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Digital Implementation of 0.5 kW Integrated Power

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Abstract* —Railway wayside signaling is a system used to control railway traffic safely, essentially to prevent trains from colliding. Therefore it is required to have a reliable power supply to keep a healthy and sustainable rail network. The methodology to develop the power supply presented in this project involves study and implementation of power factor correction (PFC) boost converter integrated with two-switch DC-DC forward-converter for high voltage and high frequency application using individual Microcontrollers.The proposed method confirms the efficient and reliable operation of the integrated converters with the line side power factor maintained to near unity for various load conditions.Total Harmonic Distortion (THD) in the input current is also considerably reduced in the proposed scheme. This approach not only reduces the size of magnetic components, but also makes it possible to achieve a fully controlled AC-DC-AC converter when further integrated with single-phase inverter

Keywords-Boost-converter; Digital implementation; Improved THD; Power factor correction; Two-switch DC-DC forward converter

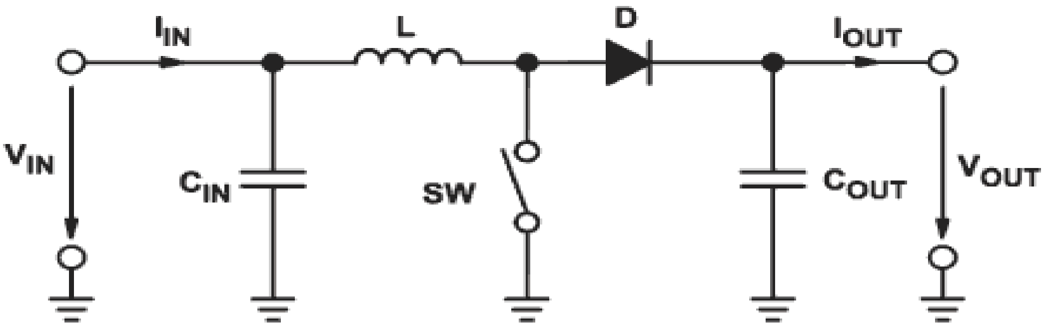
I. INTRODUCTION

Switched mode power supplies (SMPSs) are extensively used inside most of electrical and electronic appliances today such as in computers, televisions, and audio sets, drives, etc. The SMPS presents nonlinear impedance to the mains, as aresult of its input circuitry. Current harmonics produced by nonlinear loads are prevalent in today's power systems.
Widespread use of power electronic loads (identified harmonic producing loads) such as high-power diode or thyristor rectifiers , cyclo-converters, and arc furnaces, while unidentifiedharmonic producing load like a low-power diode rectifier usedas a utility interface in an electric appliance produce a largeamount of harmonic currents. These nonlinear loads generally draw non-sinusoidal unbalanced currents from ac mains resulting in harmonic injection, reactive power burden, excessive neutral currents and unbalanced loading of ac mains Conventionally, passive filters consisting of tuned L-Cfilters (single-tuned or multi-tuned) have been broadly used tosuppress harmonics because of low initial cost and highefficiency. Active power filter are also purposed as solutions for medium-power applications. Especially for low power applications, now a day, active power factor corrector (PFC) is used in order to comply with regulatory requirements according to IEC 61000-3-2 and EN 61000-3-2 harmonics standards. The basic block diagram of the proposed power supply is shown in fig.1. The power supply consists of closed-loop PFC boost-converter and closed-loop two-switch DC-DC forward-converter. The two-switch converter topology is preferred over the single switch topology as it reduces.

II. PFC boost converter and DC-DC Forward Converter

A front-end PFC boost-converter followed by a two-switch dc-dc forward-converter is one of the most extensively employed converter combinations in off-line power supplies used in wayside signalling in railway application. The frontend PFC boost-converter is employed as it offers reduced line current harmonics with power factor correction and is significantly smaller and lighter than a passive PFC circuit. To reduce the size and cost of passive filter elements, an active PFC operates at a higher switching frequency than the line frequency. The main function of the active PFC is to reshape the line current, filtering of the high frequency switching, feedback control to regulate output voltage. An insulated gate bipolar transistor (IGBT) based pulse width modulated (PWM) front-end boost-converter is proposed in offering low THD and unity power factor at supply side.

A. Design and Calculations of PFC Boost ConverterThe input power of PFC boost-converter is,
The following four parameters are needed to calculate the power stage:



1.Input Voltage Range: $V_{in(min)}$and $V_{in(max)}$

2. Nominal Output Voltage: V_{out}

3. Maximum Output Current: $I_{out(max)}$

4. Integrated Circuit used to build the boost converter. This is necessary, becausesome parameters for the calculations have to be taken out of the data sheet.If these parameters are known the calculation of the power stage can takeplace.

