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PERFORMANCE OF INDUCTION HEATING TOPOLOGIES WITH VARIOUS SWITCHING SCHEMES

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***Abstract*- Induction appliances require power converters that with accurate power control and less switching losses. The modulation techniques play an important role in the designing of the power converters. The performance of different induction heating topologies is carried out with various switching strategies. The essential performances on the output power regulation and the output current are demonstrated through simulation studies. The topologies are designed for the same specifications and are compared in aspect of the different switching schemes.**

Keywords—induction heating, high frequency resonant inverter, switching strategies

I. Introduction

The idea of electromagnetic induction generally involves two principles for its working, electromagnetic induction and skin effect. The eddy currents that are induced in the work piece produce heat loss that leads to a temperature rise in the material. The shape of the work coil is adjusted to suit the shape of the work piece, to provide uniform heat distribution and to provide a strong magnetic coupling. An interesting new area of IH is induction heating, which provides a safer way of cooking too. The heating temperatures are low and wider power range of control is necessary. The high initial cost is a disadvantage. Only material with high resistivity is preferred as work pieces. The power source for the IH applications primarily includes the following options. The supply system fed by a transformer, which provides a supply frequency of 50/60 Hz .The motor alternator set, can be also used by varying the field voltage and feeding it to the alternator. It can be used for medium power applications. The valve generator set used also uses the vacuum tubes to generate frequencies of 100 kHz. But now with the intervention of the solid state power electronic devices, power and frequency can be varied with various measures. The solid state power electronic devices have replaced all the power supply systems which were primarily used as supply systems for IH applications. There are various topologies available for IH application, using the solid state power converters. Each topology suffers from various advantages as well as disadvantages. Considerations in choosing a topology are cost, input power factor, capability to handle load variations, the complexity in controlling power and efficiency.

The IH load is represented by an equivalent transformer representation. The magnetizing inductance of the equivalent transformer is assumed to be greater than the leakage inductance; hence the load can be represented as a series combination of a resistance and an inductance. When an alternating current flows through a conductor, skin effect is produced. Skin effect increases with the frequency. The load circuit used is normally inductive; therefore a compensating capacitor is placed in series or parallel to form a series or parallel resonating circuit with its own characteristics. If the load circuit is inductive, it will draw large reactive current and hence cause stresses in the semiconductor switches as well as increases the conduction losses. Therefore, a parallel connected or series connected capacitor is used along with the inductance to get the characteristics of series or parallel resonant load circuit. The series connected resonant load circuit has minimum impedance at its damped resonant frequency where the

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inductive reactance and the capacitive reactance cancel each other and the load completely behaves as a resistive load. When the series resonant circuit is analyzed with a dc voltage across the terminals, it operates with a damped resonant frequency.

Induction heating and dielectric heating are the main classifications of high frequency heating. Induction heating is the process of heating the metals by inducing an electric current to flow in the object to be heated. It is similar to the operation of a transformer, i.e. electromagnetic induction principle by Faraday. A general induction heating system arrangement is shown in Fig. 1.1. [1]

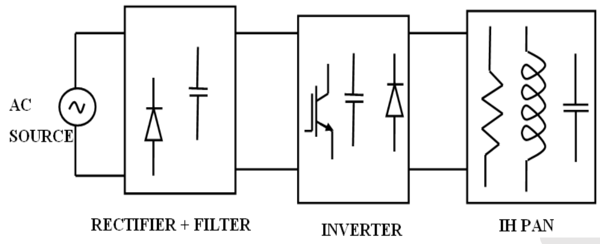

Fig. 1.1 Arrangement of an induction heating system

II. Literature Review

A. Inverter configurations used in Induction Heating

Voltage source inverter with series connected load and current source inverter with parallel resonant loads can be generally used for induction heating applications. The voltage source inverter unit has a constant voltage source at the input side, which can be maintained by high value of capacitance at the input side. The current source inverter has a constant current source at the input, which is obtained by a voltage source connected with a high inductance value at the input side. Due to the low value of the output current obtained in the current source inverter units, it is less preferred when compared to the voltage source inverter configurations. Fig 2.1 [2] shows a series resonant tank circuit. The series resonant circuit consists of the R-L combination of the work piece connected across the resonant capacitor in series. LLC combination type circuits can also be used for induction heating applications.

