

## Closed Loop Analysis of Single-Phase Soft-Switching PFC Converter

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**Abstract:** Generally converter when operated at high frequency results in losses. In this paper a single stage soft switching PFC converter analysis is done. It is developed with a new active snubber cell which provides zero-voltage transition turn ON and zero-current transition turn OFF. This type of converter circuit design does not have additional resonant components. Operating the proposed converter at high frequency, the soft switching scheme will reduce the electromagnetic interference. The simplified closed loop analysis is done to improve the overall efficiency by having good regulation capability. The simulation part is done with Matlab Simulink

**Key words:** Power factor correction (PFC) • Soft-switching (SS) • Zero-current switching (ZCS) • Zero-current transition (ZCT) • Zero-voltage switching (ZVS) and zero-voltage transition (ZVT)

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### INTRODUCTION

Nowadays, the electricity network have drawbacks like very poor power quality due to injected current harmonics which results in voltage distortion and at input ac side a poor power factor. When these converters are operated at high switching frequency it results in switching loss and increased electromagnetic interference. Therefore overall efficiency of the converter is getting reduced. In order to overcome these disadvantage a low harmonic and high-power factor converters are used with soft-switching methods. During operating a converter at a high switching frequency, the switching power loss occur which consist of the current and voltage overlap loss. A great deal of effort made by the engineers for past few years to develop efficient and cost-effective power factor correction converter.

The single-stage soft switching technique have particular attention because of its low cost, [1-4]. Lesser volumes and lowered ratings of converter results with better efficiency [5-7]. A zero voltage switching (ZVS) technique shared between the rectifier and inverter have been proposed in [8, 9]. An idea of sharing a single auxiliary switch between two stages of power conversion has been explored in [10]. In this paper, to eliminate drawbacks of the power factor correction (PFC) converter a new active snubber circuit is proposed. The proposed

converter provides a perfect ZVT turn ON and ZCT turn OFF. This is done together for the main switch. As a result no additional current or voltage stresses over the main switch. A part of this the auxiliary current switch will diverted the output with the coupling inductance, so the better switching condition is provided. In this analysis the aim of proposed circuit is to achieve high efficiency and high-switching frequency PFC converter through Matlab. The closed loop operation is done which is not discussed in above said literature survey.

**Proposed Circuit Analysis:** The newly proposed PFC converter is given in Fig. 01.a. For one switching cycle some assumptions are made to simplify the steady-state analysis circuit. A). Output voltage  $V_O$  and input current  $I_i$  are constant. B). Resonant circuits are ideal. C). The reverse recovery diodes are not taken into account. The operation of proposed converter is as below. First switches  $S_1$  and  $S_2$  are in the OFF state. During that time  $I_i$  input current passes through the DF main diode. When the gate signal is applied to the switch  $S_2$ , a resonance starts between  $LR_1$ ,  $LR_2$  and  $CR$ . Meanwhile  $S_2$  current rises and DF current falls.  $LR_2$  snubber inductance provides turn ON switching with ZCS of  $S_2$ ,  $D_1$  and  $D_2$ . When the sum of the input and output currents of transformer reaches input current  $I_i$ , the DF current falls to zero and turns OFF with ZCS[11].

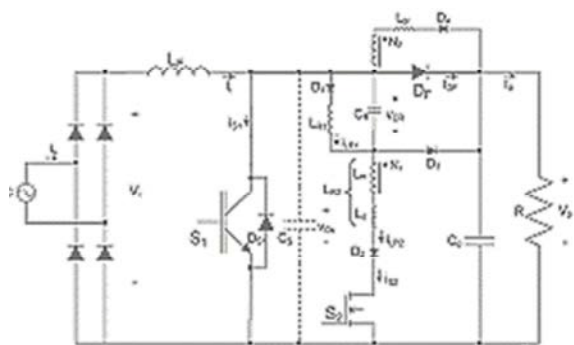


Fig. 01. a: Soft Switching based PFC Converter

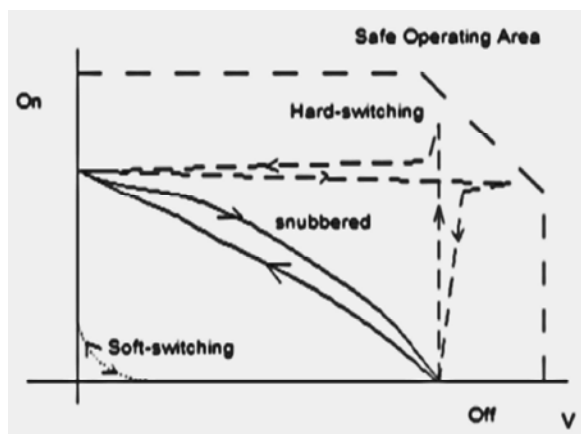


Fig. 01. b: Switching of Power Switches

During the time the switch S1 and the diode D4 are in OFF state, S2 is in ON state, capacitor CS discharges, the stored energy in LR2 is transferred to the output side and meanwhile D4 turns OFF. Two different closed circuits are valid out of which capacitor CS is charged linearly with  $I_i$ , a resonance occurs through LR1 -CR-D1. A new resonance occurs through LR1, CS and CR with  $I_i$  input current. The energy stored in LR1 inductance is transferred to the capacitors and load completely. For this Stage, no time period is determined by the PWM controller,  $iDf = I_i$  then therefore one switching period is completed. Next another switching period starts and goes on. The typical switching trajectories of power switches are shown in Fig. 01.b.

