

Micro-Controller Based LCC Resonant Converter Analysis, Design, and Simulation Results

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Abstract – The Objective of this paper is to give more insight into DCM Operation of the LCC Converter to obtain optimum design using state-space analysis and to verify the results using PSPICE Simulation for wide variation in loading conditions. We have used to motor load (R-L-E). We have used embedded based triggering circuit and the embedded 'C' Program is checked in Keil Software and also triggering circuit is simulated in PSPICE Software. To compare the simulated results with theoretical results and designed resonant converter is 200W and the switching frequency is 250 KHz.

Index Terms – Discontinuous current mode, High-frequency link, MOSFET, Zero-Current Switching.

I. INTRODUCTION

In Converter applications solid-state devices are operated at very high frequency. So the switching losses are more than the conduction losses and it becomes a major cause of poor efficiency of the converter circuit. This leads to the search of a converter that can provide high efficiency, lower component stress [1], [2], high power, high switching frequency, and lightweight as well as low cost and high power applications. In order to keep the switching power losses low and to reduce the problem of EMI, the resonant converter is suggested

The operating characteristics and analysis of series resonant converter is fixed frequency operation and parallel resonant converter operating in variable frequency operation [2], [3], [4]. But the operating characteristics and analysis of series- parallel resonant converter is both fixed and variable frequency operation.

The LCC takes all the desirable characteristics of two element resonant topologies, namely the SRC and the PRC. When the LCC is operated in DCM, it offers many advantages [4], such as negligible switching

losses due to zero current switching (ZCS), choice of higher switching frequency, smaller resonant components, etc., in addition to simple control circuitry and ease of control. Due to the advantages of the DCM operation of resonant converters, many control IC's have appeared in the market, for example, Cherry Semiconductor CS-360[4], [5],[6],[7] Genum LD405, and Unitrode UC1860.

The resonant converter is a new high performance DC-DC converter. A resonant converter can be operated either below resonant (leading p.f) mode or above resonant

(lagging p.f) mode. The most popular resonant converter configuration is series resonant converter (SRC), parallel

resonant converter (PRC) and series parallel resonant converter (LCC). A SRC has high efficiency from full load to very light loads. Where as a PRC has lower efficiency at reduced loads due to circulating currents. The limitations of two element resonant topologies can be over come by adding a third reactive element, termed as modified SRC. SRC has voltage regulation problems in light load conditions; to over come this problem the modified LCC is presented. These converters are analyzed by using state-space approach. Based on this analysis, a simple design procedure is proposed. PWM control is employed to control and regulate the output voltage [7], [8]. Using PSPICE software simulates the LCC-Resonant Full Bridge Converter. The PSPICE simulation results verified experimentally on a prototype converter. The proposed results are improved power densities in air borne applications. A Resonant Full Bridge Converter (LCC) modified by adding a capacitor in parallel with the transformer primary is presented. This configuration is referred to as an "LCC Resonance Full Bridge Converter" A three element (LCC) Resonance Full Bridge Converter capable of driving voltage type load with load independent operation is analyzed. The converter has load independent characteristics. It is shown in this paper that these type of converter requires a very narrow range of frequencies control from full load to very light loads and can operate with load short circuit while processing the desirable features of the LCC. The resonant converter operating in the above resonance (lagging power factor) mode has a number of advantages (e.g. No need for lossy snubbers and di/dt limiting inductors) [9], [10]. Therefore, the proposed converter configuration in the above resonance mode, State-space approach is used for the converter analysis. Pulse width modulation is employed to control and regulate the output voltage [11], [12], [13]. A modified LCC with capacity output filter has been presented.

