*2017 National Power Electronics Conference (NPEC)*
*College of Engineering Pune, India. Dec 18-20, 2017*

# High Gain Bidirectional DC-DC Converter With Reduced Component Count

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***Abstract*—Solar Photovoltaic system as a source and battery as an intermediary load necessitates the development of bidirectional dc-dc converter. Conventional battery loads are rated at 12 V to 48 V. High gain is required both in step up and step down modes to supply the ac grid or charge from the grid. Conventional isolated transformer based topologies can be designed with high gain at the expense of increase in component count and requirement of snubber circuits for protection as the leakage inductance causes a spike across the switch resulting in losses, complex control schemes and the requirement of over rated components. Non isolated converter circuits with coupled inductors are used for low power systems. The size of the converter, magnetic losses increase with increase in the inductance for higher power capability. The proposed converter is a non isolated converter requiring minimum number of switches. Various operating modes and the analysis of the converter are discussed. Simulation results of the system with MATLAB and PSIM are presented.**

***Keywords—Bidirectional DC-DC converter; Battery charging; High Gain; UPS,CCM,FCCM***

## I. Introduction

Bi-Directional Converters (BDC) are required for efficient charge extraction in solar photovoltaic, wind and fuel cell based applications. These converters are useful in Vehicle to Grid(V2G), Grid to Vehicle(G2V) applications for enhancing power system stability. Conventional buck- boost converter is not suitable because of the restriction in the maximum duty cycle imposed due to the capability of inductor, filter capacitor and the diodes.

High gain BDC are required in UPS applications to transfer energy from low voltage battery source to high voltage for inversion and driving an ac load. Non isolated topologies with coupled inductor, a combination buck, boost, Cuk, SEPIC and switched capacitor are explored with modifications for increasing gain.

Various isolated and transformer based topologies employing half bridge, full bridge, forward and flyback are reported with four to nine switches. With the increase in switch number, the complexity of the system increases and hence the cost. High voltage gain in isolated topologies is achieved by varying the turns ratio. But these are only suitable for low power applications because of higher voltage stress and leakage inductance increasing the losses. With more than four switches in the transformer based topologies, there is an increase in the complexity, cost and reduction in the efficiency. BDC with coupled inductor topology was proposed in [1]-[3]. The advantage of the coupled inductor based topology is that the gain can be chosen with the turns ratio. Stress due to leakage inductance is reduced. Electromagnetic interference becomes an issue with higher power levels. This converter employs simple control scheme with a single switch in the boost stage and two switches in the buck stage. Switches are required to have low on state resistance ($R_{DS-ON}$).

Coupled inductor based converters are suitable for only low power levels. Inductor size and input current ripple increases with the increase in power level. Soft switching cannot be employed and conduction losses are high. A low voltage 12/42 V system with coupled inductor topology was discussed in [4]. A BDC with coupled inductor and voltage doubler cell has been studied in [5]. Voltage clamping, synchronous rectification and soft switching was employed with minimal number of switches.

Half bridge, full bridge topologies require soft switching techniques and introduce a dead time between the pulses employing ZCS and ZVS [6]. A unidirectional topology with multiple level voltages has been proposed for dc micro grid applications in [7]. A BDC with Cuk based topology was presented in [8]. Limitation is that the topology is for low voltage high current applications and requires RCD snubbers. SEPIC derived BDC was discussed in [9]. Switched capacitor based topology has the advantage of lower power rating, output capacitance requirement and current stress but suffers from the large switch count from four to twelve for a gain of 6. The model achieves 68.2 V output from 12V input. Switching losses increase apart from the complexity in the triggering and control mechanism [10].

A boost-buck integrated flyback topology was proposed for battery charging [11]. The advantage of the system has been the recovery of leakage energy through cascaded boost stage thereby minimizing the need for clamping systems. A flyback system with non complementary active clamp circuits was discussed in [12]. The converter circulates energy, reduces voltage spikes and thereby reduces power losses. A system suitable for V2G, G2V interactions with topology of series resonant converters requiring soft switching is demonstrated in [13]. A bi directional buck boost converter with transformer coupled boost dual half bridge converter was implemented in [14]. An integrated AC/DC -DC/DC system has been designed in [15] for hybrid vehicle applications. Dual Active Bridge (DAB) topology was implemented because of its inherent capability of transmission of equal power in either direction. [16], [17]. A ZCS PWM BDC with resonant tank is proposed in

[18]. Here the voltage gain is restricted to 50%. A current fed isolated BDC with widely varying input condition is proposed [19]. A review of various non isolated topologies with high gain for PV based applications was done [20]. To improve voltage gain and reduce switch stress a passive snubber was utilized for unidirectional boost operation [21]. A unidirectional soft switched interleaved boost converter was proposed. A basic cell structure was described which can be expanded as per the requirement of gain [22].

