CLOSED LOOP CONTROLLED SERIES RESONANT PFC DC TO DC CONVERTER

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Abstract

The aim of this work is to simulate closed loop controlled 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. A model for closed loop controlled DC – DC series resonant PFC converter has been developed and it is used to perform simulation studies.

Keywords: Series Resonant DC to DC Convertor, PWM, Matlab

I. 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 [6] – [8].

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 [10].

A. *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 $C_1 = C_2 = C$.

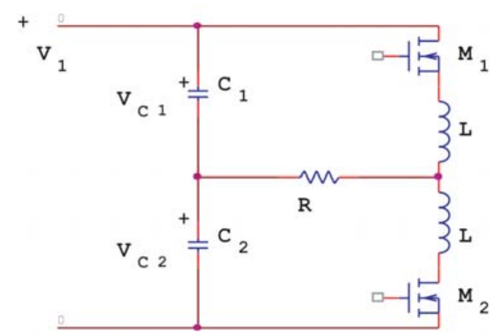


Fig. 1. Half -bridge series resonant inverter

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.

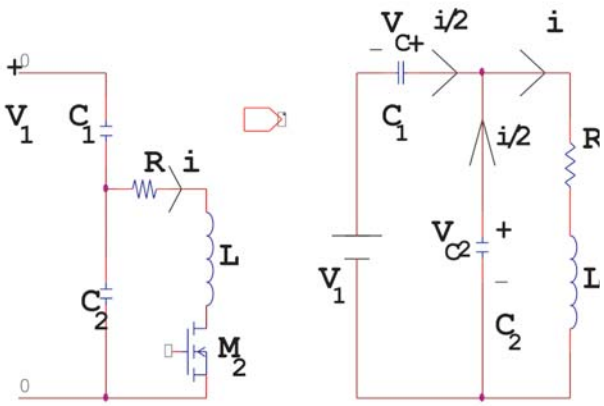


Fig. 2. Equivalent circuit of half-bridge resonant inverter

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

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

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

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

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

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

The rms load current I_L (rms) is

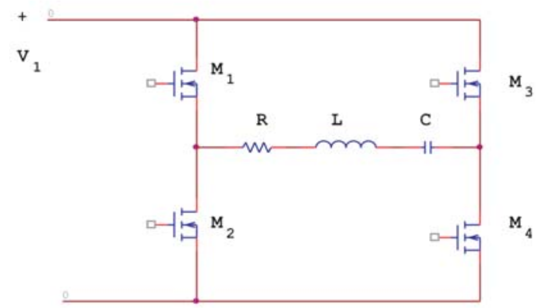
$$I_{L_{(rms)}} = \sqrt{2} I_{rms_{(MOSFET)}} \tag{4}$$

The peak supply current is

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

B. 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.



ig 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

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

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

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

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

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

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

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

The rms current is

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

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.

II. 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 [1]. Low harmonic CLL type AC to DC converter is presented by I shida [2]. Novel ZV ZC PWM converter is given in [3]. Multilevel converter for large drives are given by [4]. Analysis of series parallel resonant converter is given by Bhat [5]. In the literature [1] to [8], the simulation of closed loop controlled series resonant PFC DC to DC converter was not presented. In the present work, closed loop controlled DC to DC link converter is modeled and simulated.

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.

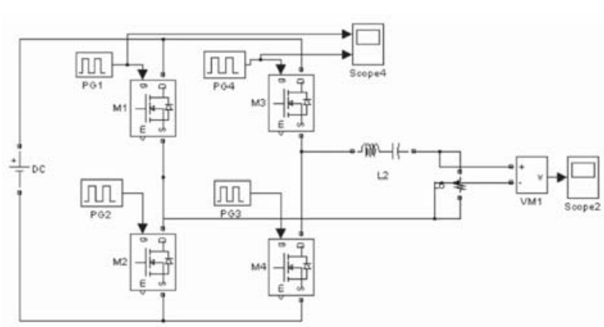


Fig. 4. Series Resonant Inverter

III. CIRCUIT DESCIPTION AND OPERATING PRINCIPLE

A. Series resonant PFC dc-dc converter

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.

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. By rectifying the voltage across the inductor or capacitor, a dc voltage is obtained which is filtered to achieve smooth dc. This dc voltage can either be lower or higher than the dc supply voltage. Thus, this can be operated as step – down or step – up converter, In the present work, step – down converter is used.

