

SIMULACIJA INVERTORA ZA INDUKCIONO GREJANJE

SIMULATION OF INVERTER FOR INDUCTION HEATING

Biljana BAKOVIĆ*¹, Zoran STEVIC²,

¹ School of Electrical Engineering - University of Belgrade, Serbia

² School of Electrical Engineering - University of Belgrade, Technical Faculty Bor,
University of Belgrade, CIK, Belgrade, Serbia

Sistemi za indukciono grejanje koriste se u elektrotermiji za zagrevanje predmeta obrade (šarže) u cilju dobijanja željenog oblika i hemijskih i mehaničkih osobina. Indukciono zagrevanje zasniva se na pojavi elektromagnetne indukcije, odnosno indukovanju vrtložnih struja u zagrevanom predmetu kada se on nalazi u promenljivom magnetskom polju induktora. Zbog toga je indukciono zagrevanje ograničeno na obradu metala. Proticanje indukovanih struja kroz šaržu dovodi do generisanja toplotne energije zbog Džulovih gubitaka. Veoma važnu ulogu igra i površinski efekat, odnosno pojava neravnomerne raspodele struja po poprečnom preseku šarže. Usled površinskog efekta, gustina indukovane struje najveća je na površini i opada ka njenoj unutrašnjosti. Brzina opadanja struje zavisi od električnih i magnetnih osobina materijala i od učestanosti magnetnog polja, pri čemu je veća na većim učestanostima. Posledica toga je da se toplotna energija generiše u sloju određene debljine na površini šarže, pri čemu je debljina određena osobinama materijala i učestanošću magnetskog polja. Za napajanje indukcionog grejanja većih i velikih snaga mogu se koristiti polumosni i mosni invertori, kao i paralelna veza više invertora. U ovom radu prikazana je simulacija jednog polumosnog invertora koji napaja indukcionu peć.

Ključnereči: Indukciono grejanje; Energetska efikasnost; Polumosni inverter; Simulacija

Induction heating systems are used in electrothermy to heat the object to obtain the desired shape and chemical and mechanical properties. Induction heating is based on the occurrence of electromagnetic induction, ie induction of eddy currents in the heated object when it is in a changing magnetic field of the inductor. Therefore, induction heating is limited to metal processing. The flow of induced currents through the object leads to the generation of thermal energy due to Joule losses. The surface effect also plays a very important role, ie the appearance of uneven current distribution across the batch cross-section. Due to the surface effect, the density of the induced current is highest on the surface and decreases towards its interior. The rate of a current drop depends on the electrical and magnetic properties of the material and the frequency of the magnetic field, being higher at higher frequencies. The consequence is that thermal energy is generated in a layer of a certain thickness on the surface of the batch, where the thickness is determined by the properties of the material and the frequency of the magnetic field. Semi-bridge and bridge inverters, as well as a parallel connection of several inverters, can be used to supply induction heating of higher power. In this paper, a simulation of a half-bridge inverter supplying an induction furnace is presented.

Key words: Induction heating; Energy efficiency; Half-bridge inverter; Simulation

1 Introduction

1.1 Power inverters

Inverters are switching regulators [1] used to supply consumers with an alternating voltage of variable RMS value and/or variable frequency. Depending on the power supply method, they can be a voltage (voltage source inverters - VSI) or current (current source inverters - CSI). In this project, a voltage half-bridge inverter will be analyzed.

The voltage-powered single-phase inverter should generate an alternating voltage of the given amplitude, waveform, and frequency at the output, taking energy from the DC voltage source at the

* Corresponding author, email: bljn.bakovic@gmail.com

input. This voltage consists of a procession of voltage pulses that are formed by the process of modulating the pulse duration. Using a simple periodic modulating signal, the inverter output voltage spectrum will consist of a fundamental harmonic, which is the desired load voltage, and a series of higher harmonics that are removed by a low-pass bandpass filter. The field of application of inverters is very wide and they are most often used for regulation of electric motor drives, in uninterruptible power supply systems, for power supply of consumers from renewable energy sources, for energy transfer from renewable energy sources to the distribution network, and so on. This paper will discuss the application of inverters in induction heating.

1.2 Induction heating

Induction heating systems are used in electrothermy to heat the object to obtain the desired shape and chemical and mechanical properties. Induction heating is based on the occurrence of electromagnetic induction, ie induction of eddy currents in the heated object when it is in a changing magnetic field of the inductor. Therefore, induction heating is limited to metal processing. The flow of induced currents through the object leads to the generation of thermal energy due to Joule losses. The surface effect also plays a very important role, ie the appearance of uneven current distribution across the batch cross-section. Due to the surface effect, the density of the induced current is highest on the surface and decreases towards its interior. The rate of a current drop depends on the electrical and magnetic properties of the material and the frequency of the magnetic field, being higher at higher frequencies. The consequence is that thermal energy is generated in a layer of a certain thickness on the surface of the batch, where the thickness is determined by the properties of the material and the frequency of the magnetic field.