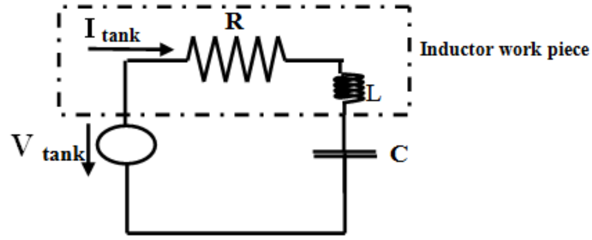

Fig. 2.1 A series tank inductor circuit

The mainly used configurations in induction heating applications include the full bridge configuration, the half bridge configuration, the configuration of three switches with asymmetrical switching scheme, the cycloconverter units, and the single ended inverter unit e.t.c. [2]. In applications which require less than 5KW of output power, the configuration used is an H bridge topology. The circuit diagram of this topology is detailed in the below given Fig. 2.2. The switches are made to conduct in the different modes of operation giving rise to an output voltage V_{dc} across the load. A small delay time is provided in between the turn on off the switches to help in the zero voltage switching of the inverter units. Since the inverter configurations used in induction heating applications are switched at a high frequency, the zero voltage switching of the units help in reducing the switching losses. The mode of switching across the switches S_2 and S_3 give an output voltage of $-V_{dc}$ across the output.

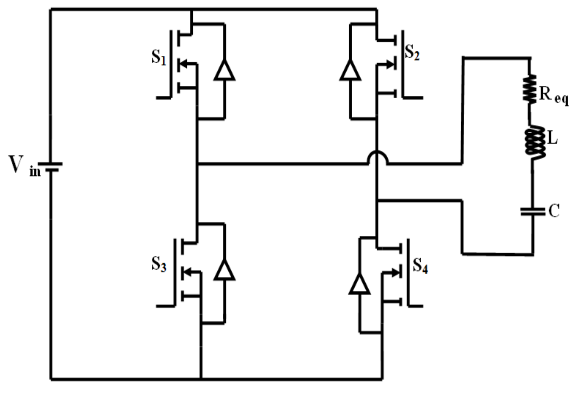

Fig.2.2. The full bridge configuration of series resonant inverter

The half bridge configuration used in IH applications can also be either current fed or voltage fed as the H bridge topology. The half bridge topology used mainly in induction cooking applications which require less output

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voltage across the load .Fig 2.3 [4] shows a half bridge series resonant inverter fed topology used in IH applications.

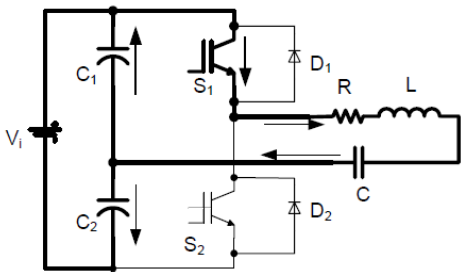

Fig.2.3 The half bridge configuration of series resonant inverter Mode 1

The topology which uses asymmetrical pattern with three switches produces a high output power density and reduced switching losses when compared to the H-bridge topology.

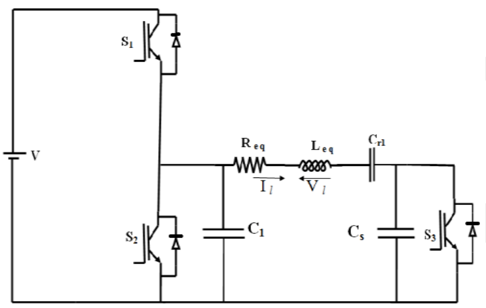

Fig. 2.4 The asymmetrical configuration of IH topology

The switching pulses for the three switches are given by the dual duty cycle control scheme method. Another configuration of inverter unit preferred is the cycloconverter configuration. They are generally used in high power industrial applications. The power factor improvement of the input side of the inverter unit can be done by the Vienna rectifier unit.

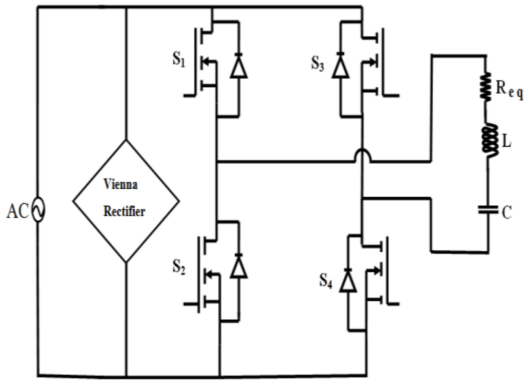

Fig. 2.5 The Vienna rectifier configuration

III. Switching Schemes

The output current regulation of the inverter topologies used in IH applications are obtained by PWM scheme by providing a delay time between the switching pulses for obtaining ZVS operation. Dual duty cycle control scheme, current phasor controlled switching scheme and pulse density modulation schemes are also used in the output power regulation. In the current phasor angle controlled configuration, the output current is controlled by varying the phase angle between the two inverter units [4]. A seamless output power regulation is obtained in this scheme. The main disadvantage is that at low output power settings, the topology has only low efficiency.

