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An AC-AC high frequency pulse density modulated full bridge series resonant converter for induction heating application

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ABSTRACT

This paper deals with a new AC-AC single stage full bridge series resonant converter for induction heating application. The proposed system is simulated with high power density modulation technique to produce an output power of 1.8Kw. The main feature of the proposed converter is to reduce the total harmonic distortion produced in the output current for the switching frequency of 29Khz.Asymmetrical pulse density modulation technique is proposed to achieve maximum output power with less harmonic content. It is found that the THD of the proposed high-power density modulated converter is 13.43%. Here, the validity of the proposed converter for domestic induction heating application is compared and summarized.

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1. INTRODUCTION

Induction heating system is the quite advanced heating system in the current scenario. This system is a contactless heating, fastness in heating, cleanliness and safety is the essential factors to be considered during heating process [1]. The principle behind the induction heating process is faradays law of electromagnetic principle. Here the material to be heated and the heating element do not come in contact. The material to be heated behaves coil 1 and heating element as coil 2. Principle of mutual inductance is applied [2]. The heating process is done in two ways one is eddy current and the other is hysteresis effect. The effect of transferring the heat energy to the working material from the heating element is called joule effect. There are other heating technologies like flame heating, resistance heating, traditional oven heating [3]. In medicinal application like heating of the biological tissues during the treatment of the cancer patients during radiotherapy converting the high frequency to the ultra high frequency for uniform spreading of the heat energy with a temperature of 25˚C and a power of 40 watts [4]. The methodology of the system is single stage (AC-AC) and multi stage operation (AC-DC-AC) this stages in operation is only to convert utility frequency input to the high frequency input which is the major requirement for the operation [5]. The recent issues of IH system deals with half and full bridge converter both in the field of industrial and domestic purpose. In industrial application like melting of alloys, forging, hardening etc. The most efficient method employed is IH system. [6-11]. Depending on the load there are other classifications like series connected load, parallel connected load, series parallel connected load [12].

This paper discusses about the single stage full bridge AC-AC converter for induction heating application in the following section II discussion is about description of the proposed converter,section III the modes of operation is elaborated and in section IV the essential results of the proposed converter is discussed. The comparison of the converter is made in section V.

2. DESCRIPTION OF THE PROPOSED FULL BRIDGE SERIES RESONANT CONVERTER

The single stage AC-AC series resonant full bridge converter is proposed for the induction heating application in the field of domestic. The Figure1depict the proposed full bridge series resonant AC-AC converter. There are various configuration and topologies for the design of the power circuit for the induction heating application familiar and the easily accesible one is the full bridge converter. Here we have single stage operation which will have a harmoniclesssystem. The output power required for the domestic application is found to be <2kilowatts that can be easily produced by the full bridge converter. The coil configuration can be series, series parallel or parallel to have efficient performance of the system series connection of the elements is preffered. Checking on the resonance condition of the coil the switching frequency is selected satisfying the condition $F=1/2\pi RC$.

For the choosen switching frequency the type modulation used should be high power density modulation for converting the utility frequency to the high frequency output. There are different types in the power density modulation one is assymmetrical and symmetrical pulse density modulation. The comparison of the results is between the two techniques and modes of operation are framed according to the pulse width.

