ANALYSIS AND EXPERIMENTAL VERIFICATION OF SERIES RESONANT PFC DC TO DC CONVERTER

Sivachidambaranathan.V[1], S.S.Dash[2]

[1]*Research Scholar, Sathyabama University, Chennai-600*
sivachidambaram_eee@yahoo.com
[2]*Professor, EEE Department, SRM University, Chennai-603 202*

Abstract: The aim of this work is to simulate and implement Series Resonant PFC DC – DC converter using Matlab Simulink. The quality of power consumption in terms of power factor and electromagnetic interference (EMI) levels are becoming one of the most important aspects in the design of static power converters. The series resonant PFC converter has many advantages such as high power density, reduced electromagnetic interference (EMI), reduced switching losses and stress. A DC – DC series resonant PFC converter has been developed. Both simulation studies and hardware implementation are done. The simulation results agrees well with the hardware results.

Keywords: DC to DC Series Resonant Converter, High frequency Inverter .

1. INTRODUCTION

There are two fundament different circuit schemes of electronic power processing technology. They are pulse width modulation (PWM) and resonance. In PWM technique the output is controlled by regulated interruption of power flow from generator to the load. In this system there are pulsating currents and voltages. The resonant technique processes power in sinusoidal form. The power switches are often turned off under zero current and turned on with large increase of device current.

The resonant converter can be operated either below resonant frequency or above resonant frequency. If it is operated at frequencies above the resonant frequency the switches are turned on at zero voltage across them but turned off abruptly. In these converters the switching losses and device stresses are lower compared to PWM converters but the conduction losses are higher because the peak and rms device currents are much higher in resonant converter.

The control of PWM technique is simpler and it is largely used in power conversion applications. But it is limited to low and medium power applications. The resonant converter can be used in low, medium and high power applications using high power switches.

Several new techniques for high frequency DC – DC conversion have been proposed to reduce component stress and switching loses while achieving high power density and improved performance (Hong Mao and Jaber Abu Qahouq, 2004; Ji and Kim, 1994; Karvelis, et al., 2001).

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The use of high-frequency resonant-converter topology DC – DC power conversion has become popular due to many advantages like

i. low switching stresses with increased reliability

ii. reduced EMI

iii. low mass and volume

Half and the full bridge configurations are better circuits because they draw power from the source in both half cycles of the output voltage. The magnitude of high pulse current from the supply is reduced (Sen, 1998).

A novel DC-AC single phase resonant inverter using soft switching boost converter was investigated in (Dong-jo Won, et al., 2009). In this paper he proposed a new topology to perform a soft switching by resonance between resonant inductor and capacitor and also reduces the switching loss and voltage stress.

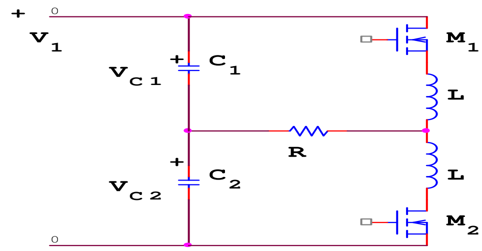
High efficiency soft-switched step-up DC-DC converter with Hybrid model LLC+C resonant tank was presented in (Wei Chen, et al., 2010). In this paper to improve the efficiency performance for the dc-dc converter used in wide input range applications, a novel resonant converter with a combinatorial LLC+C tank is proposed.

High frequency operation of the modified series resonant APWM converter with improved efficiency and reduced size was given in (Darryl J.Tschirhart and Praveen K.Jain, 2010). Zeroing Transormer's DC current in resonant converters with no series capacitors was presented in (Gertsman.A and Ben-Yaakov.S, 2010). In this paper he proposed the DC current unbalance in the windings of a transformer may initiate a runaway process and ultimately drive the transformer into saturation. Such a situation could arise in a transformer coupled resonant converter that does not include a series capacitor.

Z-source resonant DC-DC converter for wide input voltage and load variation is given by Honnyong (Honnyong Cha peng and F.Z.Dongwook Yoo, 2010) and Analysis and Design of High-Frequency Isolated Dual-Bridge series Resonant DC/DC converter by Xiaodong (Xiaodong Li Bhat, 2010).

1.1. Half Bridge Inverter.

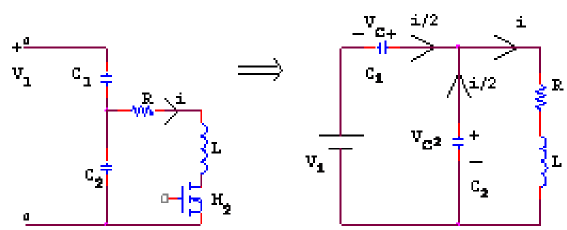
The half bridge configuration is shown in fig.1. The inductors are tightly coupled. Initially both the MOSFETs are off and power supply is on, the capacitors are charged on $V_1/2$ voltage, provided $C_1 = C_2 = C$.



