AC-DC Converter Design Using High-Voltage Resonant Mode Controllers

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Abstract

Due to higher efficiency, lower electromagnetic interference and utilization of parasitic inductance and capacitance of power stage components, Resonant Converter topologies are popular in research with small real world applications.

In this paper, we will discuss LCL resonant topology for 70w notebook adapter application with power correction. It uses High-voltage resonant mode controller IC, which can achieve 90% efficiency and is smaller in size. Step by step design procedure for Transformer, resonant tank circuit and controller circuit with experimental results will be discussed. This is to help design engineers implement their concepts in real applications with ease, to optimize cost and achieve good performance. It will also discuss ways to extend this topology to power supplies for CTV and MONITOR applications.

Introduction

The most popular Load Resonant converters are the Series Resonant, Parallel Resonant and Series-Parallel Resonant converters. Series Resonant Converter is the simplest and most understood topology with higher part load efficiency. It has a voltage regulation problem at light loads, and requires wide frequency operation with respect to O\P load and I\P Line variations.

To solve these problems, Modified Series resonant converter is implemented by adding the additional inductor across the transformer. This Converter is referred as the LCL type Series Resonant Converter. In practical designs, we can use the optimum primary inductance of the transformer as the additional inductor. This can be achieved by introducing the air gap in the transformer. Leakage inductance of the transformer can be used as Resonant inductance. This topology had Load independent characteristics for the above Resonance mode operation.

It is shown in this paper that LCL type Resonant converter requires a very narrow range of frequency control; from full load to no load, and had higher efficiency at minimum load similar to that of Series Resonant converter. Control circuit for this converter is implemented by dedicated control IC such as L6598 and L6598 using Off-line BCD technology. High side gate drive circuit was integrated, the protection features include Over voltage, Over current, Soft start features and adjustable minimum and maximum frequency limits. Secondary control circuit is implemented using TSM101 with Constant voltage and Current Characteristics which is required for Note book Adapters.

Detailed calculations will also be given for power stage components like Transformer, Resonant circuit components and Control circuit components. AC-DC Converter is developed without put ratings of 18v \4.0A with PFC front end. Resonant DC-DC Power stage achieved efficiency higher than 92%. Test results are noted down.

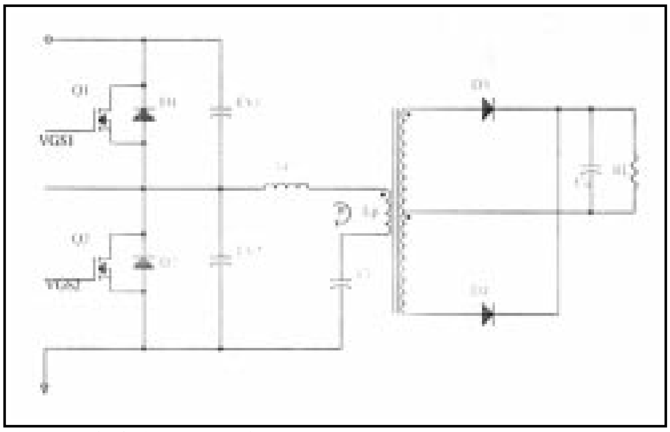

Figure 1: LCL Series Resonant Converter

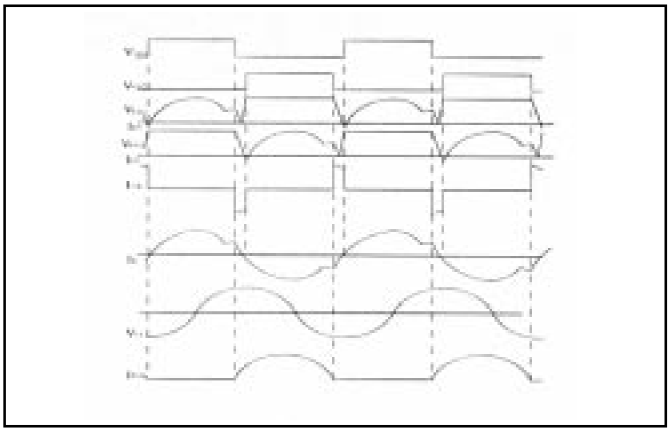

Figure 2: Operating Wave Forms

Efficiency of the converter can be further improved by utilizing Synchronous Rectifier circuit on the secondary circuit. This topology can be extended for Power supplies in TV and Monitor applications perforance in these applications.

