

# Topologies of Voltage Source Inverter for Domestic Induction Heating

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**Abstract-** Nowadays Induction heating applications are quickly gaining popularity. Induction Heating technology not only offers the advantage of having a better efficiency conversion compared to the other standard technologies like resistive heating, Electric heating, Gas heating but also offers Induction heating offers the advantages of rapid heating, local pot heating, direct heating, high power density, high reliability, low running cost and non-acoustic noise. This Paper summarizes the different Voltage Source Inverters for Induction Heating technology with its development in Domestic IH applications and contains Voltage Source Inverter topologies like Basic voltage source inverter, Single switch VSI, Multi-output VSI for Domestic IH.

**Index Terms / Keywords-** Induction Heating (IH), Electromagnetic Interference (EMI), Resonant Inverter, Voltage Source Inverter (VSI), Zero voltage switching (ZVS), Single Switch Resonant Inverter, Multi Output Voltage Source Inverter.

## 1 INTRODUCTION

The conventional model of gas and the electric stoves are still in use for domestic heating purpose. But nowadays Induction heating for cooking applications is rapidly gaining recognition. Induction cooking technology offers the advantages of superior conversion efficiency compared to the typical techniques i.e. Gas and electric stoves. The efficiency of energy transfer in IH heating is 84% whereas in non-IH heating application it is about 74%. Thereby, we save nearly 10% of energy for the same amount of heat transfer. The principle of an induction cooking stove is to supply a coil of wire and induce a current into a pot which is made of a high magnetic permeability and stands in the proximity of the above mentioned coil. The way it works is similar to an inductor where the pan having a very lossy core. The generated heat is due to the eddy currents generated in the bottom layer of pot combined with the hysteresis losses from the magnetic material of the pan. In all types of induction cooker, a ferromagnetic metal based cooking vessel or any vessel with an interface disk is used for an induction cooking [1].

In an induction cooker, a coil of copper wire is located beneath the cooking vessel. An oscillating magnetic field is produced by an alternating electric current flowing through the coil. This field induces an electric current in the pot which is responsible for producing eddy current heating which heats the food. While the current is large, it is produced by a low voltage. The main part of such systems is the electronics and which is the major challenge in terms of the design. It consists of a power stage coupled with a digital control system and also deal with the thermal management issues. The main advantages of the domestic IH technology are as follows:

**Quick Heating:** It is a non-contact heating practice in which IH technology directly heat the substance. It takes very less time than any other heating method. Table 1 shows the time required to heat 1.5L water from 20 to 900C using different technologies.

**High Efficiency:** In Induction heating the induction object is directly heated, the heat loss through the ambient and nearby

elements is less and therefore efficiency of the IH technology is very high. Table 2 gives evaluation of heating technologies.

**Safety & Cleanliness:** As IH technology directly heats the item, it avoids the burning of other surrounding substances and also avoids the food from burning. It is a clean technology, not using CO2 emission fossil fuels.

**Advanced Control Features and Improved industrial Process:** IH technology uses advance features like sensors & modern power converters to control input power. Repeatability and consistency of IH improve the quality process and increases the output of the process [2], [3], [4].

TABLE 1  
APPROXIMATE TIME TO HEAT 1.5L WATER IN VARIOUS TYPES OF HEATING

Type of Heating	Time to Heat 1.5 L Water (20 – 95 °C) (Min)
Resistive Board	9.49
Resistive	8.57
Halogen	7.53
Gas	6.02
Induction	3.54

TABLE 2  
EFFICIENCY IN VARIOUS TYPES OF HEATING

Type of Heating	Efficiency (%)
Induction	77
Microwaves	68
Halogen	53
Resistive	51
Resistive Board	44
Gas	43

## 2 INDUCTION HEATING TECHNOLOGY

Induction appliances take power from the Supply main, which is rectified by a bridge rectifier. A filter with proper design is used to allow a high-voltage ripple; as a result input power factor came close to unity. Thereby an inverter topology provides the alternating current (between 20 and 100 kHz) to the induction coil. Nowadays, Domestic induction appliances are designed up to 3.5 kW. A schematic diagram of the power stage of a domestic induction appliance is shown in Fig. 1 [4], [5].