II. CONVERTER OPERATION & ANALYSIS

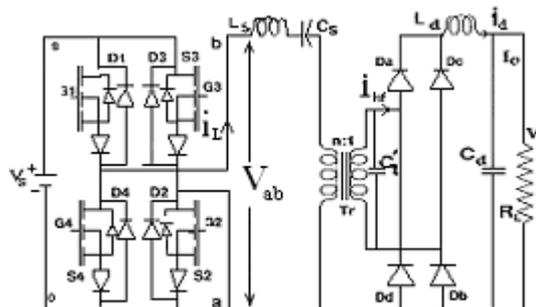


Fig.1 dc-dc converter employing LCC full bridge operating in DCM.

The resonant tank of this converter consists of three reactive energy storage elements (LCC) as opposed to the conventional resonant converter that has only two elements. The first stage converts a dc voltage to a high frequency ac voltage. The second stage of the converter is to convert the ac power to dc power by suitable high frequency rectifier and filter circuit. Power from the resonant circuit is taken either through a transformer in series with the resonant circuit (or) across the capacitor comprising the resonant circuit as shown in Fig.1 In both cases the high frequency feature of the link allows the use of a high frequency transformer to provide voltage transformation and ohmic isolation between the dc source and the load.

In Resonant Converter (LCC), the load voltage can be controlled by varying the switching frequency or by varying the phase difference between the two inverts where the switching frequency of each is fixed to the resonant frequency. The phase domain control scheme is suitable for wide variation of load condition because the output voltage is independent of load.

The filter circuit has some disadvantage. It is a capacitor input filter and the capacitor must carry large ripple current. It may be as much as 48% of the load current. The disadvantage is more severe for large output current with low voltage. Therefore, this circuit is suitable for high voltage low current regulators.

The proposed converter has ten operation intervals during a single switching cycle. Only the intervals for a half-switching cycle will be shown here as the remaining five are symmetric. The equivalent circuit for each interval during the half-cycle is shown in Fig.2& Fig.3. The derived equations characterizing the converter's behavior during each mode are based on the following assumptions:

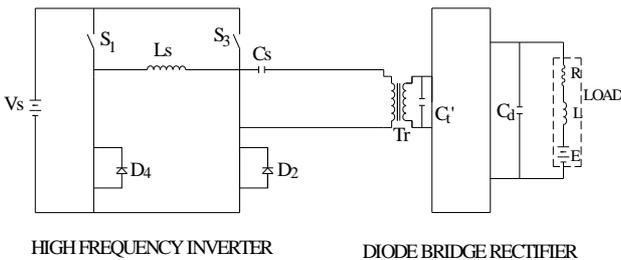


Fig.2 Circuit for Mode VI operation

- 1) I_{Lr} current is ripple free and can be considered a constant source, I_{in}
- 2) Output voltage is a constant, V_o
- 3) All components are considered ideal
- 4) From the high voltage transformer, the leakage inductance is used as L_r and its capacitance is C_r .

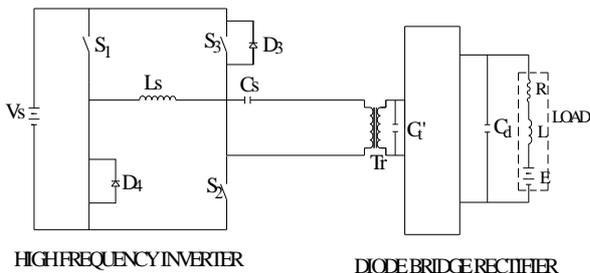


Fig.3 Circuit for Mode VII operation

Operation begins with S1, S3, S4, and D2 on at $t=t_0$. During this mode, S4 current is transferred to S3 in a non-resonant, linear fashion so that S4 can turn off with ZCS. During this mode, energy is transfer to the output. Let us assume that mode ends at $t=t_1$ when current in S4 reaches zero, $i_{Lr}(t_1)=0$, and is turned off. In this mode the resonant capacitor voltage and inductor current are:

$$i_{Lr}(t_0)=i_{Ln} \quad \text{Where } n=N_p/N_s \quad (1)$$

$$i_{Lr}(t)=i_{sw4}(t) = -(n.V_o / L_r) \cdot ((t-t_0) + i_{Lr}(t_0)) \quad (2)$$

$$V_{cr}(t) = n.V_o \quad (3)$$

Overlap of S3/S4 must be long enough to allow S4 current to reach zero. Evaluating (2.) at $t=t_1$ we obtain:

$$(t_1-t_0)=i_{Ln}/((n.V_o)/L_r) \quad (4)$$

$$i_{Lr}(t)=0 \quad (5)$$

$$V_{cr}(t) = n.V_o \quad (6)$$

The different modes of conduction are described in Table I.