Fig, 1. Half -bridge series resonant inverter

Now if M_1 is turned on and M_2 is off the situation changes. The load current is supplied by the stored charge of capacitor C_1 and the supply voltage, and at the same time C_2 gets charged resonantly to voltage greater than $V_1/2$, and at the end of this half cycle, C_2 will be charged to $V_{C2} = V_1 + V_c$. The capacitor C_1 will also be charged to a voltage $-V_c$ the value of which can be obtained from the circuit condition. Again when M_2 is turned on, M_1 will be off, the load current will be supplied in the reverse direction by the supply voltage V_1 through C_1 and also be the capacitor C_2 in the opposite direction. At the end of this cycle C_1 will be charged to $V_1 + V_c$ and C_2 will be charged to $-V_c$.

Fig. 2 shows the equivalent circuit of half-bridge resonant inverter for the condition when M_1 is off and M_2 is on.



Fig, 2. Equivalent circuit of half-bridge resonant inverter

Since $C_1 = C_2$, the load current will be shared equally by C_1 with the supply voltage. If the loop of V_1, C_1, R and L is considered, the load current can be obtained by the equation

$$(1) \quad L\frac{di}{dt} + Ri + \frac{1}{2C_1}\int i dt + V_{c_1}\big|_{t=0} = V_1$$

The equation of current in the resonant circuit for $C_1 = C_2 = C$ is given by,

$$(2) \quad i = \frac{V_1 + V_c}{\omega_r L}\sin\omega_r t e^{\frac{-Rt}{2L}}$$

The peak MOSFET current is equal to the peak load current and is expressed as,

$$(3)\quad I_p = \frac{V_1 + V_c}{\omega_r L} \sin \omega_r t_p e^{\frac{-R}{2L} t_p}$$

The rms load current I_L (rms) is

$$(4)\quad I_{L_{(rms)}} = \sqrt{2} I_{rms_{(MOSFET)}}$$

The peak **supply current** is

$$(5)\quad I_{s_{(p)}} = 0.5 \text{ peak load current}$$

1.2. Full Bridge Inverter

For higher output power full bridge circuit is normally used. The analysis of the full bridge circuit is shown in Fig. 3.

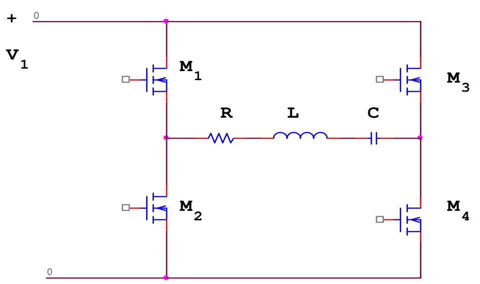


Fig. 3. Full -bridge series resonant inverter

The circuit is on when M_1 and M_4 are triggered simultaneously at t = 0.

The equation of current in the resonant circuit is given by

$$(6)\quad i = \frac{V_1 + V_c}{\omega_r L} \sin \omega_r t e^{\frac{-Rt}{2L}}$$

When $-V_c$ is the initial voltage of the capacitor. The current flows for half cycle of the resonant frequency and becomes zero at $t = t_r/2 = \pi/\varpi_r$ and both M_1 and M_4 are turned off. The capacitor voltage is

$$(7)\quad V_c = V_1 - (V_1 + V_c) e^{\frac{-Rt}{2L}} \left(\frac{R}{2L} \sin \omega_r t + \omega_r \cos \omega_r t \right) / \omega_r$$

The final value of V_c at $t = \pi/\varpi_r$ is

$$(8)\quad V_{c_1} = V_1 + (V_1 + V_c) e^{\frac{-R}{2L}\frac{\pi}{\omega_r}}$$

The final value of V_c in this half cycle is the initial value for the next half cycle. The next half cycle begins with the triggering of M_2 and M_3.

The average MOSFET current is

$$(9)\quad I_{av_{(MOSFET)}} = \frac{1}{2} I_{L_{(av)}}$$

The rms current is

$$(10)\quad I_{rms_{(MOSFET)}} = \frac{I_{L_{(rms)}}}{\sqrt{2}}$$

It may be noted that in the bridge circuit the output power is larger than that in the half bridge circuit for the same input voltage and resonant frequency.