The variable frequency magnetic field is obtained by the flow of current through the inductor winding inside when the batch is placed (Figure 1). The frequencies with which induction heating is performed depending on the desired depth of penetration of induced currents in the batch, which is dictated by the technological process, dimensions, and material of the batch and range from the network frequency (50 Hz) to several hundred kilohertz. For frequencies other than the network frequency, the inductor is powered from an inverter with an adaptive resonant circuit. Inverters enable the supply of inductors with a current in the desired frequency range, with the possibility of regulating the heating power [2].

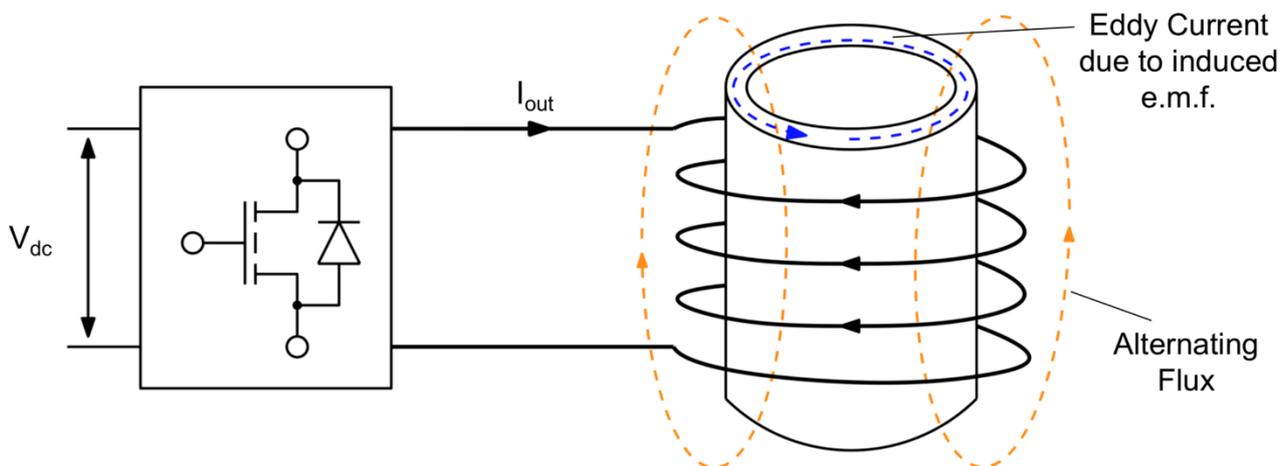


Figure 1. Induction Heater for Melting Aluminum [3]

2 The simulation

The parameters used in the simulation can be seen in the figure (Figure 2.1). The inverter is supplied with a DC voltage of 560V, the frequency in the control circuit ranges from $f_{sw}=10\text{kHz}$ to 100kHz with a step of 10kHz. The inductance L (pure inductive load) is adjusted manually. Values are given in the range of 100uH to 800uH in steps of 100uH.

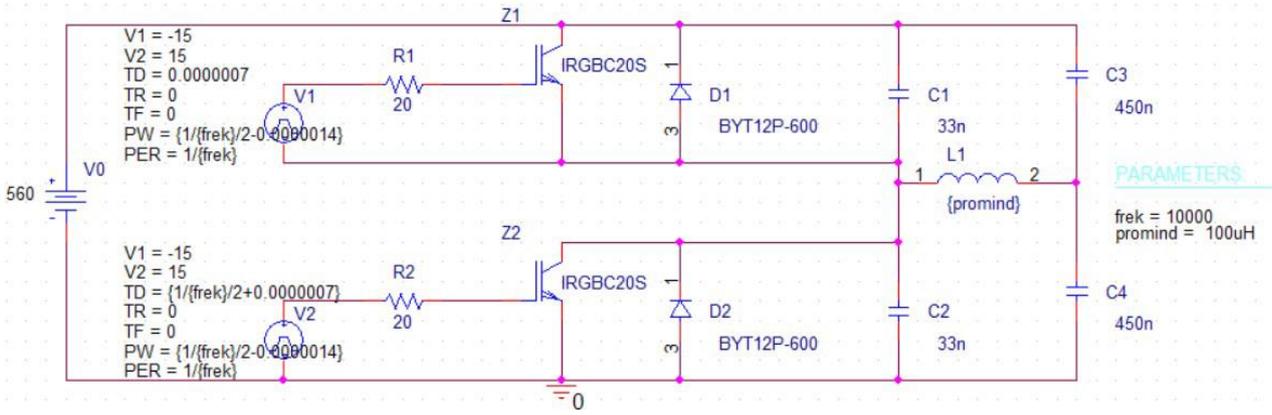


Figure 2.1. Inverter scheme

A model with real components was used. How the time and frequency of the simulation are set (Figure 2.2), and the frequency, period, and time of delay of the rectangular voltage of the switching circuit of the transistor (Figure 2.3), can be seen in the figures below.