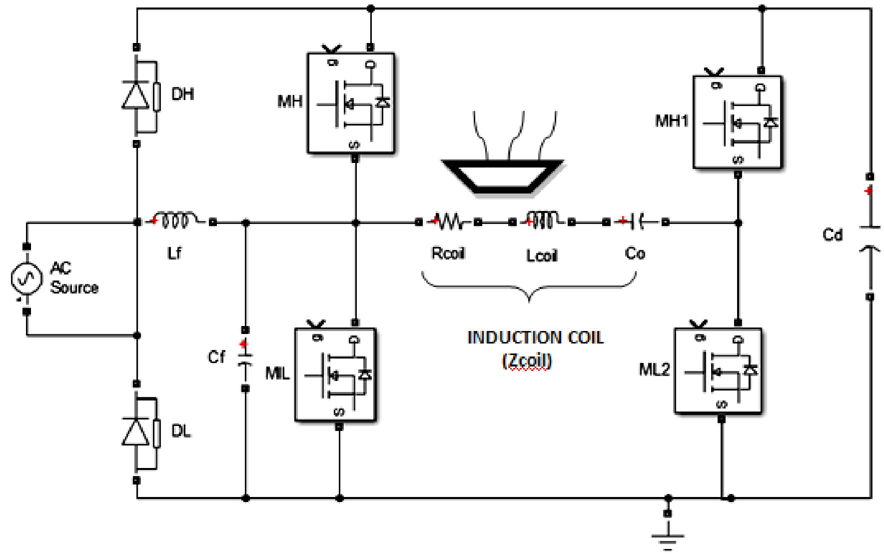

Figure 1. Full bridge series resonant converter for IH applications

3. MODES OF OPERATION

The operation of the circuit comprises of four modes from origin of the pulse generation and end of the single pulse this repeated n number of times in the one half a cycle. The operation depends on the charging and discharging the capacitor in the circuit prescribed in Figure 1. The on and off condition of the switches present in the circuit is summarised at the end of the section which clearly depicts the flow of operation and in each mode the equivalent circuit path is shown for the reference to make the analysis of each mode in Table 1. The modes of the proposed system is elaborated in the section.

Table 1. Summarization of modes of operation

Modes	Condition of the switch	Inference	Time period
Mode 1	$M_{H,}M_{L1}$(on state)	$V_{out}=0$	$T=0$
		$V_{out}=V_S$	$0<T<t_1$
Mode 2	M_L,M_{L1}(on state)	$V_{out}=0$	$T=t_1$
	D_L=RB	$V_{out}=V_{co\uparrow}$	$t_1<T<t_2$
Mode 3	M_L,M_{H1}(on state)	$V_{out}=0$	$T=t_2$
	D_L=FB	$V_{out}=V_{co\downarrow}$	$t_2<T<t_3$
Mode 4	M_L,M_{H1}(on state)	$V_{out}=0$	$T=t_3$
	D_L=FB	$V_{out}=V_{CD}= V_S$	$t_3<T<t_4$

3.1. Mode 1(0<T<t₁)

Here the power switch M_H and M_{L1} is under on state and the flow of current in the circuit from the supply is divided in to two paths and named as I_1 and I_2 and the total current of I. The period of on condition of the power switches is from 0 to t_1 for the positive half cycle of the operation with assymmetrical pulse density modulation. The equivalent circuit is depicted in the Figure 2 showing forward mode of operation the output voltage and the current follows the applied input voltage till the power switch is in the on state.

$I=I_1+I_2$

$V_S=V_m Sinwt$

$V_{cd}=V_{coil}=V_s$

So, (1)

