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# *Design and Analysis of Various Topologies in Bidirectional DC-DC Converter*

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***Abstract***

*In this paper various topologies of bidirectional dc-dc converter are analyzed. Bidirectional dc-dc converters (BDC) have recently received a lot of attention due to the increasing need to systems with the capability of bidirectional energy transfer between two dc buses. Apart from traditional application in dc motor drives, new applications of BDC include energy storage in renewable energy systems, fuel cell energy systems, hybrid electric vehicles (HEV) and uninterruptible power supplies (UPS). The circuit configuration for various topologies of dc-dc converter is analyzed. Two topologies employs the coupled inductor to the same windings turns in the primary and secondary sides. In step-up mode, the primary and secondary windings of the coupled inductor are operated in parallel charge and series discharge to achieve high step-up voltage gain. In step-down mode, the primary and secondary windings of the coupled inductor are operated in series charge and parallel discharge to achieve high step-down voltage gain. One topology employs an inductor to achieve the bidirectional conversion. Thus, the converters has higher step-up and step-down voltage gains and under same electric specifications, the average value of the switch current for all the topologies is compared and analyzed. Simulation can be done for 14/42-V circuit and 24/400-V circuit are discussed using PSIM software for the various topologies and to compare their results.*



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***Keywords:*** *Bidirectional dc-dc converters, coupled inductor.*

## I. INTRODUCTION

The DC-DC converters are used to transfer the power between two DC sources in either direction. The DC-DC converters are widely used in renewable energy application such as fuel-cell and battery hybrid supplied power systems, island photovoltaic generation systems, and wind power systems. The bidirectional DC-DC converter can be applied in uninterruptible power supplies (UPSs) to transfer the energy between source and battery. The bidirectional DC-DC converter plays an important role in system back-up or in reserving energy for the battery. The battery can balance the energy between the power source and the load.

The voltage difference between the battery and the DC bus is large, thus, a bidirectional DC-DC converter with high step-up/down voltage conversion ratio is required.

The bidirectional converter has been classified into two categories, namely, isolated and non-isolated types. Moreover, the high voltage conversion ratio of bidirectional DC-DC converters [7] is achieved by adjusting the turn ratios of the isolated transformer. For example [4], the bidirectional forward-flyback DC-DC converter is a simple and low cost configuration.

However, it is only suitable in low power applications because of its high voltage stress and leakage inductance energy. Additionally, these converters use many active components, which not only increase the cost and conduction losses of the converter, but also complicate the control circuit.

Prior arts of non-isolated bidirectional converter, the single-stage cascaded bidirectional DC-DC converter has a quadric voltage conversion ratio compared with conventional bidirectional converters. However, the active components of the single-stage cascaded bidirectional DC-DC converter will suffer higher current stress and conduction losses. The bidirectional converter used coupled-inductor technology to achieve a high voltage conversion ratio. However, the energy stored in the leakage inductor of the coupled inductor causes a high voltage spikes on the power switches. The leakage inductor problem is needed to be solved by active clamp, passive clamp, or auxiliary circuit.


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## II. VARIOUS CONVERTER TOPOLOGIES

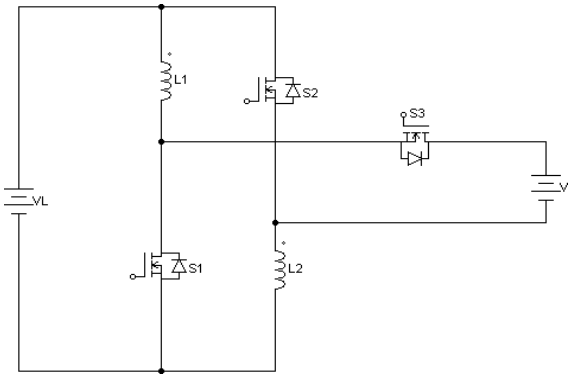



***Fig 1: A bidirectional dc-dc converter with high voltage gain***

A Bidirectional DC-DC converter with a rating of 14/42-V is designed in this paper. Its major application includes an automobile dual battery system. The circuit configuration of the converter is very simple. It also has a higher step down/step up voltage gain and reduced average value of switch current.

The simulation results are given as waveforms.

