IMPLEMENTATION OF IGBT SERIES RESONANT INVERTERS USING PULSE DENSITY MODULATION

1SARBARI DAS, 2MANISH BHARAT

1M.E., Assistant Professor, Sri Venkateshwara College of Engg., Bengaluru
2Sri Venkateshwara College of Engg., Bengaluru
E-mail: sarb.das@gmail.com, manishb87@gmail.com

Abstract- The aim of this project is to design and simulate to improve the efficiency of IGBT series resonant inverters using pulse density modulation open loop and closed loop controlled boost converter are molded and simulated using the blocks of simulate. This The aim of this project is to design and simulate to improving the efficiency converter has advantages like reduced hardware and improved efficiency. For this purpose, this project analyzes a high frequency (20 kHz) voltage-fed inverter with a series-resonant load circuit for industrial induction heating applications, which is characterized by a full bridge inverter made of insulated-gate bipolar transistor and a power control based on pulse density modulation (PDM). Results will be verified experimentally using a prototype for induction heating applications. Simulation results will be compared with hardware results. This power control strategy allows the inverter to work close to the resonance frequency for all output-power levels. In this situation, zero-voltage switching and zero-current switching conditions are performed, and the switching losses are minimized. An additional improvement of inverter efficiency is achieved by choosing appropriate values of the modulation index. The hardware is fabricated and the details are presented for the simulation.

I. INTRODUCTION

Induction heating generators are resonant inverters in which the resonant tank is formed by a heating coil and a capacitor, in a series-resonant inverter (SRI) or in a parallel resonant inverter. They are used to heat metals to be welded, melted, or hardened. The use of SRIs that are fed with a voltage source represents a cost-effective solution; however, it does not have the ability to control heating the output power by itself when a simple control circuit is used, so that the output power of such an inverter has to be controlled by adjusting the dc input voltage. A thyristor bridge rectifier having input inductors and a dc-link capacitor has been conventionally used as a variable dc-voltage power supply. This causes some problems in size and cost. In order to overcome these problems, an inverter with power control by frequency or phase-shift variation is normally used to regulate the output power and, using a diode bridge rectifier, as a dc-voltage source. These power control schemes, however, may result in an increase of switching losses and electromagnetic noise because it is impossible for switching devices to be always turned on and off at zero current. Therefore, in high-frequency induction heating applications, only MOSFET inverters can be used. Nevertheless, insulated-gate bipolar transistors (IGBTs) are preferred in high-power industrial applications (availability, cost, etc.), and it will only be possible if a low-loss power control scheme is found. This paper describes an induction system of 2 kW and 20 kHz for industrial applications that use a novel low-loss control scheme. The induction system consists of a three-phase diode rectifier, a single-phase voltage-fed inverter using four IGBTs, and a series-resonant circuit with a matching transformer. The working frequency is automatically adjusted close to the resonance frequency in order to allow zero-current switching (ZCS) inverter operation for any load condition. In fact, the inverter performs as a quasi-ZCS because the transistors are always turned off at almost zero current. The output-power control based on pulse density modulation (PDM) maintains this condition in a wide range of output power. The blanking time of the inverter transistors is designed to maintain zero-voltage switching (ZVS) mode. With this circuit, an important improvement of the inverter efficiency is expected at high-frequency working conditions.

In addition, this paper presents a study to determine the most appropriate values of the pulse density and the output current in order to obtain a further improvement of the inverter efficiency for high-frequency working conditions. Under these conditions and with fixed transistor losses, the total output power of the inverter will be increased, improving significantly the relative cost of the induction heating generators without reducing its reliability.

II. PRINCIPLE OF INDUCTION HEATING

The basic components of an induction heating system are an AC power supply, induction coil and work piece (material to be heated or treated). The power supply sends alternating current through the coil, generating a magnetic field. When the work piece is placed in the coil, the magnetic field induces eddy currents in the work piece, generating precise amounts of clean, localized heat without any physical contact between the coil and the work piece.

It is a method of providing fast, consistent heat for manufacturing applications which involve bonding or
changing the properties of metals or other electrically conductive materials. The process relies on induced electrical currents within the material to produce heat. Although the basic principles of induction heating are well known, modern advances in solid state technology have made induction heating a remarkably simple, cost-effective heating method for applications which involve joining, treating, heating and materials testing.