Table I: Device Conduction Table

Mode	S ₁	S ₃	S ₂	S ₄	D ₁ /D ₄	D ₂ /D ₃	Mode Description
I	X		X			X	S ₄ to S ₂ overlap
II	X		X				L _s charge
III	X	X	X				Resonant transfer S ₁ to S ₃
IV		X	X				C _t discharge
V		X	X		X		L _s energy to output
VI		X	X	X	X		S ₂ to S ₄ overlap
VII		X		X			L _s charge
VIII	X	X		X			Resonant transfer S ₃ to S ₁

III. DESIGN

Design Example: (Operating Switching Frequency = 250 khz)

It is desired to design the converter with the following specifications:

- Power output = 200W
- Minimum input voltage = 300v
- Minimum output voltage = 125v
- Maximum overload current = 2A
- Inductance ratio (K_L) = 1

$$C_e = (C_s \cdot C_t) / (C_s + C_t)$$

$$C_t = C_t' / n^2$$

$$\omega_o = 1/(LC_e)0.5$$

$$\omega_s = 1/(LC_s)0.5$$

Component Parameters as find out from the above Equations

$$L_s = 10.53\mu H \quad C_s = 0.033 \mu F \quad C_t' = 0.0087 \mu F$$

$$L_d = 10 \mu H \quad C_d = 1000 \mu F$$

$$f_o \text{ --- resonance frequency} = 591\text{kHz}$$

$$f_s \text{ --- switching frequency} = 250\text{kHz}$$

Since $f_o > f_s$, LCC resonance circuit is operating in discontinuous current mode. Therefore, commutation circuit is not required. Fig. 4 shows Simulation of LCC resonant circuit with R-L-E Load and Fig.5 shows the flow chart of embedded based controller for LCC resonant converter.

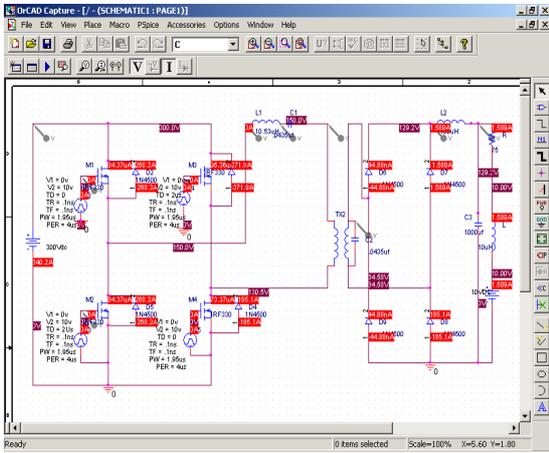


Fig. 4 Simulation of LCC with R-L-E Load

A. ABOUT KEIL

It is software, which is used to check the embedded C program and results that whether the program is correct or not, which is shown in Fig.6

