinusoids.

Description and Simulation

The circuit of the Class D voltage- source half-bridge series-resonant inverter (SRI) is shown below as Fig.1. The simulation circuit by Simulink is shown below as Fig.2.



(a)

Fig.1 Class D voltage-source half-bridge inverter with a series-resonant circuit

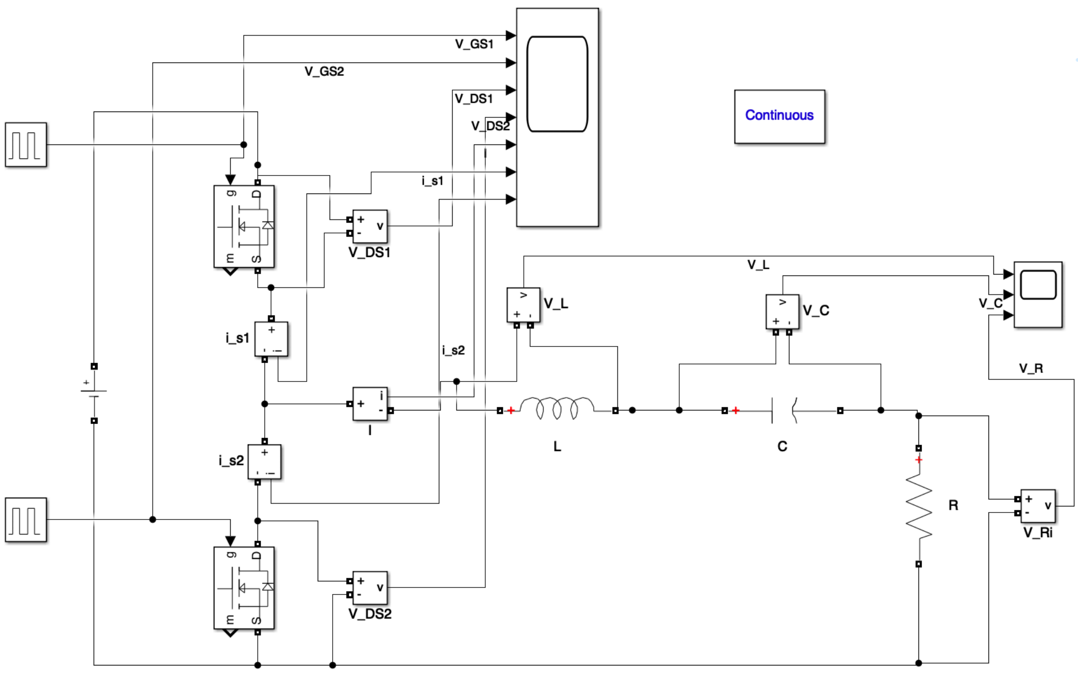


Fig.2 Simulation of Class D voltage-source half-bridge SRI circuit

Data from Chapter 6.8 example 6.2 are as follows:

EXAMPLE 6.2

Design a Class D half-bridge inverter of Fig. 6.1 that meets the following specifications: $V_I = 100\,\text{V}$, $P_{Ri} = 50\,\text{W}$, and $f = 110\,\text{kHz}$. Assume $Q_L = 5.5$, $\psi = 30°$ (i.e., $\cos^2\psi = 0.75$), and the efficiency $\eta_{Ir} = 90\%$. The converter employs IRF621 MOSFETs (International Rectifier) with $r_{DS} = 0.5\,\Omega$, $C_{ds(25V)} = 110\,\text{pF}$, and $Q_g = 11\,\text{nC}$.

1. $\boldsymbol{Q_L = 2}$

Using the data from example 6.2, which is $V_I = 100V$, $f = 110$kHz, $P_{Ri} = 50\,W$, $Q_L = 2$, $\eta_{Ir} = 90\%$, $\psi = 30°$.

From (6.69), the DC input power of the inverter is

$$P_I = \frac{P_{Ri}}{\eta_{Ir}} = \frac{50}{0.9} = 55.56W$$

Using (6.41), the overall resistance of the inverter can be calculated as

$$R = \frac{2V_I^2}{\pi^2 P_I} cos^2\psi = \frac{2 \times 100^2}{\pi^2 \times 55.56} \times 0.75 = 27.35\Omega$$

