Abstract—This paper deals with a new approach of superimposed radio frequency series resonant current source inverter circuit topology. It is commonly used for medium power induction heating applications. Different control loops, e.g. constant current, voltage or power is implemented depending on applications. There are a number of possible switching strategies that can be used to realise this control, e.g. load resonant, sweep frequency, phase shift and the burst control. In this paper it is shown that the load resonant control strategies are well suited compared to others so far as the power densities and final temperatures used for cooking are concerned.

Key Words—Series load resonant, Superimposed, Switching loss, ZCS, ZVS

I. INTRODUCTION

Induction cookers are designed to compete with conventional stove plates or electric hot plates. The main advantages (+) and disadvantages (-) are:

(+): The coil stays cool, and is therefore safer,
(+): Higher efficiency, i.e. lower electricity bills,
(+): Constant output power,
(+): Absence of shock hazard in the cooking pan,
(+): Flexible temperature control,
(+): Cheaper than readily available micro-oven,
(+): Common kitchen purpose utensils are sufficient for cooking,

(-): Only cooking vessels with a high resistivity and relative permeability can be used,
(-): Higher initial cost than an electric hot-plate,

In order to make a successful cooking apparatus the first step is to select a well-suited inverter and then do an optimal design.

II. REQUIREMENTS FOR INDUCTION COOKERS.

1) Switching in radio-frequency range
2) High efficiency
3) Power factor close to unity
4) Wide power range and
5) Reliability.

Induction cookers are usually designed to operate with a cooking vessel made from a specific material, mainly cast iron or ferro-magnetic stainless steel. The following is therefore desired characteristic for the inverter;

1) No reactive components other than the heating coil and the non-smooth filter inductor,
2) No input or matching transformers,
3) 50% duty ratio, simplifying the control and gate circuits,
4) Zero current switching (ZCS) and / or zero voltage switching (ZVS),
5) Clamped switch voltage and / or current,
6) The use of uncontrolled voltage source.

III. SUPERIMPOSED RADIO-FREQUENCY INVERTER CIRCUIT FOR PRESENT SCHEME

The present development of inverter circuit is shown in Fig. The non-smooth d.c. voltage is available across A & B points in the above mentioned circuit. At first when the inverter circuit is connected with dc power supply of the system, the capacitors C1 and C2 are charged in absence of any gate triggering pulses at G1 and G2. To start high frequency generation, gate triggering pulses are fed from software control circuit alternately to the gates of G1 and G2. When gate pulse arrives at the gate G1, IGBT-1 is turned 'ON'. The charge stored in the capacitor C1 now discharges through QRMN loop while C2 charges to full d.c. input voltage through QRMNO. The discharge of C1 and charging of C2 will both cause a current to flow through the short circuited bar ‘NM’ along M to N.

Next half cycle of operation begins when the gate pulse reaches G2 of IGBT-2 to turn it ‘ON’. However, before applying triggering pulse at the gate G2 the gate pulse of G1 is withdrawn and vice versa to avoid simultaneous conduction which would otherwise bring short circuit
across the d.c source. When IGBT-2 is in the ‘ON’ state then C2 discharges through NMPO loop but C1 charges to full d.c. input voltage through QNMPO loop. The discharge of C2 and charging of C1 will both cause a current to flow through the short circuited bar ‘N M’ along N to M.

Thus, by feeding gate triggering pulses alternately at G1 & G2, there will be generation of an alternating current in the bar ‘NM’. The frequency of this a.c. generation is determined by the frequency of the alternate gate triggering pulses. This is set in radio-frequency (33.33 kHz) range. It is interesting to note that during free-wheeling period as the inverter tries to feed back the stored energy into the d.c. supply system, this excess energy finds a low-impedance path through the capacitor C placed between terminal A & B as shown in fig-1. As a result, the generated alternating current through the bar NM will be reflected back through the induction heating working coil ‘L’ which in turn will generate the required high-frequency alternating magnetic field.

IV. STRUCTURE OF LOAD CIRCUIT

From our previous experience we can say that in high frequency AC circuit, current penetration in the induction coil circuit is very difficult for higher diameter enameled copper wire due to skin-effect. The current flows through the upper layer of the enameled copper conductor. For this reason primary current is very less in the induction coil and as well as secondary flowing eddy current is very very less in the metal pans or vessels or in metallic-packages. So, \( L^2 R \) is very less and there is no practicable heat generation in the objects. To avoid this difficulty we introduce a bundle enameled copper conductor for manufacturing the working induction coil. Inspite of using 10 SWG enameled copper wire. The high frequency current capacity higher gauge wire is produced by twisting 16 numbers of 24 SWG copper enameled wire. This is shown in fig 3.

By means of this construction we shall penetrate the current in bundle conductors assembly but the current is passing through outer skin of the individual 24 SWG copper enameled wire but according to bundle conductor assembly current is passing throughout all cross sectional layers of equivalent higher gauge of conductor. Since the current penetrates in the primary winding of the induction coil, so the secondary current which is flowing in pan or vessel (eddy current) is very much higher. It gives fruitful result in
practical induction heating equipment. Overall geometrical shape of the induction coil for better linking of magnetic flux with pan or vessel for home appliances is of spiral type like fig 4.

VI. DESIGN OF POWER SUPPLY FOR THE PRESENT SCHEME

The voltage available in the laboratory or in the house is A.C 220 V, 50 Hz. At first we take it from system bus and it has to be rectified to generate D.C voltage by full bridge rectifier before feeding to inverter circuit. Before feeding to the inverter circuit, the D.C output is filtered through a non-smoothing L-C filter circuit to get with ripple D.C supply. This non-smoothing filter works as a harmonics filter. When inverter operates then harmonics are generated. To avoid the harmonic injection in the system bus at the time of induction operation, this non-smoothing filter works as high pass filter through capacitor (C) in the figure 5.

