# SYSTEM FOR AUTOMATED DESIGN OF RESONANT INVERTERS

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**Abstract:** In the MATLAB environment, with the help of author's code, a programming environment is developed in which the input parameters are entered, the type and structure of the inverter is selected, and the values of the circuit elements are automatically calculated. Finally, for the purpose of verification, the operation of the designed inverter is simulated. From the resulting simulation, the overall behavior of the state space variables is seen.

**Key words:** automated design, Matlab, power electronic device design, resonant inverters.

## 1. INTRODUCTION

Software environments play an important role in the design of power electronic devices by providing a variety of tools for analysis, simulation, and optimization. Here are some of the main types of software and their specific role in improving the characteristics and ensuring the performance of power electronic devices [1-3]:

- ***Simulation and Modeling Software:*** SPICE (Simulation Program with Integrated Circuit Emphasis) is used to create digital models of electrical circuits. This software allows engineers to perform various types of simulations, including timing analysis, AC and DC analyses, frequency analyses, and more. SPICE is a useful tool for analyzing the behavior of circuits before their physical implementation [4].

• ***Optimization Software:*** MATLAB is a powerful programming language that is used in power electronics to implement control and optimization algorithms. Simulink, part of MATLAB, provides a graphical environment for the modeling and simulation of systems, including power electronic devices.

• ***Software for Electromagnetic and Thermal Analysis:*** ANSYS provides tools for electromagnetic and thermal analysis. This software is useful in designing inductors, transformers and other components in power electronics. It allows engineers to study the effects of electromagnetic fields and heat distribution in devices.

• ***Power Optimization Software:*** PSIM is a power electronics simulation and optimization software. It focuses on power analysis, control circuits and power circuits for electronic converters.

• ***Code Generation Software:*** For embedded power electronics systems, code generation software such as Embedded Coder (part of MATLAB/Simulink) can be used to automatically generate code from models created in Simulink.

The use of specialized software greatly facilitates the design process, allowing designers to perform complex mathematical analyzes and simulations that are key to the optimization and development of power electronic devices. In this aspect, the aim of the present work is to present a Matlab-based automated system for the design of the main types of resonant inverters.

The authors, because of their many years of work in the field of power electronics, have found that for inverter design purposes it is good to use the following inputs:

$cos(\varphi_T)$ – load power factor, from where $tg(\varphi_T) = \frac{L\,\omega}{R}$ ($R$ and $L$ are load parameters); $f$ - switching frequency; $U$ – inverter output AC voltage (RMS); $U_d$ – DC power supply voltage; $P$ – inverter active power.

When designing all types of inverters, at some stage of the design it is necessary to calculate the following basic quantities [5,6]:

$\delta = \frac{1}{2RC}$ - attenuation of a series resonant circuit;

$\omega_0 = \sqrt{\frac{1}{LC} - \delta^2}$ - resonant frequency of a series resonant circuit;

$\nu = \frac{\omega}{\omega_0}$ - frequency ratio $(\omega = 2\pi f)$;

$k = \frac{1}{1 - e^{-\delta \frac{\pi}{\omega_0}}}$ - coefficient of variation, from where $\frac{\delta}{\omega_0} = \frac{1}{\pi} \ln \frac{k}{k-1}$;

$\beta$ - dephasing angle between output current and output voltage, from where

$$tg\beta = \frac{1}{2\nu}\left(\frac{\delta}{\omega_0} + \frac{\omega_0}{\delta}\right) = \frac{1}{2\nu}\left(\frac{\pi}{\ln(k/(k-1))} + \frac{\ln(k/(k-1))}{\pi}\right) \quad (1)$$

This article presents an algorithm for designing resonant inverters, which can be divided into two stages: first, the type of inverter is selected and an optimal ratio between the coefficients *k* and *ν* is found, and then the structure (scheme) of the inverter is selected and calculate the values of the circuit elements.

Finally, the operation of the designed inverter is simulated to determine whether there are any unwanted peaks during the transient responses.

## 2. FINDING THE OPTIMUM RATIO *k* - ν.

First, the design parameters are entered $cos(\varphi_T)$, $f$, $U$, $U_d$ and $P$.