## RESULTS

Simulation is done using Matlab Simulink and the results are presented. The circuit shown in Fig. 02 has been simulated and the operating switching frequency is 25 kHz. The PFC converter is obtained by adding

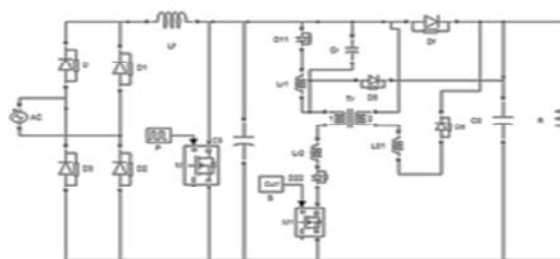


Fig. 02: Simulation of Proposed circuit

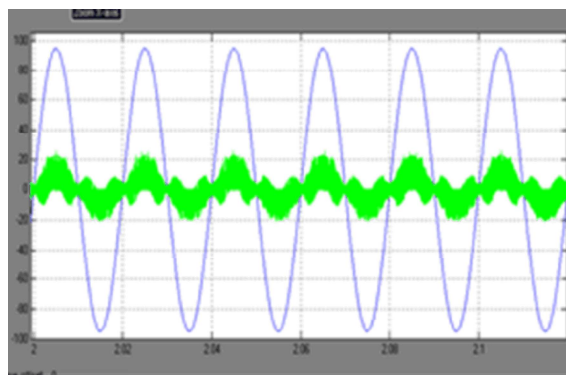


Fig. 03: Input AC voltage and current

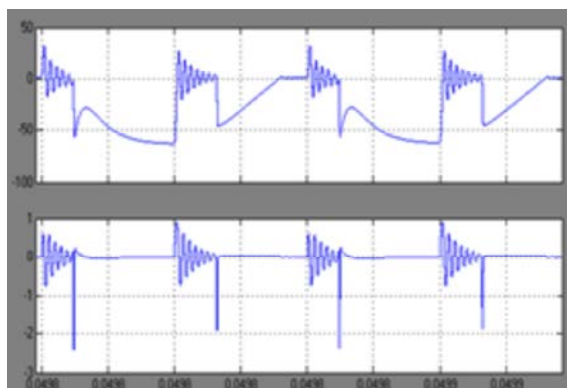


Fig. 04: Resonant Capacitor- Voltage and Current Waveform.

ZVT-ZCT PWM active snubber circuit to the step up converter, which can be fed by universal ac input line. Fig. 03 shows the input AC current which tracks the input AC voltage so input power factor is almost unity, which is measured as 0.9999. The input voltage measured is 98 volt AC. The voltage and current waveforms of the resonant capacitor are shown in Fig. 04. In both condition ZVT & ZCT the voltage across the capacitor increase, drop depending on switching. Fig. 05 and Fig. 06 shows the voltages and currents of LR2 and LR1, respectively to have constant output voltage. The voltage across the diode is shown in Fig. 07.

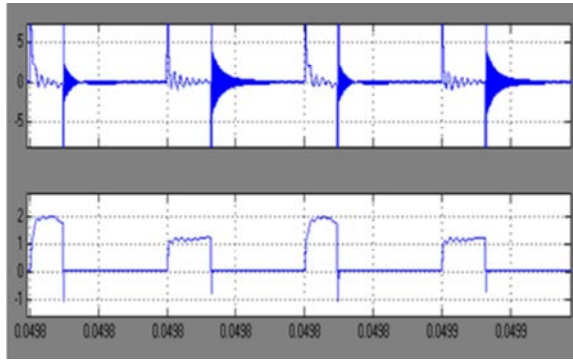


Fig. 05: Current and voltage waveform of LR2.