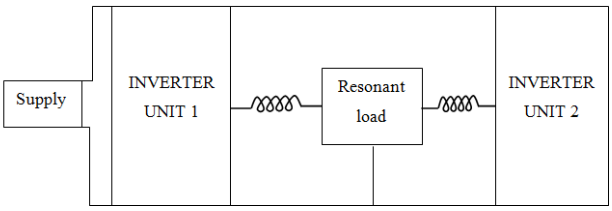

Fig.3.1 Current phasor angle controlled topology

In the PWM scheme used in the inverter units the switching is done in the same sequence as the basic inverter units, but a small delay time is provided between the switching states to provide the zero voltage switching condition of the inverter unit. In the dual duty cycle controlled scheme, the switching is done at different duty ratios among the three inverter switches. This configuration is used in the topology with three switches. It has the added advantage of low switching losses and high output power density, when compared to the H bridge topology. Fig 3.2

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gives the schematic of the dual duty cycle controlled switching pulses.

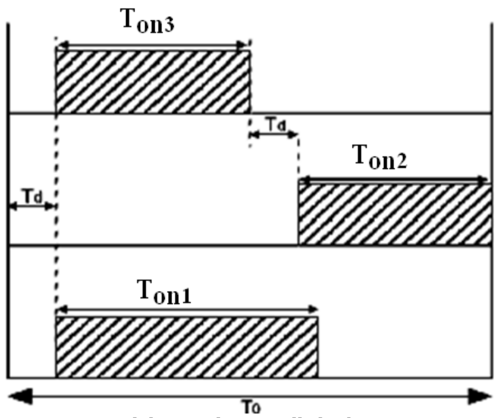

Fig.3.2 Dual duty cycle controlled scheme

Pulse Density Modulation is also a power control strategy used in induction heating appliances. The power control strategies used in resonant inverters viz. frequency control, phasor control, duty cycle control and pulse width modulation scheme does not offer zero voltage switching at all load conditions. PDM technique offers a wider range of power regulation with zero voltage switching. The time period of a PDM full cycle is equal to multiples of load resonant period. The pulse width of each pulse is equal to the time period of the RLC load. This technique allows the inverter units to work close to the resonant frequency. The zero voltage switching is also enabled in the Pulse density scheme, to avoid the switching losses. The switching frequency will be kept slightly greater than the resonant frequency in all the switching schemes. The logic circuit used for the implementation of the pulses in this scheme is shown in Fig 3.3

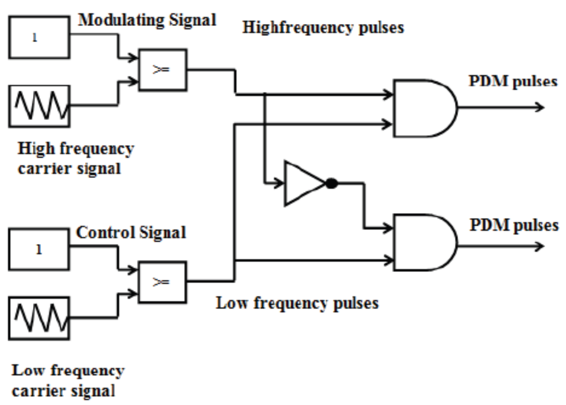

Fig.3.3 Logic circuit for PDM signals

The pulse density modulation scheme can be chosen as an alternative to pulse width modulation scheme due to its simplicity. The low total harmonic distortion of the technique is also an added importance of this scheme. Another advantage is that the zero voltage switching is obtained for all levels of load regulation. The closed loop configuration of pulse density modulation scheme can be implemented by using the block diagram given in the Fig 3.4. A Phase locked loop control along with a P I controller can be used in the closed loop.