## II. PROPOSED CONVERTER AND CONTROL SCHEME

In this paper a non isolated, high gain BDC is proposed. The circuit proposed in [21] was modified to incorporate a bidirectional feature. The system does not use coupled inductor based topology as in [21] and employs active snubbers and capacitive clamping to improve the gain. Apart from offering a high gain in step up and step down mode, the circuit has the benefit of reduced switch stress by half. The basic circuit consists of a filter inductor, an auxiliary inductor, four switches and capacitors. It uses the switches S1 in the boost mode and S4 in the buck mode for energy transfer. Passive clamping through diode and resistors do not reduce the losses and only divert the losses to the clamping circuit to reduce switch stress. Hence when S2 and S3 are switched in a alternate manner, they offer active clamping, charge an intermediate capacitor and thereby offer higher gain and reduced inductor stress.

The assumptions made in the circuit are:

1. All the components are ideal.

2. Parasitic diodes of the switches are considered.

3. All the switches are turned on / turned off with a small delay as desired.

4. Winding resistance of inductor and equivalent series resistance of capacitor are not considered.

### *A: Buck Mode or Step down scheme*

The following modes can be explained in buck mode or step down mode. The proposed circuit is as shown in Fig. 1. The voltage stress is as shown in Fig. 2. LV side stress is less than 50% of the HV side. Switches S1, S3 switch simultaneously. S2, S4 switch simultaneously. S1, S3 and S2, S4 are complementary as represented in Fig. 4. & Table: 1

TABLE1: SWITCH OPERATING SEQUENCE

| Mode | Triggering Sequence | | | |
|---|---|---|---|---|
| Buck Mode | S4, S2 | Delay | S1, S3 | Delay |
| Boost Mode | S1, S4 | Delay | S2, S3 | Delay |

Mode 1: Initially when S4, S2 are closed and S1, S3 remain open. The current through the inductor L1, L2 increases linearly and inductor L2 charges and supplies energy through the path S4, L2, Cs and the load. Capacitor C2 discharges to the load through S2 and L1.

Mode 2: All the switches are off. The body diodes will conduct, circulating the energy and return a part of energy to the source charging the capacitor C2.

Mode 3: The gate signals for S1 and S3 are applied and S2, S4 are switched off. The inductors L2, Cs, L1 supply the stored energy. The body diode of S2 conducts and completes the path. The current through the inductors start to fall linearly. The inductor currents are triangular and operate in continuous current mode (CCM) and forced continuous current mode (FCCM). The advantages are lower ripple current and higher efficiency. Voltage gain is independent of the load. The average current of the inductor L1 is same as the load current. The average current through L2 is near to zero. The inductor voltage remains clamped except during the switching instants as in Fig. 3. The ripple at the output side has been found to be minimum. The pulse sequence and inductor currents are as shown in Fig. 4

