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Inherently Non-Pulsating Input Current DC-DC Converter for Battery Storage Systems

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Abstract: With an ever-growing number of batteries being integrated into the electric grid, bidirectional converters with non-pulsating dc input current are required to replace the existing bidirectional converters so as to extend the lifetime of such dc power suppliers. Bidirectional DC-DC converters are increasingly used in a variety of applications including uninterruptable power supplies, electric vehicles and renewable energy systems. In this study, we propose a new topology of bidirectional dc-dc converter with inherently no pulsating input current (NPIC), which is intended to be used for battery energy storage systems. With simple modifications from the conventional converters, the proposed NPIC converter has no inherent pulsating input current in the step-down (buck) mode. Whereas in the step-up (boost) mode; the proposed NPIC converter retains the desired voltage gain. Underpinning theories, operating principles and steady-state performances are analyzed and presented in detail, which are then corroborated by simulation and experimentation. The proposed converter topology, with simple design principle and ease for implementation, is likely to have wide-ranging applicability in interfacing electrochemically functioned dc sources to modern power systems.

I. INTRODUCTION

Multiple dc power sources must transfer energy to other dc energy storage systems in hybrid power systems that integrate renewable energy, hybrid vehicle energy systems, and uninterruptible power supply systems. This requires directional dc-dc converters. There are two types of isolated (transformer-integrated) and no isolated (without transformer) topologies for bidirectional dc-dc converters. Due to the fact that renewable energies are characterised by being clean, affordable, and abundant, numerous efforts have been made over the years to integrate them into the electrical system. A greater emphasis on sustainable transportation and a reliance on renewable energy sources have also increased interest in electric vehicles and the investments related to them, which are distinguished by their lower fuel consumption and greenhouse gas emissions. Despite the growth and development of electric vehicles, there are still significant drawbacks, such as their high cost, lengthy charging times, and complicated power converter chargers. The onboard Energy Storage Systems, such as batteries, ultra-capacitors, or fuel cells, that voltage discharges (steps down) during high power demands and voltage charges (steps up) during low power demands, play a significant role in the operation of electric vehicles. Energy Storage Systems must be able to store a significant amount of energy and release it quickly when needed. Bidirectional battery charger architectures, which need to be isolated and galvanised to ensure safety and protection, are gaining popularity. When there is a bidirectional power flow, there is not only a load that draws power from the grid via the battery charger, but also an electrical source that, when faced with high power demands, feeds back to the grid the energy stored in its battery while also supporting other standalone loads. In this study, we propose a new bidirectional dc-dc converter topology with inherently non-pulsating input current for battery energy storage systems. The proposed converter, which can be easily modified from the conventional converters, does not naturally have pulsating input current in either the step-down (buck) mode or the step-up (boost) mode. A step-down mode and a step-up mode make up the proposed bidirectional converter's two stages. The dc voltage is increased before being converted into ac voltage and connected to the grid by DC/DC converters, also known as power optimizers.

In this research, we suggest a new bidirectional dc-dc converter topology with inherently The bidirectional dc-dc converter we propose in this study has an inherently non-pulsating input current and is designed to be used in battery energy storage systems. The proposed converter has no inherent pulsating input current in the step-down (buck) mode and step-up (boost) mode with only minor modifications from the conventional converters. On the other hand, the use of solar energy via Photovoltaic Panels (PV) in the production of electricity is growing and gaining much popularity. Consequently, PV is essential to battery energy storage systems because it can be used as a source of assisted DC charging.

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As environmental factors like temperature and irradiance are not constant, PV must always operate under Maximum Power Point Tracking (MPPT) in order to always extract the maximum power. Because solar energy through PV plays a significant role in the production of electricity because a bidirectional charging system is required to acquire a vehicle-to-grid technology home-to-grid.
The remaining sections of the essay are structured as follows. Section II goes into detail about the buck and boost modes' structure and operating principle. The results of simulations and experiments are presented in Sections III and IV, respectively. In Section V, a conclusion is reached.

II. SYSTEM CONFIGURATION

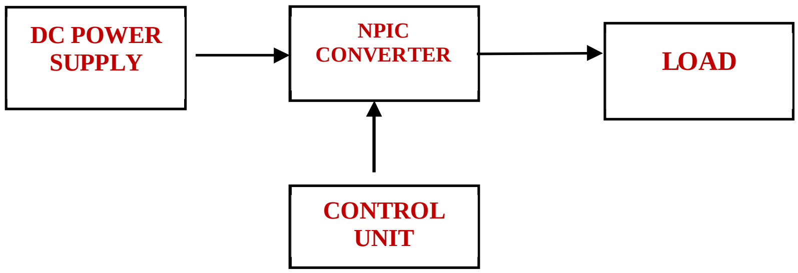


Fig. 1. Block diagram of the system

The above block diagram shows that the system consists of two main sections namely the non-pulsating input current converter part and the control unit part. The DC power supply act as both load (output) and voltage source (input). The DC power supply act as an input voltage source during the step-down mode (buck mode). The DC power supply act as a load (output) during step-up mode (boost mode).
The load side acts as both the input voltage source (input) and load (output). The load side acts as an input voltage source (input) during step-up (boost mode). The load side acts as a load (output) during step-down mode (buck mode).

