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# Phase Shifted Soft Switching High Frequency Converter with Soft Switching Boost Power Factor Correction Converter for Induction Heating

Gowtham S[1], M. Gopikrishnan [*2]

Assistant Professor, Dept. of EEE, Jerusalem College of Engineering, Chennai, Tamil Nadu, India[1]

Assistant Professor, Dept. of EEE, Bharath University, Chennai, Tamil Nadu, India[2]

[*] Corresponding Author

**ABSTRACT**: This paper deals with the suitable topologies for consumer induction heating systems. This system consists of soft switching chopper based boost pfc converter with passive snubber and phase shifted pulse width modulation PS-PWM controlled full bridge Inverter with ZVZCS. The chopper operates under the principle of ZVS turn on and ZVS turn off commutation schemes, in which inductor and capacitor in auxiliary circuit works as lossless snubber which reduces conventional switching losses and reduces EMI and PFI Noises. The operating modes of the circuit and its performance characteristics are discussed throughout this paper. A special importance is given for PF of the device as it has IH load and suitable Harmonic analysis has been done to enunciate the effectiveness of the circuit.

**KEYWORDS:** Induction Heating, Soft switching, High Frequency power converter, Chopper with single passive resonant snubber, soft switching PWM, Power factor correction.

## I. INTRODUCTION

One of the major trends in power electronics is increasing the switching frequencies. The advances in semiconductor fabrication technology have made it possible to significantly improve not only voltage – and current capabilities but also the switching speed. The faster semiconductors working at high frequencies result in the passive components of the converters – capacitors, inductors and transformers – becoming smaller thereby reducing the total size and weight of the equipment and hence to increase the power density. The dynamic performance is also improved.

This frequency elevation is responsible for the growing importance of pulse-width modulation on the one hand and for the use of resonance on the other hand. Another important trend resides in reduction of voltage and current stresses on the semiconductors and limitation of the conducted and radiated noise generated by the converters due large di/dt and dv/dt [1], [2], [3], [4], [5].

Electromagnetic induction heating applied technologies in home and business usages have been spotlighted in attractive induction heating appliances such as metal working process, heat treatment, dissolution process, induction heating soldering, and induction fusion of polyethylene pipe, induction heating IH rice cooker, IH boiler, and IH hot-water supplier. The developments on the modern electric kitchen systems with advantages as simple, reliability, safety, maintenance free, efficiency improvement of the food cooking and processing work, and reduction in total running cost have attracted special interest in modern society.

The development of the new high frequency induction heating cooker, boiler and super heated steamer, that is high-performance, high power density and high-efficiency compared with the conventional gas cooking equipment are much

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more attractive for home and business uses. By such technological background, high-frequency soft switching power supply for the electromagnetic induction heating with the control schemes has been developed in recent times.[6]

In this paper, a phase shifted soft switching high frequency inverter with boost PFC converter is simulated. It consists of two basic stages. One is Boost power converter with single auxillary passive resonant snubber, which has ZCS turn on and ZVS turn off. The other is the inverter stage soft switching Inverter stage with PS-PWM control scheme.

## II. CIRCUIT DESCRIPTION

The basic setup consists of represents power supply using a high frequency soft-switching phase-shift PWM inverter HF-INV with boost PFC converter [1]. This circuit topology consists of a boost PFC stage comprising low pass filter Lf and Cf, boost inductor L1, switching device Q1 S1/ D1 with its lossless snubber inductor $L_2$ and lossless snubber capacitor $C_1$, $C_2$, intermediate DC smoothing capacitor $C_0$ and so on. Additionally, the high frequency inverter stage comprises ZVS side switching devices $Q_2$ and $Q_3$, lossless snubber capacitor $C_{sn}$, ZCS side switching devices $Q_4$ and $Q_5$, and lossless snubber inductor $L_{sn}$. The induction heated load with working coil is described as $L_0$ & $R_0$ with a series capacitor $C_s$ [2]. In addition, the commercial AC oriented lower frequency current components through the working coil is designed to be eliminated by intermediate DC smoothing capacitor $C_0$. The switching frequency of the proposed circuit is 60kHz. High frequency output power to the IH load can be regulated by controlling the switching phase angle φ of the high frequency inverter stage, as well as intermediate DC voltage $V_{Co}$ which can be controlled by the boost PFC Duty cycle [3].