$V_{cd} = 1/C_d \int I_2dt$

$V_{coil} = I_1R_{coil} + {}_{Lcoil}\, dI_1/dt + 1/C_o \int I_1dt$

$1/C_d \int I_2dt = I_1R_{coil} + {}_{Lcoil}\, dI_1/dt + 1/C_o \int I_1dt$

Cycle continues for the period of 0 to t_1

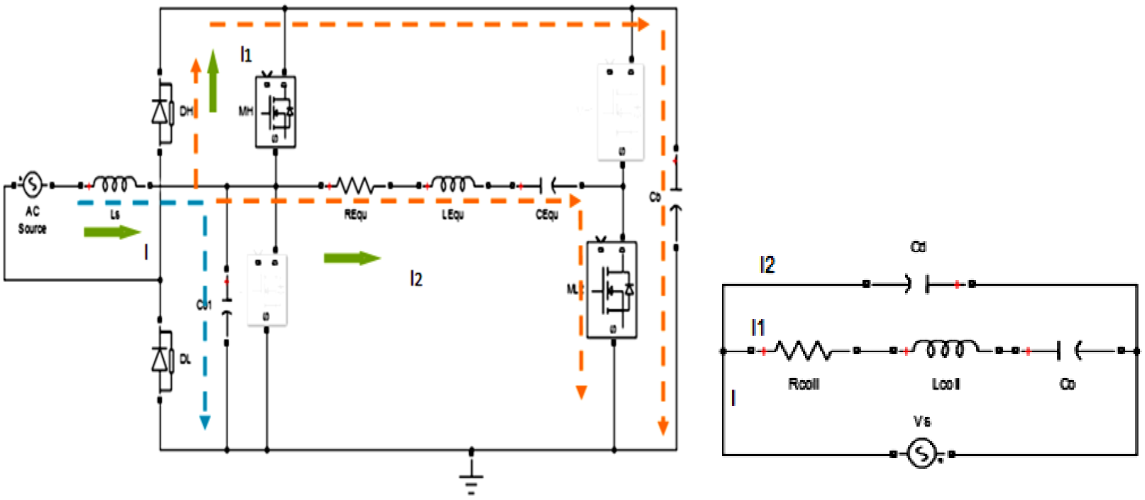

Figure 2. Mode 1(0<T<t₁),equivalentcircuit

$$1/C_{d0}\int^{t1} I_2dt = I_1R_{coil} + {}_{Lcoil}\, dI_1/dt + 1/C_{o0}\int^{t1} I_2dt \qquad (2)$$

On solving the ratio between the currents is found to be

$I_1(S)/ I_2(S)= 1/(1+RCS+LCS^2)$

(OR)

$I_2(S)/ I_1(S)= 1+RCS+LCS^2$ (3)

The DClink capacitor is charged to a voltage equivalent to the source voltage V_S. Now,

$V_{cd}=V_S$

$V_mSinwt=1/C_{d0}\int^{t1} I_2dt$

On solving we get

$I_2= V_mC/wt(coswt_1-1)$ (4)

3.2. Mode 2: (t₁<T<t₂)

By using the commutation technique the power switches M_H and M_{L1} is put to off state and the coil carries a voltage of zero at time $T=t_1$, the DC link capacitorcharges to a maximum of the input voltage in Figure 3. Now the power switch M_L and M_{L1} is put to on state,the instant the switches or put to on state.

The diode D_L moves to reverse bias condition and now the second path of the current flow is the discharging of the resonating capacitance has stored charge in the mode 1 now discharges and circulates the current to flow in the coil through out making the continuous flow of current through the coil now in this particular mode we have output voltage across the coil as the voltage in the storage element.