Next, the inverter type is selected and an angle is determined $\beta$:

$\cos\beta = \frac{\pi}{2\sqrt{2}}\frac{U_d}{U}$ - for current source inverter

or

$\cos\beta = \frac{2\sqrt{2}}{\pi}\frac{U_d}{U}$ - for a resonant inverter.

Choosing a value for ν:

$\nu \geq 2.5$ - for current source inverter

or

$\nu \in [0.8, 1.2]$ - for a resonant inverter.

After which from (1) the quadratic equation is obtained

$$x^2 - 2\nu\, tg(\beta)\, x + 1 = 0, \text{ where } x = \frac{\delta}{\omega_0} = \frac{1}{\pi}\ln\frac{k}{k-1} \quad (2)$$

Solving this equation gives

$$x = \nu\, tg(\beta) - \sqrt{\nu^2\, tg^2(\beta) - 1}.$$

Finally, the coefficient of variation is found

$$k = \frac{1}{1 - e^{-\pi x}}.$$

## 3. DESIGN OF FOUR TYPES OF INVERTERS.

With the help of already introduced design parameters $cos(\varphi_T)$, $f$, $U$, $U_d$ and $P$, and with the values obtained in the previous point for *k* and *ν*, a parallel inverter can be designed. If we add the load voltage $U_T$ to the design parameters, parallel-series and series-parallel inverters can also be designed. If we also add the voltage $U'$, a series-parallel-series inverter can also be designed. What exactly are the voltages $U_T$ and $U'$ we will clarify further in this point [7,8].

The four types of inverters we will consider in this point are bridge inverters, which generally have the structure shown in Figure 1. The difference is that circuits with a different structure are connected between points A and B.

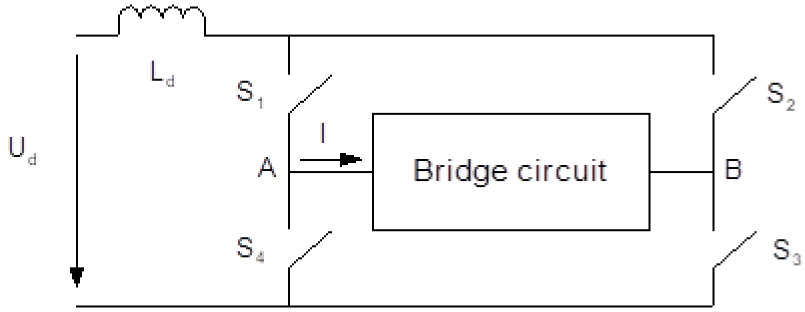


*Figure 1 Structure of a full-bridge inverter*

**3.1 Design of parallel inverter**

For the parallel inverter, the AC circuit structure is shown in Figure 2.

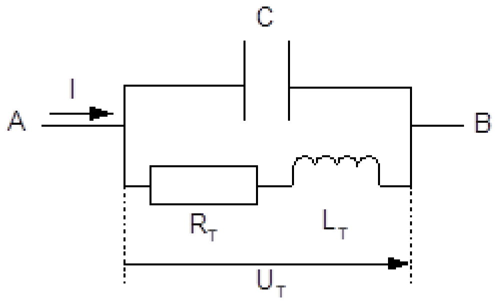


*Figure 2 AC circuit of parallel inverter*

Based on the design parameters (specified at the beginning of this point), we calculate:

- angle $\beta$

$$\beta = arctg\left(\frac{1}{2\nu}\left(\frac{\delta}{\omega_0}+\frac{\omega_0}{\delta}\right)=\frac{1}{2\nu}\left(\frac{\pi}{\ln(k/(k-1))}+\frac{\ln(k/(k-1))}{\pi}\right)\right)$$

- resistance of the substitute parallel circuit $R_e$

$$R_e = \frac{U_T^2}{P}$$

- parallel capacitor C

$$C = \frac{tg(\beta)+tg(\varphi_T)}{\omega R_e}$$

- resistance and inductance of load elements $R_T$ и $L_T$

$$R_T = R_e \cos^2(\varphi_T) \quad \text{and} \quad L_T = \frac{R_T tg(\varphi_T)}{\omega}.$$

- external inductance $L_d$

$$L_d = \frac{R_1}{2\delta}, \text{ where } R_1 = R_e \cos^2(\beta),\ \delta = \frac{\omega_0}{\pi}\ln\frac{k}{k-1} \text{ and } \omega_0 = \frac{\omega}{\nu}.$$

**3.2 Design of series-parallel inverter**

For the series-parallel inverter, the AC circuit structure is shown in Figure 3.