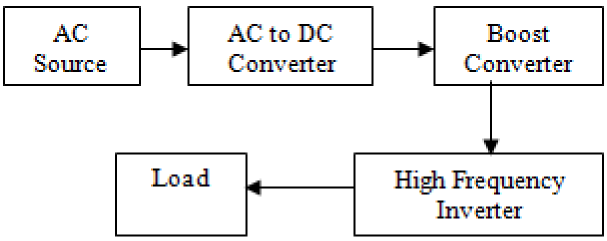


Fig 1 - Block Diagram of the IH Circuit

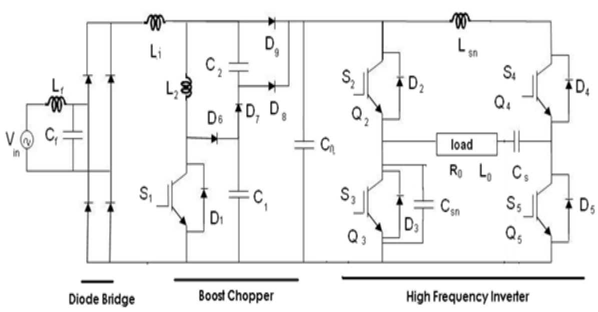


Fig – 2 Circuit Diagram

## III. CHOPPER OPERATION

The primarily connected voltage boost PFC converter stage has two functions [10]. One is power factor correction of the total system with discontinuous current mode operation; the other is the additional output power regulation for various metallic pans and kettles, by boosting intermediate voltage VCo. This circuit stage includes 10 operating

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modes during one switching period, as shown in Fig. 5 and Fig. 6. In these figures, the following high frequency inverter stage with IH load is described as simple resistance RS. The circuit operation in each operating mode is simply described as follows:

**Mode1** : At time point t0, the boost inductor current is zero. So current only flows to resistance RS and intermediate capacitor CO [4]. Then, capacitor C1 is charged to output voltage VCo, but capacitor C2 is discharged.
**Mode 2** : Switch S1 is turned on with ZCS condition at t1 and then C1 starts to discharge through C1-C2-L2-S1 loop as shown in Fig. 5, producing a sinusoidal resonant current. The current of S1 increases gradually by the effect of the lossless snubber inductor L2 [5].
**Mode 3** : At time point t2, the boost inductor current increases gradually. As a result, the current through inductor L2 contains both the current of inductor L1 and the resonant current [6].
**Mode 4** : The voltage across capacitor C1 reaches zero at time point t3 [7]. The current starts flowing through the L1-D6-D7-C2 loop.
**Mode 5** : When C2 is fully charged, switch current iS1 is equal to inductor current iL1. The turn-on commutation process is completed. The converter circuit works as a conventional boost chopper type converter circuit [8].
**Mode 6** : At time point t5, active power switch S1 is turned off [9]. The current starts to charge capacitor C1 through D6. So switch S1 is turned off under ZVS condition with the assistance of lossless snubber capacitor C1.
**Mode 7** : When the voltage across C1 reaches to the output voltage VCo, C2 start to discharge through D3. C1 is still charged by the inductor current iL2.
**Mode 8** : When the capacitor C1 voltage is charged up to the output voltage $V_{Co}$ at time point t8, flows through D6-D7-D8. Thus, the current through L2 decreases continuously.
**Mode 9** : When the inductor current iL2 becomes zero, the current iL1 flows to C2 via D7.
**Mode 10**: When the voltage across C2 goes to zero at time t9, inductor current iL1 flows into RS and Co through D9 [11].