Calculate the Maximum Switch Current:-

$$D = 1 - \frac{V_{in(min)} \times \eta}{V_{out}} \quad ....(1)$$

Where, V_{in}= minimum input voltage

V_{out}= desired output voltage

η = efficiency of the converter,

e.g. estimated 90%

$$\Delta I_L = \frac{V_{in(min)} \times D}{f_s \times L} \quad .... (2)$$

Where, D = duty cycle calculated inEquation 1

f_s = minimum switching Frequency of the converter

L = selected inductor value

The maximum output current,

$$I_{MAXOUT} = \left(I_{LIM(min)} - \frac{\Delta I_L}{2}\right) \times (1 - D) \quad ...... (3)$$

Where, $I_{LIM(min)}$ = minimum value of the current limit of the integrated switch

ΔI_L = inductor ripple currentcalculated in Equation 2

The maximum switch current in the system is calculated

$$I_{SW(max)} = \frac{\Delta I_L}{2} + \frac{I_{out(max)}}{1-D} \quad ...... (4)$$

Where, $I_{out(max)}$ = maximum output current necessary in the application

For parts where no inductor range is given, the following equation is a good estimation for the right inductor,

$$L = \frac{V_{in} \times (V_{out} - V_{in})}{\Delta I_L \times f_s \times V_{out}} ......(5)$$

The inductor ripple current cannot be calculated with Equation 1 because the inductor is not known. A good estimation for the inductor ripple current is 20% to 40% of the output current,

$$\Delta I_L = (0.2 \text{ to } 0.4) \times I_{out(max)} \times \frac{V_{out}}{V_{in}} \quad ..... (6)$$

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Rectifier Diode Selection :-
To reduce losses, Schottky diodes should be used. The forward current rating needed is equal to the maximum output current:

$$I_f = I_{out(max)} \ldots\ldots..(7)$$

Where, I_f= average forward current of the rectifier diode
$I_{out(max)}$= maximum output current necessary in the application

Schottky diodes have a much higher peak current rating than average rating.It has tohandle:

$$P_D = I_f \times P_f \ldots\ldots..(8)$$

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Output Voltage Setting :-
Almost all converters set the output voltage with a resistive divider network. With the given feedback voltage, V_{FB}, and feedback bias current, IFB, the voltage divider can becalculated.

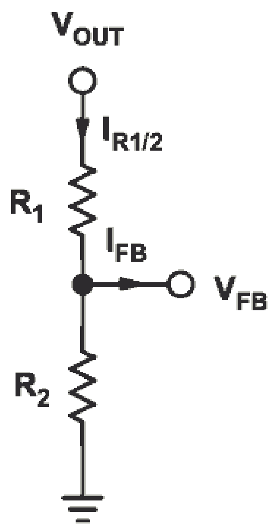

Figure Resistive Divider for Setting the Output Voltage

The current through the resistive divider shall be at least 100 times as big as thefeedback bias current:

$$I_{R1/2} \geq 100 \times I_{FB} \ldots\ldots.(9)$$

Where, $I_{R1/2}$= current through the resistive divider to GND
I_{FB} = feedback bias current from data sheet

The resistors are calculated as follows:

$$R_2 = \frac{V_{FB}}{I_{R1/2}} \qquad \ldots\ldots.(10)$$

$$R_1 = R_2 \times \left(\frac{V_{out}}{V_{FB}} - 1\right) \qquad \ldots\ldots.(11)$$

III. Simulation Result of PFC boost converter

The PFC boost-converter is designed to operate in continuous current mode control (CCMC) with the parameters as follow: L = 1000 µH, C = 1000 µF, V = 50 V, R = 40 Ω,Fsw = 10 kHz. Here, the power supply is operated at steady state condition. The simulation results of the PFC boostconverterare shown below in fig. 5 to fig. 8. In fig. 8, it is seen that input voltage and current are in phase with each other witha near unity power factor.

