A Novel Improved Resonant LLC Converter with Minimal Components

Tamilarasu Viswanathan, P Maithili

Abstract: This paper presented a novel improved resonant LLC converter with minimal components compared with existing design. Conventional Full H-Bridge in converter replace with differential boost for improving the overall gain of the circuit and also able to operated buck, boost and buck-boost. As a result, the component size is significantly reduced and enhance the size and cost of the converter. Different modes of operations presented for understanding the new converter in terms of switching frequency and gain. An Experimental and simulation result confirms the effectiveness of the proposed inverter.

Key Words: Resonant tank, DC-DC converter, buck, boost, buck-boost, switching frequency, inverter, overall gain.

I. INTRODUCTION

Resonant DC-DC converter widely used in many applications like renewable energy,hybrid vehicles and other power conversion.For all applications, the preferable converter with controllable gain and minimal components [1]-[6].The general structure of Resonant DC-DC converter is shown in Fig.1 Overall operating gain of the converter customizable with first stage inverter circuit. By adjusting the gain, the overall performance of the converter is operated in wide range of operating mode.

The main objectives of this work is

• To design a converter which can able to operate in wide range of gain (buck,boost and buck,boost) results in enhancedperformance.

• To utilize the frequency range within in the gainoperating range improvise the component used in the tank circuit.

The contribution of the work is

• To involve the boost inverter in the circuit for improvisethegain.

• To incorporate a new PWM scheme for improving the EMI inference for same Resonant Circuit.

II. PROPOSED METHODOLOGY

A. Gain of LLC converter

General functional block diagram of Resonant LLC converter [1] is shown in Fig.1The overall gain of LLC converter is product of inverter gain, tank gain and transformer turns ratio

a. Degree of Freedom in Gain

Initially,the converter depends only on tank gain and transformer design are presented in 1, which is responsiblefor performance adjustment. But, Many research works not discuss the effect of inverter gain,it can be adjust by

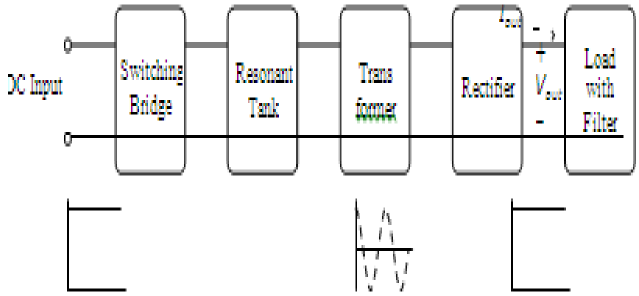

Fig 1 . Block diagram of Resonant LLC converter

means of selection proper switching techniques. By selecting the proper inverter switching able to operate in gain and also feasibilityin PWM and design. The degree of freedom in gain with respect to switching frequency interms of resonant Q value in Fig.2

b. Differential boost inverter with LLC converter

Differential boost inverter (DBI) (see Fig 3) able to operate in higher output voltage than input voltage,compared to conventional inverter.Additionally,DBI able to generate high frequency high quality sine wave output [7]- [13]. Hence the degree of freedom in this converter achieved with incorporat- ing DBI with tank circuit and rectifier load.

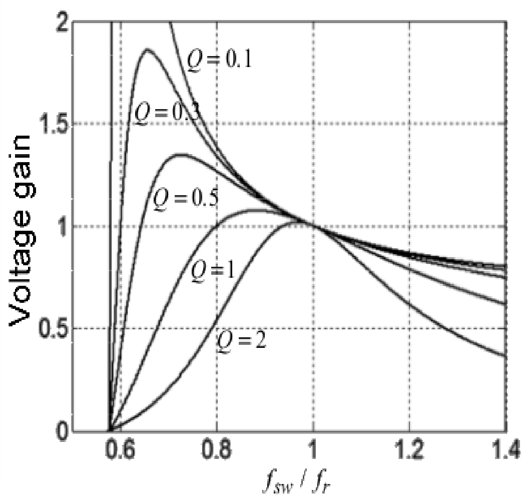

Fig. 2 General Configuration of Differential boost

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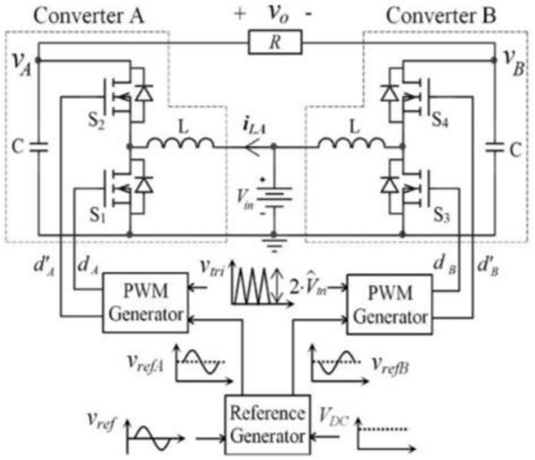

