

Implementation and Simulation of High Frequency Series Resonant Inverter for Induction Heating Application

Anuja Prashant Diwan¹ and R. Kanagaraj^{2*}

¹Department of Electrical and Electronics Engineering, Jerusalem College of Engineering, Chennai - 600100, Tamil Nadu, India; adiwan_p@yahoo.com

²Department of Electrical and Electronics Engineering, Bharath University, Chennai - 600073, Tamil Nadu, India; kanagaraj.eee@bharathuniv.ac.in

Abstract

This project presents efficient “Full Bridge High Frequency Series Resonant Inverter for Induction Heating application”. In general, the induction-heating technique requires high-frequency current that is capable of inducing high-frequency eddy current in the work piece that results in heating. In this project series resonant inverter featuring soft switch on transitions is used. A cost-effective active snubber circuit is used to optimize the switch off transition. Active snubber uses active components. This allows the converter to operate under a wide range of operating conditions. The series resonant inverter consists of resonant circuit and it delivers maximum power to the load at resonant frequency. The inverter system is designed and the simulation is done using Matlab.

Keywords:

1. Introduction

An inverter is an electrical device that converts electricity derived from a DC source to AC and can be used to drive an AC appliance like induction heater. The resonant inverter consists of resonant circuit and it delivers maximum power to the load at resonant frequency. Resonant inverters are preferred in high frequency induction heating appliances. Resonant inverters are of two types; i.e. series and parallel. Series resonant inverters offer reduced switching losses for the power-devices and possess attractive possibilities for high frequency operations. Moreover, higher efficiency, lightweight, overall simplicity in terms of inverter control, protection and maintainability have made it very attractive.

Due to high efficiency and high power density resonant power converters are widely used in induction heating applications which allow obtaining reliable and high performance implementations. Current source

resonant inverters reduce conduction losses and achieve improved load control but it requires input choke which reduces efficiency and increase size and cost. In voltage source resonant inverters though it have worse conduction properties, the input choke are removed, which leads to compact and efficient designs. Due to this reason, voltage source resonant inverters are commonly used in the domestic induction heating applications. The Full Bridge series resonant inverter has good balance between component count, efficiency and control complexity.

To reduce switching losses voltage source converters operate above the resonant frequency. In this situation, two resonant operation modes are possible, the Zero Current Switching (ZCS) during switch off transition for frequencies below resonance and the Zero Voltage Switching (ZVS) during switch on transition, for frequencies higher than resonance. But hard-switching transition is present in the turn-on for the ZCS and the turn-off for the ZVS operation mode. To reduce these

* Author for correspondence

hard-switching losses, high speed devices and lossless snubber networks are proposed. In ZCS operation mode inductive snubber networks are used, whereas capacitive snubber networks are required for the ZVS. Thus, the ZVS operation mode is chosen due to the capacitive behavior of its snubber networks.

High frequency electricity is used to drive a large alternating current through a coil. This coil is known as the work coil. The passage of current through the coil generates a very intense and rapidly changing magnetic field in the space within the work coil. The work piece to be heated is placed within this intense alternating magnetic field. The alternating magnetic field induces a current flow in the conductive work piece. The high frequency used in induction heating applications gives rise to a phenomenon called skin effect. This skin effect forces the alternating current to flow in a thin layer towards the surface of the work piece. The skin effect increases the effective resistance of the metal to the passage of the large current. Therefore it greatly increases the heating effect caused by the current induced in the work piece.

In this paper, to optimize the power converter efficiency in the whole operating conditions range an active snubber circuit is used. This allows selecting power devices with optimized conduction parameters which also improves the converter efficiency¹⁵. The proposed circuit does not add any extra complexity to the circuit.

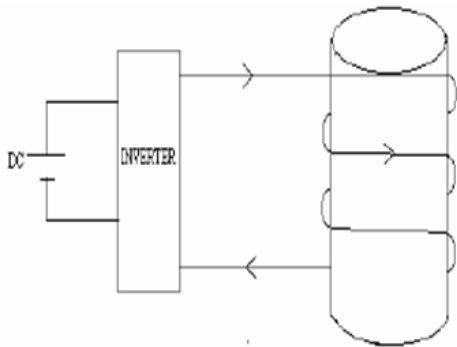


Figure 1. Induction heating system.