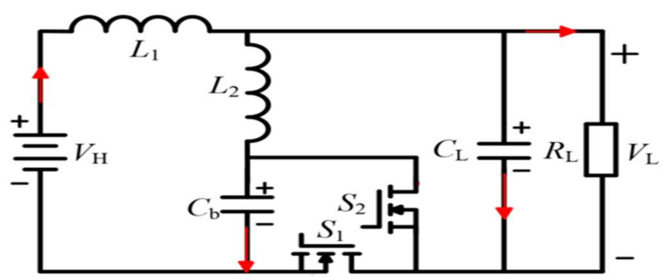


Fig. 2. Schematic diagram of the system

The proposed converter's configuration is shown in the above figure. It primarily consists of two inductors, L_1 and L_2, two capacitors, $C_b$and,C_L and two switches, S_1 and S_2. The following is a discussion of the proposed converter in step-up and step-down modes. It is important to note that the proposed converter’s feature is aided by the fact that inductor $L_1$is connected in series with the input source.

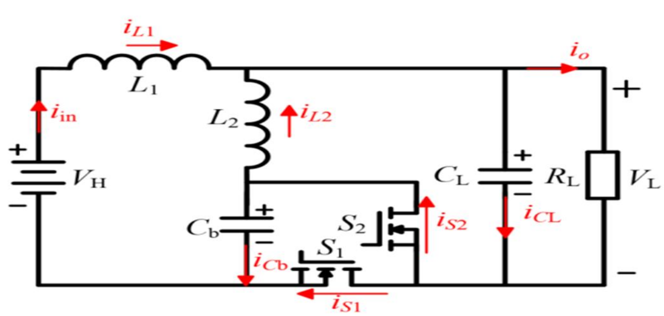


Fig. 3. Equivalent circuits in step-down mode

The proposed converter in step-down mode is shown in Fig.3.3. SwitchS_1 is turned and switch $S_2$is off. Two modes of operation in the step-down mode of the proposed converter.

MODE 1: As shown in Figure 3.4. switchS_1 is turned ON and switch S_2 is turned OFFThe input voltage source $V_H$delivers energy to inductor L_1 and the load. Therefore, induct or L_1 starts to store energy from the voltage source, and accordingly the current flowing through inductor L_1 (iL_1) increases.

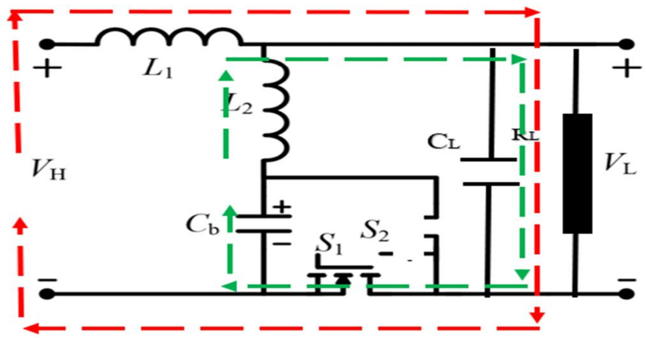


Fig .4. Equivalent circuits in step-down mode: mode 1

At the same time, energy stored in the capacitor C_b is simultaneously released to inductor L_2 and the load. In turn, the current flowing through inductor L_2 ($i\,L_2$) begins to rise.

MODE 2: As shown in Fig. 3.5.In this mode, switchS_1 is turned OFF and switch S_2 is turned ON.During this mode, energy stored in inductor L_1 and the input power source $V_H$is delivered to the load and resonant capacitor C_b. Hence, the current flowing through inductor L_1decreases. In this moment, as energy is released to the load by inductor L_1, the current through it keeps decreasing.

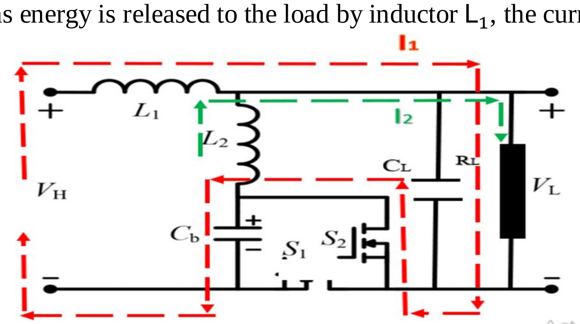


Fig .5. Equivalent circuits in step-down mode: mode 2

The proposed converter in step-up mode is shown in Fig.3.6. Two modes of operation in the step-down mode of the proposed converter. In this mode the source side of the proposed converter no pulsating input current converter) act as a load (V_H) and the load side of the converter act as a voltage source (V_L). There by it is shows that the bidirectionality of the proposed converter.