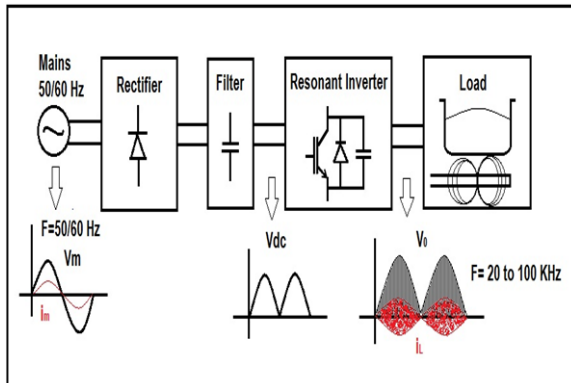


Fig.1. Schematic Block Diagram of Domestic Induction Heating Technology

## 3 INVERTER TOPOLOGIES

According to number of switching devices, Voltage source Inverter topologies used in Induction Heating are half-bridge, full bridge, single switch resonant inverter with ZCS & ZVS topology, Multi-output voltage source inverter.

### 3.1 Basic Voltage Source Inverter

Basic voltage source inverter categorized into half bridge & full Bridge voltage source Inverter.

#### 3.1.1 Full Bridge Voltage Source Inverter

The full bridge topology is shown in fig.2 which consists of four switches with load. The IH load consists of a metallic pan and the IH working coil is represented by the equivalent effective resistance  $R_0$  and equivalent effective inductance  $L_0$ . The resonant and Power factor correction tuned capacitor  $C_0$  is connected in series with the IH load. The full-bridge topology can offer the higher output power (up to 5 kW) and control flexibility, and its efficiency can be significantly optimized through the proper control strategy. However, its higher cost makes it unfeasible for the mean IH appliance [6].

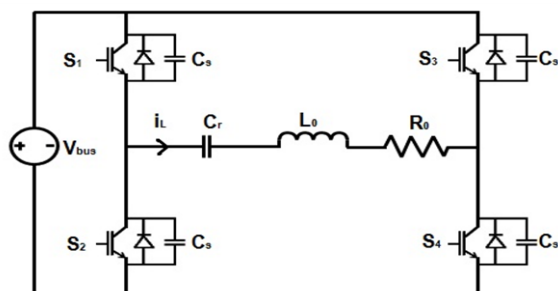


Fig.2. Full Bridge Voltage Source Inverter

#### 3.1.2 Half Bridge Series Resonant ZVS Inverter

The half-bridge series resonant inverter (Fig. 3) is the most used topology. The resonant tank consists of the induction coil, the pan, and the resonance capacitor ( $C_0$ ). Induction-coil-and-pan coupling is modeled as a series connection of an inductor and a resistor, based on the analogy of a transformer and it is defined by the values of  $L_0$  and  $R_0$ . These values change mainly with pan material, temperature, excitation frequency  $\omega$ , and inductor-pan coupling. This implies a wide operation range, where a ZVS condition must be fulfilled to ensure high efficiency. It is used to design converters with up to 3.5-kW output power. VFDC control for half bridge topology improve efficiency in whole power range & achieving power loss reduction higher than 25 % for typical domestic induction heating [7], [8].

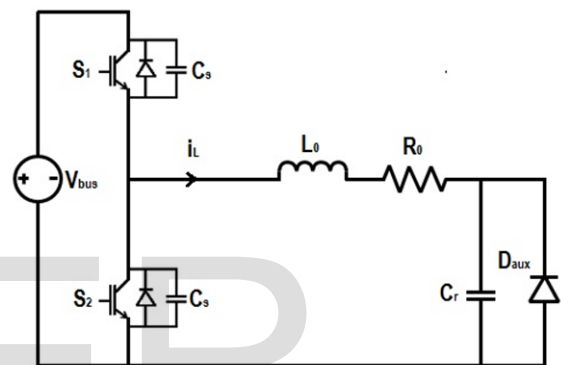


Fig.3. Half Bridge Series Resonant ZVS Inverter

Comparative study of half-bridge & full bridge voltage source inverter given in table 3.

TABLE 3

COMPARATIVE STUDY OF HALF BRIDGE & FULL BRIDGE VOLTAGE SOURCE INVERTER

Sr. No	Parameter	Full Bridge VSI	Half bridge VSI
1	Drive Technology	Dual	Single
2	Load capacity	Up to 5kW	3.5 kW
3	Thermal Efficiency	High	Low
4	Power Distribution	Simple	complex
5	Switching Losses	Small	Large
6	Life	Longer life	Reasonable life
7	Complex circuitry	More	Simple
8	cost	More	Less

### 3.2 Single Switch Resonant Inverter

The three most commonly used single switch topologies that seemed for induction cooking were selected for this comparative study. A short description of each of these topologies is as below.