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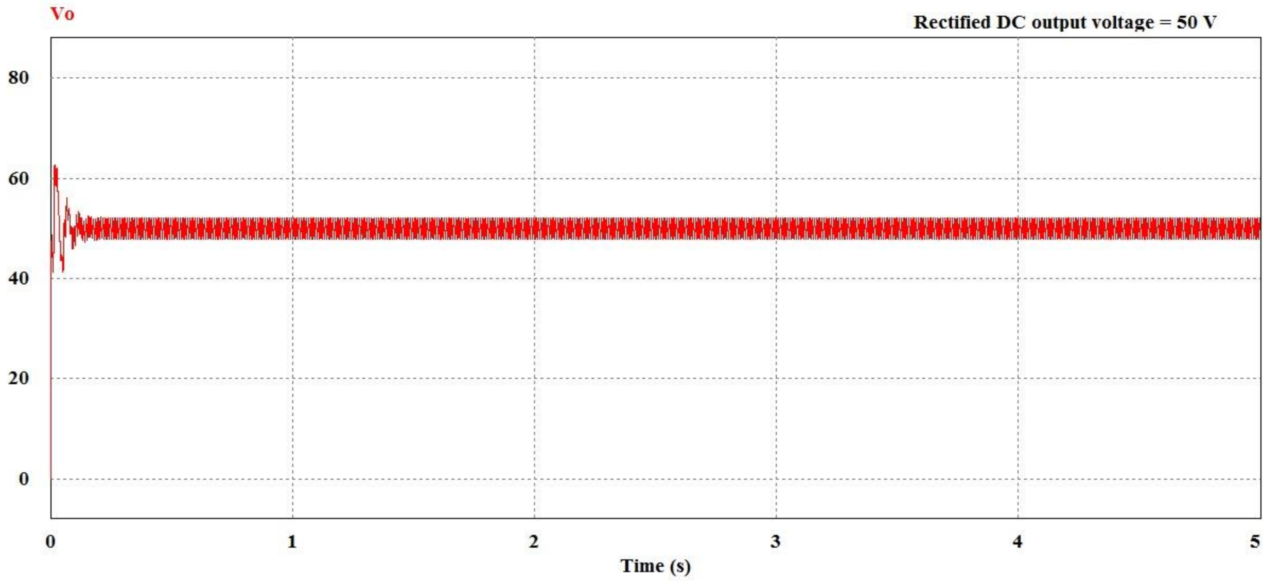
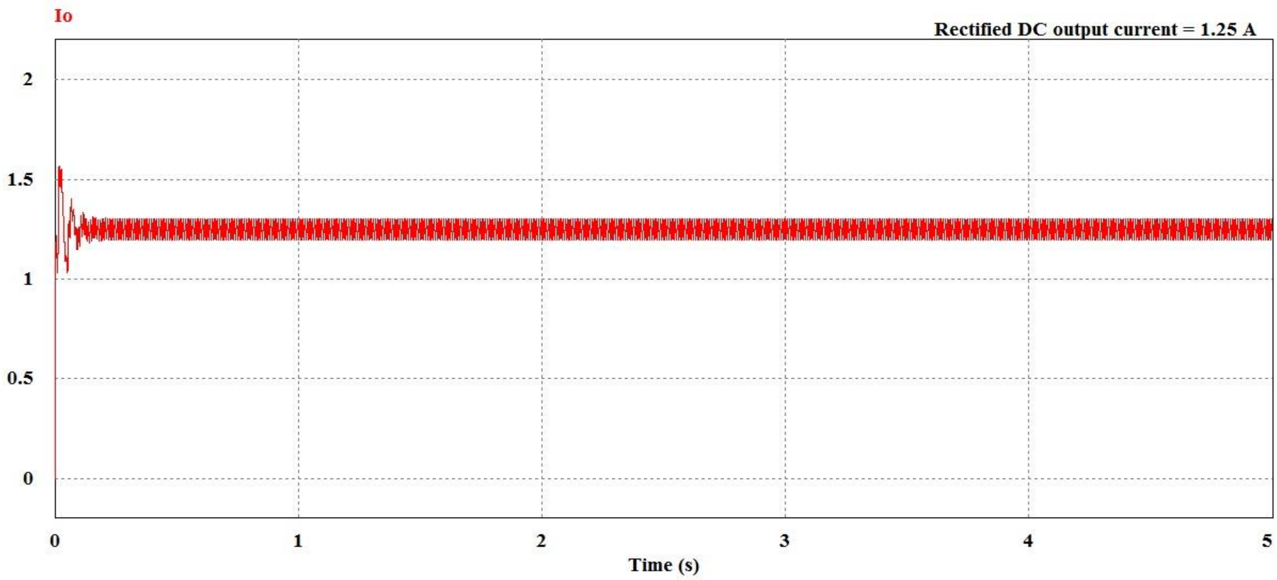
A. Steady state behaviour of PFC boost converter