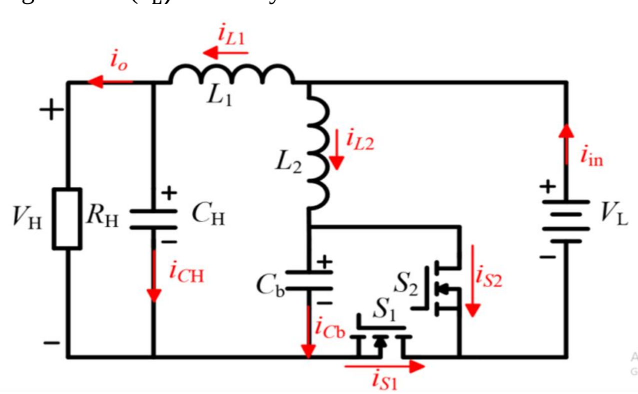


Fig .6. The proposed converter in step-up mode

MODE 1: As shown in Figure 3.7.In this mode, switchS_1 is turned ON and switch S_2 is turned OFF.The input voltage source V_L and L_1. inductorL_1supplypower to the load. Accordingly, the current flowing through inductor L_1 (iL_1) decreases. At the same time inductor L_2 and capacitor C_b release energy to the load. Correspondingly the current flowing through inductor L_2 ($i L_2$) andresonant capacitor C_b (iC_b) stars to decrease.

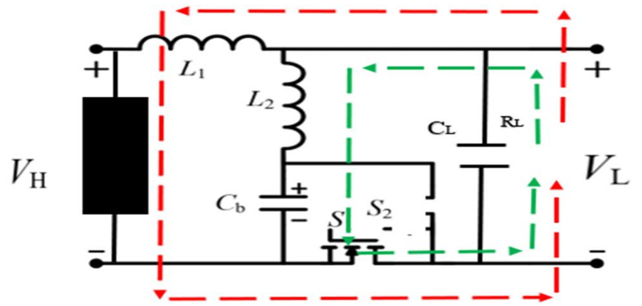


Fig.7. Equivalent circuits in step-up mode: mode 1

Mode 2: As shown in Fig3. 8.In this mode, switchS_1 is turned OFF and switch S_2 is turned ON. The input voltage source V_L and L_1. InductorL_2supply power to the load. Accordingly, the current flowing through inductor L_2(iL_2) decreases. At the same time inductor L_1 and capacitor C_b release energy to the load. Correspondingly the current flowing through inductor L_1 ($i L_1$) and resonant capacitor C_b (iC_b) stars to decrease.

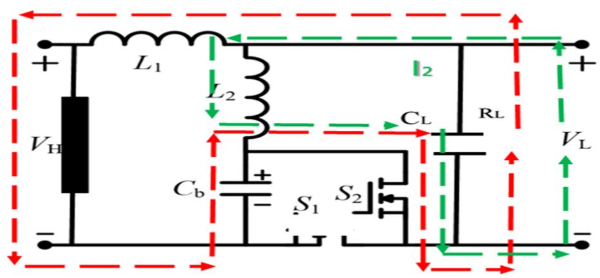


Fig .8. Equivalent circuits in step-up mode: mode

III. PERFORMANCE ANALYSIS OF THE SYSTEM

In order to test the steady-state and the dynamic performance of the proposed power electronics converter for in this section. proposed converter module is implemented on MATLAB/SIMULINK using the Sim Power block set to illustrate the real model of the converters. The control parameters used along with their numerical values are listed in Table 4.1 below: Step-down mode (buck mode) and step-up mode (boost mode) of Simulationparameters are including in this table.

SL.NO	COMPONENTS	PARAMETER	
		STEP-DOWN	STEP-UP
1	Switching frequency (f_s)	30kHz	30kHz
2	Duty cycle (D)	0.5	0.5
3	Input Voltage (V_H/V_L)	24V	12V
4	Load (R)	100Ω	100Ω
5	Inductors (L_1 and L_2)	2.6mH	2.6mH
6	Output capacitor (C_L / C_H)	4700µF/35V	4700µF/35V
7	Resonant Capacitor (C_b)	10µF/100V	10µF/100V

TABLE .1. Simulation Parameters

The parameters of interest on each operation mode (step-down and step-up) are the input DC voltage, twooutput capacitors, resonant capacitorsand output voltage. The proposed converter circuit always deliver bidirectionally the voltage flow.Step-down mode (buck mode) and step-up mode (boost mode) of Simulation results for the proposed converter. Step-down mode and step-mode simulation results are demonstrated in Fig. 4. and 5.

The simulation diagram of the modified proposed non pulsating input current converter is shown in fig 4..The simulation is carried out in the discrete powergui. The simulation is carried out in the SIMULINK/MATLAB. After compiling and running the simulation diagram we obtain the output waveform in the scope. The current id drawn from the input, which is lower value of current in step-up mode when compared to step-down mode. The current in step –up and step-down modes results are illustrated below fig.2 and 3.