Relationships (6.69) and (6.13) give the load resistance

$$R_i = \eta_{Ir} R = 0.9 \times 27.35\Omega = 24.62\Omega$$

The peak value of the switch current is

$$I_m = \sqrt{\frac{2P_{Ri}}{R_i}} = \sqrt{\frac{2 \times 50}{24.62}} = 2.02A$$

and from (6.45) the peak value of the switch voltage is equal to input voltage

$$V_{SM} = V_I = 100V$$

Using (6.26), one arrives at the ratio f/f_0 at full load,

$$\frac{f}{f_0} = \frac{1}{2}\left(\frac{tan\psi}{Q_L} + \sqrt{\frac{cos^2\psi}{Q_L^2} + 4}\right) = \frac{1}{2}\left(\frac{0.5774}{2} + \sqrt{\frac{0.5774^2}{2^2} + 4}\right) = 1.155$$

from which

$$f_0 = \frac{f}{(f/f_0)} = \frac{110 \times 10^3}{1.155} = 95.2kHz$$

The values of the reactive components of the resonant circuit are calculated from (6.10) as

$$L = \frac{Q_L R}{\omega_0} = \frac{2 \times 27.35}{2\pi \times 95.2 \times 10^3} = 30\mu H$$

and

$$C = \frac{1}{\omega_0 Q_L R} = \frac{1}{2\pi \times 95.2 \times 10^3 \times 2 \times 27.35} = 30nF$$

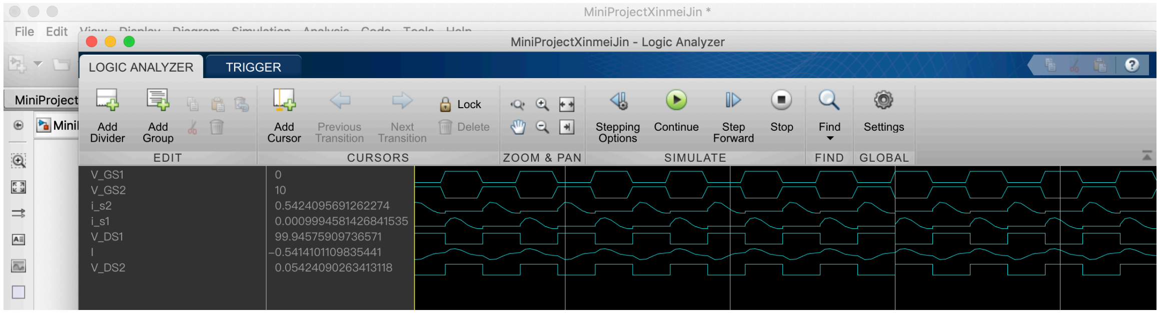


Fig.3 Current and voltage waveforms of Class D inverter ($Q_L = 2$)

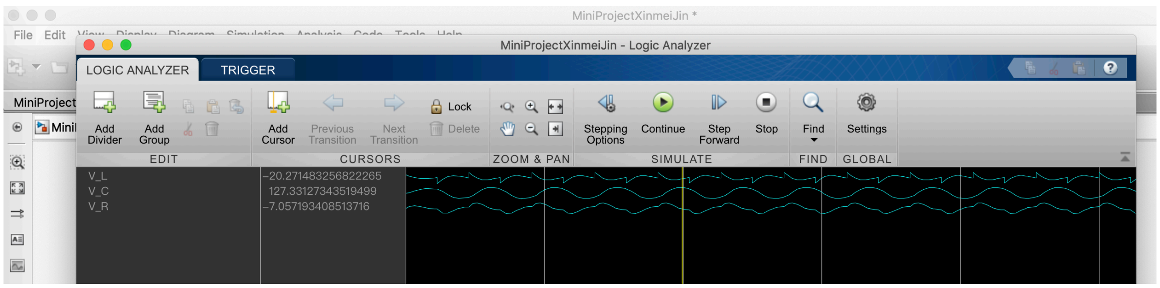


Fig.4 Voltage waveforms of L, C and R component ($Q_L = 2$)

2. $Q_L = 5$,

If the loaded quality factor Q_L is changed to $Q_L = 5$.

Using (6.26), the ratio f/f_0 at full load

$$\frac{f}{f_0} = \frac{1}{2}\left(\frac{tan\psi}{Q_L} + \sqrt{\frac{cos^2\psi}{Q_L^2} + 4}\right) = \frac{1}{2}\left(\frac{0.5774}{5} + \sqrt{\frac{0.5774^2}{5^2} + 4}\right) = 1.059$$

from which,

$$f_0 = \frac{f}{(f/f_0)} = \frac{110 \times 10^3}{1.059} = 103.9kHz$$

The values of the reactive components of the resonant circuit are calculated from(6.10) as

$$L = \frac{Q_L R}{\omega_0} = \frac{5 \times 27.35}{2\pi \times 103.9 \times 10^3} = 209\mu H$$

and

$$C = \frac{1}{\omega_0 Q_L R} = \frac{1}{2\pi \times 103.9 \times 10^3 \times 5 \times 27.35} = 11.2nF$$

