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# A Novel Approach of Buck/Boost Converter and its Certain Analysis

[1*]Jaffer Mohammed, [2*]G. Ravikiran, [3*]Md. Sajid, [4*]Kotha. Ramakrishna
Department of Electrical & Electronics Engineering,
Osmania University
Muffakhamjah College of Engineering and Technology[*]

***Abstract*— A new Buck/boost converter is prescribed in this paper. The proposed converter is easy to control. An inductor is used in this proposed converter with the same number of winding turns on both sides. In step-up mode, the two side windings of the coupled inductor are operated in parallel charging and series discharging. By this technic we can achieve high step-up voltage gain. In step-down mode, the both windings of the coupled inductor are operated in series charging as well as parallel discharging to achieve high step-down voltage gain. The proposed converter has higher step-up as well as down voltage gains than the conventional buck/boost converter. The rated voltage of the proposed converter is lower than the conventional converter. The operating principle and certain analysis are discussed in detail in MATLAB/SIMULINK.**

***Index Terms*—buck/boost converter, coupled inductor.**

## I. INTRODUCTION

To transfer the power between two dc sources in bi-directional way the buck/boost converters are used. These converters are widely used in applications, such as, uninterrupted power supplies [5], [6],photo voltaic hybrid power systems [11],[12], and battery chargers [13]–[15].The bidirectional dc–dc fly-back converters are more attractive due to simple structure and easy control [2],[16], [17]. But these converters suffer from high voltage stresses on the power devices due to the leakage inductor energy of the transformer. In order to reproduce the leakage inductor energy and to minimize the voltage stress on the power devices, Some literatures research the isolated buck/boost converters, which include the half-bridge [21] and full-bridge types [13], [22]. These converters can provide high step-up and step-down voltage gain by adjusting the primary and secondary turns of the transformer. The non-isolated buck/boost converters, which include the conventional buck/ boost multilevel [4], three-level [10], sepic/zeta [25], switched capacitor [24], and coupled inductor types [25], are presented. The multilevel type is a magnetic less converter uses less number of switches . In case of higher step-up/down voltage gains are required, more switches are needed. This control circuit becomes more complicated. In the three-level type, the voltage stress across the switches on the three-level type is average of the conventional type. However, the step-up/down voltage gains are low. Since the sepic/zeta type is combined of two power stages, the conversion efficiency will be reduced. The switched capacitor & coupled inductor types can provide high step-up/down voltage gains, but their circuit configurations are complicated. Fig. 1 shows the conventional bidirectional dc–dc boost/buck converter which is simple structure and easy control. the step-up/down voltage gains are low for this converter.

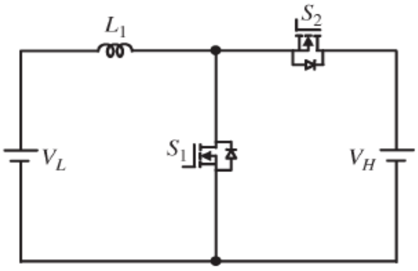



Fig. 1. Conventional bidirectional dc–dc boost/buck converter.

A modified dc–dc boost converter is presented [26]. The voltage gain of this converter is higher than the conventional dc–dc boost converter. Based on this converter, a new buck/boost converter is proposed, as shown in Fig. 4. The proposed converter employs a coupled inductor with same winding turns in the primary and secondary sides.



## II. CONVENTIONAL BUCK/BOOST CONVERTER.

Steady-state analysis of conventional buck/boost converter can be examined in both the step-up/down modes. For the conventional converter, the equivalent circuits in step-up mode are shown in fig.2. $r_{l1}$ represents the ESR of the inductor. $r_{s1}$ and $r_{s2}$ denote ON-state resistance of S1 and S2.