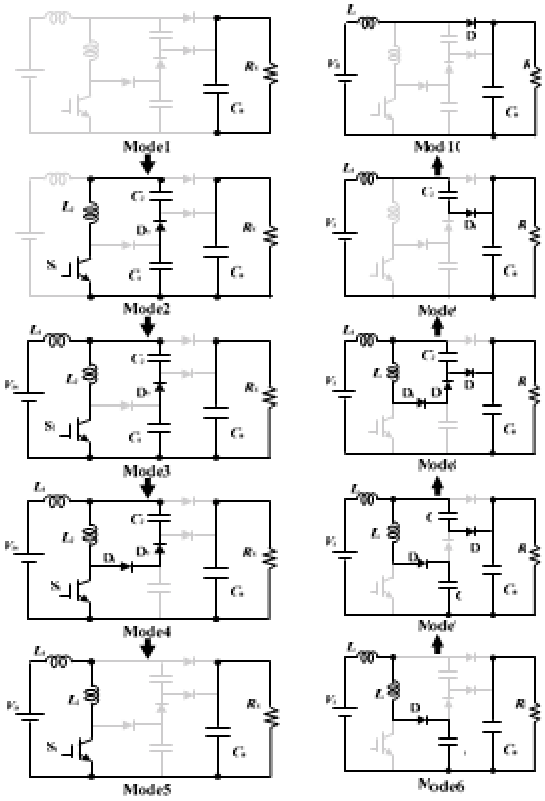


Fig 3 Modes of operation of Chopper

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In this operation principle, the boost switching device S1 can operate under the condition of ZCS turn on and ZVS same time, the current through D5 starts to decrease

## IV. INVERTER OPERATION

The principle of the soft switching phase-shifted PWM inverter stage is explained below. This circuit includes ten operation modes during one switching period. Switching devices Q2 and Q3 in the current lagging leg operate under the conditions of ZVS & ZCS turn on and ZVS turn off by the lossless snubber capacitor Csn. On the other hand, switching devices Q4 and assisted by lossless snubber inductor L , and ZCS & ZVS turn on. The high frequency output power is regulated by the phase shift angle φ as shown in this figure [12]. The circuit operation in each operating mode is simply described as follows,

**Mode 1:** The switch S4 is turned on under ZCS condition the current begins to flow through the resonant circuit as S4-Cs-R0-L0-D2-Lsn loop. The gate signal of S2 turns on while D2 is conducting [13].
**Mode 2**: Due to load resonance, the current flowing to S4 turns to zero and then the regenerative current flows through anti-parallel diode D4. The gate signal of S4 is turned off under ZVS&ZCS condition.
**Mode 3**: Switch S5 is turned on. The current through D4 reaches zero linearly due to continuous current of the lossless snubber inductor Lsn. This current has a gradient of constant value [14]. Therefore S5 is turned on under ZCS condition with the assistance of lossless snubber inductor Lsn.
**Mode 4** : Both switches S2 and S5 are conducting. The high frequency power is supplied from the DC voltage source to the load. Lossless snubber capacitor Csn starts to discharge Therefore, S2 is turned off under ZVS condition [15].
**Mode 5** : When switch S2 is turned off, time point t4, the loseless snubber capacitor Cn starts to discharge. Therefore, S2 is turned off under ZVS condition.
**Mode 6**: When Csn is fully discharged, the current flows through the resonant loop S5-D3-L0-R0-Cs. At this time, the gate signal S3 is turned on [16].
**Mode 7**: Due to the circuit resonance, the current through S5 turns to zero and then the regenerative current flows through the anti-parallel diode D5. The gate signal of S5 is turned off under ZVS&ZCS condition.
**Mode 8**: Switch S4 is turned on with ZCS condition. At the

.