Fig. 3 General Configuration of Differential boost inverter

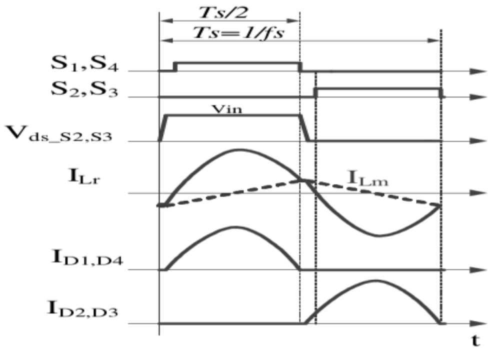

Fig. 4 Operating Mode with *f* sw= *f* r

B. Other Blocks

The gain of the resonant circuit is given as (Equ.1)

$$K(Q,m,F_x)=\left|\frac{V_{o\_ac}(s)}{V_{in\_ac}(s)}\right|=\frac{F_x^{\,2}(m-1)}{\sqrt{(m\cdot F_x^{\,2}-1)^2+Fx^2\cdot(F_x^{\,2}-1)^2\cdot(m-1)^2\cdot Q^2}}$$

(1)

$Q=\frac{\sqrt{L_r/C_r}}{R_{ac}}$ Quality factor

$R_{ac}=\frac{8}{\pi^2}\cdot\frac{N_P^{\,2}}{N_S^{\,2}}\cdot R_o$ Reflected load resistance

$F_x=\frac{f_s}{f_r}$ Normalized switching frequency

$f_r=\frac{1}{2\pi\sqrt{L_r\cdot C_r}}$ Resonant frequency

$m=\frac{L_r+L_m}{L_r}$ Ratio of total primary inductance to resonant induc

III. OPERATING MODES

Generally, the resonant tank circuit with transformer is controlled with different operating modes (Normal,Buck and Boost) depends on switching frequency and resonant fre- quency is shown in Table 1.

Mode	Voltage	Frequency
Normal	*V* in =*V* in	*f* sw= *f* r
	V in = *V* in	*f* sw= *f* r
	V in = *V* in	*f* sw>*f* r
Buck	*V* in >*V* in	*f* sw= *f* r
	V in >*V* in	*f* sw= *f* r
	V in >*V* in	*f* sw>*f* r
Boost	*V* in <*V* in	fsw= fr
	V in <*V* in	fsw<fr
	V in <*V* in	*f* sw>*f* r

Table IDB Based LLC Converter - Modes

A. Normal Mode

In this mode f sw= f r, same switching and resonant frequency of this converter. It depends on resonant capacitor and inductor. Technically, this scheme is preferred mode for ideal operation. Efficiency is achieved at max comparatively with other modes but with best perfect turn on and off operating period. On the other hand, f sw>f r, high switching than resonant frequency of this converter.indirectly operate with small resonant tank components. Efficiency is drastically reduced with non zero current but achieved zero voltage switching. Subsequently, f sw<f r, small switchingthanreso- nant frequency of this converter.indirectly operate with high resonant tank components. Efficiency is drastically reduced with non zero voltage but achieved zero current switching shown in Fig 4.

a. Buck Mode

In this mode the output voltage is less than output voltage f sw= f r, same switching and resonant frequency of this converter. It depends on resonant capacitor and inductor. Technically, this scheme is preferred mode for light load operation. On the other hand, f sw>f r, high switching than resonant frequency of this converter.indirectly operate with small resonant tank components. Subsequently, f sw<fr, small switching than resonant frequency of this converter. indirectly operate with high resonant tank components. It includes non zero current but achieved zero voltage switching shown in Fig 5.

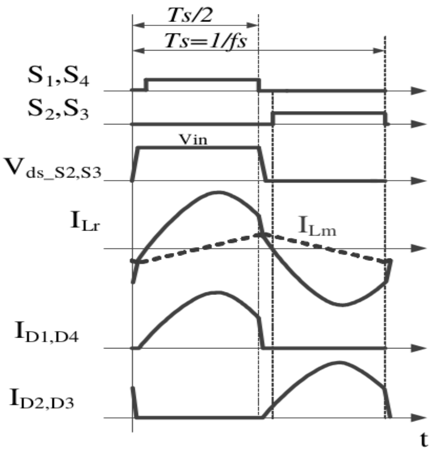

Fig. 5 Operating Mode with *f* sw<*f* r

b. Boost Mode

In this mode the output voltage is less than output voltage *f* sw= *f* r, same switching and resonant frequency of this converter. It depends on resonant capacitor and inductor.Technically, this scheme is preferred mode for

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heavy load operation. On the other hand, $f_{sw} > f_r$, high switching than resonant frequency of this converter.indirectly operate with small resonant tank components. Subsequently, $f_{sw} < f_r$, small switching than resonant frequency of this converter.indirectly operate with high resonant tank components. It includes non zero voltage but achieved zero current switching shown in Fig 6.

c. Selection of Modes

Among nine possible operating modes, each one have its own advantage. In order to select the suitable method for wide range of load variations, the inverter output voltage and switching frequencies make huge impact within the range shown in Fig 7.