In Step-down mode we are applying Switching frequency 30kHz, Duty cycle 0.5, Input Voltage V_H = 24V, Load 100Ω and Inductors (L1 and L2) 2.6mH.There by we are to get the output of the converter is step-down voltage of 12 V.

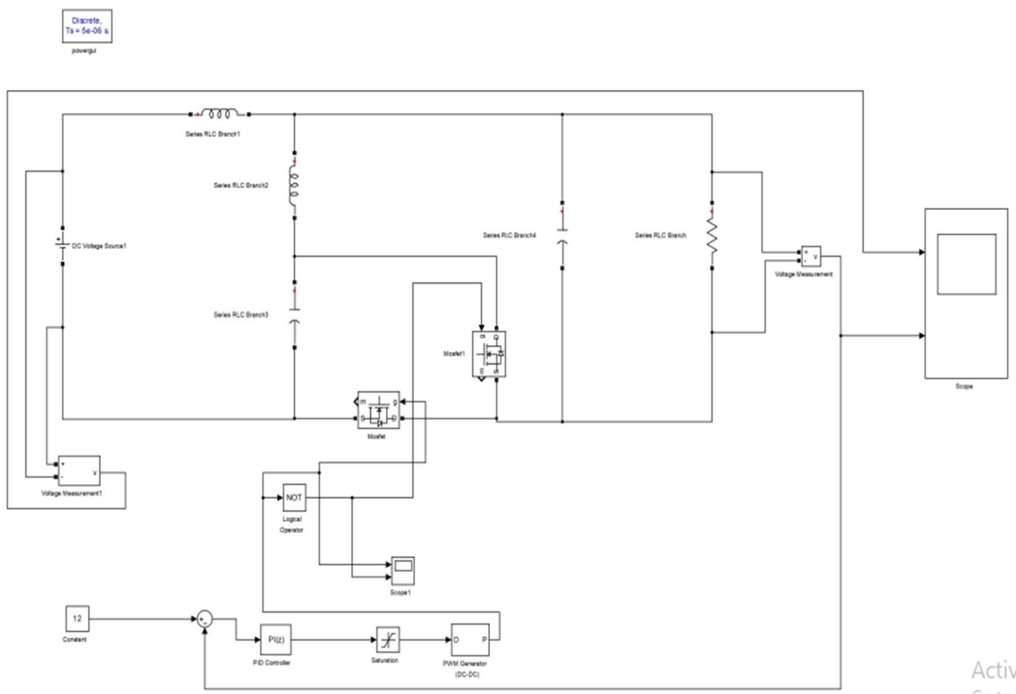
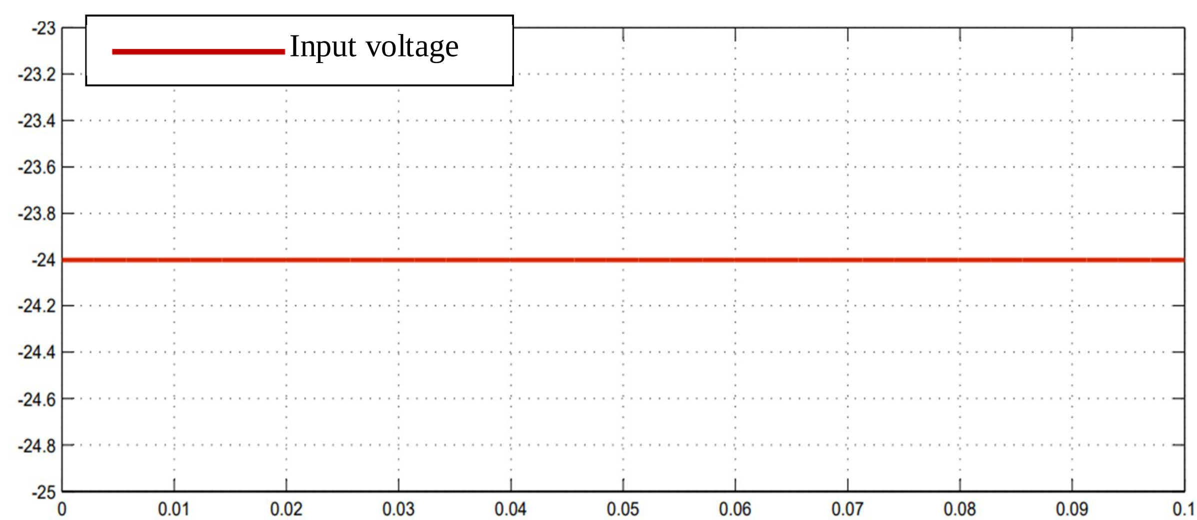
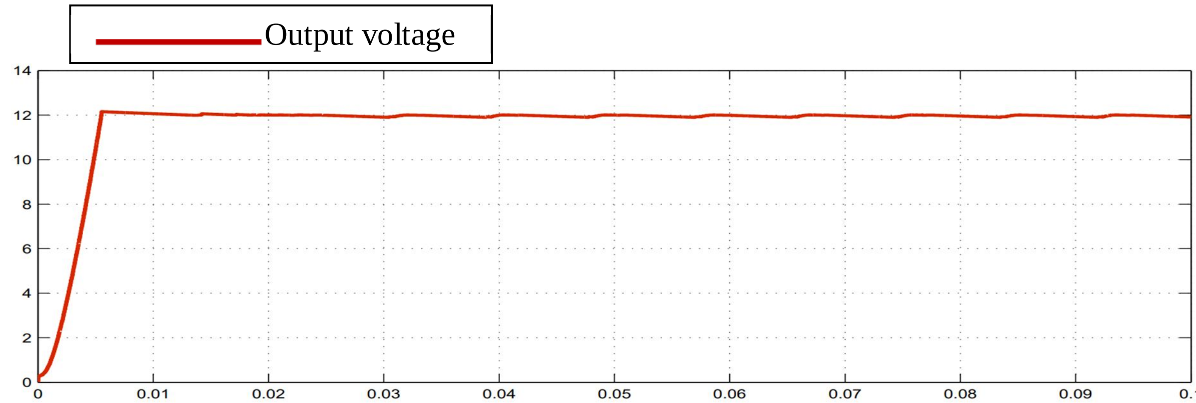