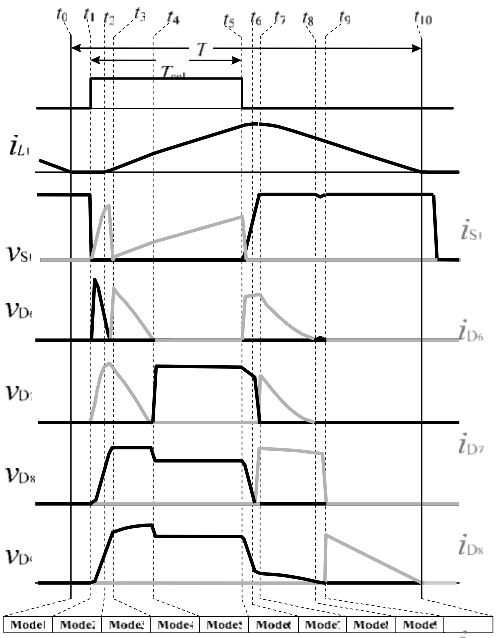


Fig 4, Theoretical waveforms of the Chopper

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**Mode 9**: Both S4 and S3 are on state. The IH power is supplied from the DC voltage source to the IH lo

**Mode 10** S3 is turned off at the time point t9 with ZVS condition by the assistance of the lossless snubber capacitor Csn