(a) Output voltage of PFC boost converter



(b) Output current of PFC boost converter



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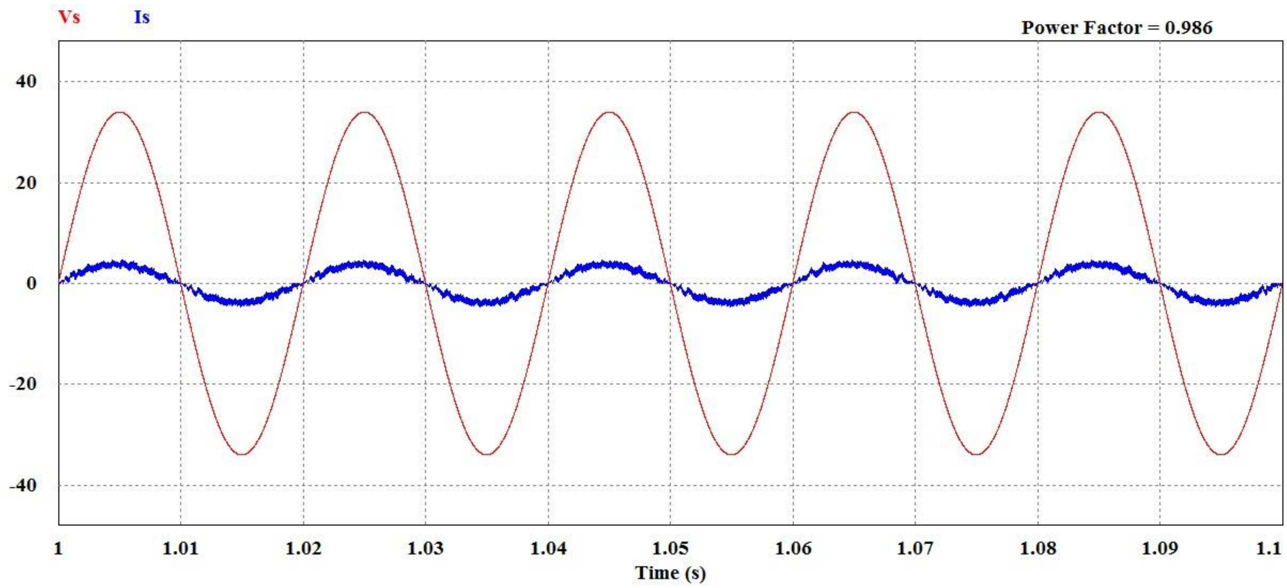
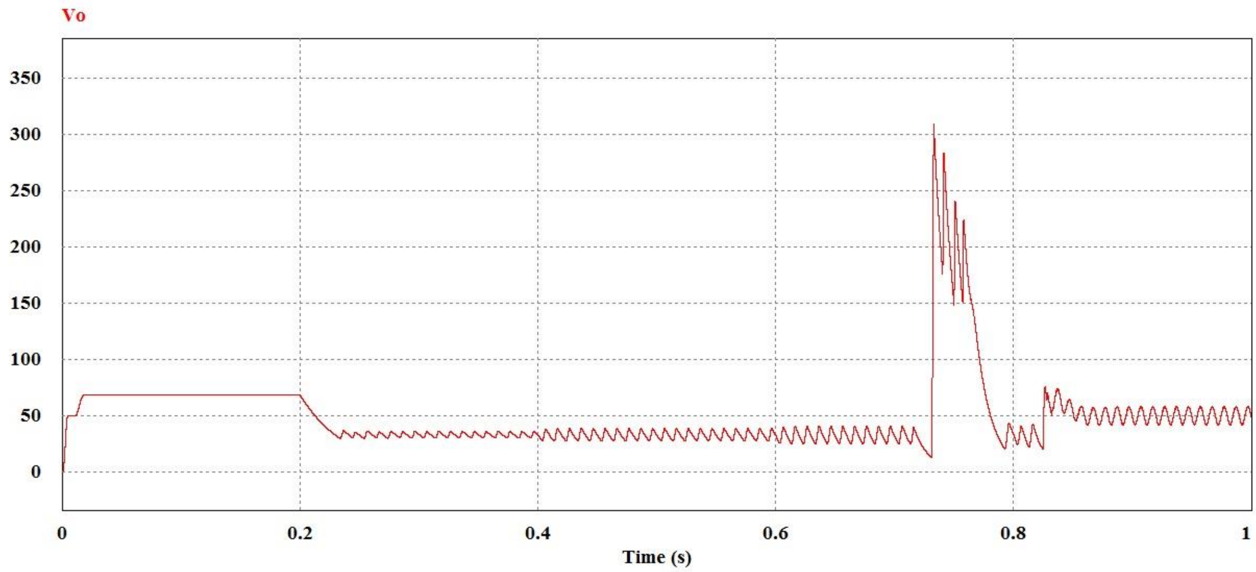
(c) Input power factor



B.Transient behaviour of PFC boost-converter in transient analysis of closed-loop PFC boost-converter,the output voltage is regulated by the outer voltage control loopand the input power factor and current wave shape are controlled by the inner current control loop. Both controllersare chosen as PI type compensator. Fig. below depict the transient behaviour of the proposed converter. In fig below it isseen that input voltage and current are in phase with each other with a near to unity power factor in transient conditions.