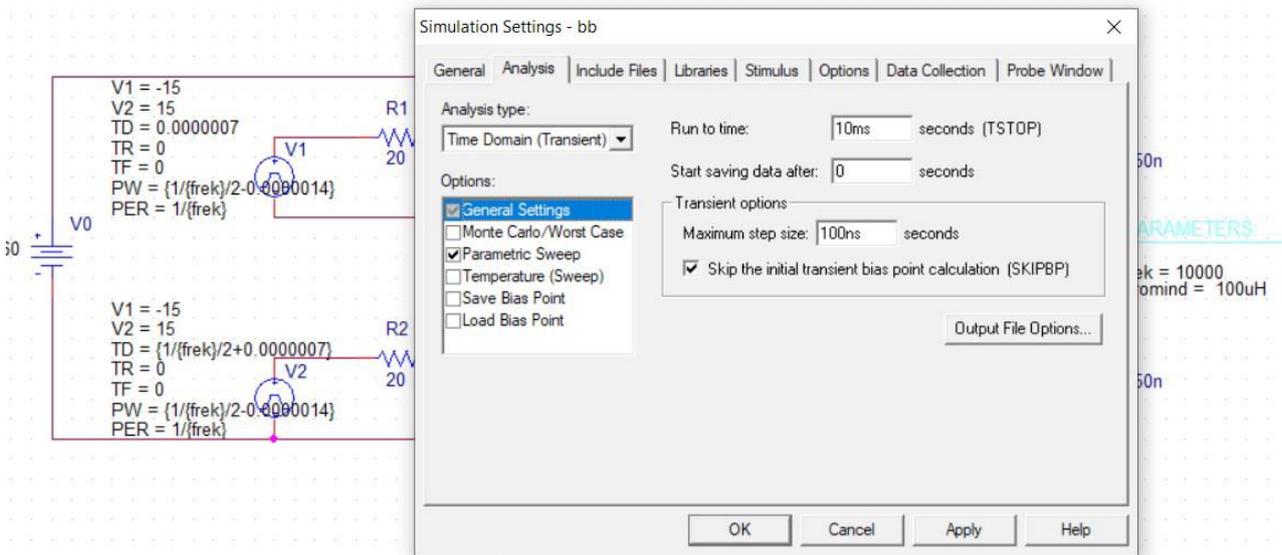


Figure 2.2. The simulation time setting

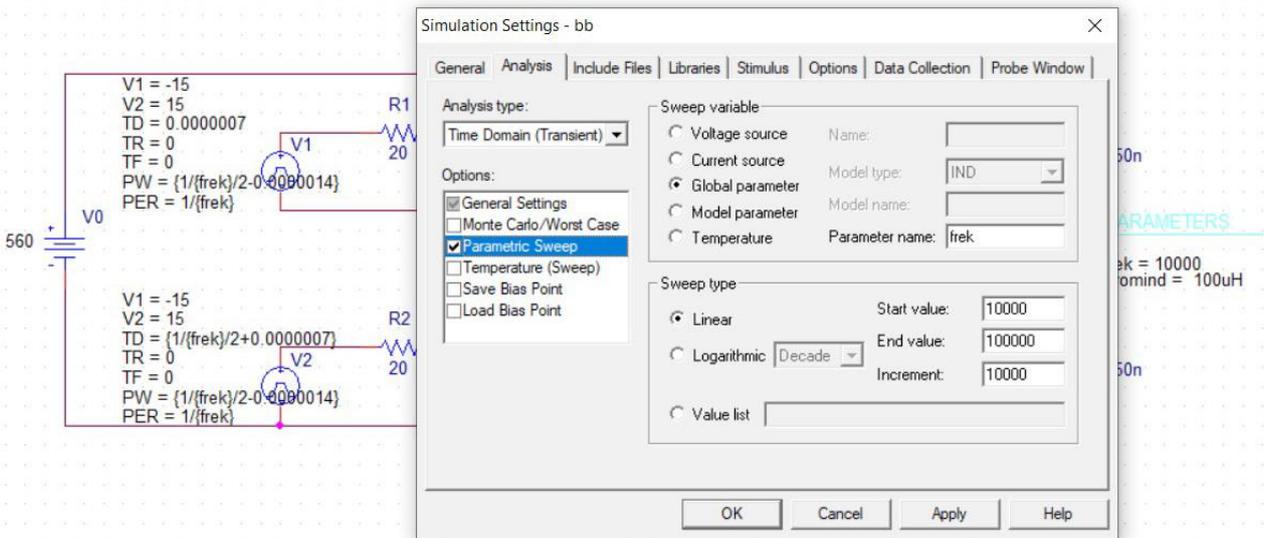


Figure 2.3. Setting f_{sw}

3 The results of the simulation

The graphs obtained as a result of the simulation show the currents and voltages for each frequency from the range $f_{sw}=10\text{kHz}$ to 100kHz with a step of 10kHz . This means that each graph shows 10 currents/voltages and they