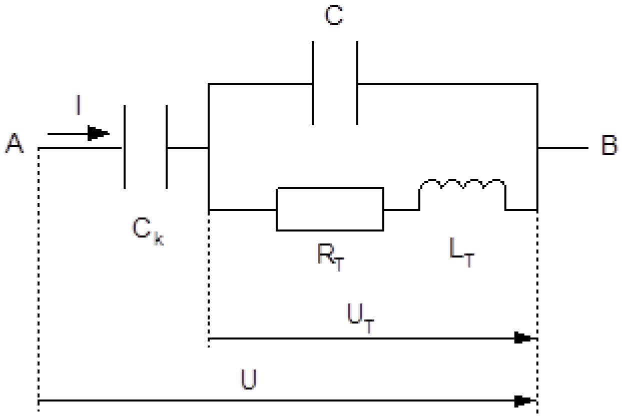


*Figure 3 AC circuit of series-parallel inverter*

Obviously, in this case we have $U \neq U_T$, which requires $U_T$ to be added as an input parameter in the design. The rest of the design parameters are the same.

The design algorithm includes calculation of:

- angle $\beta$

$$\beta = arctg\left(\frac{1}{2\nu}\left(\frac{\delta}{\omega_0}+\frac{\omega_0}{\delta}\right)=\frac{1}{2\nu}\left(\frac{\pi}{\ln(k/(k-1))}+\frac{\ln(k/(k-1))}{\pi}\right)\right)$$

- resistance of the substitute parallel circuit $R_e$ of the load

$$R_e = \frac{U_T^2}{P}$$

- parallel capacitor $C$

$$C = \frac{tg(\beta)+tg(\varphi_T)}{\omega R_e}$$

- resistance and inductance of the load elements $R_T$ and $L_T$

$$R_T = R_e \cos^2(\varphi_T) \quad \text{and} \quad L_T = \frac{R_T tg(\varphi_T)}{\omega}.$$

- external inductance $L_d$

$$L_d = \frac{R_1}{2\delta}, \text{ where } R_1 = R_e \cos^2(\beta) \text{ and } \delta = \frac{\omega}{\pi\nu}\ln\frac{k}{k-1}$$

- capacitor $C_k$

$$C_k = \frac{C_e C_1}{C_1 - C_e}, \text{ where } C_e = \frac{1}{Ld(\omega_o^2+\delta^2)},\ C_1 = \frac{1}{\omega X_1} \text{ and } X_1 = R_e \cos(\beta)\sin(\beta).$$

**3.3 Design of parallel-series inverter**

For the parallel-series inverter, the AC circuit structure is shown in Figure 4.

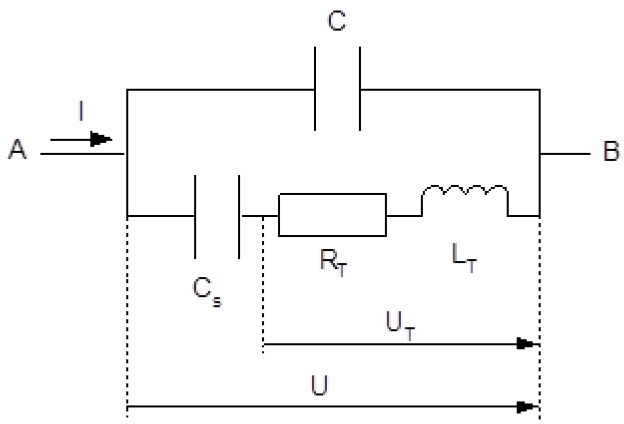


*Figure 4 AC circuit of parallel-series inverter*

Again, $U_T$ has to be added as an input parameter in the design. The rest of the design parameters are the same.