#### 3.2.1 Single-switch Voltage Source ZVS inverter

Fig.4 illustrates the conventional single-ended ZVS inverter with a single IGBT. The quasi resonant ZVS inverter can be operated under zero-voltage soft-switching control condition for the output power regulation due to the simple PFM scheme. This topology has the significant disadvantage of high peak voltage across the active switch. Therefore, this circuit topology is not suitable for 200-V utility power source connected high-power applications. Advantages of topology are good power ranges for small value of  $R_0$ . The limitations of the frequency range are, If  $f_s$  is too high there will not be enough energy stored in the inductor to obtain ZVS and theoretically there is not a minimum switching frequency where ZVS will be lost. This limit is usually set by the minimum allowable switching frequency, i.e. 20 kHz [9].

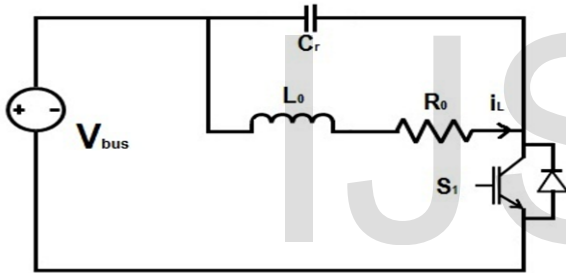


Fig.4. Single-switch ZVS voltage source inverter

#### 3.2.2 Single Switch Voltage Source ZCS Inverter

Fig.5 gives the circuit diagram for Single Switch Voltage Source ZCS inverter. When the switch starts to conduct the currents in  $L_0$  and  $L_{aux}$  are equal and the switch current is zero. Capacitor  $C_r$  discharges through the output circuit ( $L_0$  and  $R_0$ ) and then switch starts to charge in the opposite direction. Meanwhile the current in the input inductor is increasing linearly due to the dc input voltage directly across it. The conduction cycle ends when the capacitor recharging current is equal to the input inductor current, i.e. when the switch current returns to zero. The duration of this cycle is constant due to  $C_r$  and  $L_0$  resonating. The switch must be ON so that the voltage across  $C_r$  and the current through  $L_0$  are large enough and of the right polarity at the end of this cycle to ensure zero current switching (ZCS). Boundaries of soft switching are, if switching Frequency ( $f_s$ ) become too high, ZCS will be lost because a too large inductor current will be flowing in the positive direction at the start of the conduction cycle and if  $f_s$  become too low ZCS will be lost because the voltage across the capacitor will be too small at the beginning of the conduction cycle [10].

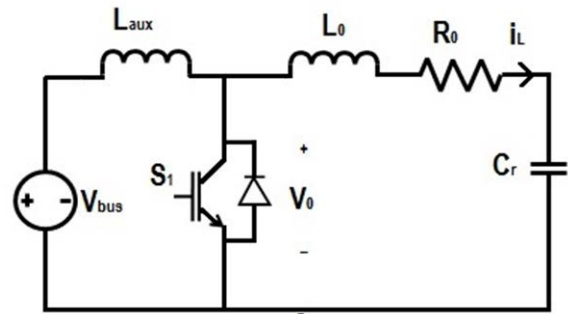


Fig.5. Single-switch ZVS voltage source inverter

#### 3.2.3 Active clamped Single-switch Voltage Source ZVS Inverter-

Fig.6 shows a schematic circuit system of the single-ended push-pull-type ZVS-PWM resonant inverter using new-generation IGBT's. This inverter is to be operated under a condition of CFVP control strategy. This IH cooking appliance connected to a 200V utility ac power grid is especially introduced for the multi-burner system structure and induction-heated cooker with microwave oven for home and business uses. This inverter is able to combine with multiple IH load vessels or pans coupled to the working heating coil. Its control circuit is based on microcomputer based power regulation and system protection, and IGBT IC driver modules are incorporated into this inverter. This inverter has advantages of High performance, High efficiency, compact volumetric size and light weight, lowered harmonic current, unity power factor and it is operating over wide range ZVS [10].