$$V_{coil}= V_{co,}$$
$$V_{coil}=1/C_0\int I_1dt \quad (5)$$

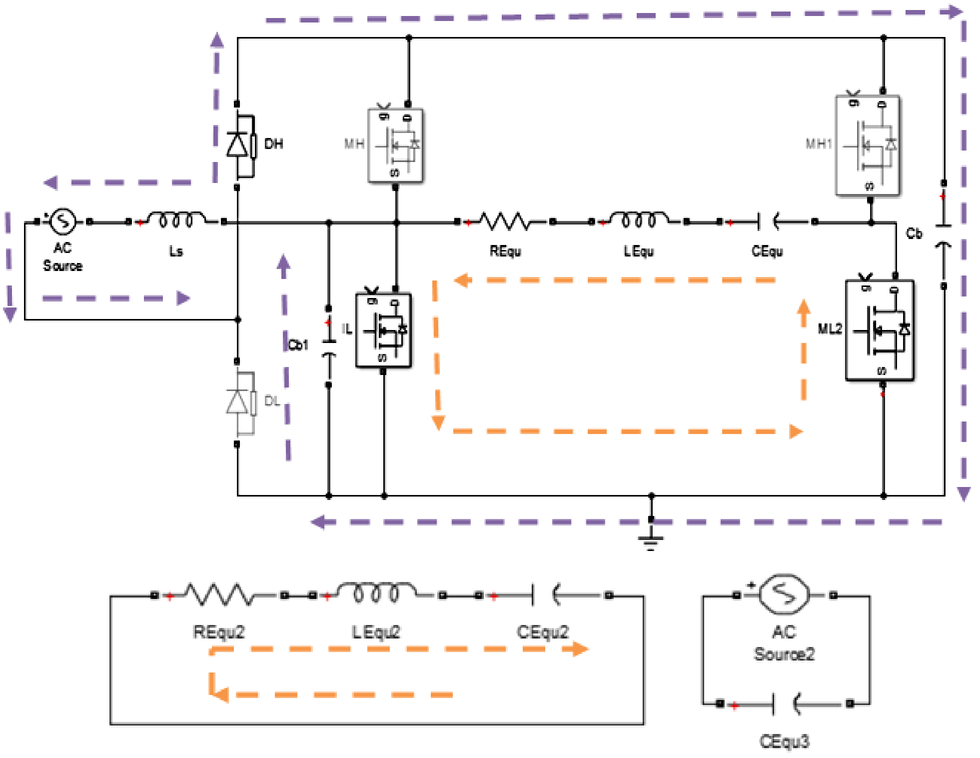

Figure 3. Mode 2: (t_1<T<t_2)

3.3. Mode 3: (t_2<T<t_3)

When the DC link capacitor is fully charged during the mode2 operation,the excess charge from the DC link capacitor starts discharging now this discharing of the capacitor makes the current to flow in a reverse diresction so now the diode D_LIS moved to the forward bias condition Making the power switch M_{L1} to move to off state and allowing the switch M_{H1} to go to on state in Figure 4. The discharging current finds the path through the coil and now we have the current from the source also flowing via coil so the additive current flows through the coil. This mode of operation allows the maximum current to flow through the coil.

$$I_{Coil}=I_{supply}+I_{CD} \quad (6)$$

The voltage across the coil is found to be either V_S or V_{CD}

$$V_{Coil} = I_{Coil}*Z_{coil}$$
$$V_{Coil} = V_S = V_{CD} \quad (7)$$

3.4. Mode 4: (t_3<T<t_4)

The DC link capacitor has discharged to a minimum value in the previous mode of operation in Figure 5, now the diode D_L moved to the reverse bias condition following two path.The capacitor now finds the path to charge itself to the source voltage and the other path the resonating capacitor in the coil starts charging and the coil carrying the voltage in the previous mode 2. So the cycle repeats for the times the pulse generated for the half a cycle.