are marked with different symbols (circle, square, triangle, inverted triangle, and so on). The following figures (Figure 3.1, Figure 3.2, Figure 3.2, Figure 3.3) show graphs of currents and voltages in the frequency domain for induction values $L=100\mu\text{H}$ and $L=800\mu\text{H}$:

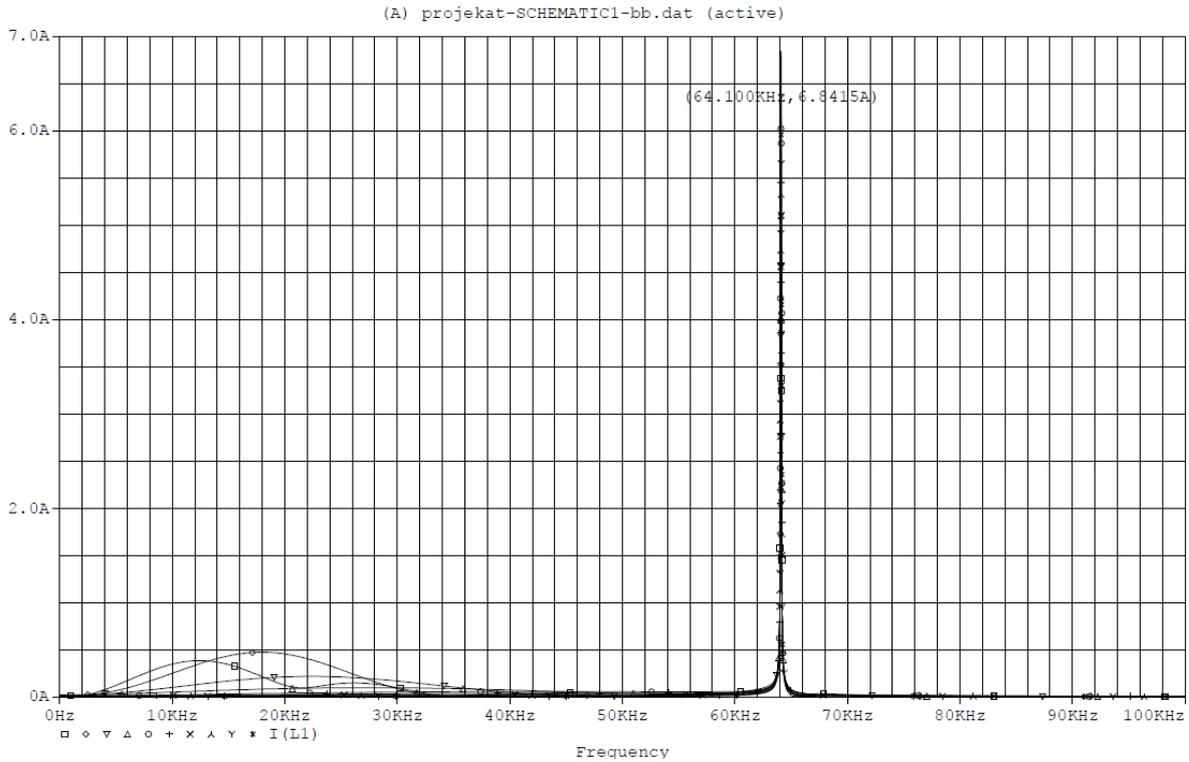


Figure 3.1. A plot of currents for $f_{sw}=10\text{kHz}$ to 100kHz and $L=100\mu\text{H}$