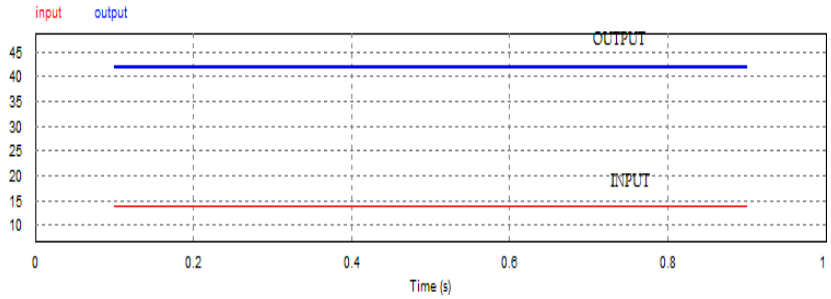



***Fig 2 Input and output voltage waveform***

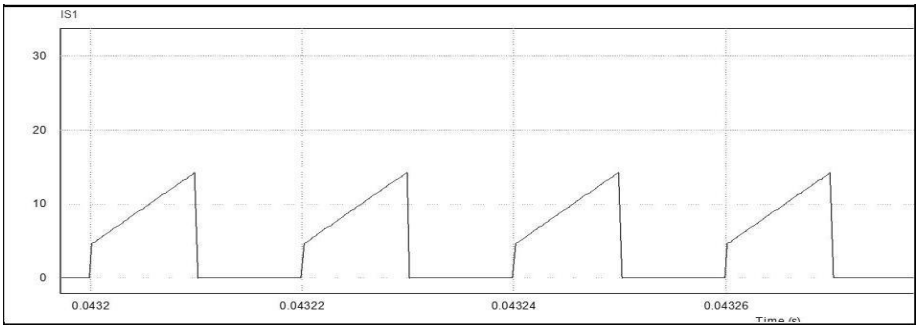



***Fig 3.Switch current waveform***


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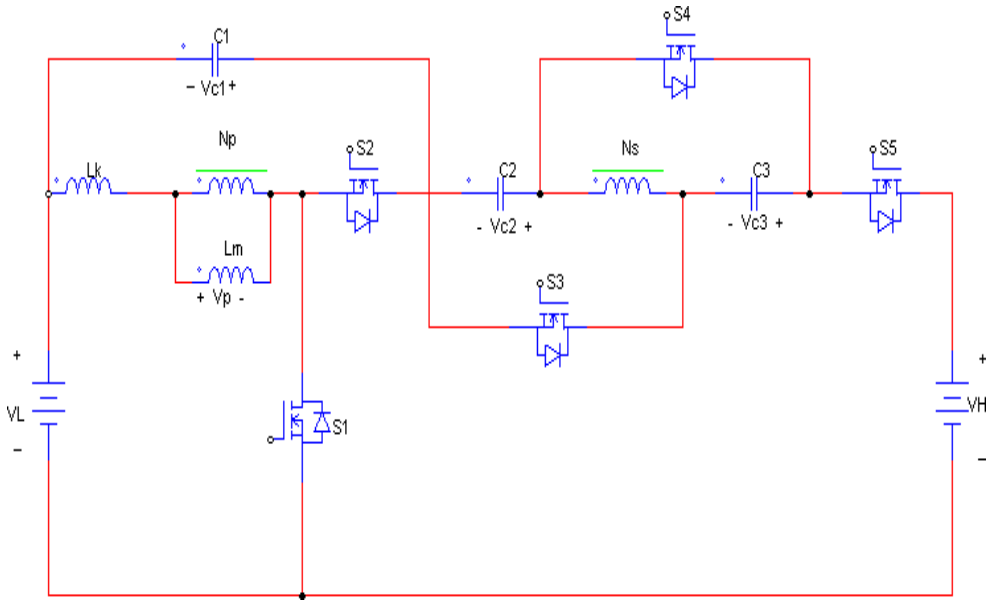



***Fig 4.Bidirectionaldc-dc converter with high conversion ratio***

A bidirectional dc-dc converter with high conversion ratio has been proposed in this paper. The converter can be used for charging and discharging battery applications. It has high step up and step down voltage gain when compared with the conventional bidirectional dc- dc converter. The proposed converter achieve high step up gain by parallel charged and series discharged capacitors. High step down gain can be achieved by series charged and parallel discharged capacitors. Aside from that, the energy of the leakage inductor has been recycled with the active clamp circuit. The converter operating modes are analyzed.