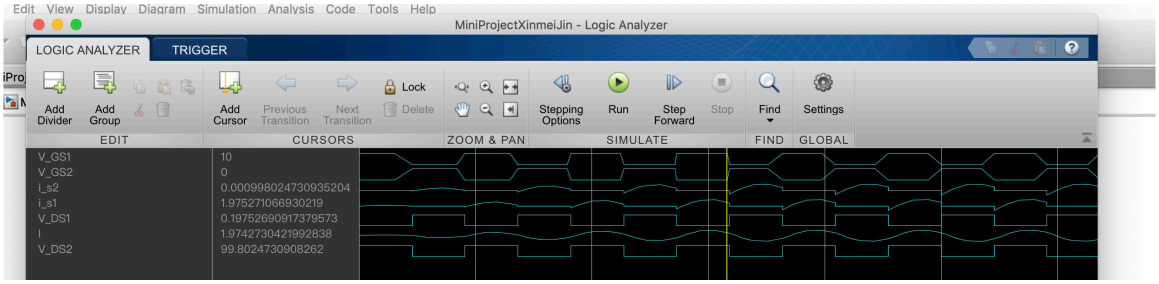


Fig.5 Current and voltage waveforms of Class D inverter ($Q_L = 5$)

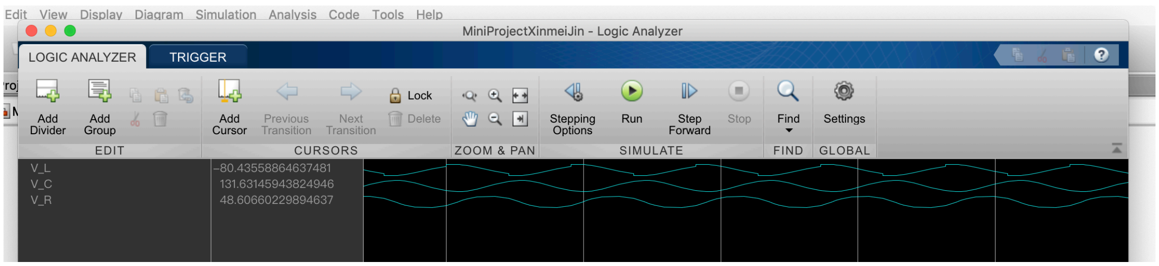


Fig.6 Voltage waveforms of L, C and R component ($Q_L = 5$)

3. $Q_L = 10$,

If the loaded quality factor Q_L is changed to $Q_L = 10$.

Using (6.26), the ratio f/f_0 at full load

$$\frac{f}{f_0} = \frac{1}{2}\left(\frac{tan\psi}{Q_L} + \sqrt{\frac{cos^2\psi}{Q_L^2} + 4}\right) = \frac{1}{2}\left(\frac{0.5774}{10} + \sqrt{\frac{0.5774^2}{10^2} + 4}\right) = 1.029$$

from which,

$$f_0 = \frac{f}{(f/f_0)} = \frac{110 \times 10^3}{1.059} = 106.9kHz$$

The values of the reactive components of the resonant circuit are calculated from (6.10) as

$$L = \frac{Q_L R}{\omega_0} = \frac{10 \times 27.35}{2\pi \times 106.9 \times 10^3} = 407\mu H$$

and

$$C = \frac{1}{\omega_0 Q_L R} = \frac{1}{2\pi \times 106.9 \times 10^3 \times 10 \times 27.35} = 5.4nF$$

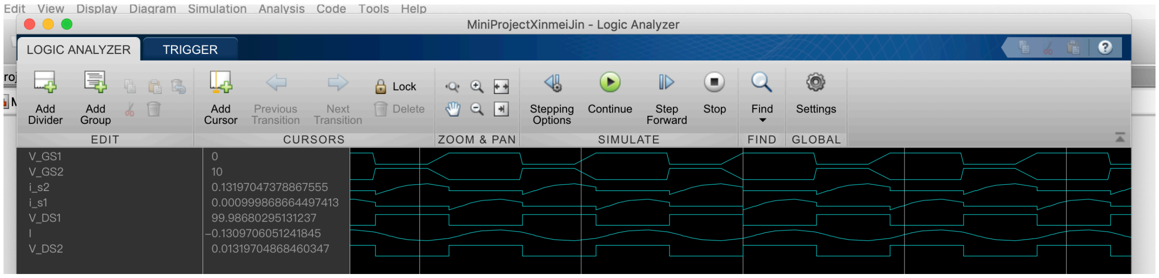


Fig.7 Current and voltage waveforms of Class D inverter ($Q_L = 10$)