Power Stage Operation

Fig.1 shows the basic circuit diagram of the LCL type Series Resonant converter. The operation of this converter in resonance mode can be explained in a simple way. In Q1, reverse current flows through parasitic diode and Q2 is OFF. During this period, Q1 is on and this results in negligible turn on losses because of zero voltage across Q1. When Resonant current flows through Q1, Resonant inductor Lr, Transformer primary inductance Lp and Resonant Capacitor Cr, will at the same time Transferred to the secondary. Diode D3 is conducting during this period, charging the filter capacitor C and supplying the energy to load. After some time, current through diode D reaches zero and will be turned off with less losses. At this time, Lr +Lp will resonate with Cr and no current will flow through secondary. Q1 will be off, voltage across Q1 will build up by charging its output capacitance and voltage across Q2 is reducing by discharging its output capacitance. If we allow sufficient dead time, Q1 will turn off with less losses.

Adding extra snubber capacitors across the switches will

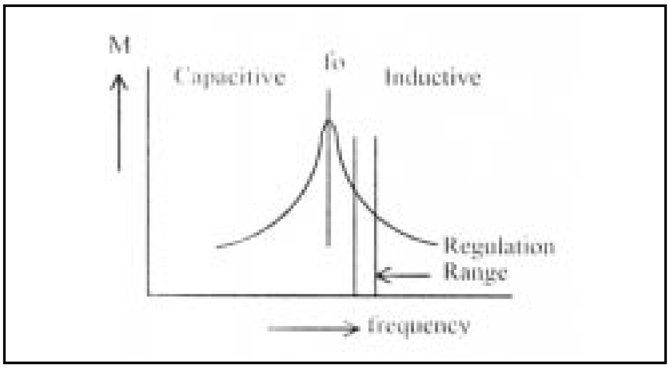

Figure 3: Resonance Impedance vs. Frequency

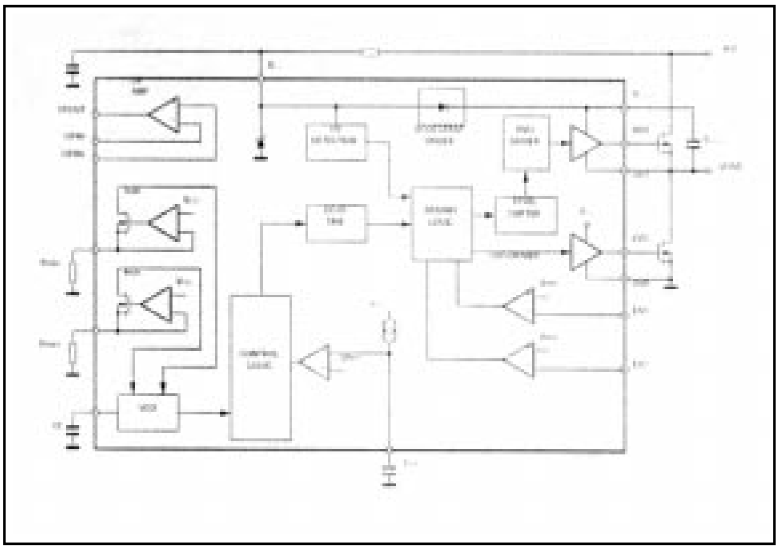

Figure 4: HV Resonant Mode Control Circuit

achieve optimum performance. When the voltage across Q1 reaches to Vi, parasitic diode Q2 will turn on and the reverse current will flow through Q2. Q2 will turn on and this results in negligible turn on losses. Operation during the secondh a l f cycle is the same as the first half cycle.