2. SERIES RESONANT INVERTER

Resonant inverters can be realized with thyristor switches, because the resonant load can be used to commutate the thyristor. In order to achieve effective commutation, the load must be driven at a frequency such that a leading power factor is presented to the inverter. The operating frequency in a thyristor inverter can not be sufficiently high, because of its high turn-off time. Consequently in modern dc to dc converters, high frequency high power switching devices such as BJT, IGBT or power MOSFETs are used. Here we are using MOSFETs.

A PWM pulse shift controlled bidirectional DC to DC converter is presented in (Dchong Xn, 2004). Low harmonic CLL type AC to DC converter is presented (Chakraborty and Shida, 2001). Novel ZV ZC PWM converter is given (Satoshi amada and Mutso a Nakoka, 2002). Multilevel converter for large drives are given (Tolbert et al., 1999). Analysis of series parallel resonant converter is presented (Bhat, 1993).

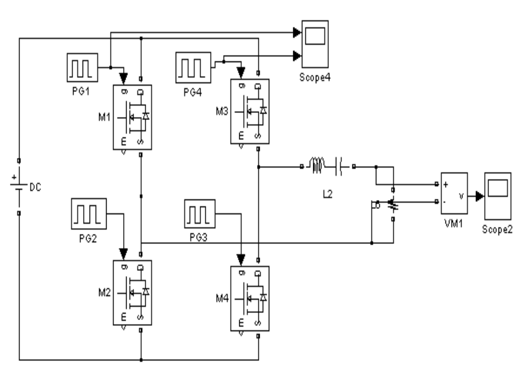
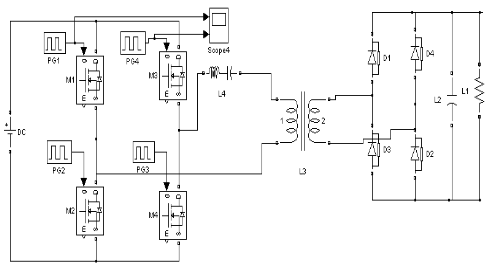


Fig. 4 Series Resonant Inverter

Fig. 4 shows the series resonant inverter. The circuit consists of a full bridge MOSFET inverter, a series inductor and a capacitor. Pulse generator are connected to the gate of the MOSFET. Scopes are connected to display the gate pulses. Gate pulses are given in such a way that M_1 and M_4 are conducted simultaneously, when M_2 and M_3 are in off condition. Similarly, gate pulses are given for M_2 and M_3 at a time when M_1 and M_4 are off, in order to avoid short circuit.

3. CIRCUIT DESCIPTION AND OPERATING PRINCIPLE

Fig.5 shows the Series Resonant PFC DC – DC converter. The circuit consists of a full bridge MOSFET inverter having a high frequency resonant circuit. This is a high frequency link. A load can be connected to the high frequency link circuit with secondary rectifier and smoothing capacitor. A HF transformer provides voltage transformation and isolation between the DC source and the load.



Fig,5. Series Resonant Power Factor Correction DC – DC Converter

The resonant link circuit is driven with either square waves of voltage or current in the inverter. The voltage or current in the resonant components becomes maximum at the resonant frequency and by altering the frequency around the resonant point, the voltage on the resonant components can be adjusted to any desired value. The DC voltage can either be lower or higher than the DC supply voltage. Thus,

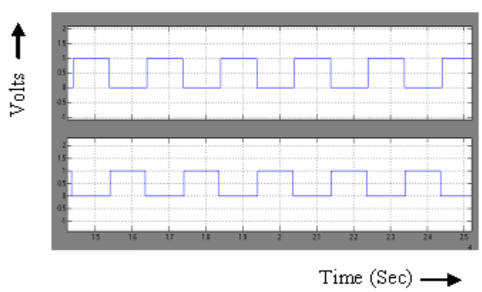


Fig.6. Pulses for M_1 and M_3

this can be operated as step – down or step – up converter. In the present work, step – down converter is used.

4. SIMULATION RESULTS

The simulation of series resonant DC – DC converter is done using Matlab and the results are presented. The driving pulses for the MOSFETs M_1 and M_3 are shown in Fig.6. The output of series resonant inverter is shown in Fig.7. The peak value of AC voltage is 48V. Sinusoidal voltage is obtained by using series resonance. The driving pulse for M_1 and voltage across M_1 are shown in Fig.8. Driving pulse for M_2 and Voltage across M_2 are shown in Fig.9. DC voltage at the output is shown in Fig.10. Its value is 12V.