According to this method, the efficiency is derived as follows:

$$\eta = \frac{P_o}{P_{in}} = \frac{(1-D)^2 R_H}{(1-D)^2 R_H + D(r_{L1} + r_{S1}) + (1-D)(r_{L2} + r_{S2})}$$

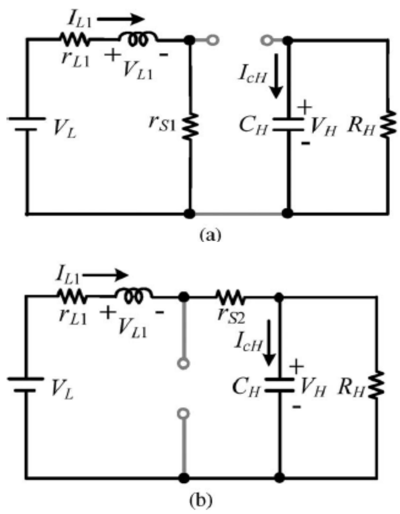
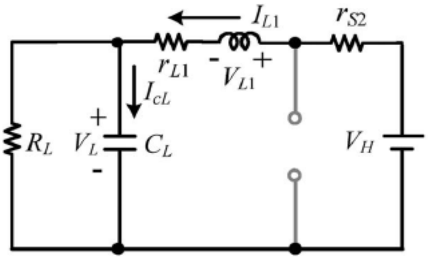
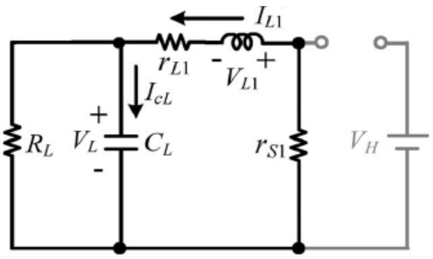



Fig. 2 Equivalent circuit of the conventional converter in step-up mode.
(a) *S*1 ON and *S*2 OFF. (b) *S*1 OFF and *S*2 ON.

For the conventional converter, the equivalent circuits in step down mode are shown in Fig. 3.



(a)



(b)

Fig. 3. Equivalent circuit of the conventional converter in step-down mode.
(a) $S2$ ON and $S1$ OFF. (b) $S2$ OFF and $S1$ ON.

According to this method, the efficiency is calculated as follows:

$$\eta = \frac{P_o}{P_{in}} = \frac{R_L}{R_L + D(r_{L1} + r_{S2}) + (1 - D)(r_{L1} + r_{S1})}$$

De-merits of conventional converter:

1. Circuit configurations are complicated. 2. The step-up/down voltage gains are low.

To overcome the above disadvantages now considering the new proposed buck/boost converter. Comparing to the proposed converter and the conventional bidirectional buck/boost converter, the proposed converter has the following advantages: 1) Higher step-up /down voltage gains and 2) Lower average value of the switch current under same electric specifications.

## III. PROPOSED BIDIRECTIONAL DC–DC CONVERTER.

The working principles and steady state analysis for proposed converter is given below. For the analysis of steady –state characteristics of this converter we have to ignore the ON-state resistance of the switches and the equivalent series resistance of the capacitor & coupled inductor.

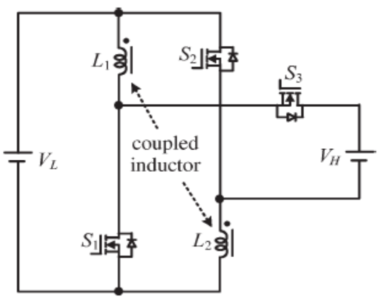
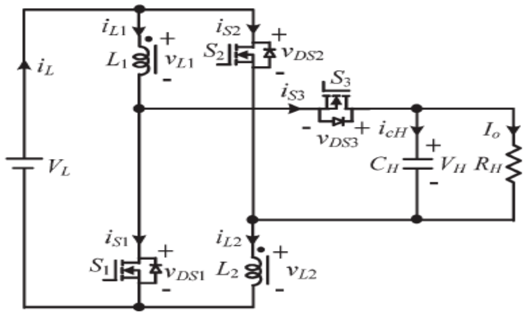



Fig 4: Proposed bidirectional dc–dc converter.

There are two modes of operation of the proposed converter. They are A) STEP_UP MODE and B) STEP_DOWN MODE

### A. STEP-UP MODE:

In order to control the switches $S_1$ and $S_2$ simultaneously the pulse-width modulation is used and the switch $S_3$ is synchronous rectifier. Since the secondary and primary winding turns of the coupled inductor is same.



Proposed converter in step-up mode.