Control Circuit Operation

The converter output voltage is regulated by varying the frequency operation of power stage. In the continuous mode, the slope of the resonant impedance curve is used to control the output. Working with a switching frequency close to the resonance one (Fig.3), small variation of the frequency allows the output regulation. The current shape is closed to a sinusoidal. On the contrary, when the operation is distant from the resonance, the current moves away from sinusoidal shape. This reduces its peak and wide frequency range is necessary to control the output. Closely Control circuit can be implemented by the dedicated control IC L6598. Q2 and Q3 will be driven by L6598 directly.

Floating drive of Q2 is achieved by Bootstrap drive circuit of IC, which can withstand up to 600v. Fig 4 will explain the details of the dedicated control circuit. This IC has Voltage Controlled Oscillator circuit block with adjustable maximum and minimum frequency limits. By choosing the proper values of Rfmin and Rfstart, we can fix the minimum and maximum frequency limits. Minimum frequency has to be chosen above the resonance frequency of power stage circuit. Soft start function can be achieved by connecting a capacitor at Css pin. Start frequency is Fmax. and will gradually change to normal operating frequency with specified soft start time.

Low side and High side gate drive circuits provide driving the external Power MOS or IGBT. A high sink \ source drive currents (450mA\ 250mA) ensure fast switching times. The internal logic ensures a minimum dead time to avoid cross conduction of the power devices. Integrated Bootstrap function section replaces the external bootstrap diode, and together with a bootstrap capacitor, is used to make available the Bootstrapped voltage to drive the high side Power MOS. This function is achieved using an HV DMOS, driven synchronous with the low side external Power MOS. For safe operation, Current flow into the Vboot pin is inhibited, even when a ZVS operation is not ensured.

Two CMOS comparators are available to perform protection functions. Short pulses (>200nsec.) On comparators are recognized. EN1 input (active high) has a threshold of 0.6v (typical) forces the IC in a latched shut down state. Normal operating conditions are resumed after a power-off power-on sequence. Latched Over voltage protection function can be achieved using this comparator. EN2 input (active high) with a threshold of 1.0V (typical) restarts a soft start sequence. In addition, the EN2 comparator, when activated remove a latched shutdown caused by EN1. Over power protection can be achieved using this comparator. The integrated OP AMP is designed to offer low output impedance, wide bandwidth, high input impedance and wide common mode range. It can be used to implement a closed loop control or protection function. In this application, we use this opamp as current amplifier. This IC has Under voltage lock out section with a start up current of 250uA and operating current of 2-4mA.

Secondary control circuit is implemented using dedicated control IC. By using this device, we can get Constant voltage and constant current characteristics on output that is required for Adapter applications. This IC integrates precision reference of 1.25v, and two OP AMPS, and current generator. We are using one OP AMP for voltage feedback, and second OPAMP for current feed back.

Compensation circuit is implemented by using Two Pole Two Zero network around voltage feed back amplifier. Regulation of the O\P is achieved by closed feedback loop. Secondary control IC senses the O\P voltage and drives the optocoupler and control the current drawn from Rfmin. Pin. This in turn adjusts the operating frequency of the power stage and keeps the O\P voltage in regulation.

We are able to achieve very narrow operating frequency (50-60KHz) range from no load to full load with fixed input voltage of 380V DC.

Calculation of Power Stage & Control Circuit

Input Voltage = 200V—380V DC.
Output Voltage = 18V DC
Output Current = 4.0A

We choose an EE30 CORE with split bobbin for transformer design. Area of cross section is 0.6 Sq. cm. Maximum flux density is 0.6 Tesla.