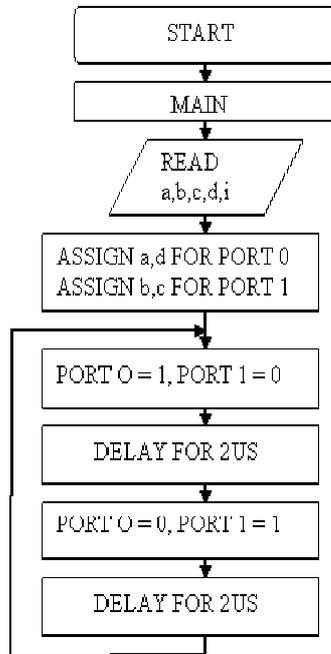


Fig.5 Flow chart for Embedded Controller 89C51

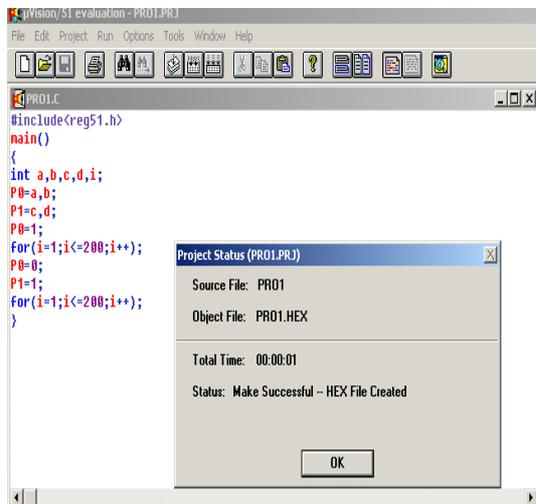


Fig.6 Program result for Embedded Controller output using Keil Software.

IV. RESULTS AND DISCUSSION

The converter has been optimized in terms of peak component stresses. Based on the optimization procedure a 200W, 250-kHz resonant converter has been implemented for illustration and to verify the theoretical and PSPICE simulation results as shown in table II.

TABLE II. COMPARISON OF THEORETICAL & PSPICE SIMULATION RESULTS OBTAINED FROM THE MODEL FOR A 200W, 250 KHZ DC-DC LCC RESONANT CONVERTER OPERATING IN DISCONTINUES CURRENT MODE (THEORETICAL OUTPUT VOLTAGE = 125 V Ls = 10.53MH Cs = 0.033 MF C = 0.0087 MF LD = 10 MH CD = 1000 MF LOAD L=10MH, E=10V) Input Voltage = 300 V

Load Resistance (Ohm)	Load Current (ampere)	Simulation Result (Volts)	Theoretical Results (Volts)
1	1.5625	127.9	125
20	1.556	128.5	125
30	1.554	128.7	125
50	1.55	129	125
100	1.548	129.2	125
200	1.548	129.2	125
300	1.548	129.2	125
400-1K	1.548	129.2	125

Fig.7 shows the simulation result for gate voltages of G1, G2& G3, G4 and Fig.8 shows output voltage across RLE load.

The LCC converter operating in DCM requires very small resonant inductance and capacitors compared to continuous current mode operation [3]. Also, due to recent developments in fast IGBT's (some of them include fast internal ant parallel diode) with low on-state drops, this ZCS converter can be designed to operate at high frequency with high efficiency. Although the frequency variation required in the designed converter was 2.1: 1, it must be noted that the supply voltage variation considered is very wide (1 : 2). Since the switches and diodes turn-on and turn-off at zero current, this converter is expected to have lower EMI compared to a pulse width modulated (PWM) converter.

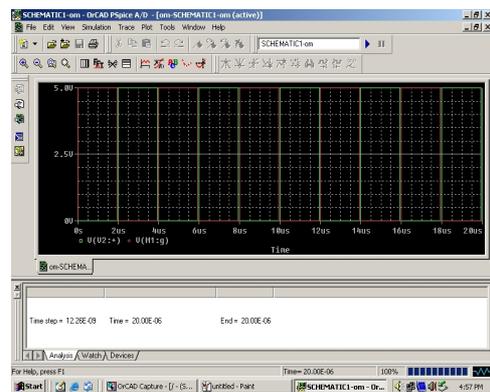


Fig. 7 Simulation result of G1 & G3 X axis 1cm=2μs and Y axis represents Gate Voltage. The amplitude is 5V. If G1 is conduct 0-2μs then G3 is OFF State. If G3 is conduct after 2μs - 4μs then G1 is OFF State.