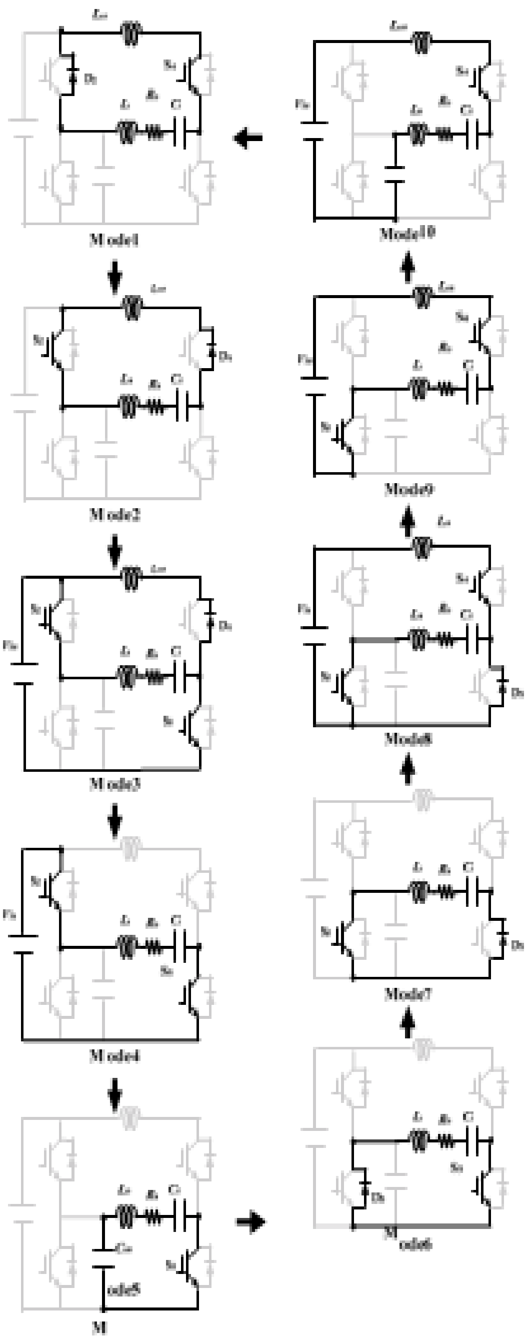

Fig 5, Modes of operation of HF Inverter

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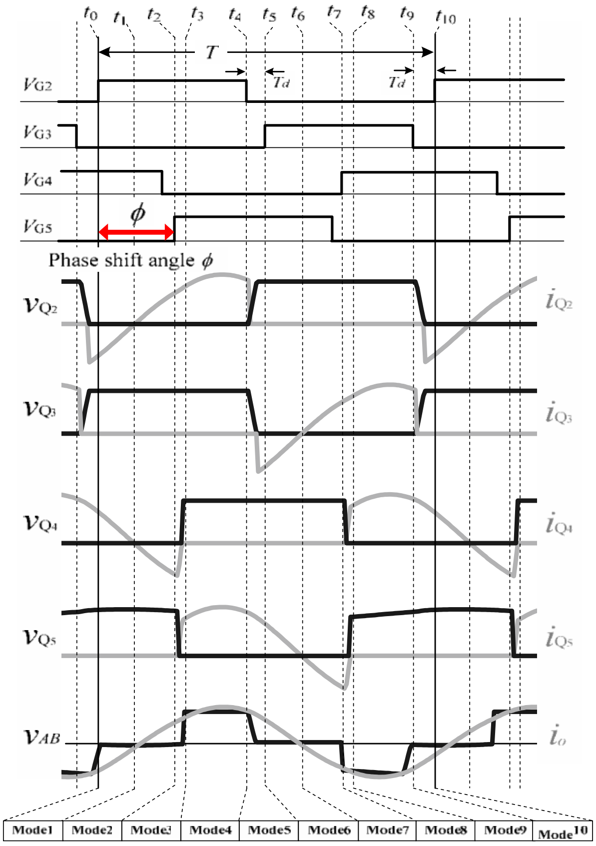


Fig 6, Waveforms of Inverter

## V. SIMULATION PARAMETERS

The simulation for the above circuit is done using MATLAB- SIMULINK. The parameters considered are given below in the table.

.The above parameters are of the filter circuits and the chopper circuit. The below table consists of the inverter circuit parameters.

| Item | Symbo | Value |
|---|---|---|
| Utility AC side Voltage | $v$ | 200V |
| Utility AC Frequency | $f$ | 60Hz |
| Switching Frequency | $f_{SW}$ | 60kHz |
| Filter Capacitance in Utility AC | $C_f$ | 5µF |
| Filter Inductance in Utility AC | $L_f$ | 900µH |
| Boost Inductance | $L$ | 28µH |
| Lossless Snubber Inductance | $L$ | 2µH |
| Lossless Snubber Capacitance | $C$ | 0.043µ |
| Lossless Snubber Capacitance | $C$ | 0.7µF |
| DC Filter Capacitance | $C$ | 3900µF |

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| | | | |
|---|---|---|---|
| Lossless Snubber Inductance | | $L_{sn}$ | 2μH |
| Lossless Snubber Capacitance | | $C_{sn}$ | 0.01μF |
| Power Factor Compensation | | $C$ | 0.032μ |
| Load 1 | Load Inductance | $L$ | 242.3μ |
| | Load Resistance | $R$ | 25Ω |
| Load 2 | Load Inductance | $L$ | 216μH |
| | Load Resistance | $R$ | 1.8Ω |

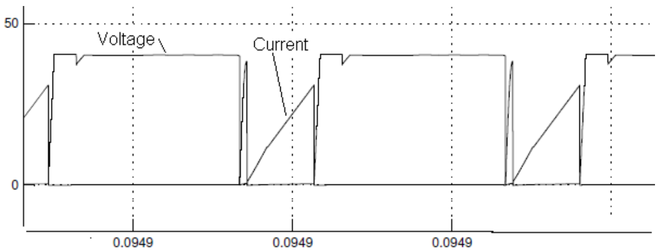


Fig 7, Soft switching Chopper

The soft-switching of the chopper is shown in the above waveform. It is noted that the voltage waveform is scaled to 1/5$^{th}$ of its original waveform and the current waveform is to the original scale [17]. The soft switching is shown in following figures.