The design algorithm includes, calculation of:

- angle $\beta$

$$\beta = arctg\left(\frac{1}{2\nu}\left(\frac{\delta}{\omega_0}+\frac{\omega_0}{\delta}\right)=\frac{1}{2\nu}\left(\frac{\pi}{\ln(k/(k-1))}+\frac{\ln(k/(k-1))}{\pi}\right)\right)$$

- resistance of the substitute parallel circuit $R_e$ of the load

$$R_e = \frac{U_T^2}{P}$$

- resistance of the substitute parallel circuit $R'_e$ of the bridge

$$R'_e = \frac{U^2}{P}$$

- parallel capacitor $C$

$$C = \frac{tg(\beta)+tg(\varphi)}{\omega R'_e}, \text{ where } \cos(\varphi) = \frac{U_T}{U}\cos(\varphi_T)$$

- resistance and inductance of the load elements $R_T$ and $L_T$

$$R_T = R_e \cos^2(\varphi_T) \quad \text{and} \quad L_T = \frac{R_T tg(\varphi_T)}{\omega}.$$

- external inductance $L_d$

$$L_d = \frac{R_1}{2\delta}, \text{ where } R_1 = R_e \cos^2(\beta),\ \delta = \frac{\omega_0}{\pi}\ln\frac{k}{k-1} \text{ and } \omega_0 = \frac{\omega}{\nu}.$$

- capacitor $C_s$

$$C_s = \frac{1}{\omega R_T (tg(\varphi_T) - tg(\varphi))}$$

### 3.4 Design of serial-parallel-parallel-serial inverter

For a serial-parallel-parallel-serial inverter, the AC circuit structure is shown in Figure 5.

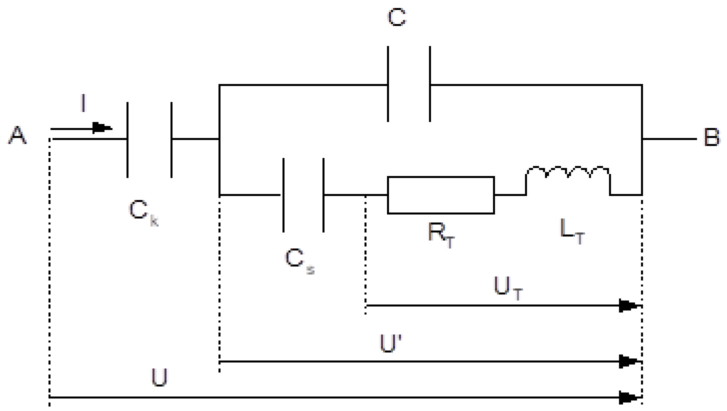


*Figure 5 АЦ circuit of serial-parallel-parallel-serial inverter*

Again we have to add the design data $U_T$, but we also have to add the voltage $U'$. The rest of the design parameters are the same.

The design algorithm includes calculation of:

- angle $\beta$

$$\beta = arctg\left(\frac{1}{2\nu}\left(\frac{\delta}{\omega_0} + \frac{\omega_0}{\delta}\right) = \frac{1}{2\nu}\left(\frac{\pi}{\ln(k/(k-1))} + \frac{\ln(k/(k-1))}{\pi}\right)\right)$$

- resistance of the substitute parallel circuit $R_e$ of the load

$$R_e = \frac{U_T^2}{P}$$

- resistance of the substitute parallel circuit $R'_e$ of the bridge

$$R'_e = \frac{U^2}{P}$$

- parallel capacitor $C$

$$C = \frac{tg(\beta) + tg(\varphi)}{\omega R'_e}, \text{ where } \cos(\varphi) = \frac{U_T}{U}\cos(\varphi_T)$$

- resistance and inductance of the load elements $R_T$ and $L_T$

$$R_T = R_e \cos^2(\varphi_T) \quad \text{and} \quad L_T = \frac{R_T tg(\varphi_T)}{\omega}.$$

- external inductance $L_d$

$$L_d = \frac{R_1}{2\delta}, \text{ where } R_1 = R_e \cos^2(\beta),\ \delta = \frac{\omega_0}{\pi}\ln\frac{k}{k-1} \text{ and } \omega_0 = \frac{\omega}{\nu}.$$

- capacitor $C_k$

$C_k = \frac{C_e C_1}{C_1 - C_e}$, where $C_e = \frac{1}{Ld(\omega_o^2 + \delta^2)}$, $C_1 = \frac{1}{\omega X_1}$ and $X_1 = R_e \cos(\beta)\sin(\beta)$.