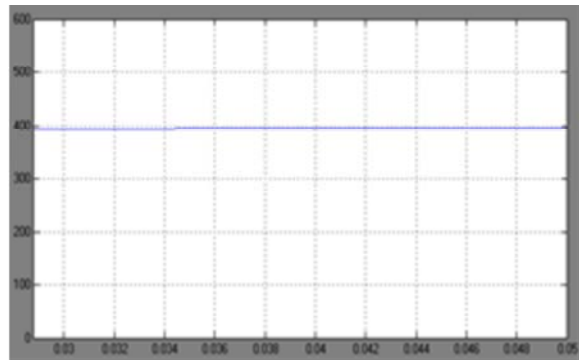


Fig. 08: Output voltage measures 395 v across

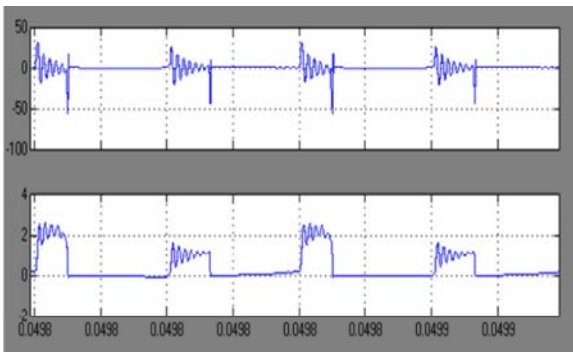


Fig. 06: Current and voltage waveform of LR1

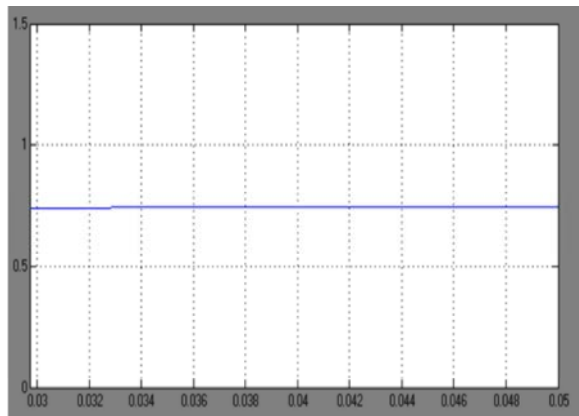


Fig. 09: Output current measures 0.75 amps Proposed Circuit across Proposed Circuit

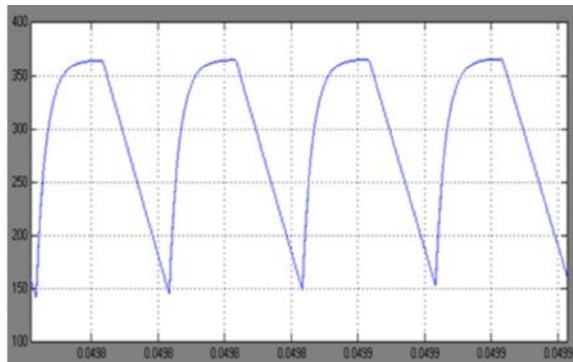


Fig. 07: Voltage measures 370 volts across the diode

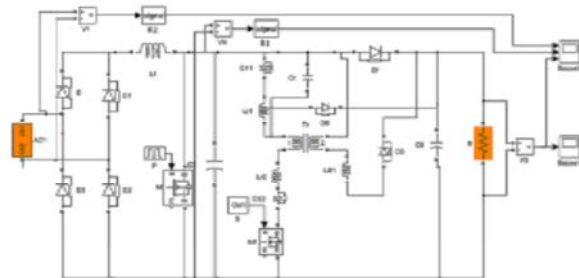


Fig. 10: Open loop control of Proposed Ckt

The output voltage measured as 395 volt and the current measured as 0.5amp as shown in Fig. 08 and 09, respectively. An Open loop system with some disturbance at the input which is shown in Fig. 10. A step rise in input voltage is applied at time  $t=0.2$ sec as shown in Fig. 11. Output voltage also increases. The Closed loop system with a PI controller is shown in Fig. 12 [12]. Output voltage is sensed with a sensor and it is compared with a reference gain voltage. Usually the error will be processed by the PI controller and the output of PI controller adjusts the pulse width to maintain the output voltage constant. The input voltage and output voltage

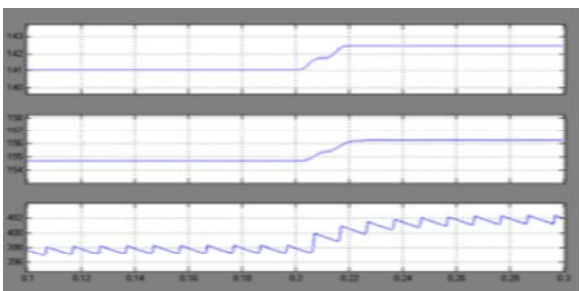


Fig. 11: As the disturbance created at time=0.2sec, the corresponding voltage and current