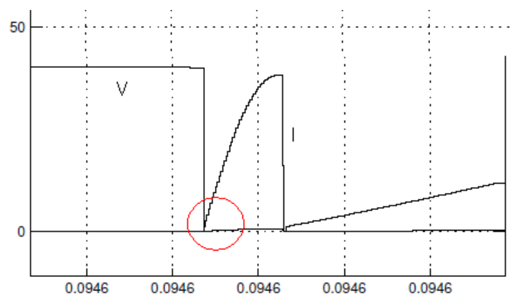


Fig 8, Turn On State of Chopper

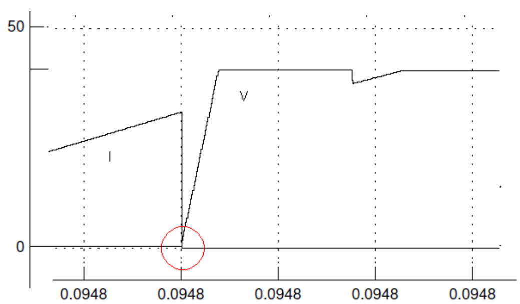


Fig 9, Turn OFF state of chopper

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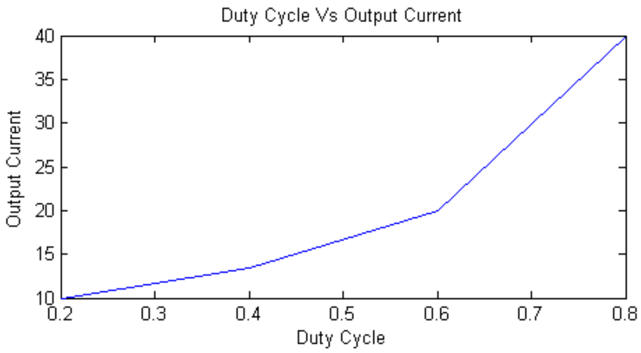


Fig 10, Duty cycle vs Output Current

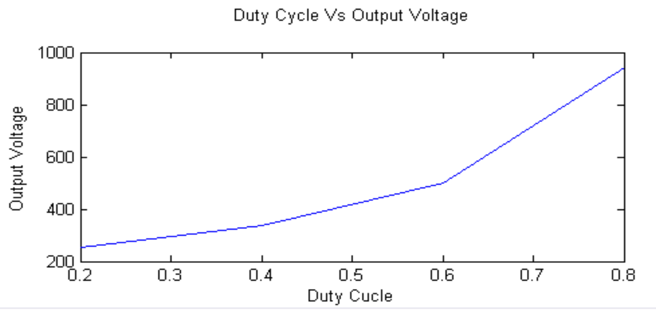


Fig 11, Duty cycle vs Output Voltage

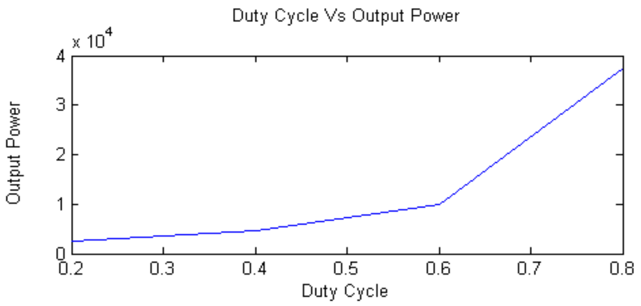


Fig 12, Duty cycle Vs output power

**Inverter Simulations:**

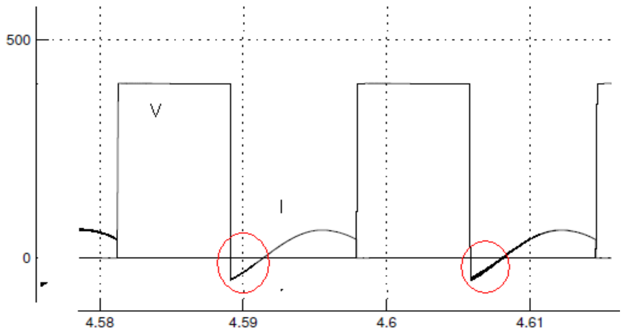


Fig 13, V and I across switch 2

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The above Graph is the Soft Switching scheme for the Leading Leg switches [18]. The above switching is the scheme of switch 2. It constitutes of Zero Current, Zero Voltage turn ON and ZVS turn off by the lossless capacitor.