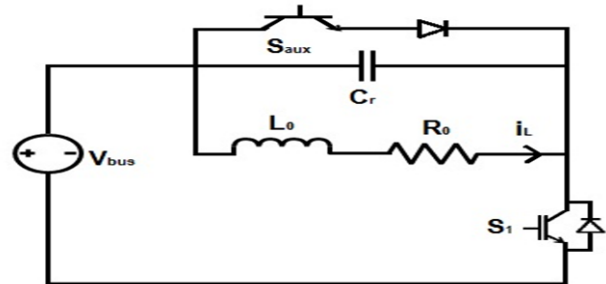


Fig.6. Active clamped Single-switch ZVS VSI

Above mentioned three topologies are operated under Zero-voltage or zero-current soft switching used in 1-2 kW Domestic Heating for the 100-V AC Supply. Comparison Study of above three topologies are given in table 4.

TABLE 4  
 COMPARISON OF SINGLE SWITCH VSI TOPOLOGIES

Sr. No	Parameter	Single-switch ZVS VSI	Single-switch ZCS VSI	Active clamped Single-switch ZVS VSI
1	Operation	ZVS	ZCS	Active Clamp ZVS
2	Peak voltage across Switch	6-7 times Input voltage	2-3 times Input voltage	2-3 times Input voltage
3	Soft Switching range	Small (20kHz-100kHz)	Small	Wide
4	Efficiency	Normal	Normal	High
5	Harmonic current	Ample	Ample	Very Small
6	Power Range	Aproprate for high value of R0	Small For Small value of R0	High for High Value of R0
7	Acoustics	Yes	Yes	No

**3.3 Multi output Voltage Source Inverter**

Multi output and multisource systems are widely present in the current technology. These systems require supplying either a fixed voltage or power for each load. Domestic induction heating appliances are an example, where different output powers are required for each load. Besides, it requires a cost-effective and high-power density realization to compete in nowadays Domestic induction-heating market.

**3.3.1 Dual series resonant Voltage Source half-bridge Inverter**

This first topology only includes three IGBT devices for two coils as shown in Fig. 7. It makes possible the power regulation on each coil with the same switching frequency. The three devices can be held in ZVS conditions in all the power range. The operating mode is based on a master-slave principle. A master coil and its resonant capacitor (Coil 1) are classically supplied by a symmetric voltage square wave, so the power is adjusted by the variation of the switching frequency. The slave coil (Coil 2) and its capacitor are supplied by a voltage pulse, time-included in the previous one and whose width is variable. So the power on Coil 2 is adjusted by a pulse width modulation (PWM) control mode, following the switching frequency imposed by the master coil [11].

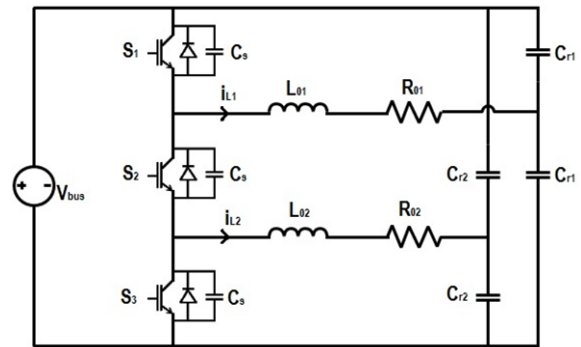


Fig.7. Dual series resonant half-bridge VSI

**3.3.2 Dual series resonant Voltage Source full-bridge Inverter**

The synthesized (fig.8) converter can be considered as a two-output extension of a full-bridge topology. It allows the control of the two outputs, simultaneously and independently, up to their rated powers saving component count compared with the two-converter solution and providing a higher utilization of electronics. A fixed-frequency control strategy is digitally implemented with good final performances for the application, including ZVS operation for active devices and a quick heating function. Although it is low-power induction heating, it may be possibly useful for other power electronic applications [12].

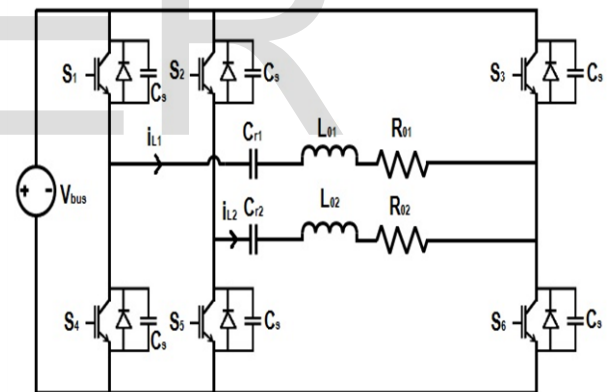


Fig.8. Dual series resonant full-bridge VSI

**3.3.3 Frequency Multiplexed Voltage Source half bridge Inverter**

Fig.9 shows a half-bridge topology featuring frequency selectable resonant loads. Each resonant tank is tuned at a different resonant frequency, allowing selection among them with the inverter operating frequency. The main drawbacks of this topology are the limited & complex power control, uses for small loads, the acoustic noise, the high range of frequency required, and the less speed of electromechanical switches [13].