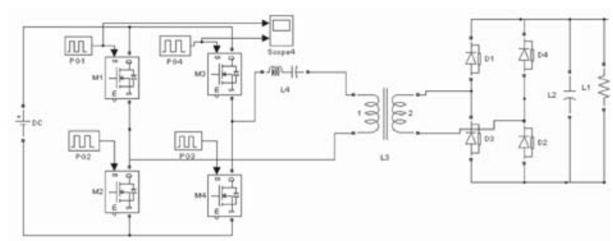


Fig. 5. Series Resonant Power Factor Correction DC – DC Converter

B. Open loop series resonant pfc dc-dc converter with disturbance

Fig.6 shows the open loop series resonant PFC DC – DC converter with disturbances. The input dc voltage is altered by introducing an additional error signal. Scopes are connected to display the gate pulses. A disturbance is given at the input.

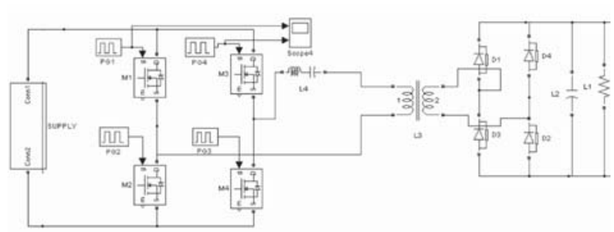


Fig. 6. Open Loop Controlled Series Resonant DC – DC Converter with disturbance

C. Closed loop controlled series resonant PFC dc-dc converter

Fig.7 shows the closed loop circuit for series resonant DC – DC converter with disturbance. The closed loop system consists of comparator and PI controller. The output voltage is sensed and it is compared with the reference voltage. The error signal is applied to a PI controller. The output of the PI controller is given to the MOSFET. The steady state error signal is reduced by properly tuning the PI controller.

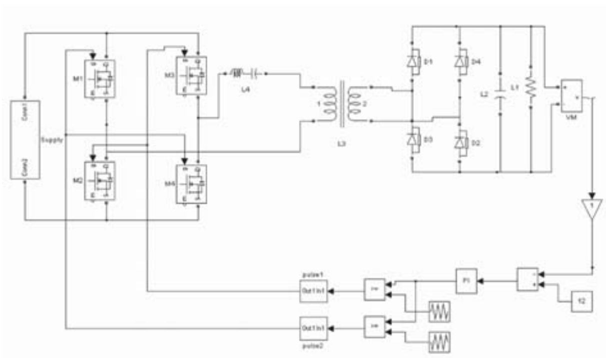


Fig. 7. Closed Loop Controlled Resonant DC – DC Converter with disturbance

IV. SIMULATION RESULTS

The simulation of series resonant DC – DC converter is done using Matlab and results are presented. The driving pulses for the MOSFETs M_1 and M_3 are shown in Fig.8. The output of series resonant inverter is shown in Fig.9. Sinusoidal voltage is obtained by using series resonance. The driving pulse for M_1 and voltage across M_1 is shown in Fig.10. Driving pulse for M_2 and Voltage across M_2 is shown in Fig.11. DC voltage at the output is shown in Fig.12. DC output voltage with disturbance for open loop system is shown in Fig.13.

From the output it can be seen that the output voltage increases when the input voltage increases. There is a steady state error in the output of open loop system. The output voltage is sensed and it is compared with the reference voltage. The error signal is given to the comparator through PI controller. The output pulses of PWM generation system are given to the MOSFET. The response of closed loop system is shown in fig. 14. From the response it can be seen that the output voltage reduces and settles at the set value. The steady error becomes zero.