Path for Inductor Discharge represented with

Path for Inductor Charging represented with

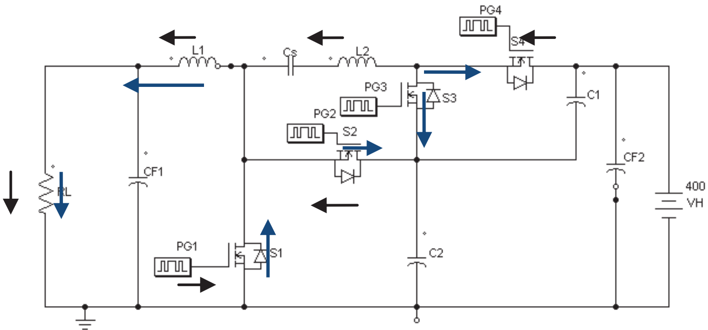


Fig. 1 : Bidirectional DC-DC Converter in Buck Mode

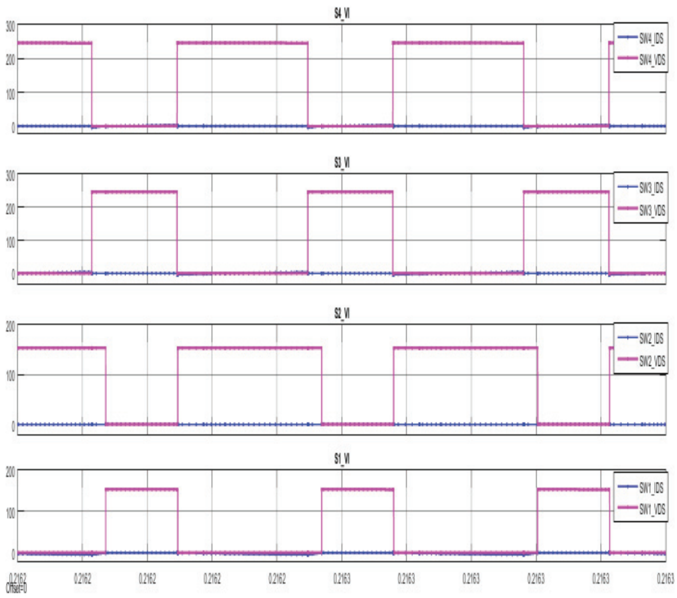

Fig. 2 : Switch Voltage and Current Stress (S4-S1)

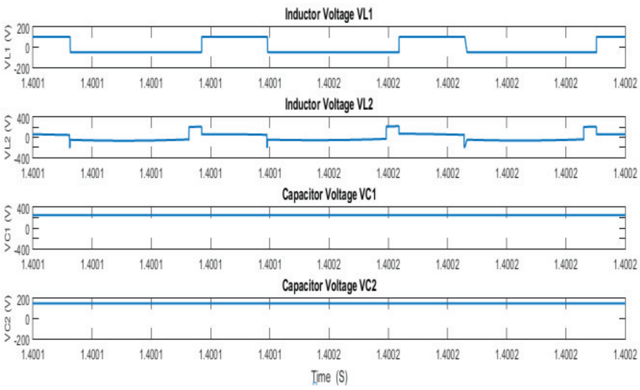


Fig. 3 : Voltage across the Inductor(L1,L2) and Capacitor( C1,C2)

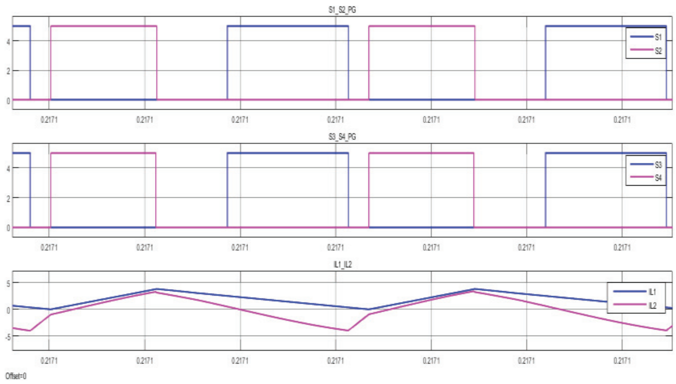

Fig. 4: Pulses S1-S4 with inductor currents

By varying duty cycle of S4 from 33% to 55%, output voltage can be varied from 48V to 60V and hence suitable for maintaining dc link voltage or battery charging applications. High step-down gain is obtained as shown in the Fig. 9.

*B: Boost Mode or Step up Mode*

Conventional boost circuit gives a maximum gain of twice the input with 50% duty cycle. The topology is described with lower input side voltage of 48V as shown in Fig. 5. The limitation of maximum duty cycle is overcome in the proposed circuit and the following modes are being observed.

Mode1: S1 and S4 are switched. When S1 is switched, the inductor L1 is charged and inductor currents starts increasing. Simultaneously S4 is also switched. The inductor L2 begins to discharge and simultaneously charge the capacitor through Cs and the body diode of S2. S4 switched off ahead of S1.

Mode 2 :All the switches are in off condition. The energy stored in the inductor and the supply is transferred to the load through the body diode of S2,S3 and S4. The current through the inductor L2 starts to rise from negative peak value.

Mode 3:. When the inductor current L2 reaches zero, at that instant the switches S2,S3 are switched on. The inductor L1 energy along with supply discharges to the load through the path.

Voltage across the inductors and capacitors is as shown in Fig 6. The input of 48V is stepped up to 400V and is indicated by the voltage across C1 and C2. Stress across the switches and the inductor current variation with the pulse sequence is presented in Fig. 7 , 8.

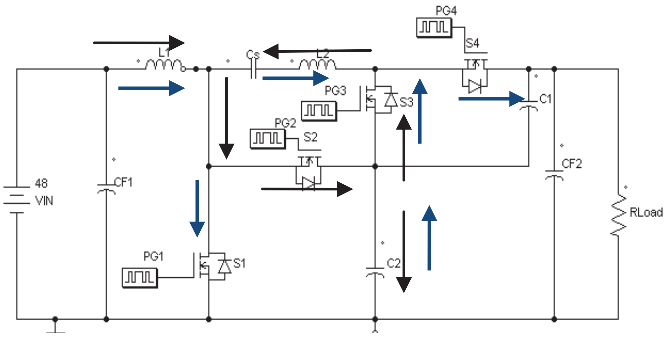


Fig. 5: Proposed Converter in step up mode.