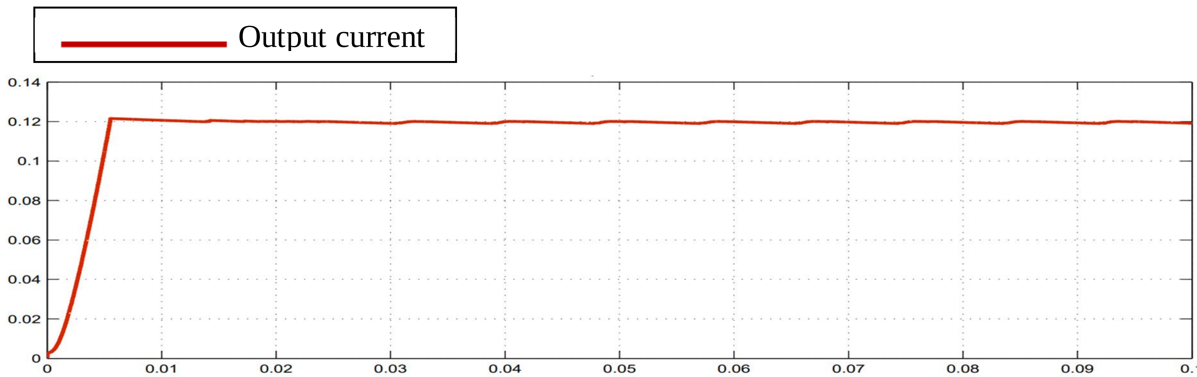
Fig.9. Simulation results for the proposed converter Step-down mode model



(a)



(b)



(c)

Fig .10. Simulation results for proposed non pulsating input current converter in Step-down mode (a) input voltage (b) output voltage (c) output current

The simulation diagram of the modified proposed non pulsating input current converter is shown in fig 4.1.The simulation is carried out in the discrete powergui. The simulation is carried out in the SIMULINK/MATLAB. After compiling and running the simulation diagram we obtain the output waveform in the scope. The current id drawn from the input, which is lower value of current in step-up mode when compared to step-down mode. In Step-up mode we are applying Switching frequency 30kHz, Duty cycle 0.5, Input Voltage V_H = 12V, Load 100Ω and Inductors (L1 and L2) 2.6mH. There by we are to get the output of the converter is step-down voltage of 24 V. the step-up simulation results are demonstrated in Fig.4.3 and 4.4.the converter is working bidirectional.