The inductance of the coupled inductor in the secondary and primary sides are expressed as

$$L_1 = L_2 = L \dots\dots\dots(1)$$

Thus, the mutual inductance $M$ of the coupled inductor is given by

$$M = k\sqrt{L_1 L_2} = kL \dots\dots\dots(2)$$

Where $k$ is the coupling coefficient of the coupled inductor. The voltages across the primary and secondary windings of the Coupled inductor are as follows:

$$v_{L1} = L_1\frac{di_{L1}}{dt} + M\frac{di_{L2}}{dt} = L\frac{di_{L1}}{dt} + kL\frac{di_{L2}}{dt} \dots\dots\dots(3)$$

$$v_{L2} = M\frac{di_{L1}}{dt} + L_2\frac{di_{L2}}{dt} = kL\frac{di_{L1}}{dt} + L\frac{di_{L2}}{dt} \dots\dots\dots(4)$$

The operating principles and steady-state analysis of the step-up modes discussed in continuos and discontinuous modes as follows:

1. Continuos Conduction Mode Operation (CCM):

i. Mode 1 [$t_o \le t \le t_1$] **:** During this time interval [$t0$, $t1$], $S1$ and $S2$ are turned on and $S3$ is turned off. The energy is transferred to the coupled inductor from the low voltage side $V_L$ where the primary and secondary windings of the coupled inductor are in parallel. The energy stored in the capacitor $C_H$ is discharged to the load. The current flow path is as shown in fig.5 (a).The voltages across $L_1$ and $L_2$ are

$$v_{L1} = v_{L2} = V_L \dots\dots\dots(5)$$

Now substituting the (3) & (4) in (5), we get

$$\frac{di_{L1}(t)}{dt} = \frac{di_{L2}(t)}{dt} = \frac{V_L}{(1+k)L} \quad ,t_0 \le t \le t_1 \dots\dots\dots(6)$$

ii. Mode 2 [t1 ≤ t ≤ t2]:

During this time interval [$t1$, $t2$], $S1$ and $S2$ are turned off and $S3$ is turned on. The energy is transferred to the capacitor $CH$ and the load from the low-voltage side $VL$ and the coupled inductor which are in series as shown in fig.5(b)

Thus, the following equations are found to be

$$i_{L1} = i_{L2} \dots\dots\dots(7)$$

$$v_{L1} + v_{L2} = V_L - V_H \dots\dots\dots(8)$$

Now substituting the (3) , (4) & (7) in (8), we get

$$\frac{di_{L1}(t)}{dt} = \frac{di_{L2}(t)}{dt} = \frac{V_L - V_H}{2(1+k)L} \quad ,t_1 \le t \le t_2 \ldots\ldots\ldots(9)$$

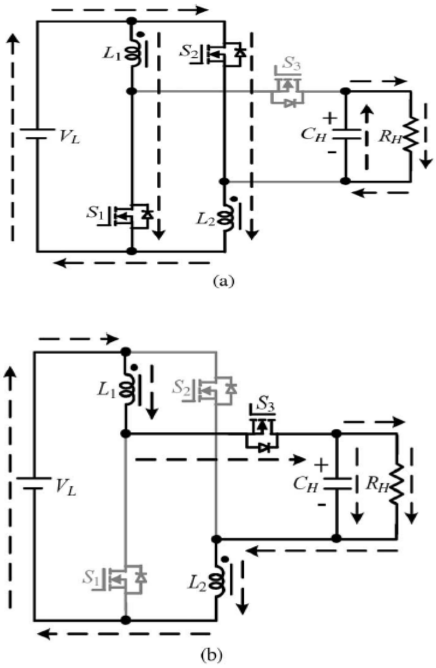



Fig. 5 Current flow path of the proposed converter in step-up mode.(a) Mode (b) Mode 2.

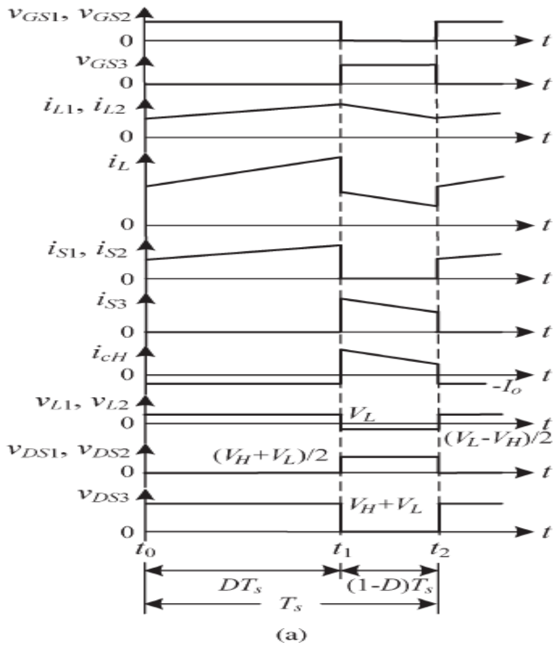
2. Discontinuous Conduction Mode Operation (DCM):