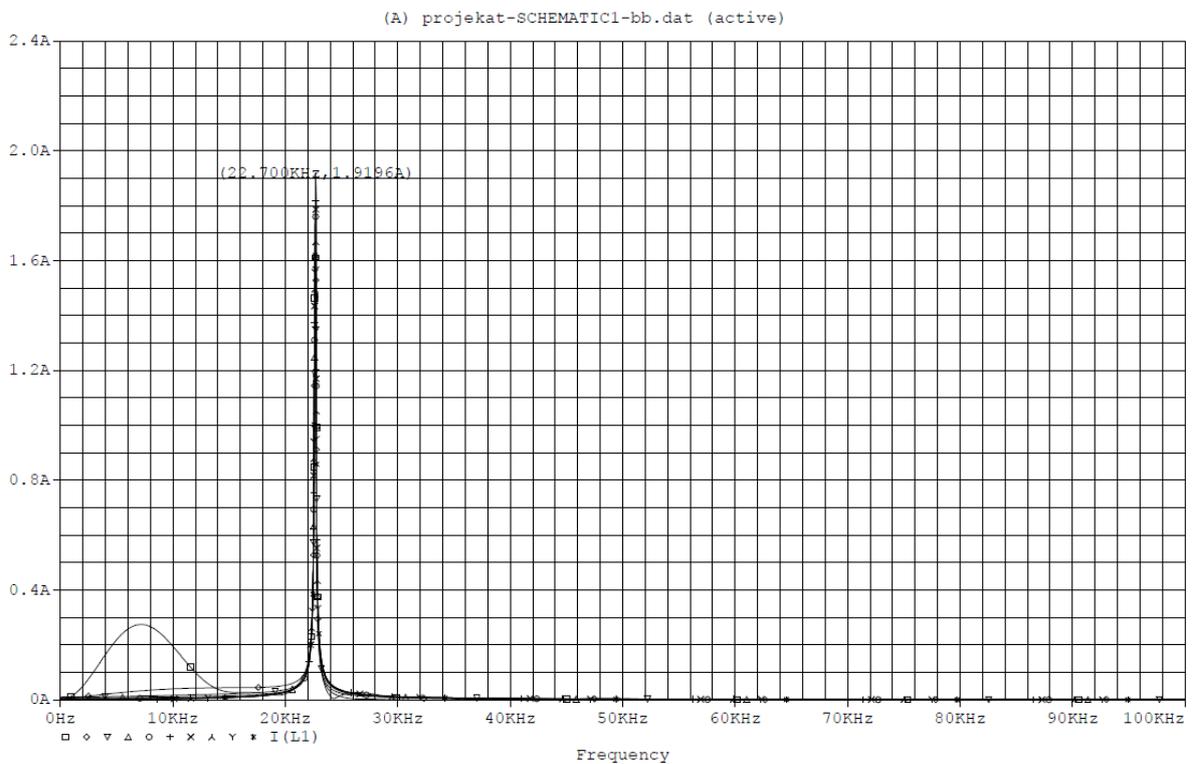


Figure 3.2. A plot of currents for $f_{sw}=10\text{kHz}$ to 100kHz and $L=800\mu\text{H}$