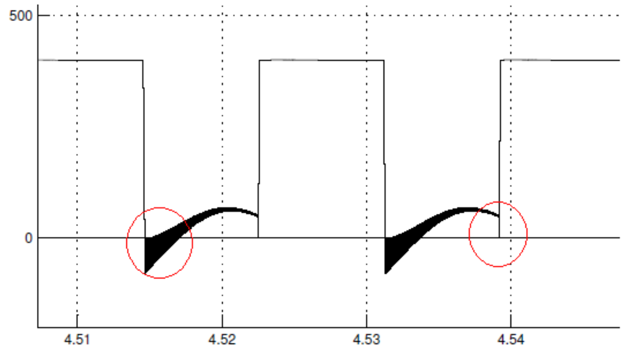


Fig 14, V and I across switch 3

The above is the switching of the switch 3. This follows the same switching scheme as like the switch 2.

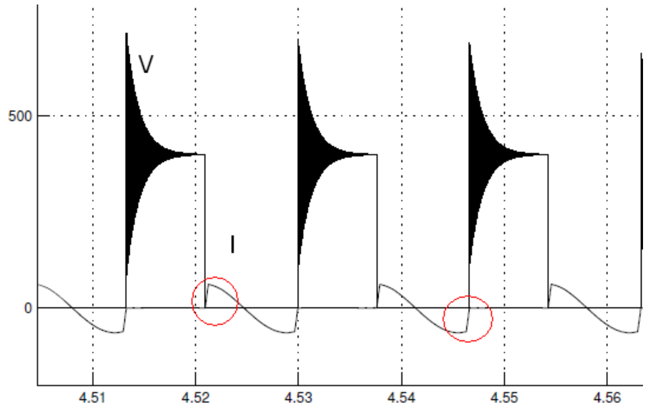


Fig 15, V and I across switch 4

The Switches 4,5 Operate on the principle of ZCS turn on due to the assistance of the lossless inductive snubber and ZVS ZCS Turn Off [19].

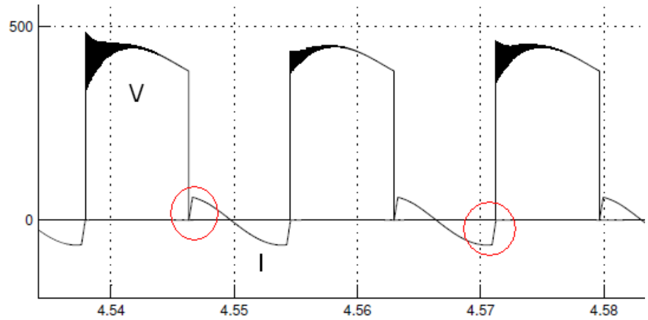


Fig 16, V and I across switch 5

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Thus the switching Parameters of the Inverters explained using the Figures 8 to 15.

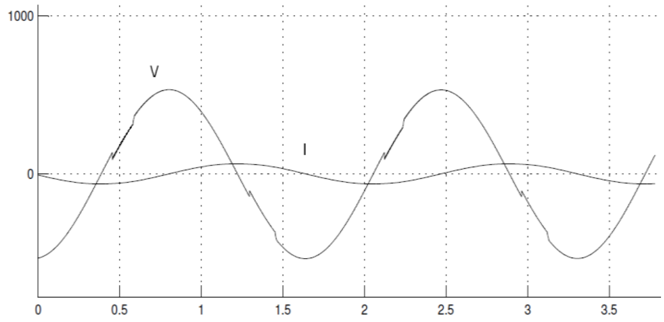


Fig 17, V and I across RL Load

The total output across the load is shown above. The V-I waveforms is shown. The scale in time margin is $10^{-5}$ seconds.