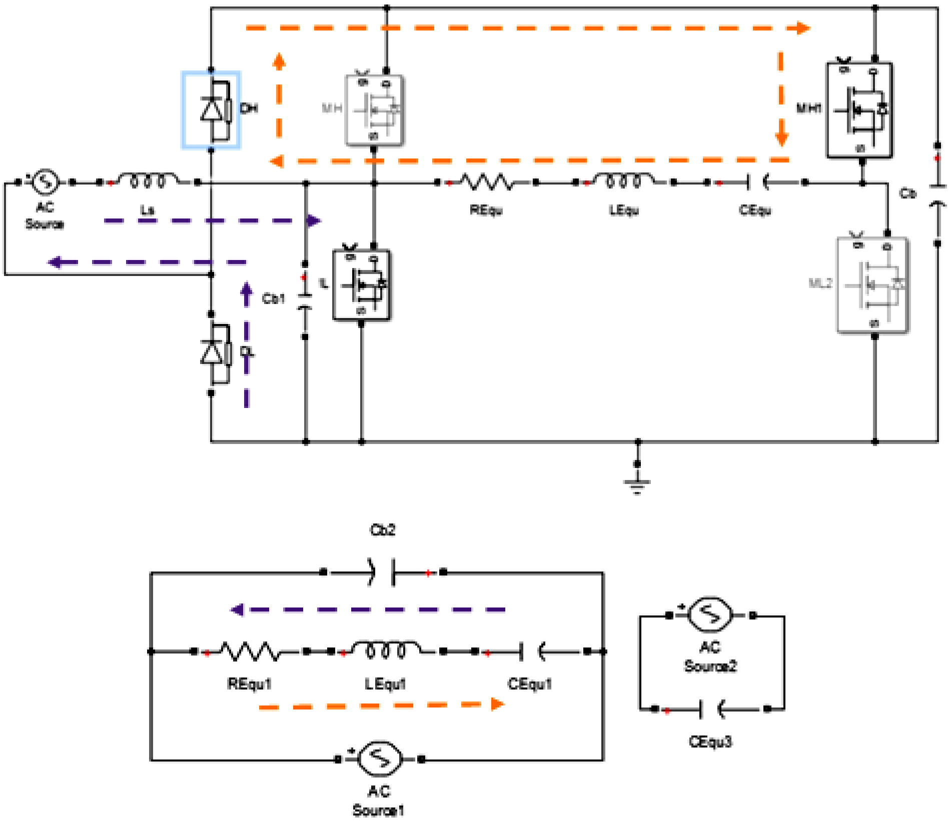

Figure 4. Mode 3: (t_2<T<t_3)

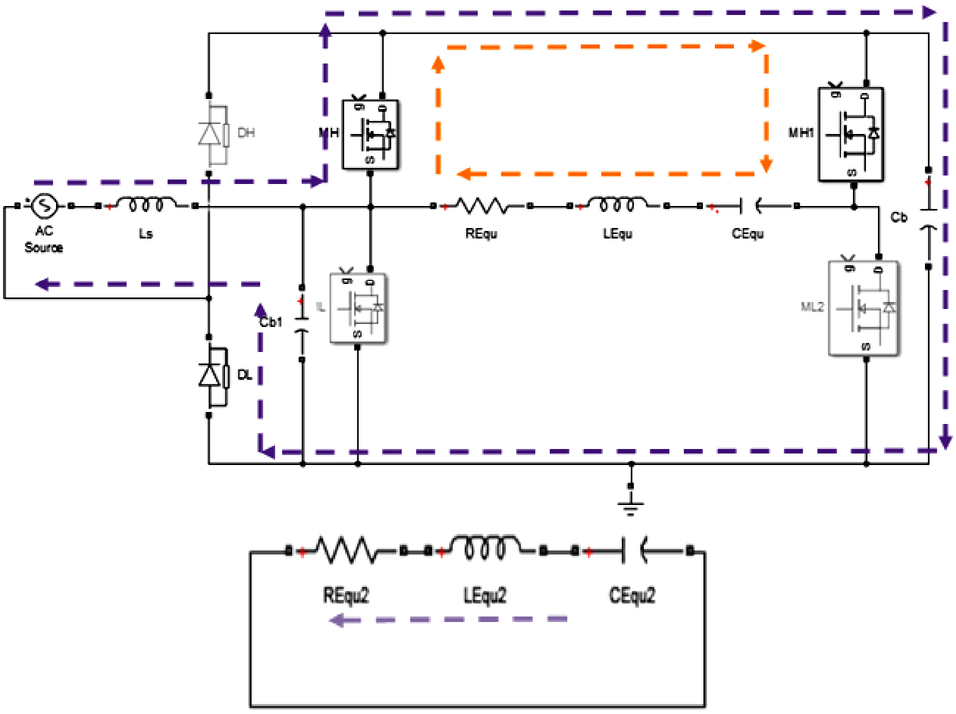

Figure 5. Mode 4: (t_3<T<t_4)

4. SIMULATION RESULTS

Simulation of the proposed system was carried out for the asymmetrical pulse density signal the output waveforms of the simulated system is as in the Figure 6. The waveform of the filtering elements in the input part is also shown in Figure 7. The on time of the switch is restricted to 30% and the respective power output is also shown in Figure 8 the output power reached with this technique is 1.8Kwatts.