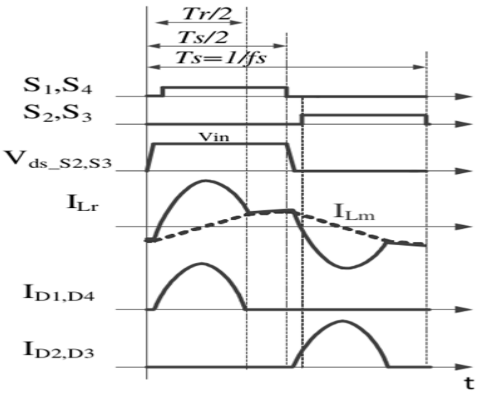

Fig. 6 Operating Mode with $f_{sw} > f_r$

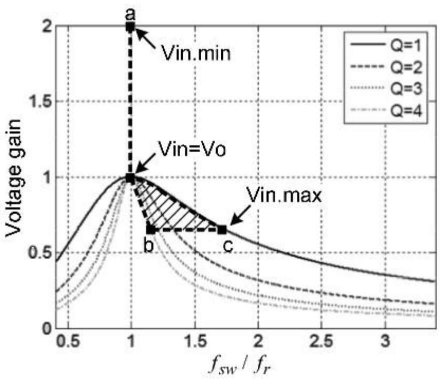

Fig. 7 Selection of operating modes

IV. RESULTS AND DISCUSSION

A. Impact on inductance ratio (m)

The entire resonant tank circuit with transformer highly impact on the inductance ratio (m).As the value of m in- creases, theover all gain and regulation improved with small switching frequency range. In other side of high m value, increase the magnetizing inductance along with over allef- ficiency and reduce the magnetizing current. To utilize the both side advantage the selection of switching frequency with inverter gain (mode selection) make impact on designing the tank circuit.

B. Design Aspects

Table 2 show the comparison of the component size used in resonanttank with transformer. There sonant tank circuit

Parameters	Existing	Proposed
Output Voltage	400 V	
Input Voltage	18 V	
Output Power	125 W	
Resonant frequency f_r	100 kHz	10-250 kHz
Switching frequency f_{sw}	50 kHz	25-125 kHz
Resonant Capacitor C_r	940 pF	520 pF
Resonant Inductor L_r	2.2 µH	1 µH
Magnetizing Inductor L_m	12.2 µH	7 µH

Table IIComparison Of DB Based LLC

Converter Design Aspect WithConventional LLC ConverterComponent values reduced by half and reduced the cost in significantly for same output power and input/output voltages without any losses.

C. Results

Fig 10 and Fig 11 shows the resonant tank voltage and current of existing scheme with proposed scheme. The new scheme shows the smooth ZVS and ZCS compare with Exist- ing design. This new design is most preferable of conventionaland enhance the size and cost of the converter. Differentmodes of operations presented for understanding the new converter in terms of switching frequency and gain.

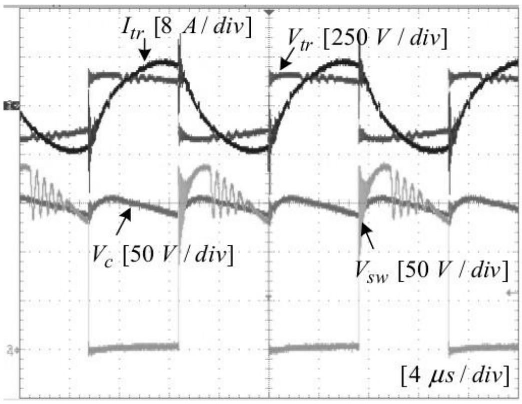

Fig. 8 Experimental results of Existing Scheme

V. CONCLUSION

A novel improved resonant LLC converter was design with minimal components compared with existing system. This new converter able to operate in wide range of gain (buck,boost and buck,boost) results in enhanced performance. .Here Con- ventional Full H-Bridge in converter replace with differential boost for improving the overall gain of the circuit and also able to operated buck,boost and buck-boost. experimental and simulation results confirmed the effectiveness of the proposed inverter.

As a result,the component size is significantly reduced Aided Design and Optimization of High-Efficiency LLC Series Resonant Converter, IEEE Trans. Power Electron., renewable energy scheme and hybrid vehicles schemes.

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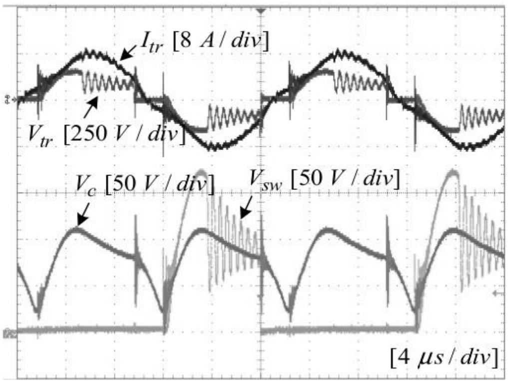

Fig. 9 Experimental results of Proposed Scheme

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