(a) Output voltage of PFC boost converter

Average Output Voltage = 50 V DC



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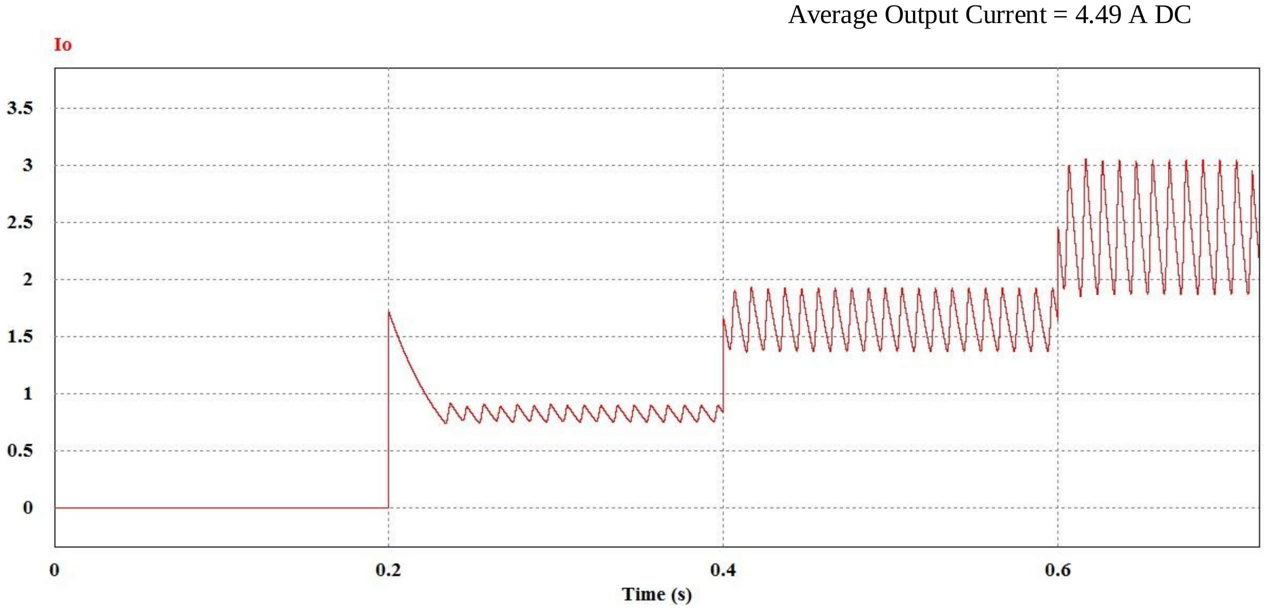
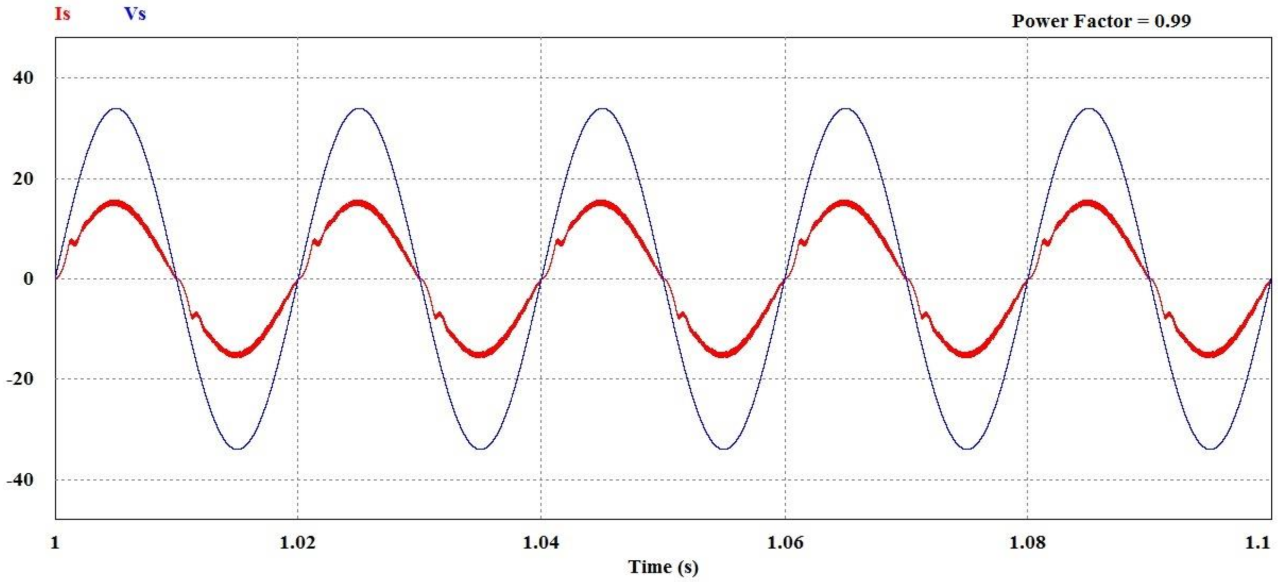
(b) Output current of PFC boost converter