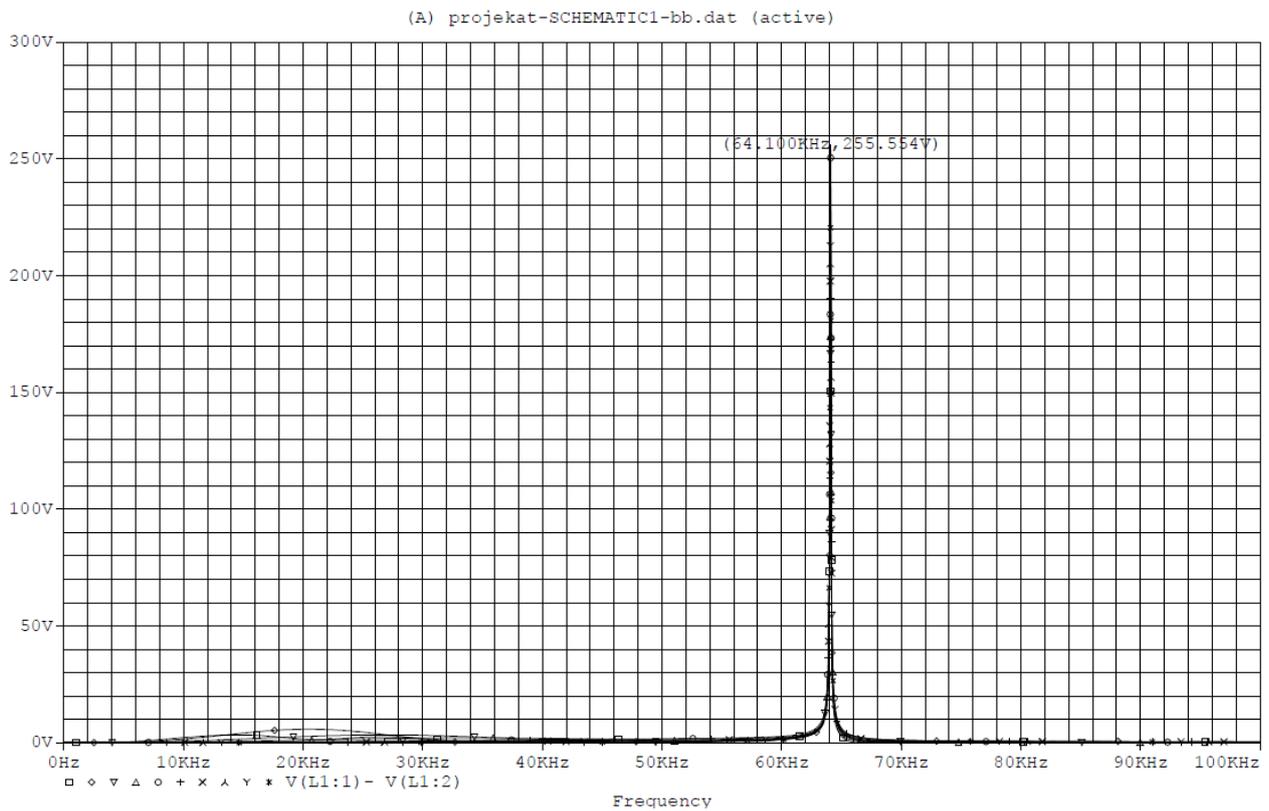


Figure 3.3. A plot of voltages for $f_{sw}=10\text{kHz}$ to 100kHz and $L=100\mu\text{H}$

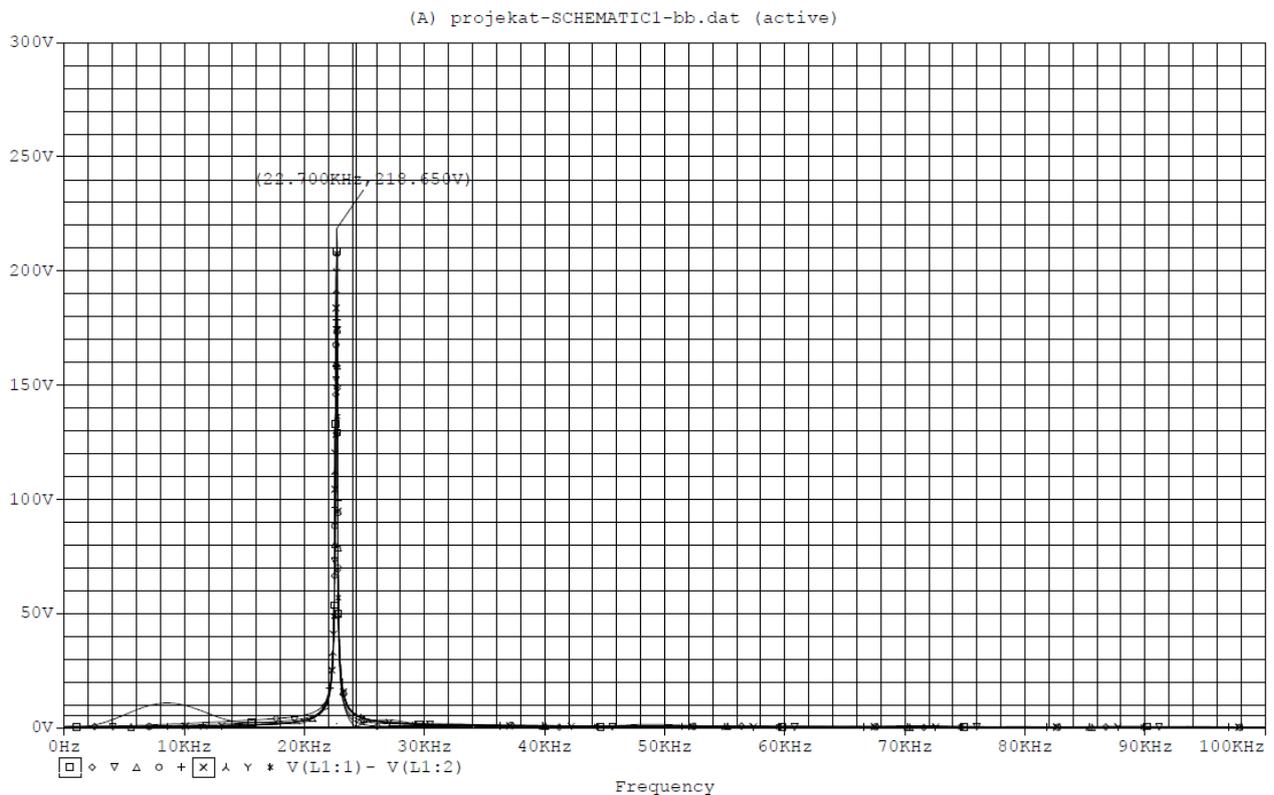


Figure 3.4. A plot of voltages for $f=10\text{kHz}$ to 100kHz and $L=800\mu\text{H}$