5. EXPERIMENTAL RESULTS

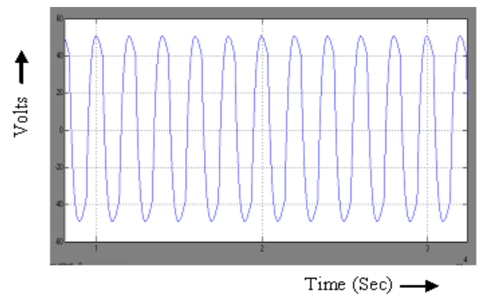


Fig.7. Output of series resonant inverter

The Hardware is tested using microcontroller and the results are presented. The top view of the hardware is shown in Fig.11. DC input voltage is shown in Fig.12. Its value is 24V. Driving pulse to the MOSFETs are shown in Fig.13. The input and output voltages to the MOSFET are shown in Fig. 14. High frequency AC output of the inverter is shown in Fig. 15. Its peak value is 24V. DC output voltage is shown in Fig.16. The output voltage is 12V.

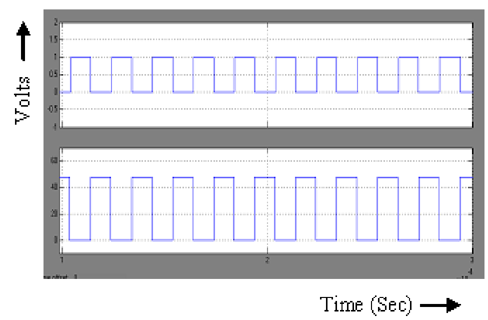


Fig.8 Driving pulse for M_1 and Voltage across M_1

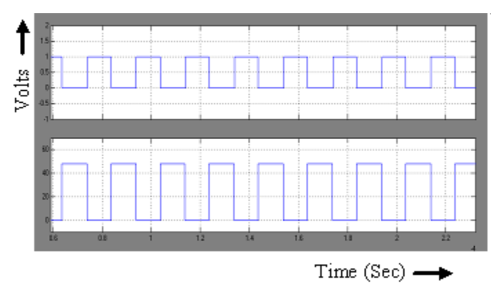


Fig.9. Driving pulse for M_2 and Voltage across M_2

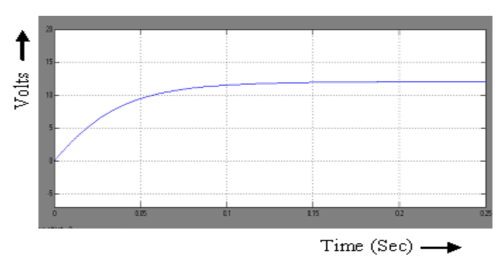


Fig.10. DC output voltage

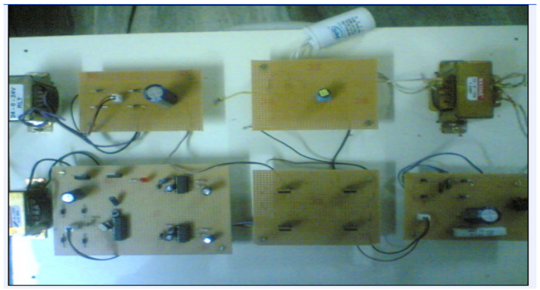
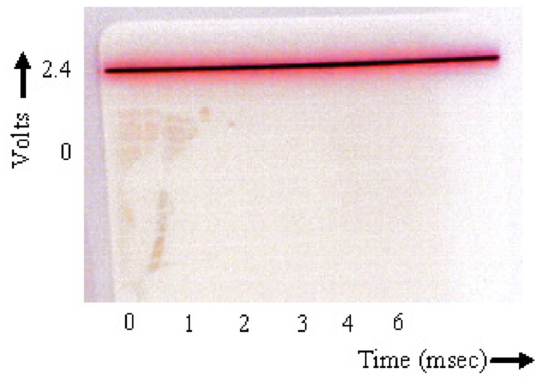
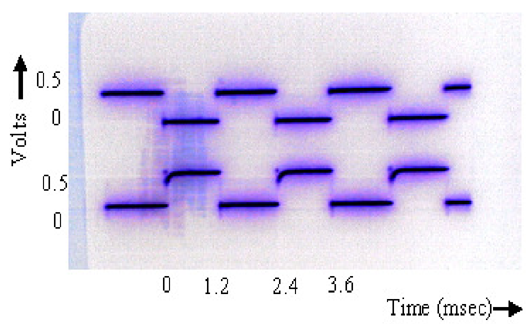