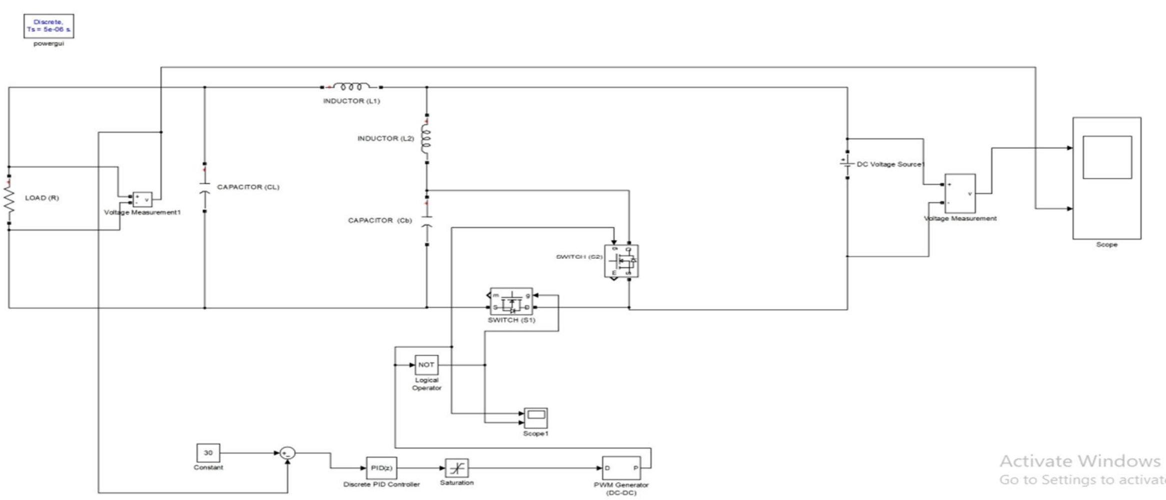


Fig 11. Simulation results for the proposed converter in Step-up mode model

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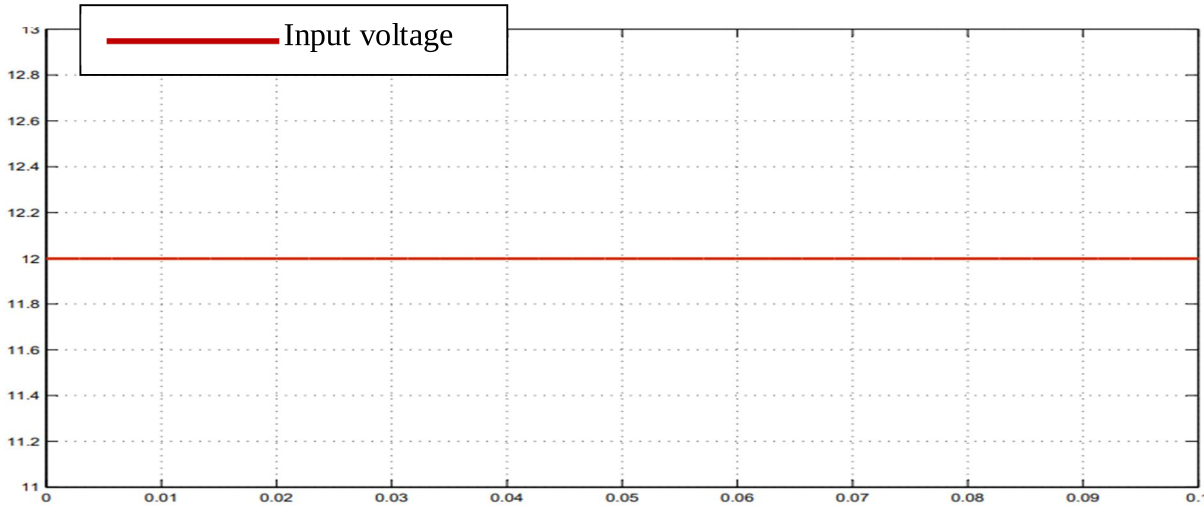
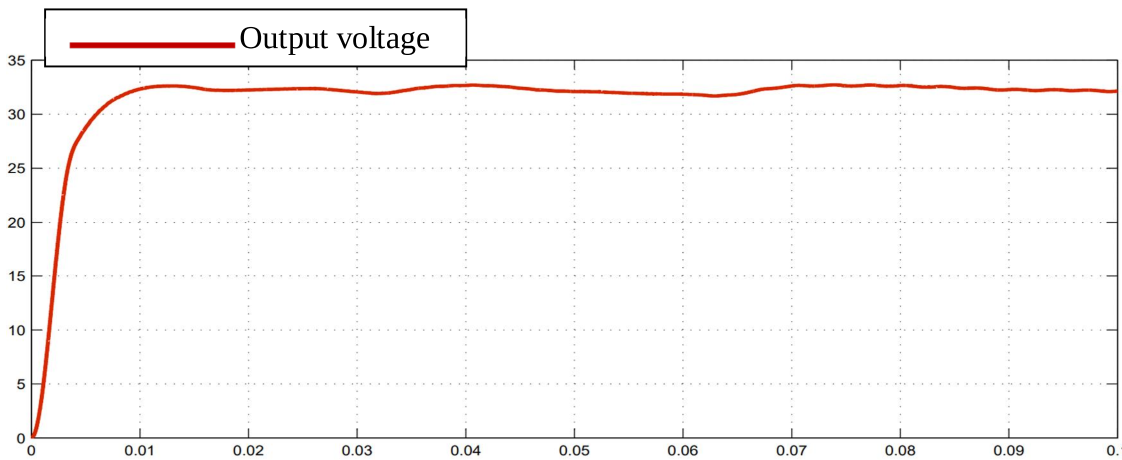


(a)



(c)