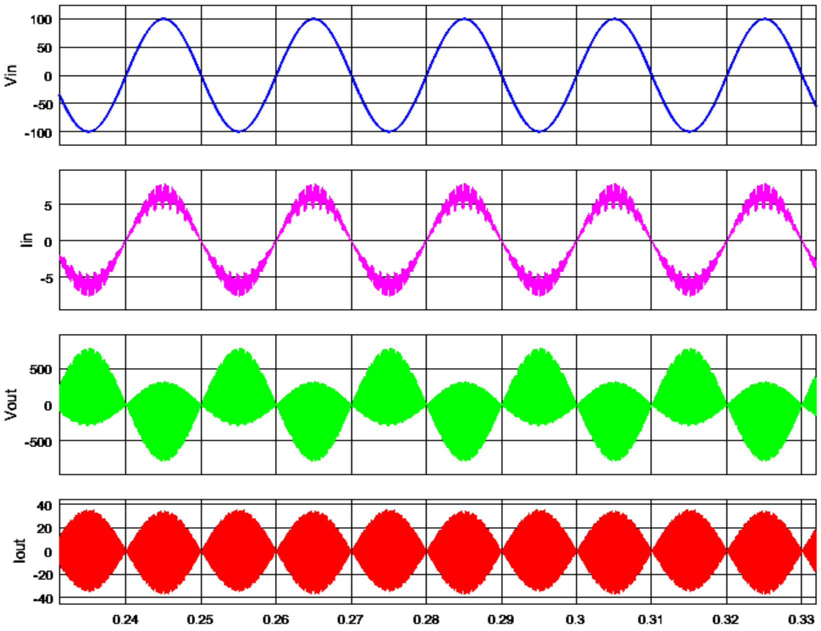

Figure 6. Asymmetrical pulse density modulated output waveform

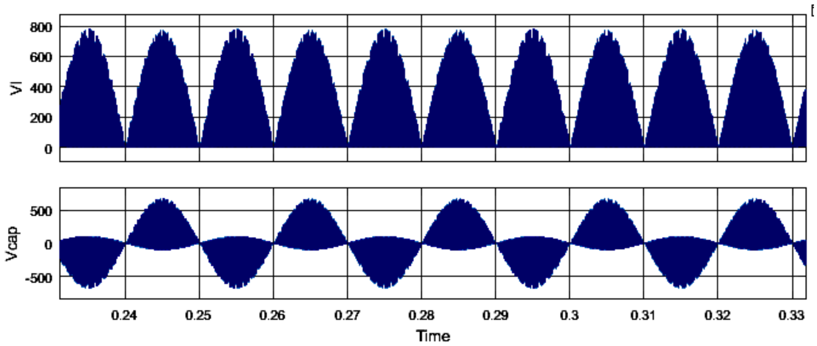

Figure 7. Voltage across filtering component

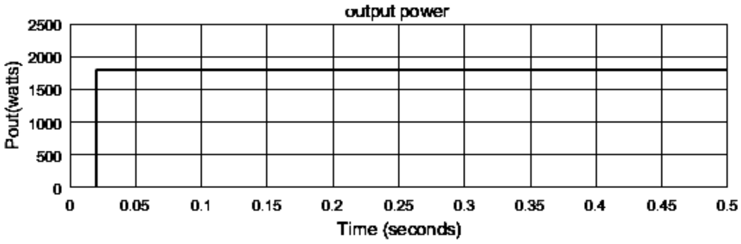

Figure 8. Pout VS time(ms) curve

The total harmonic content of the output current is analysed by FFT analysis tool and found to be lesser compared to the symmetrical pulse density modulation. The filtering components in the input part of the circuit filters the maximum harmonic content in the output and provides us the undistorted output waveforms and the FFT analysis depicts the THD level of the output current produced in the coil.practically in the simulation it is found the the harmonics level is 13.43%which is less compared to the symmetrical pulse density modulated output in Figure 9. Simulation results for symmetrical pulse density modulated full bridge series resonant converter is as follows and the results produced at the output of the system and the filtering elements are depicted in Figure 10 and the output power verses the time curve is shown in Figure 11. The output power is found to be 2.89Kw. Figure 12 depicts the waveforms of the filtering component and here THD is calculated practically and found to be 36.66% in Figure 13.