- serial capacitor $C_s$

$$C_s = \frac{1}{\omega R_T (tg(\varphi_T) - tg(\varphi))}$$

## 4. SIMULATION OF THE OPERATION OF THE SYSTEM FOR AUTOMATED DESIGN.

Block diagram of the developed automatic design system is shown in Figure 6.

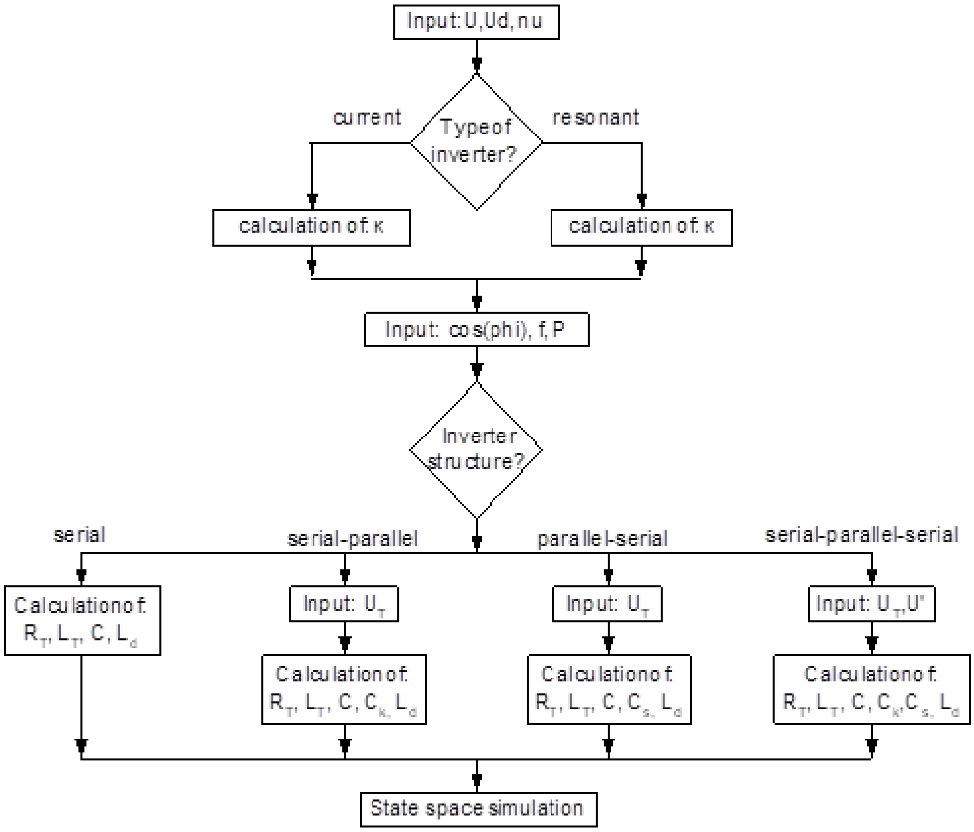


*Figure 6. Automatic design system (block diagram)*

The first part of the developed automated design system allows, after entering the design parameters, to calculate the values of the circuit elements and the coefficient of variation.

In the second part of this program (based on equations used to model the dynamics of the corresponding inverter) the behavior of the state space variables is simulated.

The operation of the program is tested for the design of a parallel current-source inverter.

For this inverter, we choose the following design parameters ν=3, $cos(\varphi_T)$=0.1, $f$=2400 Hz, $U$=850 V, $U_d$ =500 V and $P$=160 kW.

We get the values of circuit elements $C$=1.6314e-004F, $L$=2.9795e-005H, $R$=0.0452Ω and $L_{d.}$= 0.0013H, as well as coefficient of variation $k$=2.7.