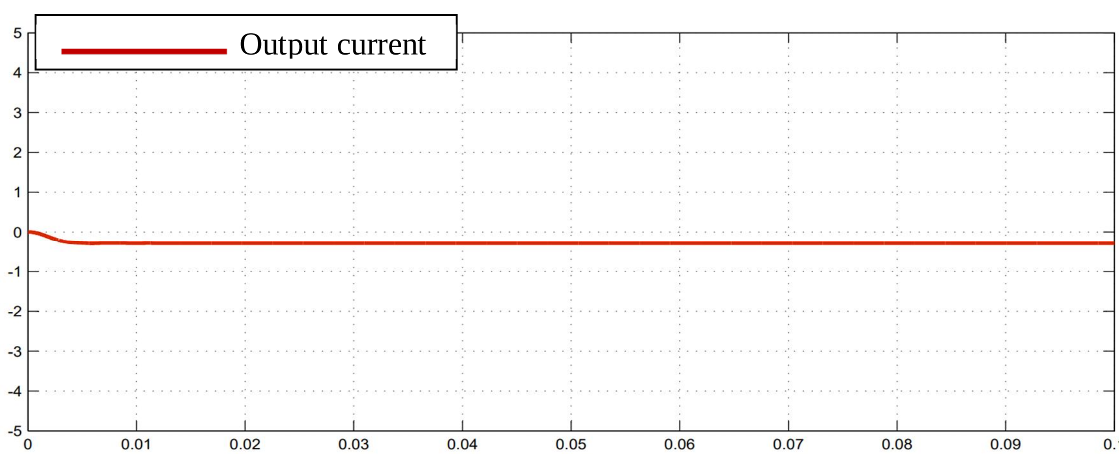


Fig .12. Simulation results for proposed non pulsating input current converter in Step-up mode (a) input voltage (b) output voltage (c) output current

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IV. DESIGN OF THE SYSTEM

This section discusses the design of proposed non pulsating input current converter. The rating and specifications of components used for design is illustrated in below table 4.1.Permitted ripple current in inductor $L_1(\Delta iL_1) = 30\%$of input current and inductor $\Delta iL_2 = 30\%$ of current. Permitted ripple voltage in load side capacitor $C_L(\Delta V_{CL})$ = 1% of the DC voltage.

SL.NO:	PARAMETER	SPECIFICATION
1	Input voltage	$V_H = 24V$
2	Output voltage	$V_L = 12V$
3	Output power,	$P_O = 6W$
5	Efficiency	90%

Table .2.design parameters

A. Duty ratio

$$D = \frac{V_L}{V_H}$$

$$D = \frac{12}{24} = \frac{1}{2} = 0.5$$

B. Inductor (L_1)

$$\Delta iL_1 = \frac{V_H - V_L}{L_1} DT_S$$

- $T_S = \frac{1}{f_S} = \frac{1}{30000} = 3.3333 \times 10^{-5}$
- $\Delta iL_1 = DI_0 \times 0.3 = 0.5 \times 0.5 \times 0.3$=0.075
- $I_0 = \frac{P_0}{V_0} = \frac{6}{12} = \frac{1}{2} = 0.5$
- $\Delta iL_1 = \frac{V_H - V_L}{L_1} DT_S$

$$L_1 = \frac{V_H - V_L}{\Delta iL_1} DT_S = \frac{24 - 12}{0.075} \times 0.5 \times 3.3333 \times 10^{-5} = 2.6666 \times 10^{-3}$$

=2.6mH

C. Inductor (L_2)

$$\Delta iL_2 = \frac{V_H - V_L}{L_2} DT_S$$

- $T_S = \frac{1}{F_S} = \frac{1}{30000} = 3.3333 \times 10^{-5}$
- $\Delta iL_2 = (1 - D)I_0 \times 0.3 = (1 - 0.5) \times 0.5 \times 0.3$=0.075
- $I_0 = \frac{P_0}{V_0} = \frac{6}{12} = \frac{1}{2} = 0.5$
- $\Delta iL_2 = \frac{V_H - V_L}{L_1} DT_S$

$$L_2 = \frac{V_H - V_L}{\Delta i L_1} DT_S = \frac{24-12}{0.075} \times 0.5 \times 3.3333 \times 10^{-5}$$

$$= 2.6666 \times 10^{-3}$$
$$= 2.6\text{mH}$$

D. Capacitor (C_L)

- $V_{CL} - rip = \frac{V_L (V_H - V_L)}{8L_e C_L V_H f_S^{\,2}}$

$$C_L = \frac{V_L (V_H - V_L)}{8L_e V_H f_S^{\,2} (V_{CL} - rip)} = \frac{V_L (V_H - V_L)}{8L_e V_H f_S^{\,2} (\Delta V_{CL})}$$

- $L_e = L_1 // L_2$

$$L_e = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2}} = \frac{1}{\frac{1}{2.6\times10^{-3}} + \frac{1}{2.6\times10^{-3}}} = \frac{1}{769.2306} = 1300\mu\text{H}$$

- $V_{CL} = 12V$

$\Delta V_{CL} = 12 \times 0.01 = 0.12$

- $C_L = \frac{V_L(V_H - V_L)}{8L_e V_H f_S^{\,2} (\Delta V_{CL})} = \frac{12\ (24-12)}{8\times1300\times10^{-6}\times24\times(300000)^2\times0.12}$

$$= 5.34188 \times 10^{-6} \cong 10\mu\text{F}$$

E. Capacitor (C_b)

- Resonant capacitor

$$C_b = \frac{1}{4\pi^2 L f_{R^2}} = \frac{1}{4\pi^2 \times 2.6\times10^{-3} (30000)^2} \cong 10\mu\text{F}$$