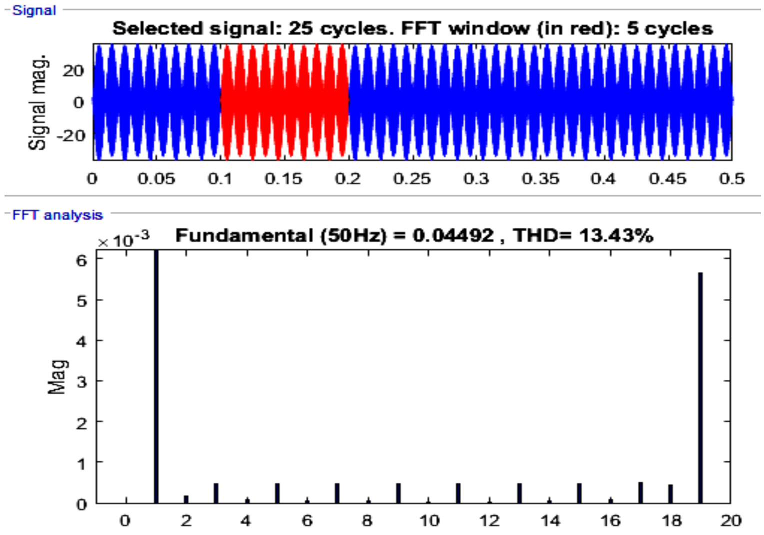

Figure 9. THD of output current produced in the proposed system

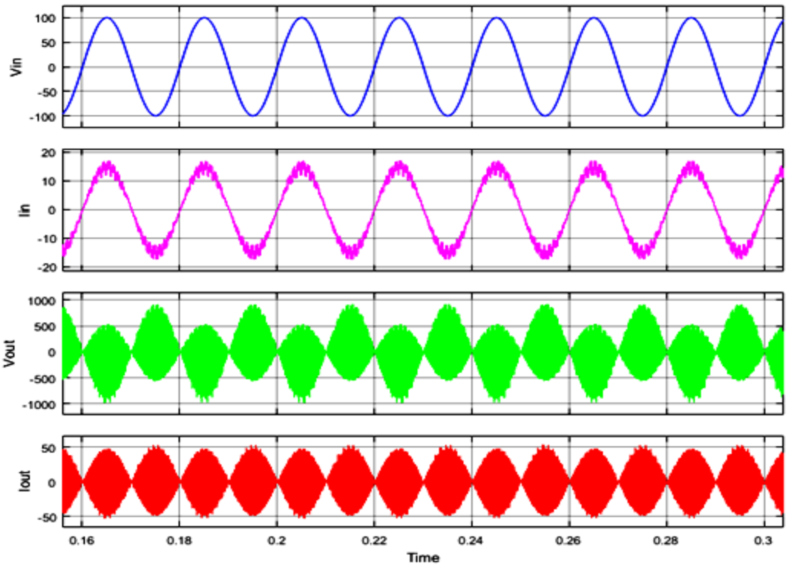

Figure 10. Symmetrical pulse density modulated output waveforms of full bridge series resonant converter