i. Mode 1 [$t_o \le t \le t_1$] : During this time interval [$t0$, $t1$], $S1$ and $S2$ are turned on and $S3$ is turned off. The operating principle is same as that for the mode 1 of CCM operation. The current flow path is shown in fig.5(a). The two peak currents through the primary and secondary windings of the coupled inductor are given by

$$I_{L1p} = I_{L2p} = \frac{V_L D T_S}{(1+k)L} \ldots\ldots\ldots(10)$$

ii. Mode 2 [t1 ≤ t ≤ t2] : During this time interval [$t1$, $t2$], $S1$ and $S2$ are turned off and $S3$ is turned on. The energy is transferred to the capacitor $CH$ and the load from the low-voltage side VL and the coupled inductor which are in series as shown in fig.5(b) The currents iL1 and iL2 through the primary and secondary windings of the coupled inductor are decreased to zero at t = t2. Another expression of IL1p and IL2p is given by

$$I_{L1p} = I_{L2p} = \frac{(V_H - V_L)D_2 T_S}{2(1+k)L} \ldots\ldots\ldots(11)$$




Some typical waveforms of the proposed converter in step-up mode CCM operation.

iii. Mode 3 [t2≤ t ≤ t3] :

During this time interval [$t2$, $t3$], $S1$ and $S2$ are still turned off and $S3$ is still turned on. The energy stored in the coupled inductor is zero. Thus, iL1 and iL2 are equal to zero. The energy stored in the capacitor $C_H$ is decayed to the load.

From (9) &(10),$D_2$ is

$$D_2 = \frac{2DV_L}{V_H - V_L} \ldots\ldots\ldots(12)$$

The current flow path is shown in Fig.5(c)

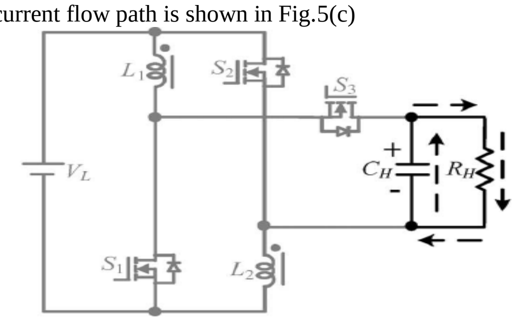
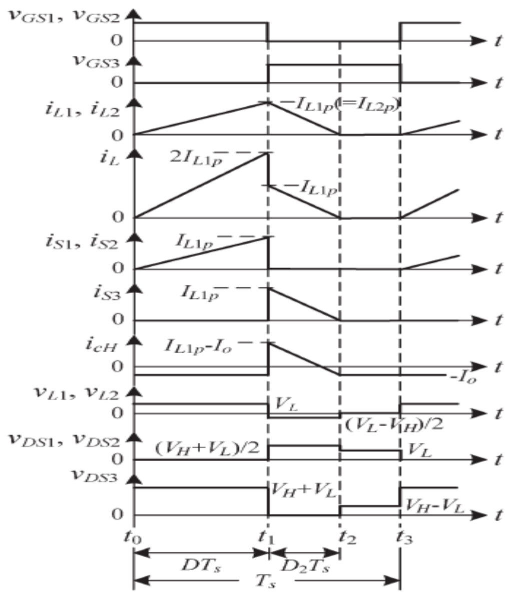



Fig. 5(c) Current flow path of the proposed converter in step-up mode in mode 3.

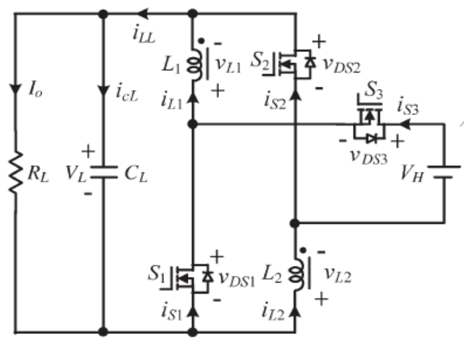


(b)

Some typical waveforms of the proposed converter in step-up mode DCM operation.