Primary number of turns for half bridge transformer can be calculated as

Npmin = (Vin min. x 10**4)\ 2 x Fs min.x Ae x Bmax
= (200 x 10**4)\ 2 x 50x 10**3 x0.6 x0.6
= 55.5

To meet the no load operation, we need to ensure the transformer turns ratio

n =Np\Ns > (Vinmax\2) \ (Vo+Vf)
>(380\2) \ (18.0+0.5)
>10.27

Choose Np\Ns as 13
Ns = Np\ n= 55.5\13 = 4.26

Choose Ns as 4T
No.of primary turns Np= Ns x n= 4x13= 52 T.
Assume Series Resonant frequency as Fsr=45 KHZ.
Assume normalised out put voltage as M=0.9.
Assume normalised operating current as J=0.15
Resonant impedance Zo can be calculated as

Zo = (Vin max.\2) (Vin max.\2) x J x M \(V0 xIo)
= (380\2)(380\2)x0.15x0.9 \ (18.0 x 4.0)
= 67.7 Ohm

Resonant Inductor Lr = Zo \Wo
= 67.7 \2 x3.14 x 45x 10**3
= 0.239 mH

Resonant Capacitor Cr = 1\Zo x Wo
= 1\ 67.7 x 2 x3.14x 45 x 10**3
= 52.2 nF

Equivalent AC resistance refereed to primary side of transformer Ri as

Ri = 8 x n x n x Rl \ (3.14 x 3.14)
= 8 x 13 x13 x 4.5 \ (3.14 x 3.14)
= 617 Ohm.

In LCL Resonant converter the second resonant inductor is achieved by utilizing the proper value of Primary inductance of Transformer. To get proper no load operation and higher efficiency entire load range we can choose Lp \Lr as 5

So Primary inductance Lp= 1.195 mH
Primary peak current through switches Ip
= 2 x Vmin \ (3.14 x Ri)
= 2 x 380 \ (3.14 x 617) = 0.39A

Peak current of Secondary Diode Id
= 3.14 x Io \ 2

= 3.14x 4.0 \2 = 6.28A

Reverse peak voltage of Diode
= 2 x Vo=2x18=36v

components can be calculated as follows
Choose Oscillator capacitor

Coss = 330pF
Fmin = 50KHZ
Rf min. = 1.41\ (Fmin.x Coss)
= 1.41\(50x10**3 x 330pF)=85.4 KOhm
Fmax. = 250KHZ
Rf max. = 1.41\(Fmax x Coss) =1.41\(250x 10**3 x330pF)=
17.0KOhm
Choose Css as 220 nF..

Practical Implementation

Prototype is developed for fixed I\P voltage of 380V. Transformer was built with Np=52T Ns = 2x 4T, Naux =3T. Lp=1.1mH. Leakage inductance obtained was 220uH. So leakage inductance is considered as Resonant inductance Lr=220uH. No additional inductance is added. STP6NB50 was chosen as switches, and STPS20L45 chosen as Rectifier. Two 560uF\25V, low esr capacitors are chosen as filter capacitors.

Efficiency of the converter with 72.0 w Out power is higher than 92%. Operating frequency at this condition is 53.5KHz. In put power at min. load (0.01A) is 2.9w and operating frequency

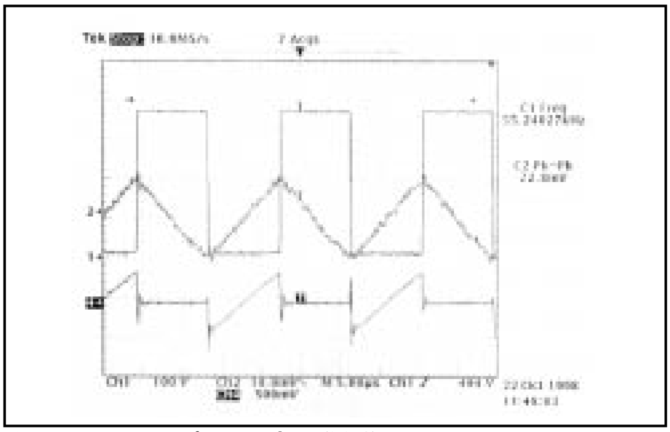

Figure 5a: Wave Forms of Iq1, Ir and Vq1 (0.01A)