(c) Input Power Factor of PFC boost converter



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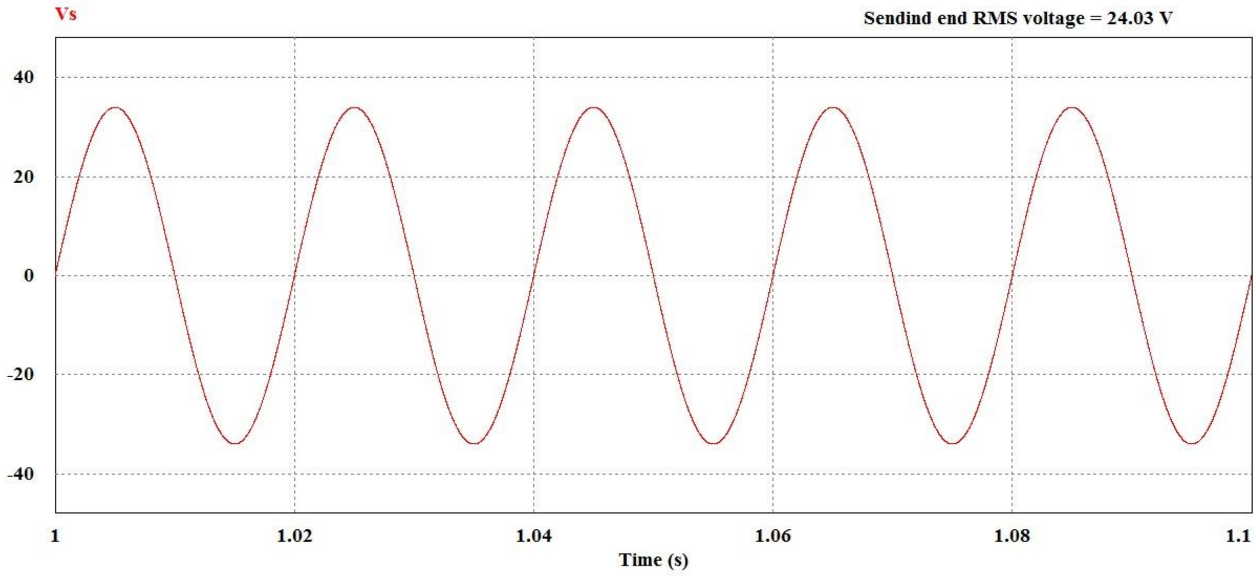
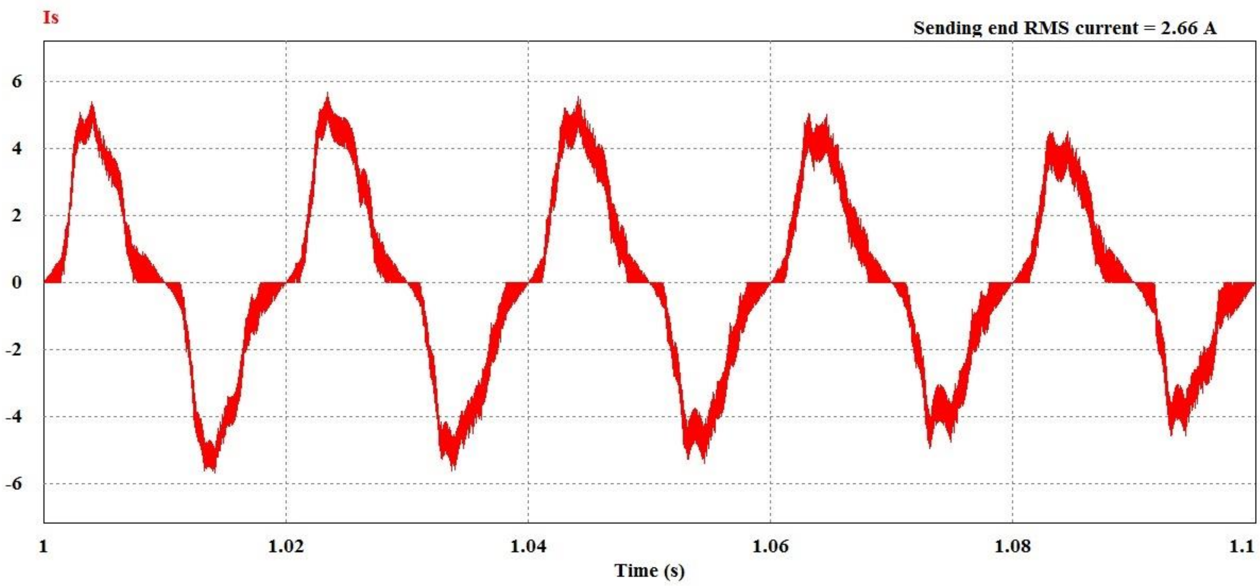
IV. Simulation of PFC boost converter when integrated with DC-DC converter