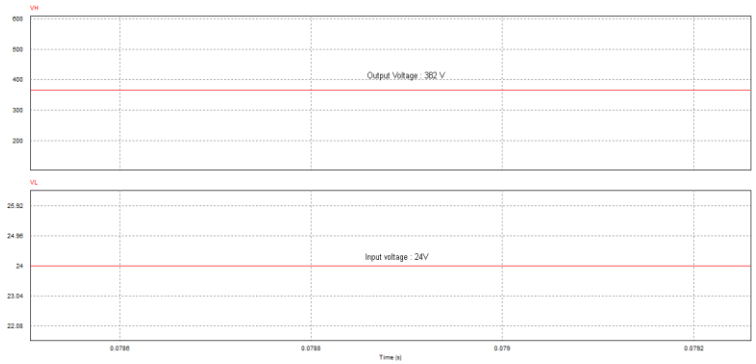



***Fig 5. Input and output voltage waveform***


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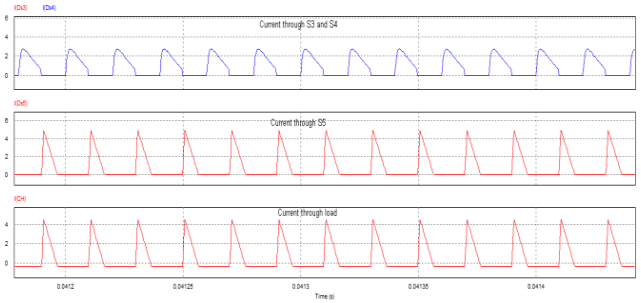



*Fig6.Switch current waveforms*

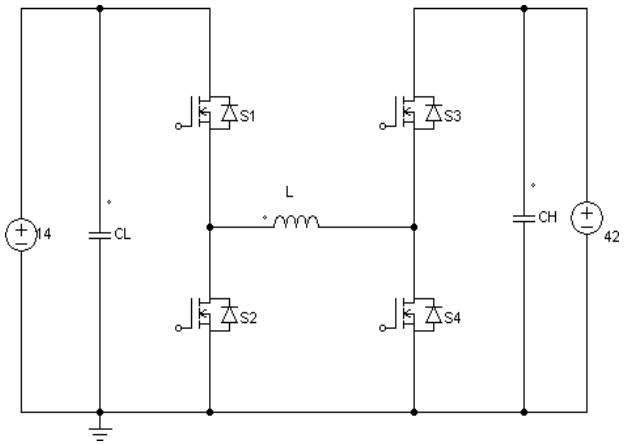



*Fig7. None isolated bidirectional dc-dc converter.*

### *1. Step-Up Mode of Operation:*

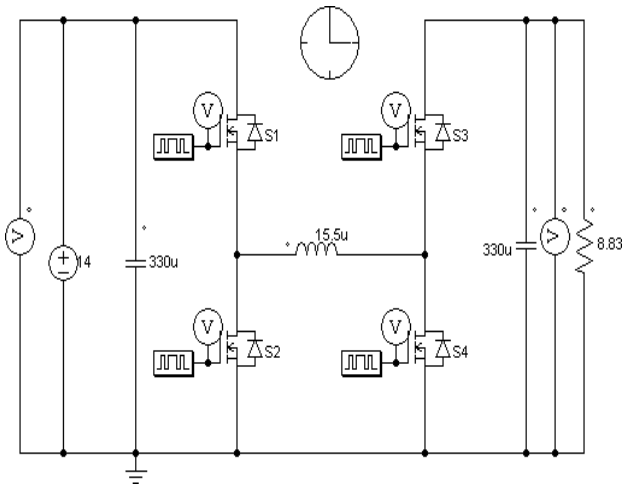



*Fig 8. Circuit diagram of step up converter*


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

Pulse width modulation (PWM) technique is used to control the switch*S*1, S4. The switch *S*2,S3 are synchronous rectifier.

## 1. CONTINUOUS CONDUCTION MODE

**Mode 1**: During this time interval [$t_0$, $t_1$], *S*1,S4 areturned on and *S*2,S3 are turned off. The current flow path is shown in fig. The energy of the low-voltage side *VL* is transferred to the inductor. The energy stored in the capacitor *CH* is discharged to the load.