B.STEP-DOWN MODE:

In step down mode the PWM technique is used to control the switch $S_3$.The switches $S_1$ and $S_2$ are the synchronous rectifiers. The step-down mode of the proposed converter as shown in fig.



Proposed converter in step-down mode.

The operating principle and steady-state analysis of continuous and discontinuous conduction modes are discussed below:

1. Continuous Conduction Mode Operation (CCM):

i. Mode 1[$t_o \le t \le t_1$]: During this time interval [$t0$, $t1$], $S_3$ is turned on and $S_1/S_2$ are turned off. The energy is transferred to the coupled inductor, the capacitor, the load from the high voltage side $V_H$ where the primary and secondary windings of the coupled inductor are in series. Hence the following equations are obtained as:

$$i_{L1} = i_{L2} \ldots\ldots\ldots (13)$$

$$v_{L1} + v_{L2} = V_H - V_L \ldots\ldots\ldots (14)$$

Now substituting the (3) , (4) & (13) in (14) we get

$$\frac{di_{L1}(t)}{dt} = \frac{di_{L2}(t)}{dt} = \frac{V_H - V_L}{2(1+k)L} \;, t_0 \le t \le t_1 \ldots\ldots\ldots (15)$$

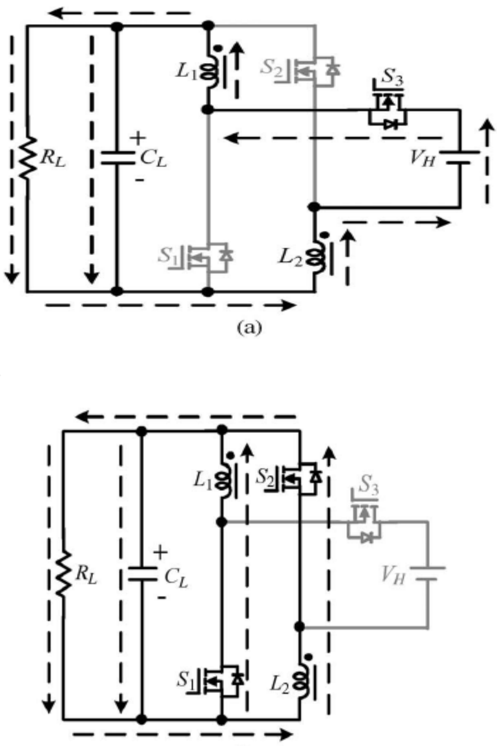
ii. Mode 2[$t_1 \le t \le t_2$]:

During this time interval [$t1$, $t2$], $S_3$ is turned off and $S_1/S_2$ are turned on. The energy is decrease through capacitor $C_L$ and the load which is stored in the coupled inductor where the primary and secondary windings of the coupled inductor are in parallel. Hence the voltage across the inductors $L_1$ and $L_2$ are obtained as:

$$v_{L1} = v_{L2} = -V_L \ldots\ldots\ldots (16)$$

Now substituting the (3) , (4) in (16) we get

$$\frac{di_{L1}(t)}{dt} = \frac{di_{L2}(t)}{dt} = -\frac{V_L}{(1+k)L} \;, t_1 \le t \le t_2 \ldots\ldots\ldots (17)$$



(a)

(b)

Fig. 6. Current flow path of the proposed converter in step-down mode. (a) Mode 1. (b) Mode 2.

2. Discontinuous Conduction Mode Operation (DCM):

The operating modes in DCM are divided into three modes. They are as mode 1, mode 2, and mode 3.

i.Mode 1[$t_0 \le t \le t_1$]:

During this time interval [$t0$, $t1$], $S_3$ is turned on and $S_1/S_2$ are turned off. The operating principle is same as that of mode 1 in CCM operation. The current flow path is shown in Fig.6 (a). The two peak currents through the primary and secondary windings of the coupled inductor are:

$$I_{L1p} = I_{L2p} = \frac{(V_H - V_L)DT_S}{2(1+k)L} \ldots\ldots\ldots (18)$$

ii.Mode 2[$t_1 \le t \le t_2$]:

During this time interval [$t_1$, $t_2$], $S_3$ is turned off and $S_1/S_2$ are turned on. The energy is decayed through capacitor $C_L$ and the load which is stored in the coupled inductor where the secondary and primary windings of the coupled inductor are in parallel. The currents $i_{L1}$ and $i_{L2}$ in the primary and secondary windings of the coupled inductor are decreased to zero at time $t=t_2$. The current flow path is shown in Fig.6 (b).Hence the two peak currents $I_{L1p}$ and $I_{L2p}$ are obtained as:

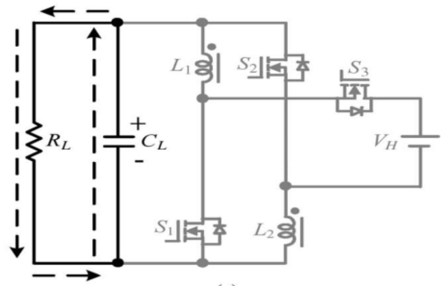
$$I_{L1p} = I_{L2p} = \frac{V_L T_S D_2}{(1+k)L} \dots\dots\dots(19)$$

iii.Mode 3[$t_2 \le t \le t_3$]:

During this time interval [$t2$, $t3$], $S3$ is still turned off and $S_1/S_2$ are still turned on. The energy stored in the coupled inductor is zero. The current flow path is shown in Fig.6(c). Thus, $I_{L1}$ and $I_{L2}$ are equal to zero. Since the energy stored in the capacitor $C_L$ is discharged to zero.

From (18) & (19),$D_2$ is obtained as

$$D_2 = \frac{D(V_H - V_L)}{2V_L} \dots\dots\dots(20)$$




(c)

Fig. 6(c).Current flow path of the proposed converter in step-down Mode 3 in DCM.

## IV.COMPARISION BETWEEN THE PROPOSED CONVERTER AND CONVENTIONAL BIDIRECTIONAL CONVERTER

A. Voltage Gain:

The curves of the voltage gains of the step up/down modes are shown in Fig.7.From the figures we have observed that the voltage gains of the proposed converter are higher than the conventional buck/boost converter.

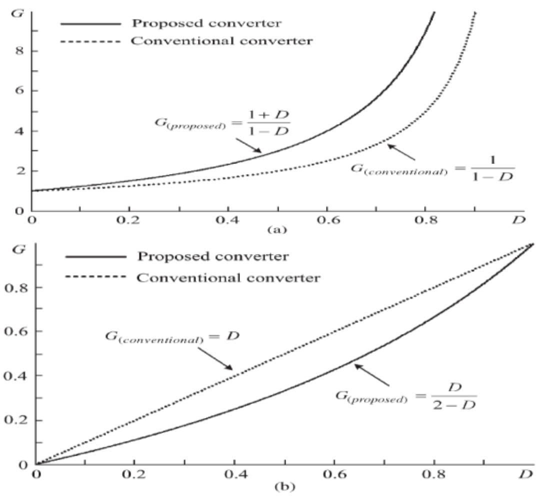



Fig.7. Voltage gain of the proposed converter and conventional buck/boost converter in CCM operation. (a) Step-up mode. (b) Step-down mode.

## V. EXPERIMENTAL RESULTS

In order to verify the performance of the proposed converter, some of the electric specifications and circuit components are selected as $VL$ = 14 V, $VH$ = 42 V, $fs$ = 50 kHz, $Po$ = 200 W, $CL$ = $CH$ = 330 $\mu$F, $L1$ = $L2$ =15.5 $\mu$H ($rL1$ = $rL2$ = 11 mΩ). Also, MOSFET IRF3710 ($VDSS$ = 100 V, $RDS(ON)$ = 23 mΩ, and $ID$ = 57 A) is selected for $S1$, $S2$, and $S3$. .

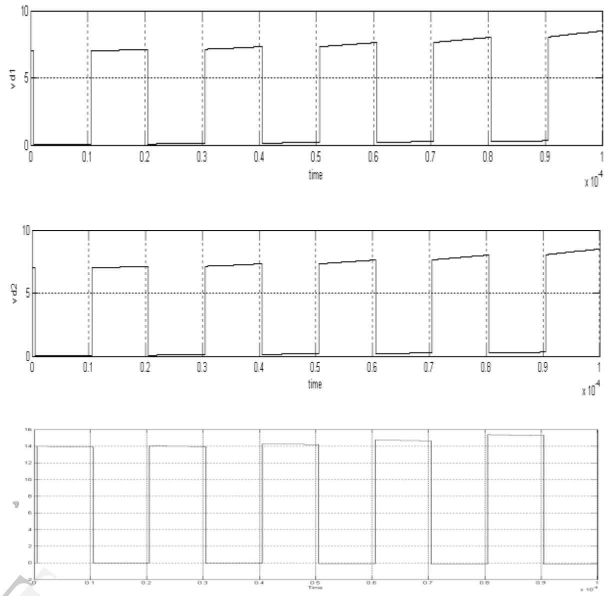


Fig.8 Some experimental waveforms of the proposed converter in step-up mode. $VD_1$,$VD_2$ & $VD_3$