(a) Input Voltage waveform



(b) Input Current Waveform



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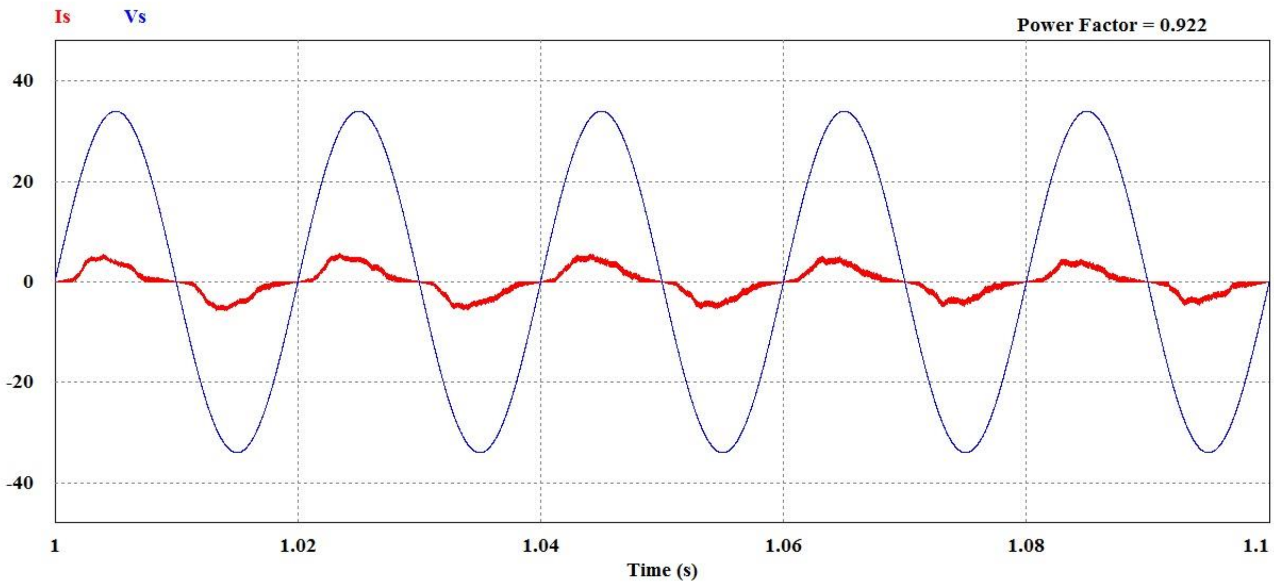
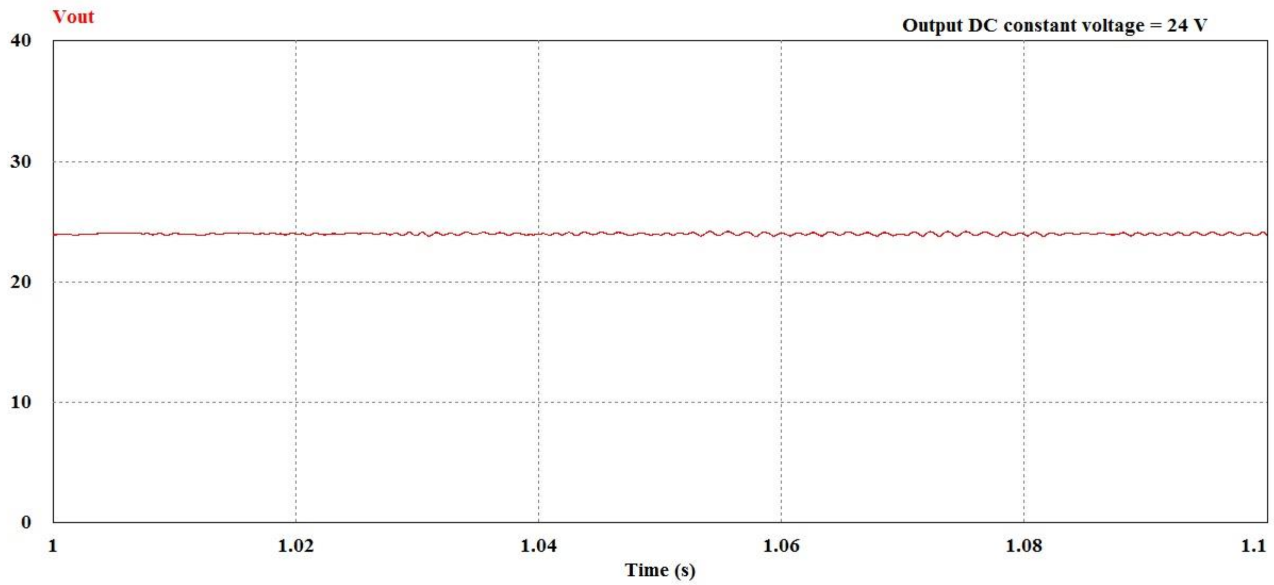
(c) Input Power Factor Waveform