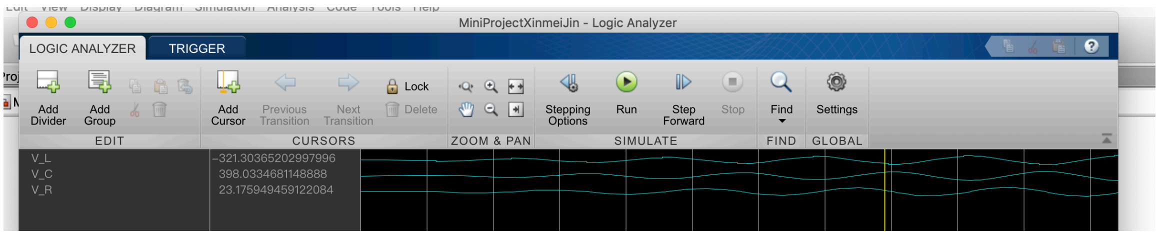


Fig.8 Voltage waveforms of L, C and R component ($Q_L = 10$)

4. Magnitude of voltage transfer function $|M_{Vr}|$

The magnitude of the voltage transfer function $|M_{Vr}|$ is given as:

$$|M_{Vr}| = \frac{V_{Ri}}{V_{rms}} = \frac{\eta_{Ir}}{\sqrt{1 + Q_L^2\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)}}$$

The parameters are setting as: $\omega = 2\pi f, \omega_0 = 2\pi f_0$, $\eta_{Ir} = 90\%$, $f_0 = 104.4kHz$.

From the plotted figure Fig.9 below, it is obvious that $|M_{Vr}|$ will be affected by the switching frequency f and loaded quality factor Q_L. From Fig.9 below, we can see that $|M_{Vr}|$ reaches its peak when $f/f_0 = 1$.

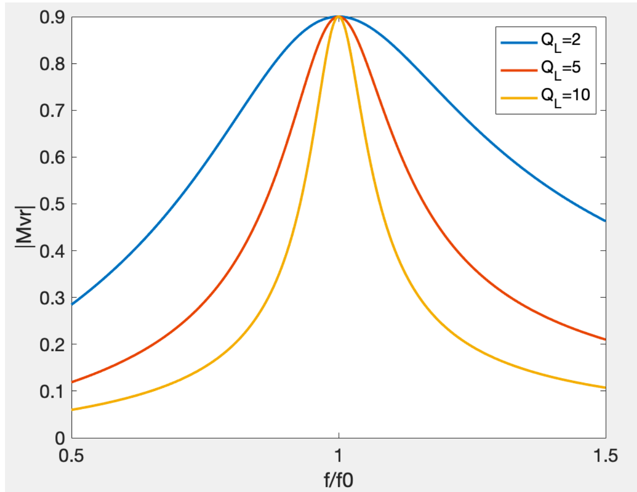


Fig.9 $|M_{Vr}|$ of the series-resonant circuit versus normalized operating frequency f/f_0 at fixed values of Q_L at $\eta_{Ir} = 90\%$.

Compare Fig.9 with figure 6.19 from textbook as below, the similarity of these two figures shows the correctness of my project.

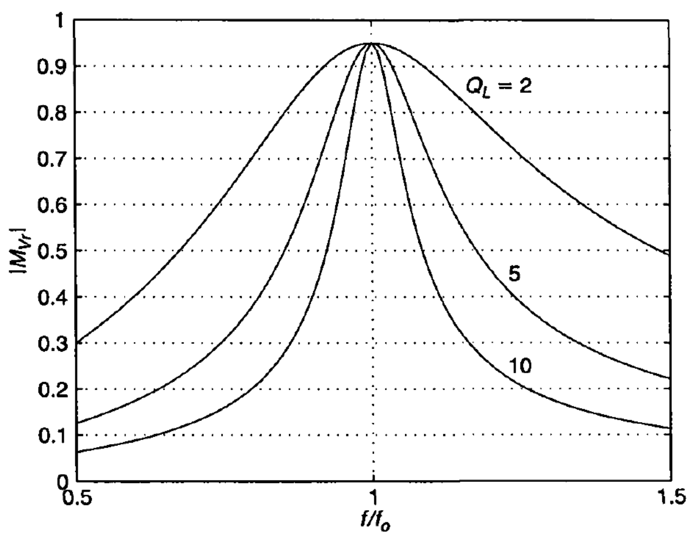


FIGURE 6.19 Magnitude of voltage transfer function $|M_{Vr}|$ of the series-resonant circuit versus normalized operating frequency f/f_o at fixed values of Q_L at $\eta_{Ir} = 95\%$.

References

[1] Resonant Power Converters, second edition, Marian K.Kazimierczuk, Dariusz Czarkowski.