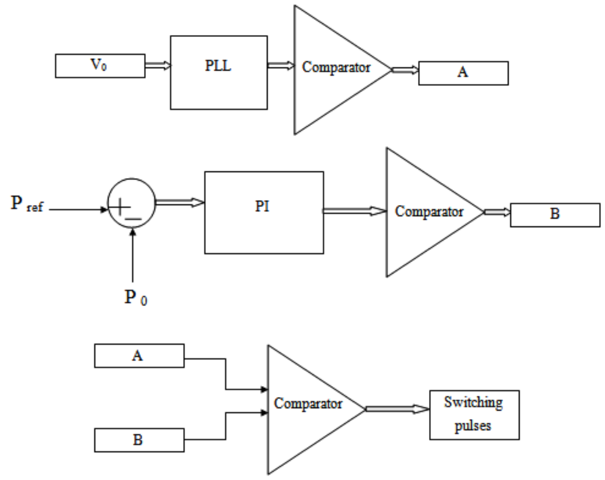

Fig. 3.4 Closed loop configuration of PDM scheme

IV. Simulation Results

The simulation studies are done using a switching frequency of 60 kHz, load inductance of 50 μH, resonant capacitor of .112 μF and an input dc voltage of 240 V.

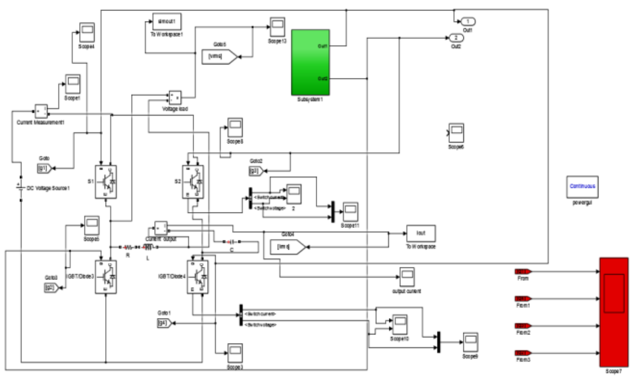

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Fig.4.1 Simulink diagram of a FB topology using PDM

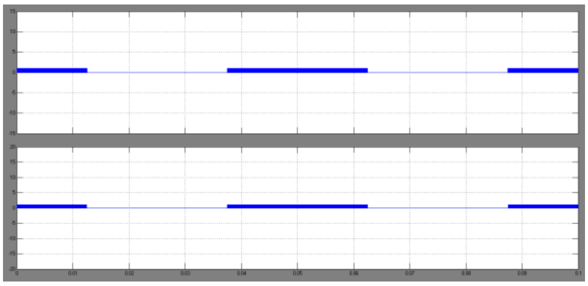

Fig.4.2 Pulses obtained using PDM

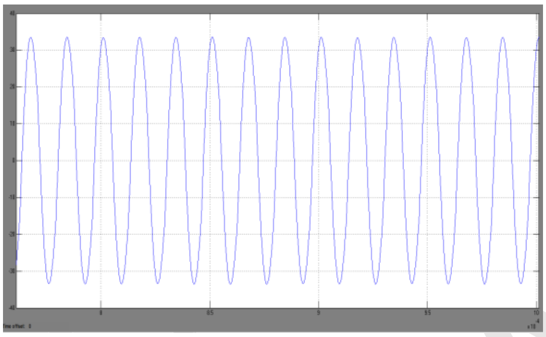

Fig. 3.4 Output current of PDM scheme

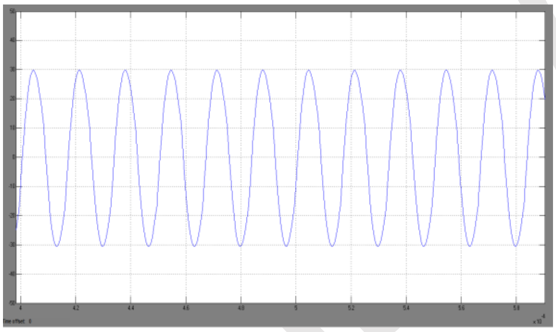

Fig. 3.4 Output current of full bridge configuration

V. Conclusion

The full bridge configuration using the PDM scheme has less THD and higher output current when compared to the normal PWM scheme. The current phasor controlled twin bridge configuration, has high switching current at low output power conditions. The efficiency also decreases at low output power conditions. The asymmetrical switching scheme with three switches can be used to obtain a high output power density and it has higher efficiency when compared to the full bridge configuration. The closed loop control of PDM scheme using PI controller and PLL circuit gives a sinusoidal output current and zero voltage switching conditions. It can be used effectively with modifications.

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