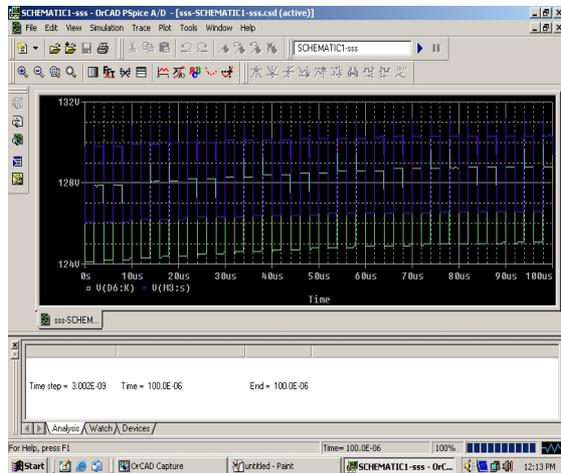


Fig. 8 Output Voltage across Load X axis 1cm=2 μ s and Y axis represents output Voltage. The amplitude is 128V.

However, no EMI measurements have been made and this topic is beyond the scope of this project. In the future, EMI studies have to be done for this converter. Some of the disadvantages of the presented converter are: higher peak current through the switches, higher voltage stress on the output capacitor and diodes, and requirement of small snubber resistors. Further regarding dc analysis, the state space model developed in this paper has been extended to carryout large signal analysis using a discrete-time domain state-space model for DCM operation of the LCC [7].

V. EXPERIMENTAL RESULTS AND CONCLUSION

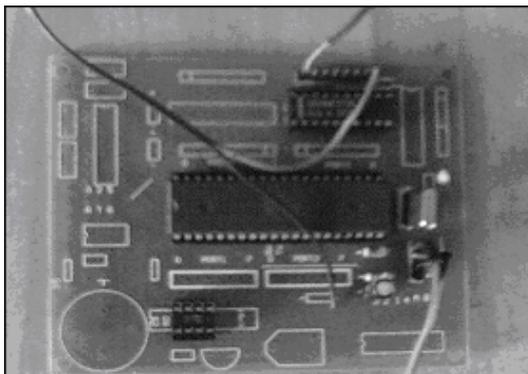


Fig.9 Fabricated Micro Controller Unit

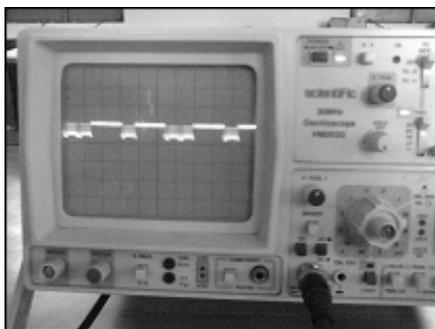


Fig.10 Observation Of Micro Controller Output of G1 X axis 1cm=2 μ s and Y axis represents Gate Voltage. The amplitude is 5V.

A. CONCLUSION

Fig.9 shows the fabricated embedded based controller unit and Fig.10 shows the output pulse of the fabricated embedded based controller unit. A modified SPRC which

employs a LCC-Resonant Full Bridge Converter circuit and operating above resonance (lagging power factor) mode has been presented. This converter with a voltage type load shows it provide load independent operation above the resonance frequency. So, the switching power losses are minimized. This new DC-DC converter has achieved improved power densities for air borne applications. The LCC-resonant full bridge converter is simulated by using PSpice software. The simulation is carried out for 125V of output voltage and 250 kHz of switching frequency. The designed output voltage is 125 V, but the obtained simulation result is varying from 127.9V to 129.2V. So, it is concluded to go for the closed loop design instead of open loop design for the scope of future extension. Since our ultimate aim is to achieve 125V.

B. SCOPE OF FUTURE EXTENSION

- Fabrication of the experimental converter
- Comparison between simulation results and experimental converter results.
- Analysis, design, simulation and fabrication of closed loop LCC resonant converter.
- Comparison result of open loop and closed loop LCC resonant converter.

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