When it comes to the time domain, currents and voltages for inductance $L=100\mu\text{H}$ are observed, because it is in the interest only to see whether the correct sinusoids are obtained at the output of the inverter, ie at the load. This can be seen in the pictures (Figure 3.5 and Figure 3.6):

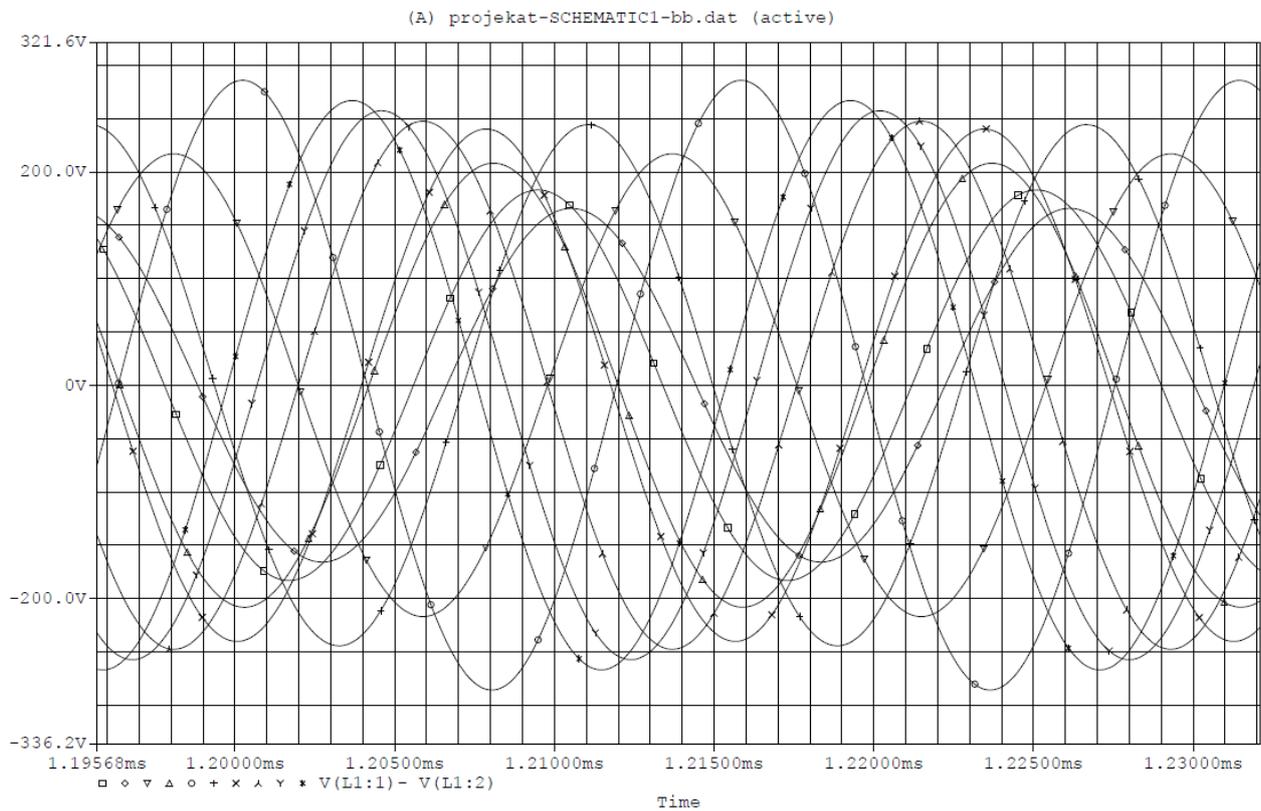


Figure 3.5. Inverter output voltages plot for $f=10\text{kHz}$ to 100kHz and $L=100\mu\text{H}$