Fig.11. Top View of Hardware



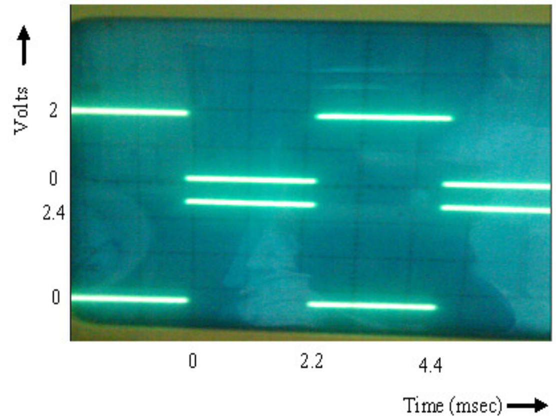
X Axis : 1 Unit = 1 m sec
Y Axis : 1 Unit = 10V

Fig.12. Dc input Voltage



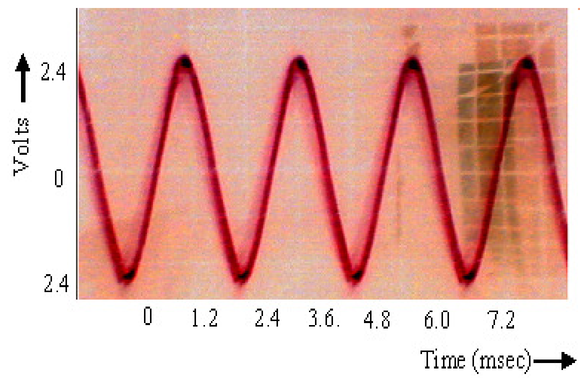
X Axis : 1 Unit = 1 m sec
Y Axis : 1 Unit = 10V

Fig.13. Driving Pulses



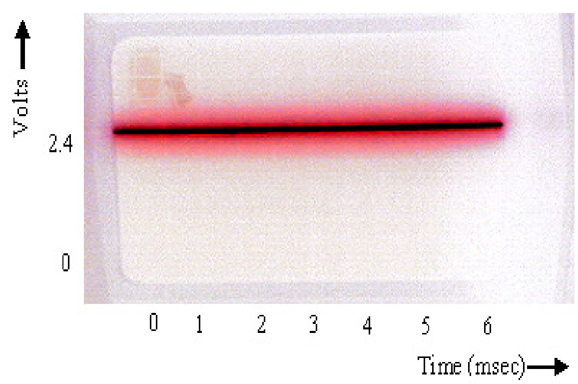
X Axis : 1 Unit = 0.5 m sec
Y Axis : 1 Unit = 5V (for input)
Y Axis : 1 Unit = 10V (For V_{ds})

Fig.14. Input and Output of MOSFET



X Axis : 1 Unit = 1 m sec
Y Axis : 1 Unit = 10V

Fig.15. High Frequency AC



X Axis : 1 Unit = 1 m sec
Y Axis : 1 Unit = 5V

Fig.16. DC Output Voltage

6. CONCLUSION

Series resonant PFC DC – DC converter is analysed and simulated using Matlab simulink version 7.3. The open loop DC – DC converter system is simulated. From the simulation results, it is evident that there is no voltage stress across the switches during switching. Hence the switching losses are alleviated. The circuit is fabricated and the experimental results are presented here. The experimental results closely agree with the simulation results.

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BIO-DATA

V.Sivachidambaranathan has completed Diploma in Electrical and Electronics Engineering, DOTE, Chennai, India in 1994, AMIE degree in Electrical Engineering from the Institution of Engineers (INDIA), Section A and Section B in 1997 and 2002, and M.E. degree in Power Electronics and Industrial Drives from Sathyabama Institute of Science and Technology, Chennai, India in 2005. He is a life member of Indian Society for Technical Education. Presently he is pursuing Ph.D. programme at Sathyabama University, Chennai, India. His research interests include DC - DC converters and power factor correction converters.

Dr.S.S.Dash is presently working as a Professor and Head of the Department of Electrical and Electronics Engineering, SRM Engineering College, SRM University, Chennai, India. He has completed his graduation in Electrical Engineering in the year 1994. He got his M.E. in Power Systems Engineering from University College of Engineering, Burla, Orissa, India in 1996 and obtained his Ph.D degree from College of Engineering, Guindy, Anna University, Chennai, India in the year of 2004. He was formerly a faculty member of Anna University, College of Engineering, Guindy, Chennai, India. He has published more than 50 papers in International Journal and conferences. His research areas are Modelling of FACTS Controller, Power Electronics and Drives, Power System Stability and Artificial Intelligence. He is a life member of Indian Society for Technical Education and Institution of Engineers, India.