2.1 ANALOGY BETWEEN INDUCTION HEATING AND THE TRANSFORMER PRINCIPLE

The inductor is similar to a transformer primary, and the work piece is equivalent to the transformer secondary (fig.2.1). Therefore several of the characteristics of transformers are useful in the development of guidelines for coil design. One of the most important features of transformers is the fact that the efficiency of coupling between the windings is inversely proportional to the square of the distance between them. In addition, the current in the primary of the transformer, multiplied by the number of primary turns, is equal to the current in the secondary, multiplied by the number of secondary turns. Because of these relationships, there are several conditions that should be kept in mind when designing any coil for induction heating.

1) The coil should be coupled to the part as closely as possible for maximum energy transfer. It is desirable that the largest possible number of magnetic flux lines intersect the work piece at the area to be heated. The denser the flux at this point, the higher will be the current generated in the part.

2) The greatest numbers of flux lines in a solenoid are toward the centre of the coil. The flux lines are concentrated inside the coil, providing the maximum heating rate there.

3) Since the flux is most concentrated close to the coil turns themselves and decreases farther from them, the geometric centre of the coil is a weak flux path. Thus, if a part were to be placed off centre in a coil, the area closer to the coil turns would intersect a greater number of flux lines and would therefore be heated at a higher rate, whereas the area of the part with less coupling would be heated at a lower rate. This effect is more pronounced in high frequency induction heating.

4) At the point where the leads and coil join, the magnetic field is weaker; therefore, the magnetic centre of the inductor is not necessarily the geometric centre. This effect is most apparent in single-turn coils. As the number of turns increase and the flux from each turn is added to that from the previous turns. Due to the impracticality of always centering the part in the work coil, the part should be offset slightly toward this area.

5) The coil must be designed to prevent cancellation of the magnetic field.

Because of the above principles, some coils can transfer power more readily to a load because of their ability to concentrate magnetic flux in the area to be heated.

III. DESIGN AND DESCRIPTION OF IGBT SERIES RESONANT INVERTER

It includes the total schematic block diagram and design and description of each block. Design considerations of each and every block and design equations are explained here.

Power circuit unit consists of a full bridge rectifier. The AC supply given to the bridge rectifier is converted into DC. The AC supply given to the rectifier is 24V, 50 Hz. The output power stage consists of a single phase voltage source inverter using four IGBTs.

The DC supply from the rectifier is given to the resonant inverter to convert it into AC. The output of the inverter is connected to a series resonant circuit with a matching transformer.

The resonant inverter here operates at high frequency of 20 KHz. A PIC microcontroller of input voltage 5 V RPS is used.

The microcontroller here used is 16F877A PIC. A pulse amplifier of 12 V (RPS) is also used. Its main function is to amplify the PIC microcontroller voltage. Resonant inverter requires 10 V supply whereas the voltage generated by PIC microcontroller is only 5V. So to amplify and increase the voltage up to 10V, pulse amplifier is used. It reduces the output current ripple and has a very fast response.
Implementation of IGBT Series Resonant Inverters Using Pulse Density Modulation

The proposed circuit diagram is shown in Fig 3.2. An AC supply of 230V; 50 Hz is available which is given to the 4-bridge diode rectifier. Since the available supply frequency is only 50Hz but we are analyzing for only 20 KHz which is high, we first need to convert it to DC then AC by using inverter. Then by using transformer its frequency is increased and feed it to the RLC load. The transformer used here is high frequency step down transformer. The use of Series Resonant Inverters (SRIs) that are fed with a voltage source represents a cost-effective solution; however, it does not have the ability to control the output power by itself when a simple control circuit is used, so that the output power of such an inverter has to be controlled by adjusting the dc input voltage. A thyristor bridge rectifier having input inductors and a dc-link capacitor has been conventionally used as a variable dc-voltage power supply. This causes some problems in size and cost. In order to overcome these problems, an inverter with power control by frequency or phase-shift variation is normally used to regulate the output power and, using a diode bridge rectifier, as a dc-voltage source. These power control schemes, however, may result in an increase of switching losses and electromagnetic noise because it is impossible for switching devices to be always turned on and off at zero current. Therefore, in high-frequency induction heating applications, only MOSFET inverters can be used. Nevertheless, insulated-gate bipolar transistors (IGBTs) are preferred in high-power industrial applications (availability, cost, etc.), and it will only be possible if a low-loss power control scheme is found. This paper describes an induction heating system of 20KHz for industrial applications that use a novel low-loss control scheme. The induction system consists of a three-phase diode rectifier, a single-phase voltage-fed inverter using four IGBTs, and a series-resonant circuit with a matching transformer. The working frequency is automatically adjusted close to the resonance frequency in order to allow zero-current switching (ZCS) inverter operation for any load condition. In fact, the inverter performs as a quasi-ZCS because the transistors are always turned off at almost zero current. The output-power control based on pulse density modulation (PDM) maintains this condition in a wide range of output power. The blanking time of the inverter transistors is designed to maintain zero-voltage switching (ZVS) mode. With this circuit, an important improvement of the inverter efficiency is expected at high-frequency working conditions.