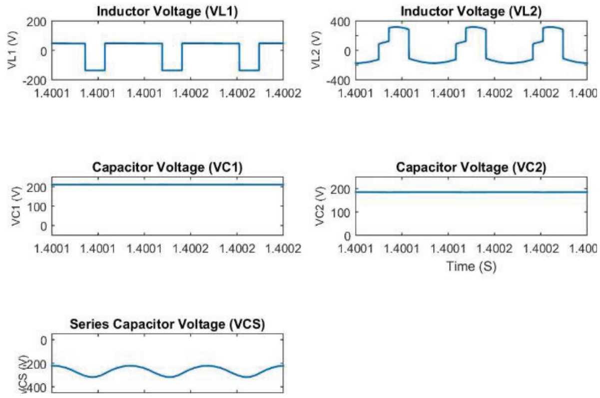


Fig.6. Inductor and Capacitor Voltages

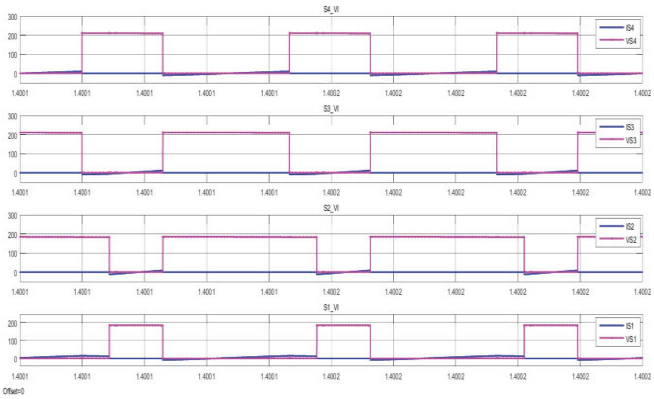

Fig. 7 : Switch Stress (VI) in step up mode

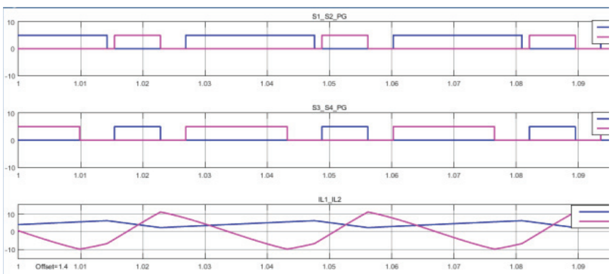

Fig. 8 : S1_S4 pulses with inductor currents

## III. SIMULATION RESULTS

The circuit is simulated using MATLAB Simulink. The various parameter as mentioned in Table 1 are used. Conventional buck / boost converter give a gain of maximum of two in the step up/ down mode. The proposed converter gives a high gain of over 8.3 in both step up and step down mode as shown in Fig. 9, 10. Duty cycle is varied from 25% to 65% for both the step up and step down modes of operations.

The proposed circuit gives a high gain of 8.3 for a duty cycle of 33% in buck mode and 62 % in boost mode. The gain is found to reduce with the duty cycle for step down mode. In step up mode, the gain increases with increase in duty cycle from 25 % to 65%. The variation of gain with change is duty cycle is plotted in Fig. 11.