For a parallel resonant inverter, the equations that simulate the behavior of the state space variables $u(t)$, $i_d(t)$ and $i(t)$ are:

$$C\frac{du}{dt} + i = control(t) i_d$$
$$L_d \frac{di_d}{dt} + control(t) u_C = U_d \text{ , for } control(t) = \begin{cases} -1, & \text{for odd half period} \\ 1, & \text{for even half period} \end{cases} . \qquad (3)$$
$$L\frac{di}{dt} + R\, i = u$$

The output of the program is shown in Figures 7, 8 and 9. These figures contain: values of the design elements (i.e. input inductance $L_d$, load elements $R$ and $L$, parallel capacitor $C$, switching frequency 1/T, supply voltage $U_d$, simulation time $t$, in milliseconds) and the graphs of the state space variables $u(t)$, $i_d(t)$ and $i(t)$.

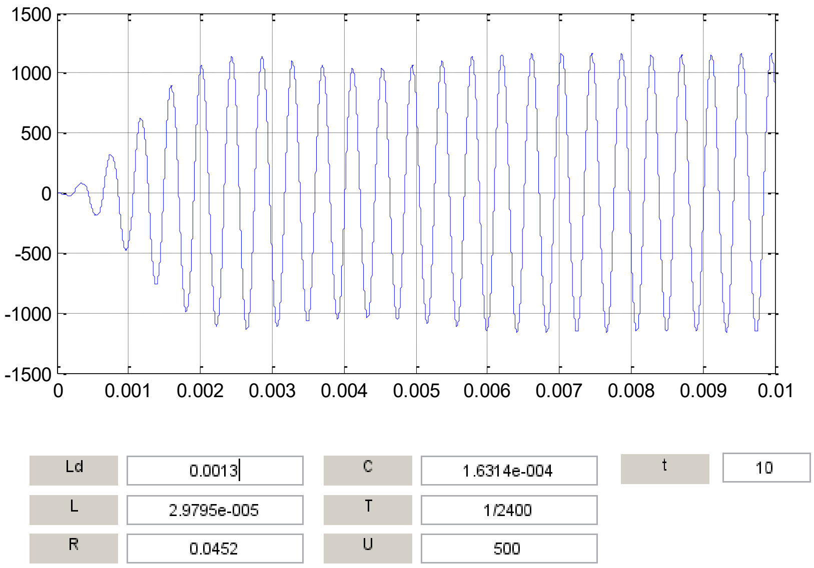


*Figure 7. Output voltage of a parallel current inverter - u(t)*

The simulated results for $u(t)$, $i_d$(t) and $i(t)$ show that for the so designed inverter the desired design objectives are achieved and there is no overshot in transient responses, therefore we can consider that the design is successful.

For the other types of resonant inverters discussed in the previous two points, the design system works similarly.