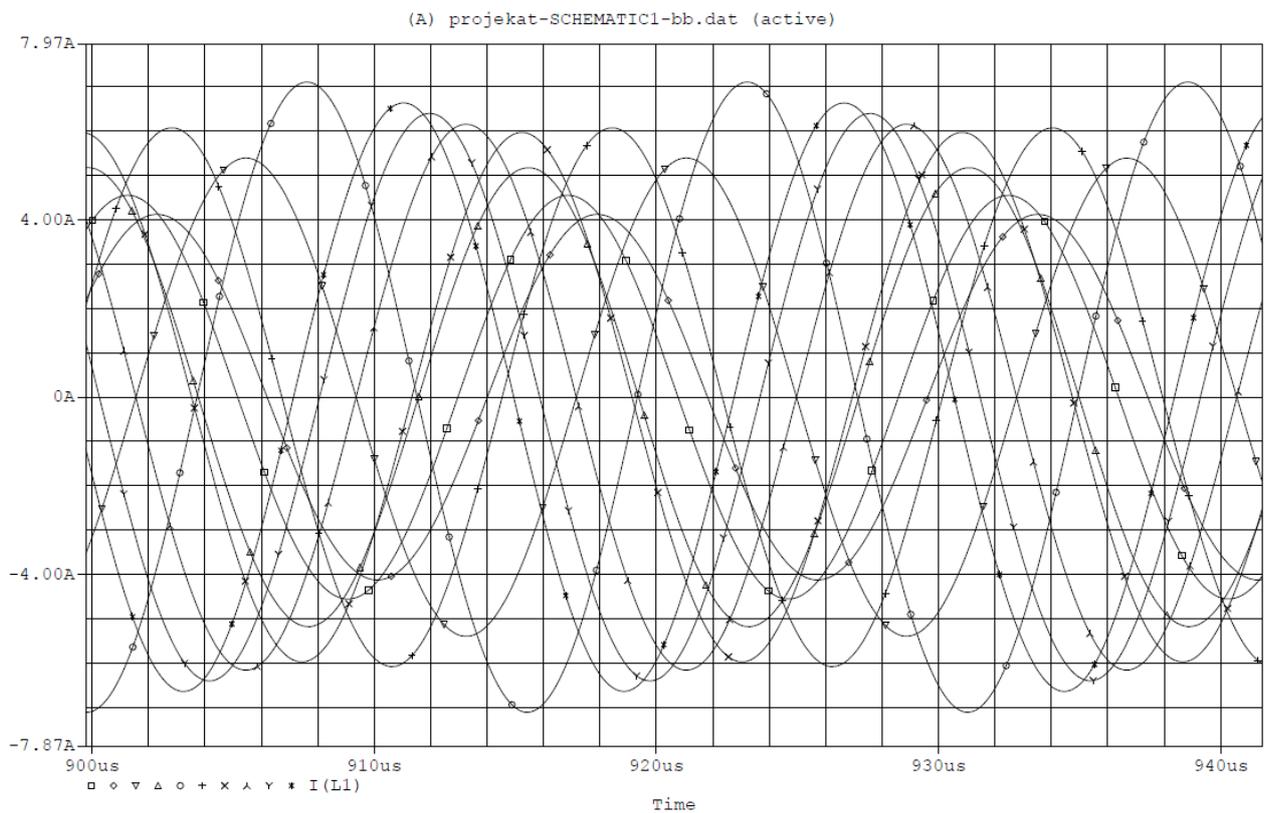


Figure 3.6. Inverter output currents plot for $f=10\text{kHz}$ to 100kHz and $L=100\mu\text{H}$

4 Conclusion

On the graphs of currents and voltages in the time domain, it can be noticed that the sinusoidal alternating voltages are correct, so the choice of components of this inverter is good.

The resonant frequency is shown on graphs with a frequency horizontal axis. This is the frequency for which the currents/voltages from the entire switching frequency range (10kHz-100kHz) have the maximum value.

On the graphs in the frequency domain, it can be seen that with increasing inductance, the current decreases as well as the resonant frequency. Such a result was also expected considering that it can be concluded from the formula for the natural frequency that with increasing inductance the natural frequency decreases. In contrast to the frequency, small deviations for some inductance values were seen in the current.

Finally, since the simulation works with variable parameters all the time, it is expected that the output voltage will change. Inverters are usually designed to give a certain value of the voltage at the output depending on the load and this could be adjusted by introducing certain changes in the control circuit.

5 Acknowledgement

The authors gratefully acknowledges financial support from the Ministry of Education and Science, Government of the Republic of Serbia.

6 References

- [1] **Miloš R. Nedeljković, Srđan L. Srdić**, Power converters 1 - Basic topologies of power converters(2016), University of Belgrade School of Electrical Engineering, Akademska misao, Belgrade, 114-117
- [2] **Miloš R. Nedeljković**, Power converters 2 – The topologies of power converters(2016), University of Belgrade School of Electrical Engineering , Akademska misao, Belgrade, 85-91
- [3] **Yuvın Kokuhenadige, Md Masum Billah, Joni-Markus Hietanen, Jaakko Lind**, Induction Heater for Melting Aluminum, Aalto University, School of Electrical Engineering, Automation and Electrical Engineering (AEE) Master's Programme, Project, Helsinki, Finland, 2019