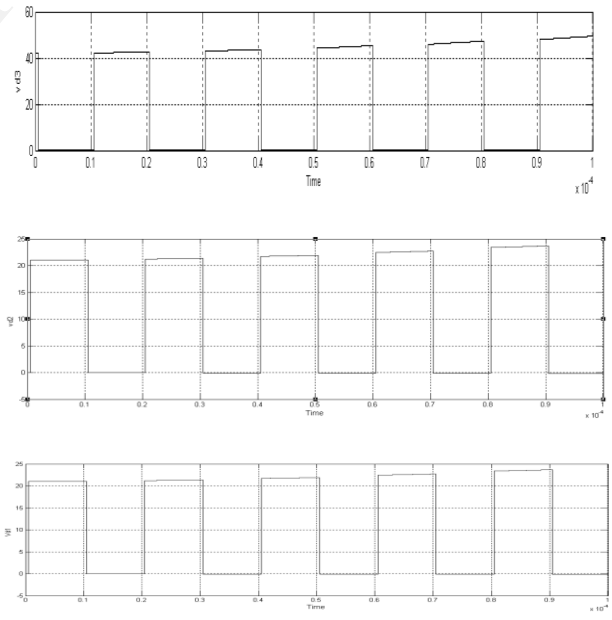


Fig.9 Some experimental waveforms of the proposed converter in step-down mode. $VD_3$,$VD_2$ & $VD_1$

## VI. CONCLUSION

This paper researches a new buck/boost converter. The circuit configuration of the proposed converter is very simple. The proposed converter has higher step-up/down voltage gains than the conventional buck/boost converter. From the experimental results, it is see that the experimental waveforms agree with the operating principle and steady-state analysis.

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Mr Mohammed jaffar was born in Hyderabad ,Ranga Reddy. Dist, Telangana, India, in 1986. He received bachelor’s degree in Electrical & Electronics Engineering from JNTU, Hyderabad and Master degree in Power Electronics from JNTU, Hyderabad, in 2008 and 2012 respectively. His research interest in Multilevel Inverter, Power system protection and control. Presently he is working as Assistant Professor in Electrical Engineering department, Muffkham Jah College of Engineering and Technology, Banjara Hills,Hyderabad,Telangana, India.

Mr Guntuku Ravikiran was born in Nizamabad Dist, Telangana, India, in 1984. He received bachelor’s degree in Electrical & Electronics Engineering from Padmasri B.V. Raju Institute of Technology,JNTU Hyderabad and Master degree in Embedded Systems from JNTU, Hyderabad, in 2005 and 2010 respectively. His research interest in Power Electronics, Embedded Systems and Machines. Presently he is working as Assistant Professor in Electrical Engineering department, Muffkham Jah College of Engineering and Technology, Banjara Hills,Hyderabad,Telangana, India.

Mr. Mohammed Sajid was born in Shankerpally, Ranga Reddy. Dist, Telangana, India, in 1988. He received bachelor’s degree in Electrical & Electronics Engineering from JNTU, Hyderabad and Master degree in Power Electronics from JNTU, Hyderabad, in 2009 and 2011 respectively. Presently pursuing PhD in EEE from JNTUH. His research area is Power systems and Drives. Presently he is working as Assistant Professor in Electrical Engineering department, Muffkham Jah College of Engineering and Technology, Banjara Hills, Hyderabad, Telangana, India.

Mr. Kotha.RamaKrishna was born in Narashimhapuram, Khammam. Dist., Telangana, India, in 1990. He received bachelor’s degree in Electrical & Electronics Engineering from ANU, Guntur and Master degree in Electrical Machines & Drives from JNTUK, Kakinada, in 2011 and 2013 respectively. His research area is Power systems and Drives. Presently he is working as Assistant Professor in Electrical Engineering department,Sri Venkateswara College of Engineering and Technology, Srikakulam.