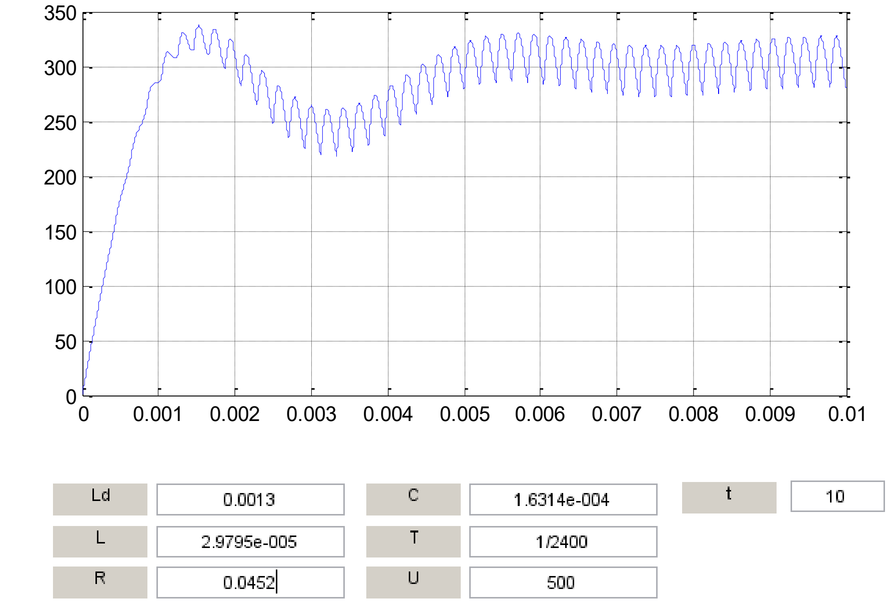


*Figure 8. Input current of a parallel current inverter - $i_d(t)$*

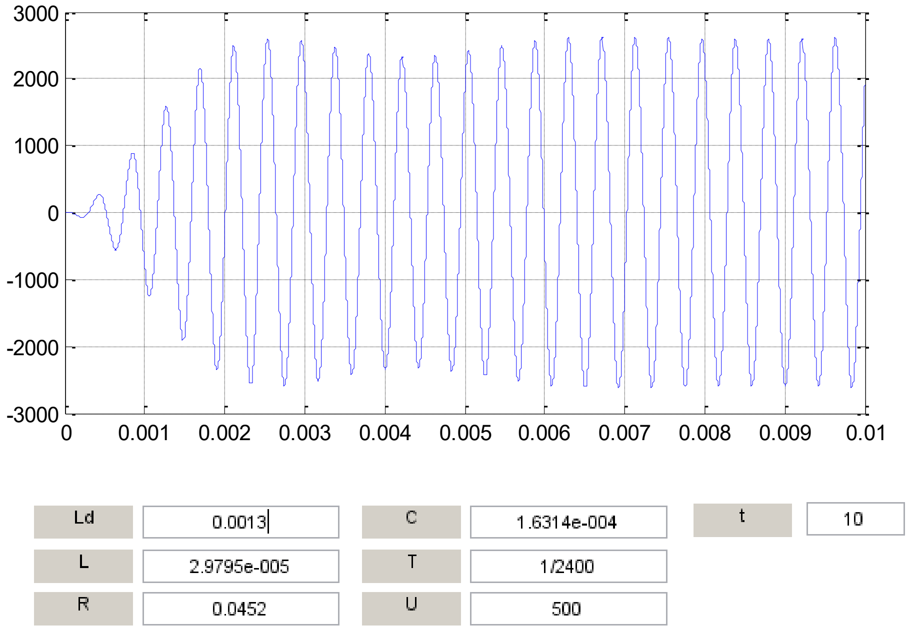


*Figure 9. Current through the load of a parallel current inverter - i(t)*

## 5. CONCLUSION

The work presents an automated system for the design of resonant inverters operating in different modes, based on Matlab. For this purpose, rational design methods are used, through a general description of the electromagnetic processes in a series RLC circuit.

Automating the design of power electronic devices provides a number of advantages, but also has some potential disadvantages. It is important to note that possible benefits or problems may depend on the specific application context and how the automation tools are used. In summary, they can be presented as follows:

***1. Advantages:***

- Faster Development: Automation enables a faster and more efficient design process as numerous steps can be performed automatically.
- Resource Optimization: Automation software tools can optimize the use of resources, such as the energy and materials used in power electronic devices.
- Greater Flexibility: Automation enables easy testing of different configurations and variants, giving greater design flexibility.
- Better Project Management: Project management and documentation generation software tools can greatly improve project tracking and documentation.
- Compliance with Standards: Automation can help facilitate compliance with regulatory standards and regulations.

***2. Disadvantages:***

- Need for Expert Supervision: Automation cannot always replace expert human supervision, especially for complex and specific projects. Engineers must monitor and analyze the results provided by the automated tools.
- Limited Creativity: Automation is based on programs and algorithms that can be limited in their creative potential. In some cases, human intuition and creativity are essential in designing.
- Software Complexity: Some automation software tools can be complex to use and set up, which may require time and training on the part of engineers.
- Need for Updates and Maintenance: Automation software needs to be regularly updated and maintained to cope with the fading technological challenges.
- Potential for Remote Problems: If the automated process is set up incorrectly or is not suitable for the particular application, it can lead to serious design problems.

Indeed, the successful use of automation in power electronics requires a balance between the use of technology and engineering skills to ensure that the result is reliable, efficient and meets the requirements of the application. One development of the system is its combination with tools for model-based optimization and other artificial intelligence techniques, in order to obtain an optimal design according to certain criteria. The presented platform is useful both for practicing design engineers and in power electronics education.

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