In addition, this paper presents a study to determine the most appropriate values of the pulse density and the output current in order to obtain a further improvement of the inverter efficiency for high-frequency working conditions. Under these conditions and with fixed transistor losses, the total output power of the inverter will be increased, improving significantly the relative cost of the induction heating generators without reducing its reliability.

IV. PULSE DENSITY MODULATION

It is a form of modulation used to represent an analog signal with digital data. In PDM, instead of specific amplitude values, the relative density of the pulses corresponds to analog signal’s amplitude.

Pulse density = Pulse volume / Pulse width

PDM is a commonly used technique for controlling power to inertial electrical drives. PWM is a special case of PDM where all pulses corresponding to one sample are contiguous in the digital signal. The average value of voltage and current fed to the load is controlled by turning the switch between supply and load on and off at a fast pace. The longer the switch is on compared to off period, the higher the power supplied.

The block diagram of the designed circuit is shown in Fig. 4.1. The aim is to create a pulse density modulation circuit, that does conversion of the input signal into constant length pulse packet and the pulse density depends on the input signal voltage level. The purpose of the designed circuit is to use it to control power inverters. Therefore, mathematic analysis is performed for components that are used in this circuit (Fig. 4.1), such as non inverting integrator, exponential signal generator and integrator reset unit. The pulse density circuit operating principle is that the input signal is integrated into the integration of capacity, up to a certain voltage level. In the moment when the integrating capacitor voltage reaches this voltage level the discharge switch is opened; while the capacitor is being discharged the circuit outlet forms a pulse. After the capacitor is discharged it is being charged again.
V. MODES OF OPERATION

It shows the equivalent circuit of the voltage fed series resonant PDM inverter and its switching modes. In mode 1 & 2 SRI, produces a square wave ac voltage. In mode 3 & 4, it produces a zero voltage state at its output terminals. It shows the PDM based power control. The PDM inverter repeats “run and stop” in accordance with a control sequence to adjust its rms output voltage.

RUN MODE I

In this mode Q1 & Q3 conducts whereas Q2 & Q4 are off. This mode produces a square wave AC voltage. In positive half cycle, the current given is

VI. EXPERIMENTAL RESULTS

The circuit of IGBT series-resonant inverters using pulse density modulation is shown in figure. This AC supply is converted into DC then it is given as input to the inverter. Then it is boosted by using a high frequency transformer then this boosted ac voltage is passed through RLC load. The AC input voltage
waveforms are shown in figure. The switching pulses for Q1 & Q2 is shown in figure 5.9. The switching pulses given to Q1 & Q2 is similar that of Q3 & Q4. The gate voltage and drain to source voltage waveforms of the switches is shown.

Simulation results for the circuit with T_on/T = 0.5 is shown.

Finally the output voltage waveform of the circuit is shown in figure 6 (f).

Then the output current waveforms of the circuit are also is shown in figure 6 (g). The output voltage and output current in same scope is shown in It can be seen the DC output voltage is free from repulse. Meters are connected to display the voltage and current at the input and output DC. The pulse given to Q2 & Q4 is complement of pulse given to Q1 & Q3.

CONCLUSION

Series resonant inverters have become an important part of the new generation power supplies. These type of power supplies are mainly used in high current applications in industries like induction heating, plastic mouldings etc.

The main problem with the conventional type power supplies were high cost and bulky size. Many new series resonant inverters based on phase shifting are employed to avoid these problems. But most of them are suffering from the problem of low efficiency as the switching frequency is increased.

Even though the high frequency operation decreases the component size and increases the power density, the efficiency of the resonant inverters is reduced due to higher switching losses. Switching losses can be reduced by using ZVS & ZCS. Hence a microcontroller based new high frequency resonant inverter is simulated to achieve the low voltage condition at a high current.

The output of the inverter can be varied by changing the modulation index of the inverter used in the system. So this new high current, high frequency resonant inverter has the features of low cost, low power density and fast response.

REFERENCES