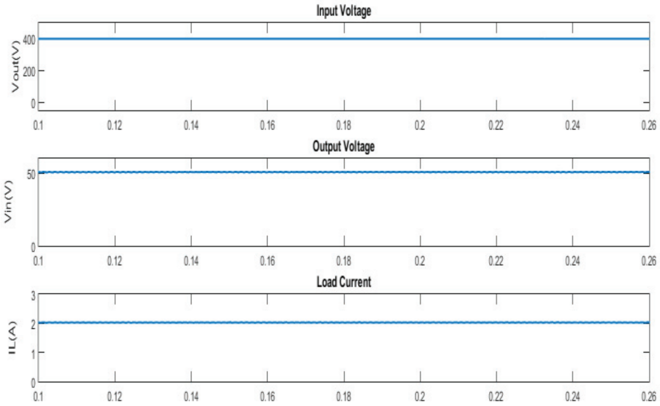


Fig. 9: Input, Output voltage in buck mode and the load current

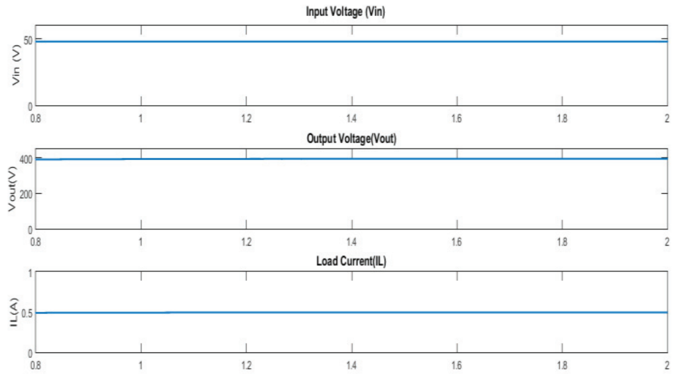


Fig.10: Input, Output voltage in boost mode and the load current

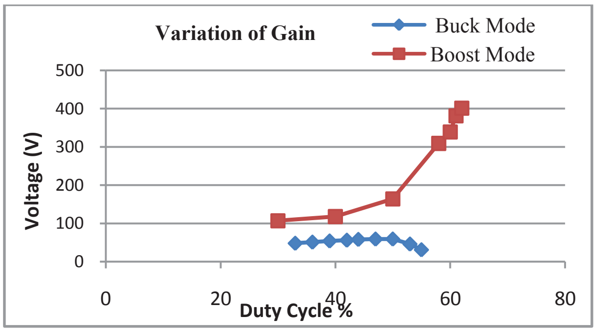


Fig. 11: Variation of gain with duty cycle

TABLE 2: PARAMETERS USED

| Parameters | Values |
|---|---|
| Switching Frequency | 30 kHz |
| Inductor L1 | 300 uH |
| Inductor L2 | 150 uH |
| Capacitors CF1, CF2 | 220 uF |
| Series Capacitor Cs | 1 uF |
| Filter Capacitors C1,C2 | 47 uF |
| RL (Low Voltage Bus) | 25 Ω |
| RH (High Voltage Bus) | 800 Ω |

TABLE 3: COMPARISION OF BDC TOPOLOGIES

| Ref. No | *Topology* | *Voltage Range* | *Switching Frequency* | *Power* | *Efficiency* | *No. of Switches* |
|---|---|---|---|---|---|---|
| 1 | Coupled inductor based | 24 V to 200 V | 50 kHz | 200 W | 91.6-94.3 | 3 |
| 2 | ZVS –ZCS Application | (72-100) V to 400 V | 30 kHz | 5 kW | 97.9 | 4 |
| 4 | Isolated Cuk-low voltage high current | (1.5-6) V to 24V | 50 kHz | 1.2 kW | 84.3 | 4 |
| 5 | SEPIC derived | 48 V to 380 V | 50 kHz | 400 W | 95-96.4 | 4 |
| 6 | Coupled inductor voltage doubler | (40-60) V to 400 V | 100 kHz | 1 kW | 95 | 4 |
| 7 | Switched Capacitor | 12 V to 68 V | 100 kHz | 450 W | 92-95 | 12 |
| 9 | Coupled Inductor | 14 V to 42 V | 50 kHz | 200 W | 92-97 | 3 |
| 11 | Coupled Inductor | 48V to 360V | 100 kHz | 2 kW | 92-95 | 3 |
| 18 | Resonant tank | 200V to 400V | 50 kHz | 2.2 kW | 94% | 3 |
| 19 | CF -DAB | (30-60)V to 400 V | 100 kHz | 1 kW | 91.7% | 6 |

## IV. COMPARISION WITH EXISTING SYSTEM

The different topologies found in literature are compared and results were described in Table 3. The proposed circuit presents a higher gain over existing topologies using inductors of smaller ratings. Coupled inductor topologies are used with smaller size rating for lower gain. The inductor size is found to be increasing for higher power levels, outweighing the advantage. Switched capacitor models offer higher gain with increase in number of switches and hence increase in complexity.

## V. CONCLUSION

In this paper a bidirectional converter with higher gain is proposed. The proposed converter has higher gain, lower component number and reduced size. The converter offers flexibility of its simple design, arrangement and control scheme. Absence of coupled inductors makes it possible to achieve higher gain with lower inductance. Stress on the switches is reduced to half. Simulation results and investigations are presented. Comparison with other existing similar configurations is discussed. Applications of the topology include the regulation of dc link voltage, battery charging / discharge and extracting power from solar photovoltaic panels. Further hardware work is in progress and will be presented in future papers.

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