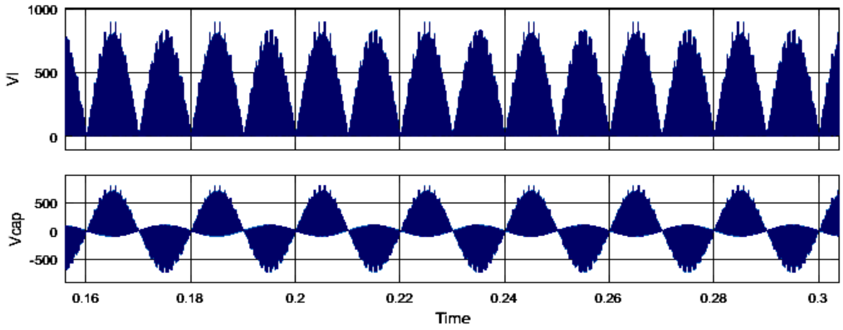

Figure 12. Voltage across the filtering element

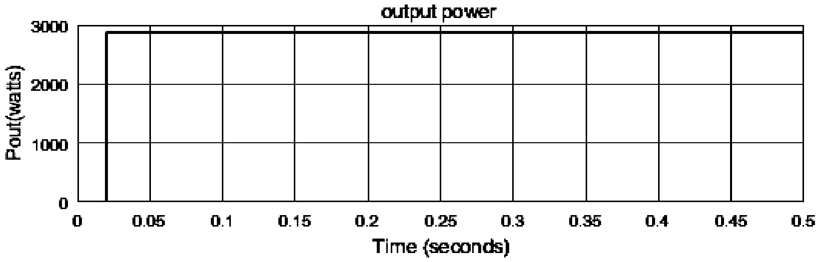

Figure 11. Output power VS T time(ms)

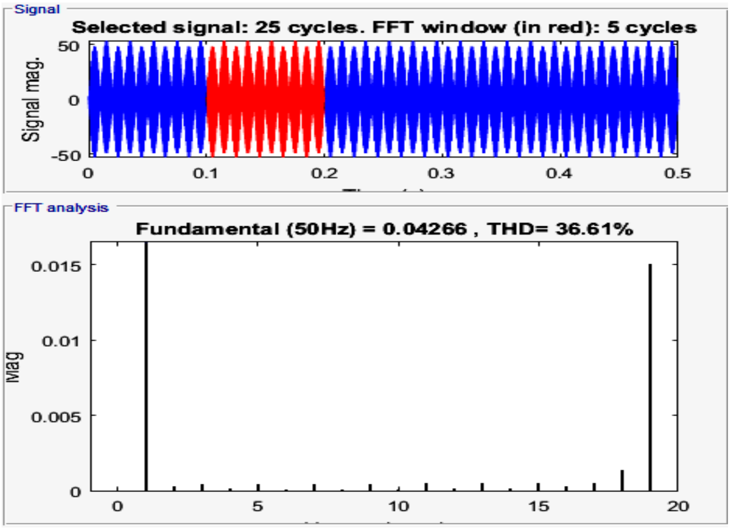

Figure 13. THD of the output current for the proposed system

Here the asymmetrical pulse density modulated and symmetrical pulse density modulated signals are compared and the comparison chart is shown in the Table 2. The result of the system is as tabulated in the following Table 2.

Table 2. Result comparison

Parameter	Asymmetrical modulated output	Symmetrical modulatedoutput
Vout(volts)	124.9	150.4
Iout(amps)	13.26	21.02
Pout(kw)	1.8	2.8
THD%	13.43	36.61
Power factor	1.08	0.9

5. CONCLUSION

The system simulated for the design of the induction heating system for domestic application. The above depicted results on comparison explicit the performance of the system. Here the asymmetrical pulse density modulated and symmetrical pulse density modulated signals are compared and the comparison chart is shown in the Table 2. The results have a contradictory view like we could see the THD of the simulated system to be 13.43% and 36.63% for the respective system and on behalf of power is found to be 1.8KW and 2.8 KW in the respective part of the system. Power factor of the system simulated is calculated by comparing the phase difference between the output voltage and output current.

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