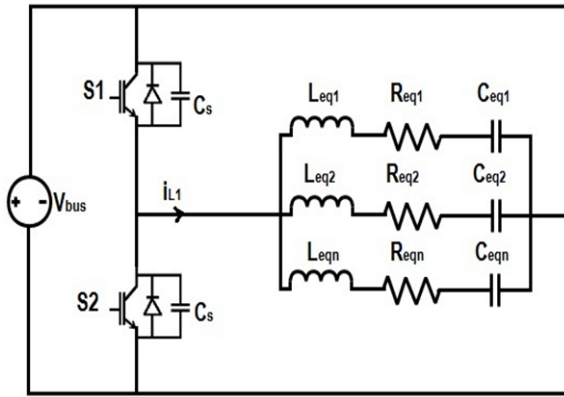


Fig.9. Frequency multiplexed half bridge VSI

**3.3.4 Series Resonant Voltage Source Multi- inverter**

Fig.10. Shows an n-output series-resonant inverter topology called series-resonant multi output inverter is a dc-link inverter based on a common inverter block and a resonant-load block. The basic inverter topology chosen for the common inverter block is the half bridge, due to its appropriate balance between number of switches, electrical stress, and performance. These systems require controlling either the supplied voltage or power to several loads with different requirements at once. As a outcome, the cost and size of the power stage

may increase beyond the admissible limits for certain applications. System has higher utilization ratio of Electronics switches [14].

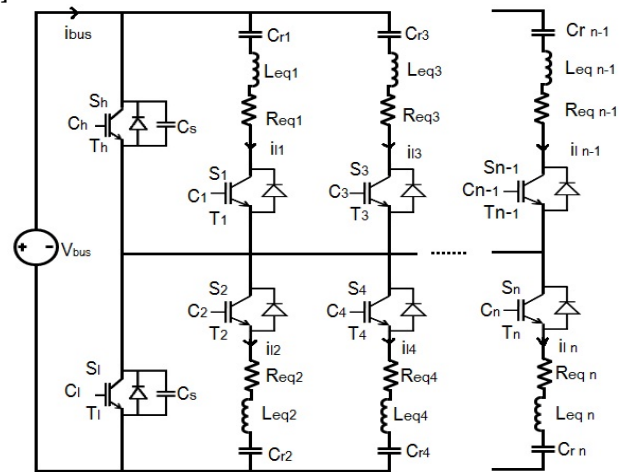


Fig.10. Series resonant multi output inverter

Comparisons of all four multi-output voltage source inverter topologies for n- load inverter are given in table 5.

TABLE 5  
 COMPARATIVE STUDY OF MULTI-OUTPUT VOLTAGE SOURCE INVERTER FOR N-LOAD INVERTER

Sr. No.	Parameter	Dual series resonant half-bridge VSI	Dual series resonant full-bridge VSI	Frequency Multiplexed half-bridge VSI	Series Resonant Multi-inverter VSI
1	Power Per Load	$P_0$	$P_0$	$P_0/3$	$P_0$
2	Power Per Converter	$nP_0$	$nP_0$	$P_0$	$< nP_0$
3	Switches and Drive Circuit	3	$2+2n$	2	$2 + n$
4	Resonant Capacitors	$2n$	$n$	$n$	$n$
5	Snubber Capacitor	3	$2+2n$	2	2
6	Power Density	Poor	poor	Poor	Good
7	Switching Losses	More	More	Less	Less
8	Conduction Losses	Less	Less	More	More
9	Controllability	Poor	poor	poor	Good



## IV. CONCLUSION

This paper has provided the details of present Induction Heating Technologies and currently used Inverter topologies. Features of domestic induction heating applications are discussed and compared on the basis of various performance parameters. The comparison shows the design & performance details of individual IH system. Induction heating technology is very easy & convenient to operate. Due to research carried out in recent years, IH technology widely used in domestic heating application. Basically, Voltage Source Inverter Topologies categories into Basic Voltage Source Inverter, Single Switch Voltage Source inverter, Multi-output Voltage Source Inverter are discussed and compared.

The reduction of Switching and conduction losses in domestic IH is a main concern for the researcher. The future research work will be lead to improve the performance and reducing the prices of IH systems.

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