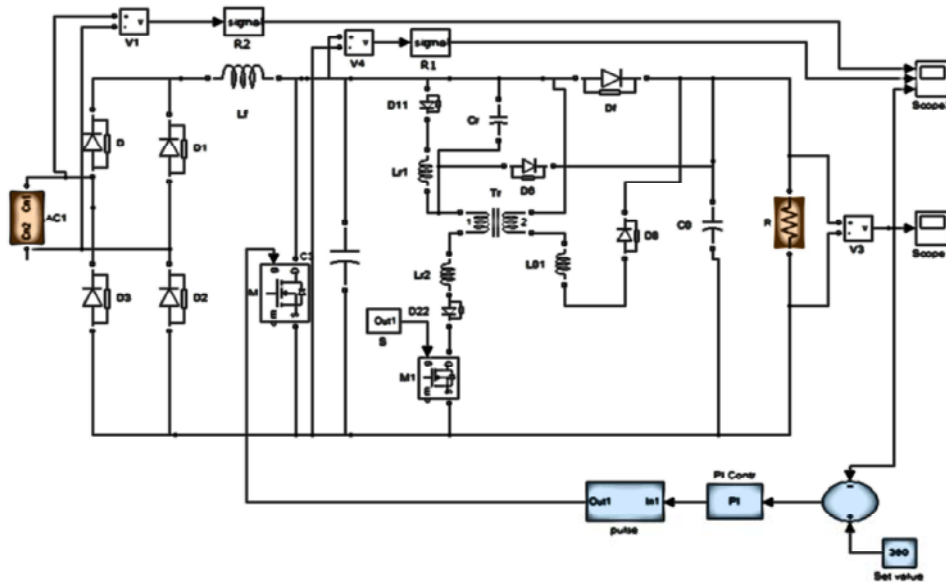


Fig. 12: Closed loop Control of Proposed Ckt

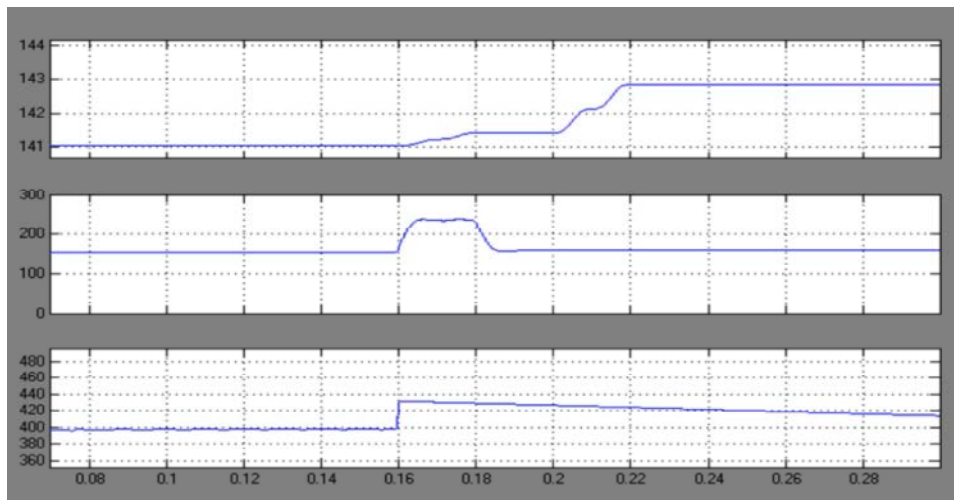


Fig. 13: Output current and voltage reaches the set value after the disturbance created at 0.2 sec

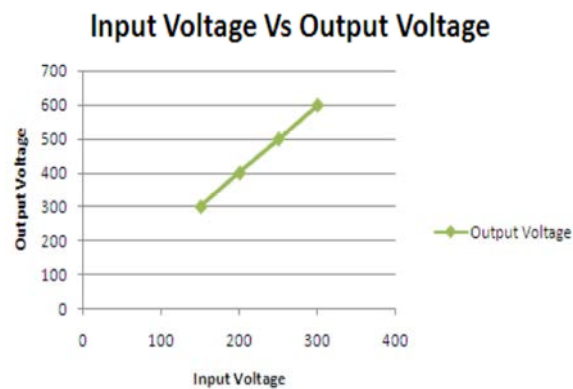


Fig.14. Variation of O/P Voltage with I/PV Voltage

of closed loop system is shown in Fig. 13, output voltage reduces and reaches the set value. Variation of output voltage with input voltage is shown in Fig. 14. Output Voltage gets increased with input.

### CONCLUSION

It is very clear from above analysis that the single stage soft switching converter is suitable for power factor correction. Due to high switching frequency operation the proposed converter can operate at high power density, also at the same time it helps to reduce the component count and cost. It was observed from the result that the

operation principles of the proposed circuit were exactly verified by Matlab simulation. Closed loop simulations have proved that the proposed PI Controller is a better replacement of the open loop system, even when the system voltages and currents are more distorted. Also transients are avoided in the waveform.

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