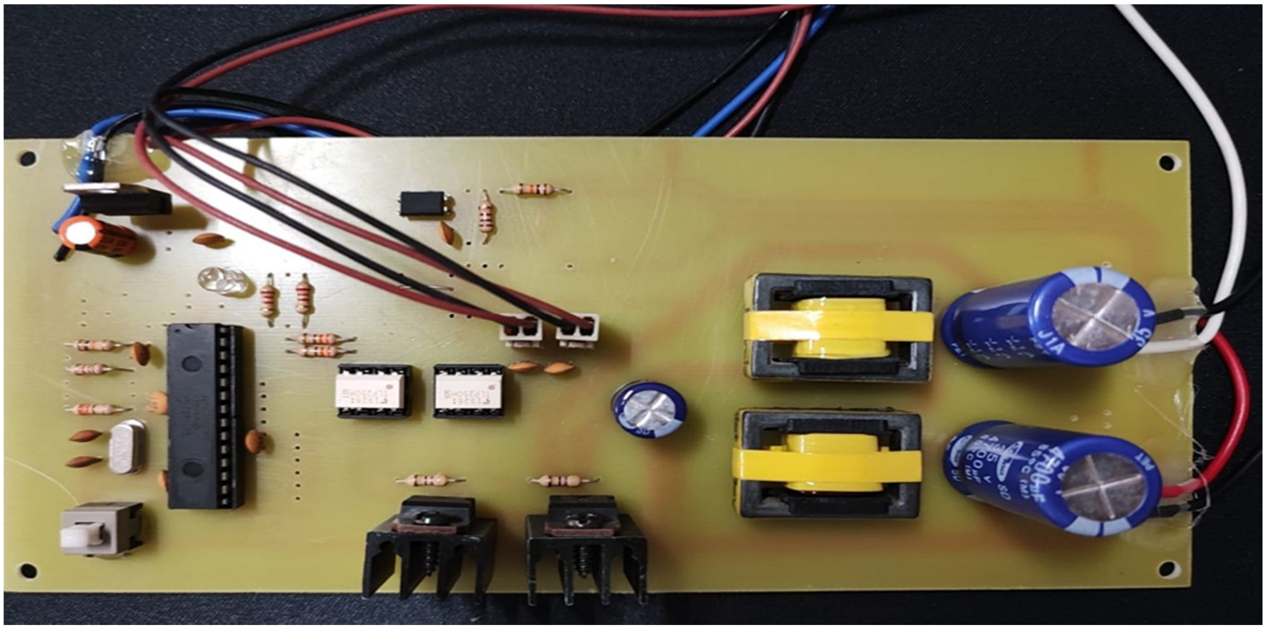

Fig.13. hardware setup

SL.NO	COMPONENTS	PARAMETER	
		STEP-DOWN	STEP-UP
1	Switching frequency (f_s)	30kHz	30kHz
2	Duty cycle (D)	0.5	0.5
3	Input Voltage (VH/VL)	24V	12V
4	Load (R)	100Ω	100Ω
5	Inductors (L1 and L2)	2.6mH	2.6mH
6	Output capacitor (CL / CH)	4700µF/35V	4700µF/35V
7	Capacitor (Cb)	10µF/100V	10µF/100V
8	Filter capacitor	22 µF	22 µF
8	Driving IC	TPL250	TPL250
9	MOSFET (S1, S2)	P55	P55
10	Voltage sensor	VS14	VS14
11	Crystal oscillator	8MHz	8MHz

TABLE.3. Experimental Parameters

V. CONCLUSION

In this study, a unique bidirectional dc-dc converter has been proposed that operates in step-down mode without any inherent pulsing input current. The converter that is being designed has less active and passive parts. And in step-down mode, the proposed converter's input current is greater than zero. Can maintain the desired voltage gain in step-up mode. The efficiency of the suggested converter gradually improves as output power increases. As can be observed, the examined efficiency ranges between 90 and 91.5% in step-up mode and 91 to 94 percent in step-down mode. Applications like battery storage systems, which need constant input current, are a good fit for this converter.

The proposed NPIC converter overcomes the drawbacks of conventional converters and can better preserve the lifespan of electrochemically functioned dc sources like batteries and fuel cells by producing a continuous non-pulsating input current in the step-down mode as opposed to traditional boost/buck bidirectional converters whose input current is inherently intermittent or pulsating.

The suggested NPIC converter topology's functionality and distinguishing characteristics have been confirmed by first providing a thorough demonstration of the operating principle and steady-state performance of the proposed NPIC current. The suggested converter's minimal output voltage ripples, high efficiency, and capacity to maintain the necessary voltage gain in the step-up mode have all been demonstrated in this study.

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