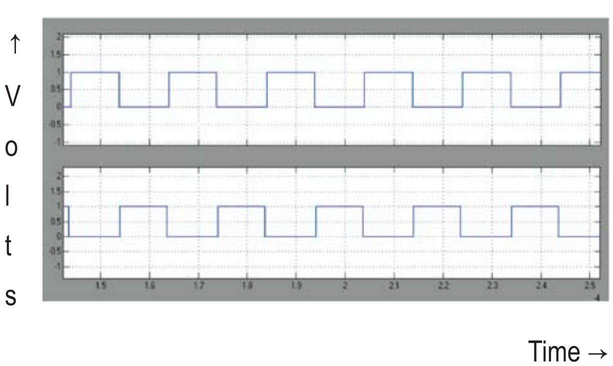


Fig. 8. Pulses for M_1 and M_3

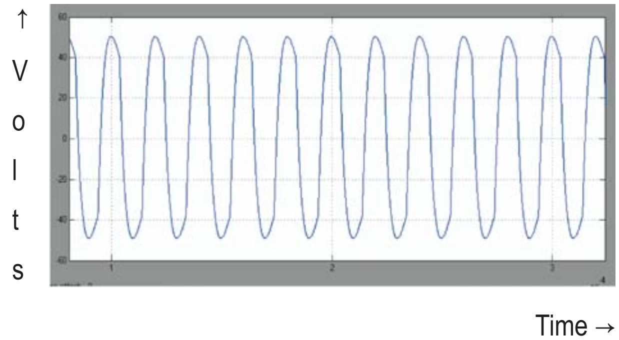


Fig. 9. Output of series resonant inverter

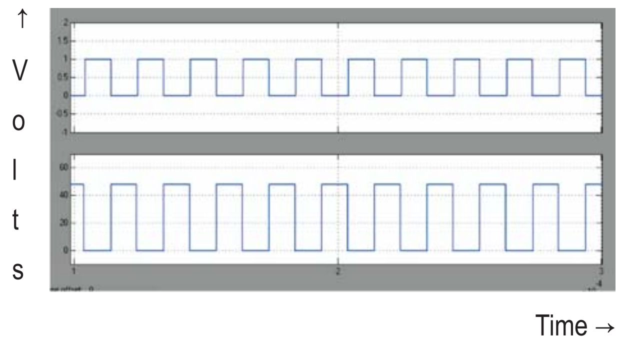


Fig. 10. Driving pulse for M_1 and Voltage across M_1

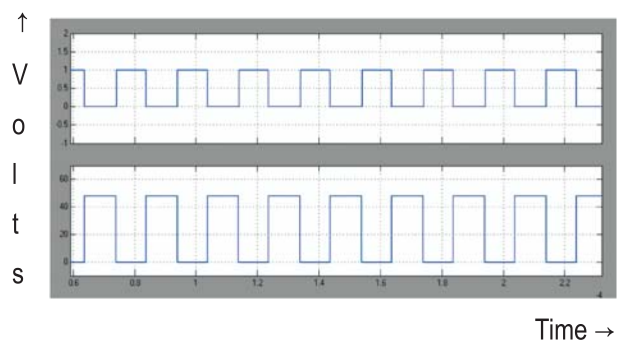


Fig. 11. Driving pulse for M_2 and Voltage across M_2

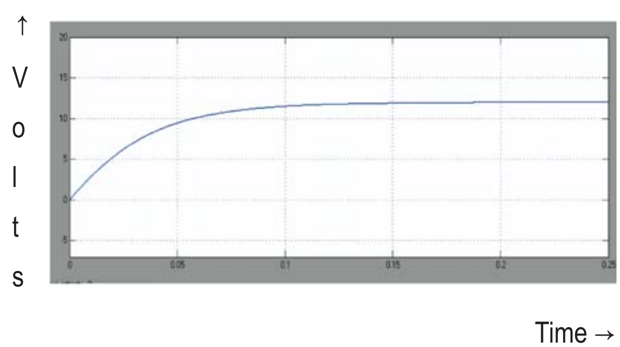


Fig. 12. DC output voltage

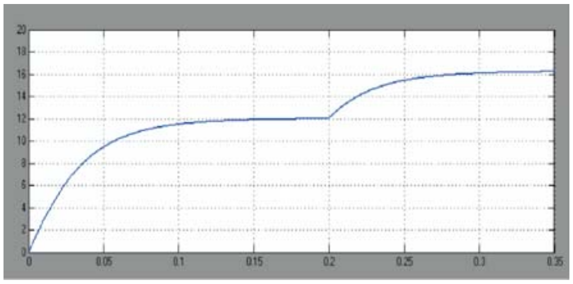


Fig. 13. Response of open loop system

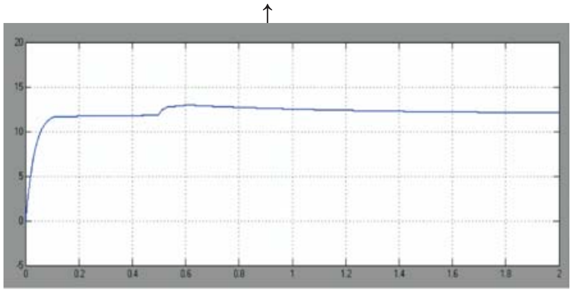


Fig. 14. Response of closed loop system

V. CONCLUSION

Series resonant PFC DC – DC converter is analysed and simulated using Matlab simulink version 7.3. The series resonant inverter and open loop DC – DC converter systems are simulated. The circuit model for the closed loop system is developed and it is used to perform simulation studies. The closed loop system has been successfully simulated and the results are presented here. The closed loop response is improved by tuning the parameters of PI controller.

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