2. Full Bridge Series Resonant Inverter with Active Snubber Network

2.1 Full Bridge Series Resonant Inverter

Series resonant inverters are widely used for induction heating over the wide range of high frequency from 4 kHz to 500 kHz¹⁻³. Full-bridge circuit is normally used

for higher output power. Full bridge series resonant inverter circuit is shown in the Figure 2. Series R-L-C load is connected in conventional position of the circuit. In this circuit, four MOSFETs are used, out of which two switches are triggered simultaneously. One anti-parallel diode is connected with each MOSFET which allows the current to flow when the main switch is turned OFF⁴⁻⁶. The load circuit is on when switches S1 and S4 are triggered simultaneously at $t=0$. The current equation of resonant circuit is $i = \frac{V_i - (-V_c)}{\omega L} \sin \omega t$, when $-V_c$ is the initial voltage of the capacitor. The current flows for a half cycle of the resonant frequency and become zero at $t = \frac{t_r}{2} = \frac{\rho}{\omega}$ and both switches S1 and S4 are turned off. When S1 and S4 stop conducting and switch S2 and S3 are not yet turned ON the current through the load reverses and are now carried by D1 and D4, the anti-parallel diodes which connected with the respective switches. The voltage drops across diodes appear as a reverse bias voltage across switch S1 and S4. To reduce turn-off losses in the ZVS soft-switching turn-on behavior, a small-value snubber capacitor, C_s , is used (Figure 2). It decreases the MOSFET voltage slope during the switch-off transition, reducing switching losses⁷⁻¹⁰. On the other hand, the capacitor snubber, C_s , charge time, must be longer than the total current turn-off time to reduce turn-off losses.

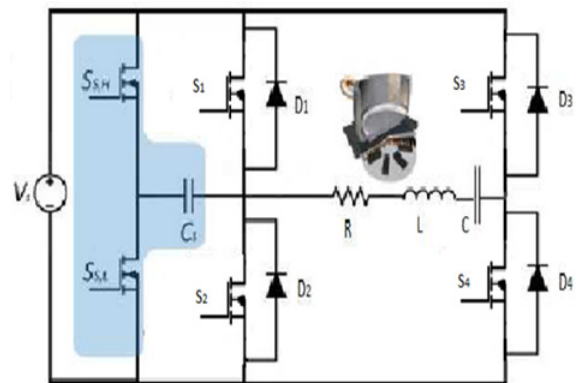


Figure 2. Full bridge series resonant inverter.

2.1 Active Snubber Circuit

Snubbers are frequently used in electrical systems with an inductive load where the sudden interruption of current flow leads to a sharp rise in voltage across the current switching device, in accordance with Faraday's law. This transient can be a source of Electromagnetic Interference (EMI) in other circuits¹⁶⁻¹⁸. Additionally, if the voltage generated across the device is beyond what the device is intended to tolerate, it may damage or destroy it. The

snubber provides a short-term alternative current path around the current switching device so that the inductive element may be discharged more safely and quietly.

The main advantage of active snubber is the ability to adapt the lossless snubber network to any operating condition. The snubber time, t_{snb} , is divided into two terms¹¹⁻¹⁴. Firstly, interval t_1 is used to activate the active snubber network while the high-side MOSFET is activated. As the snubber capacitor impedance is lower than the impedance of the high-side MOSFET, load current flows through the snubber and, thus, MOSFET current becomes zero. Next, during t_2 interval, the MOSFET is deactivated under zero voltage switching, reducing switching-off losses.

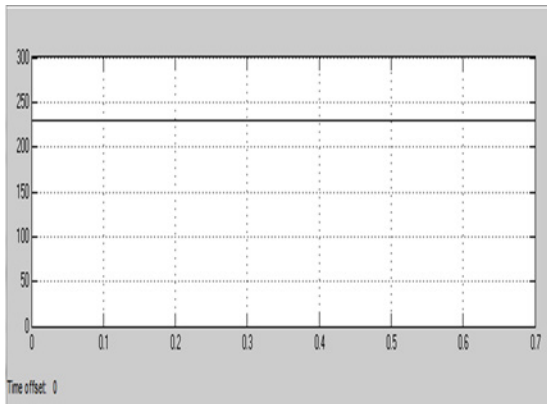


Figure 3. Input voltage.

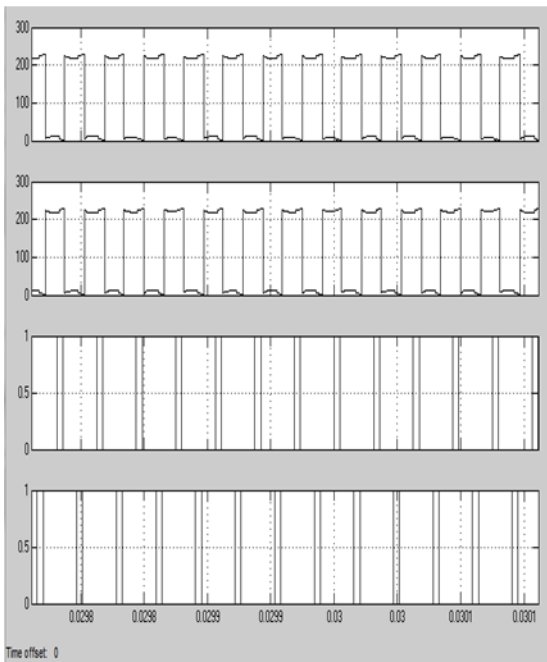


Figure 4. Drain to source voltage and switching pulses of the active snubber circuit.