(d) Output Voltage Waveform



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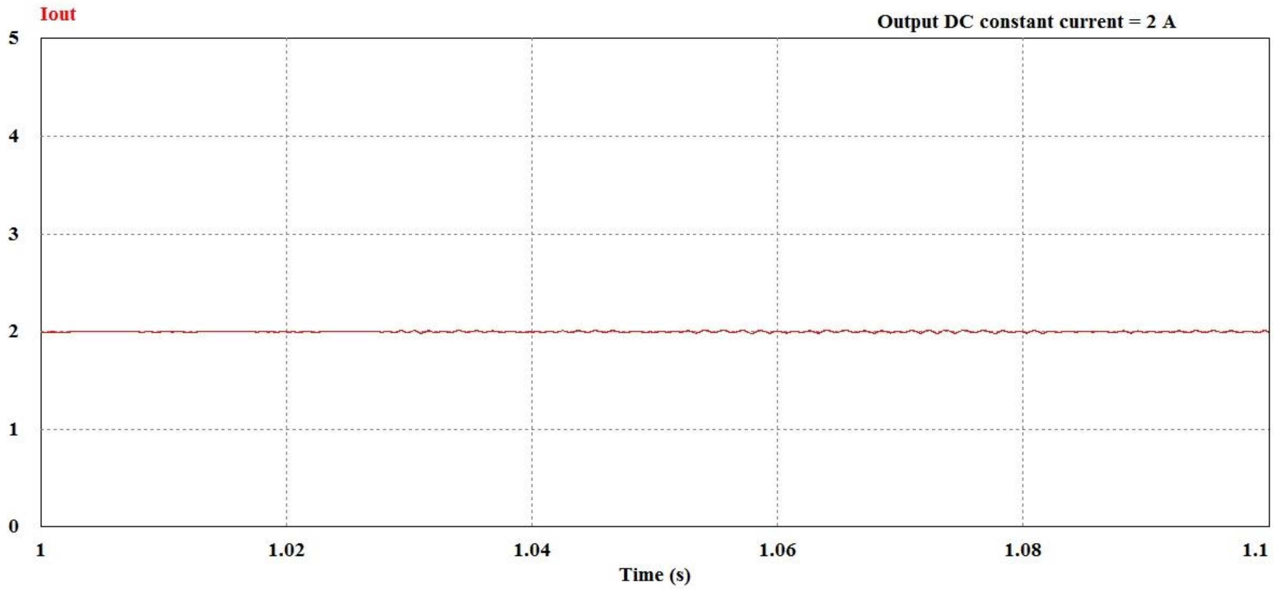
(e) Output Current Waveform



Conclusion – Input power factor is improved as well as Total Harmonic Distortion is decreased.

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