The power factor for the above curve is measured.

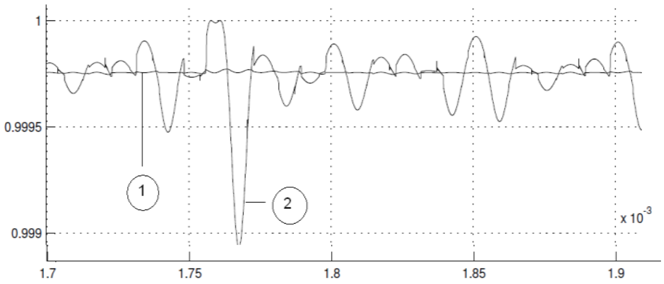


Fig 18, Power Factor curve

1-> P.F when the capacitor cr is included in the circuit.

2->P.F when the capacitor cr is not included in the circuit.

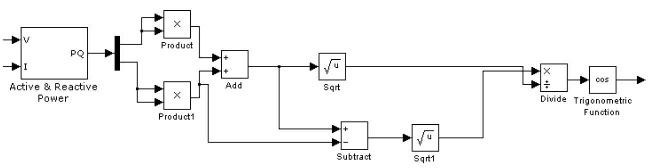


Fig 19, Power factor measurement circuit

A new novel way to measure the power factor is proposed here. The simulink model is given above which can predict the real time powerfactor of the circuit.

$$p^2 + q^2 = s^2$$

Where,

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p = Real power
q=Reactive power
s=Absolute power
Power factor, $\cos\emptyset = \frac{\sqrt{s^2-q^2}}{s}$

It is noted from above curve that a high PF is obtained using this circuit.

The Harmonic analysis of the output wave is done as follows.

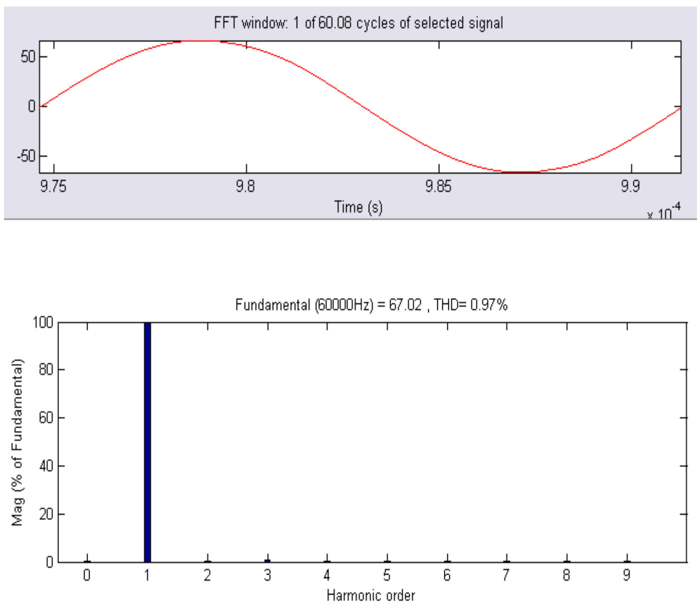


Fig 20, FFT Spectrum of Load current

Hence From the FFT Spectrum, it is noted that the current harmonics are 0.97%

## VI. CONCLUSION

Thus the HF- Soft switching Induction heating appliance is simulated and the effectiveness of the circuit is pronounced with the graphs, power factor and the harmonic spectrum. Future scope of this experiment is that the converter can be still developed for multiple burner type that can cook many type of heat levels and proper closed loop control for such applications shall be developed.

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