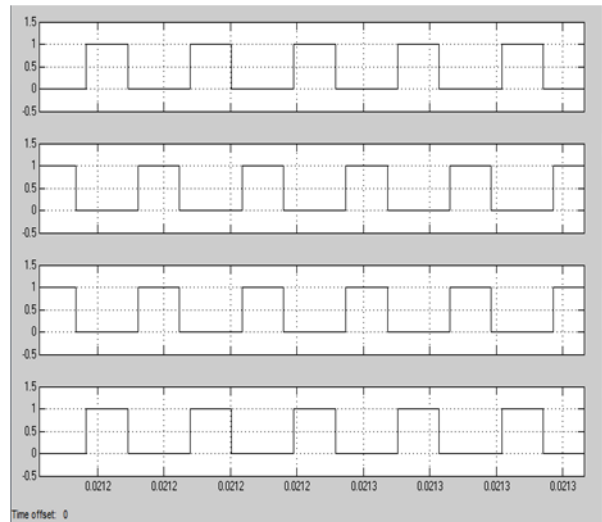


Figure 5. Switching pulse for M2, M3, M4, M5.

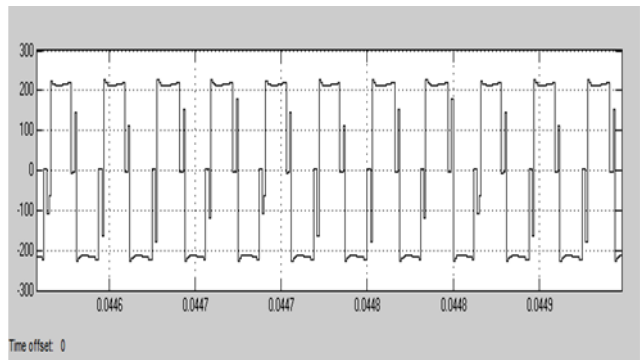


Figure 6. Output voltage.

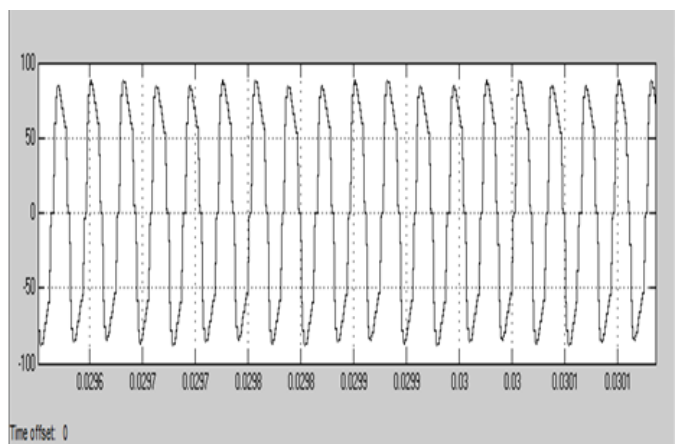


Figure 7. Output current.

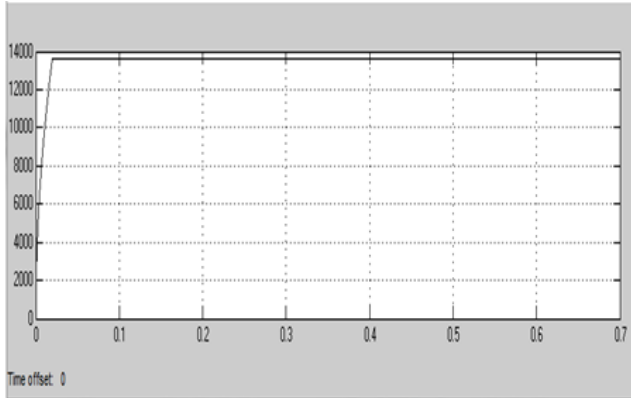


Figure 8. Output power.

3. Conclusion

This project has presented the design of the “Full Bridge High Frequency Series Resonant Inverter fed Induction Heater using microcontroller” with active snubber circuit for improved efficiency operation applied to domestic induction heating. In this project, an active snubber network has been proposed to reduce switch off transition losses and optimize the converter efficiency under highly variable operating conditions. The proposed circuit allows obtaining a simple and cost effective solution and allows the designer to select power devices with optimized conduction parameters, further improving the converter efficiency. The soft switching technique used in this project helped to reduce the switching transitions and to reduce mechanical stress on the switches. The heating time is reduced due to the usage of high frequency and it helped in reducing the rating of the inductor and the capacitor used for the resonant circuit. The cost for the induction heating is reduced.

4. References

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