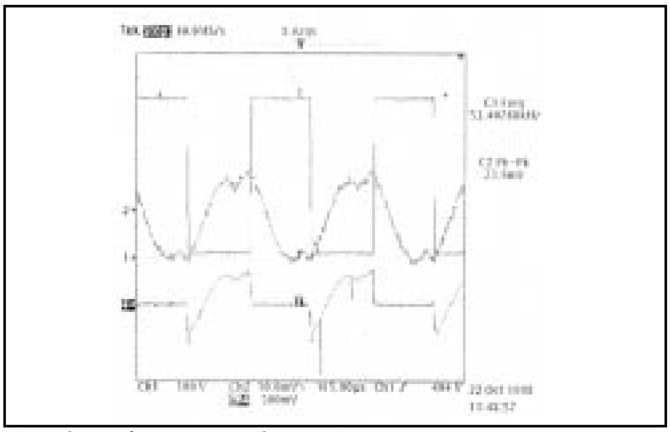

Figure 5b: Waveforms Iqq1, 1r and Vq1 at min

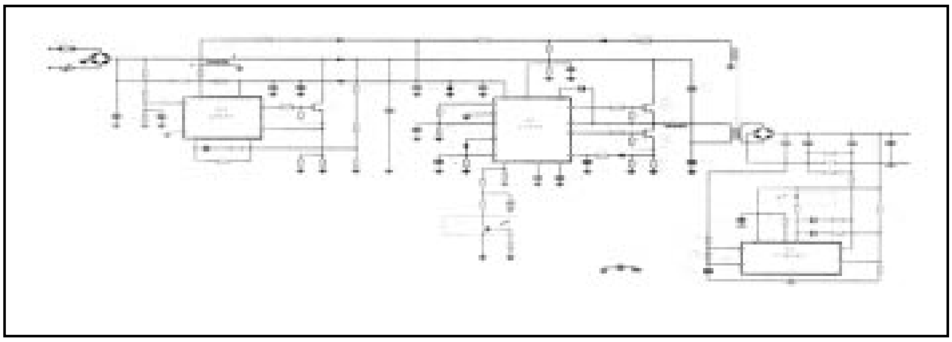

Figure 6: 72W Adapter Schematic for Notebook Application

S.NO	Vin AC	Pin (w)	Vo(V)	Io(A)	Fs (KHz)
1	264	6.4	17.846	0.1	55.7
2	264	82	17.846	4	53.46
3	220	82	17.846	4	55
4	220	6	17.842	0.1	58.75
5	110	84	17.845	4	53
6	110	5.3	17.842	0.1	59
7	90	5.3	17.842	0.1	59
8	90	85.5	17.845	4	53

Table 1: Test Results of Prototype Board

is 59.0 KHz. Work is under progress to improve the input power at No Load condition.

To get real application on wide range input Adapter, we incorporated PFC stage with O\P voltage of 380V DC. The Table 1. Give the results of Prototype with wide input range. Fig 5, will give some of the practical Waveforms.

Application schematic for Adapter is shown in Fig 6. Application for TV application with I\P voltage of 180v-264v AC and180w power can be implemented.

Conclusion

Simple design procedure for LCL type Series Resonant Converter for Notebook Adapter Application is presented. Detailed explanation of Dedicated controller IC for Resonant Converter Application is also being outlined. Experimental prototype was built and results are presented. This shows that new topology is suitable for real world applications. No Heat sink is provided for Power devices which helps in reducing the weight of the converter.Further work is going on to improve no load Efficiency and full load efficiency by utilizing Synchronous Rectifier on the secondary side. We are investigating the concept for TV Power supply application, with I\P voltage from 180-264VAC.

References

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