VIII. EXPERIMENTAL RESULTS

SET-I :-

<table>
<thead>
<tr>
<th>Temperature response setting</th>
<th>ON PERIOD (µ SEC)</th>
<th>OFF PERIOD (µ SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature set 1</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Temperature set 2</td>
<td>8</td>
<td>22</td>
</tr>
<tr>
<td>Temperature set 3</td>
<td>12.6</td>
<td>22</td>
</tr>
<tr>
<td>Temperature set 4</td>
<td>16</td>
<td>21</td>
</tr>
<tr>
<td>Temperature set 5</td>
<td>19.6</td>
<td>21</td>
</tr>
</tbody>
</table>

Here we designed the firing pulses through software as per the following table.

\[
\eta_{h1} = \frac{P_o}{P_I} \times 100 = \frac{150.29 \text{ W}}{216 \text{ W}} = 69.5 \%
\]

SET-II :-

<table>
<thead>
<tr>
<th>Temperature response setting</th>
<th>ON PERIOD (µ SEC)</th>
<th>OFF PERIOD (µ SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature set 1</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Temperature set 2</td>
<td>8</td>
<td>22</td>
</tr>
<tr>
<td>Temperature set 3</td>
<td>12.6</td>
<td>22</td>
</tr>
<tr>
<td>Temperature set 4</td>
<td>16</td>
<td>21</td>
</tr>
<tr>
<td>Temperature set 5</td>
<td>19.6</td>
<td>21</td>
</tr>
</tbody>
</table>

Efficiency of the home appliance system at temperature Set-I = \eta_{h1} = 150.29 / 216 = 0.695 = 69.5 %
Taking $L = 2256.9$ KJ / Kg (some fluid will be evaporated which is nearer layer of steel vessel or pan)

Heat power transfer to fluid $P_o = (m_C p (T_2 - T_1) + m_v L)/$
time in Sec = $100815.74$ J/ 360 Sec       =280.0437 W
Input power taken from source = $P_i = V_i I_i \cos \phi$ , here $\cos \phi = 1$

Efficiency of the home appliance system at temperature Set-II = $\eta_{h2} = 280.0437 / 308 = 0.909 = 90.9 \%$

\[ \text{SET-III : -} \]

Input no load current $= I_0 = 0.05$ amp
Input load current $= I_2 = 2.34$ amp
Input voltage = $V_i = 200$ volt
Initial temperature of fluid (Ambient)$T_i = 20.5 \degree C$
Final temperature of fluid $T_f = 97 \degree C$
Initial fluid mass (water) $m_i = 125.29$ gm
Stainless steel package (bowl) weight $m_0 = 73.14$ gm
Mass of fluid after experiment $m_f = 93.97$ gm
Mass of evaporated fluid $= m_v = m_i - m_f = 125.29 - 93.97 = 31.32$ gm
Total time taking for reaching final temperature = 300 Sec
Taking $L = 2256.9$ KJ / Kg (some fluid will be evaporated which is nearer layer of steel vessel or pan)

Heat power transfer to fluid $P_o = (m_C p (T_2 - T_1) + m_v L)/$
time in Sec = $110817.184$ J/ 300 Sec       =369.4 W
Input power taken from source = $P_i = V_i I_i \cos \phi$ , here $\cos \phi = 1$

Efficiency of the home appliance system at temperature Set-III = $\eta_{h3} = 369.4 / 468 = 0.789 = 78.9 \%$

\[ \text{SET-IV : -} \]

Input no load current $= I_0 = 0.05$ amp
Input load current $= I_2 = 4.40$ amp
Input voltage = $V_i = 200$ volt
Initial temperature of fluid (Ambient)$T_i = 20.5 \degree C$
Final temperature of fluid $T_f = 97 \degree C$
Initial fluid mass (water) $m_i = 123.19$ gm
Stainless steel package (bowl) weight $m_0 = 79.33$ gm
Mass of fluid after experiment $m_f = 43.86$ gm
Mass of evaporated fluid $= m_v = m_i - m_f = 123.19 - 43.86 = 79.33$ gm
Total time taking for reaching final temperature = 300 Sec
Taking $L = 2256.9$ KJ / Kg (some fluid will be evaporated which is nearer layer of steel vessel or pan)

Heat power transfer to fluid $P_o = (m_C p (T_2 - T_1) + m_v L)/$
time in Sec = $218859.37$ J/ 300 Sec       =729.53 W
Input power taken from source = $P_i = V_i I_i \cos \phi$ , here $\cos \phi = 1$

Efficiency of the home appliance system at temperature Set-IV = $\eta_{h4} = 729.53 / 880 = 0.8286 = 82.86 \%$

\[ \begin{array}{|c|c|}
\hline
\text{Temperature response settings} & \text{Efficiency of cooking appliance} \\
\hline
\text{Temperature Set-I} & 69.5 \% \\
\text{Temperature Set-II} & 90.9 \% \\
\text{Temperature Set-III} & 78.9 \% \\
\text{Temperature Set-IV} & 84.7 \% \\
\text{Temperature Set-V} & 82.8 \% \\
\hline
\end{array} \]

IX. CONCLUSIONS

The above mentioned inverter circuit uses a point source current inverter for various applications. It can be used over a range of frequency from 4 kHz to 500 kHz with more safety, enhanced efficiency and faster response. It consumes less electricity and hence cheaper but quite reliable. The most important feature is its eco-friendly nature with no contamination and absence of combustion waste. Employment of IGBT permits better control and compact size.

X. REFERENCES