Thus the voltage across the inductor L1 obtained as

$$\frac{di_{L1}}{dt} = \frac{V_L}{L}$$

The operating principles and steady-state analysis of CCM an

**Mode 2**:During this time interval [*t*1, *t*2], *S*1, S4turned off and *S*2, S3 turned on. The current flow path is shown in figure 8. The low-voltage side *VL* and the inductor is transfer their energies to the capacitor *CH* and the load. The following equation to be found.

$$\frac{di_{L1}}{dt} = \frac{VL-VH}{L}$$

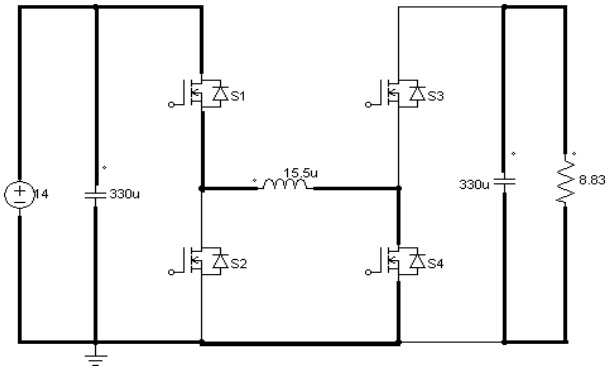



***Fig 9. When switch S1, S4 are Turned ON***

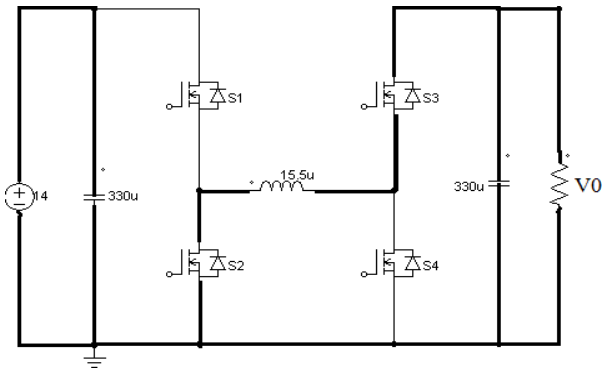



***Fig 10.When S2,S3 is turned on***


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## 2. DISCONTINUOUS CONDUCTION MODE

Mode 1: During this time interval [t0, t1], S1,S4 are turned on and S2,S3 are turned off. The current flow path is shown in Fig 10.

Mode 2: During this time interval [t1, t2], S1, S4 turned off and S2, S3 is turned on. The current flow path is shown in Fig. The low-voltage side VL and the inductor energy deccreased to zero.

Mode 3: During this time interval [t2, t3], S1, S4 is still turned off and S2,S3is still turned on. The current flow path is shown in Figure 11. The Energy stored in the inductor is zero. The energy stored in the capacitor CH is discharged to the load.

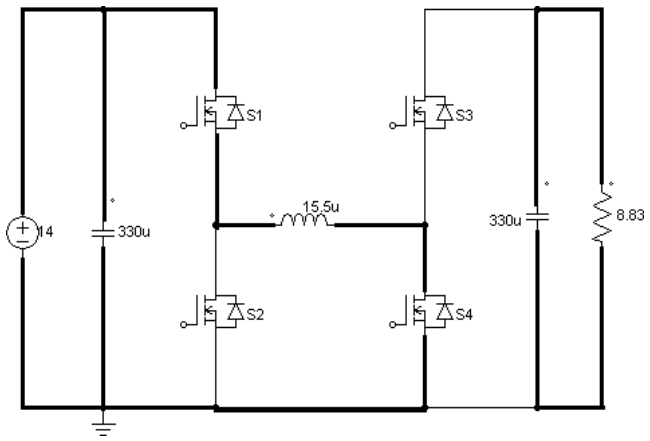



***Fig 11. when switch S1, S4 are turned ON***

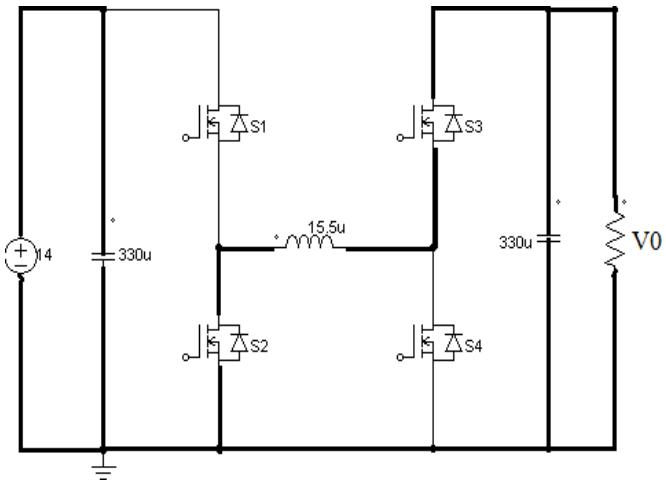



***Fig 12. When S2 andS3 turned on***


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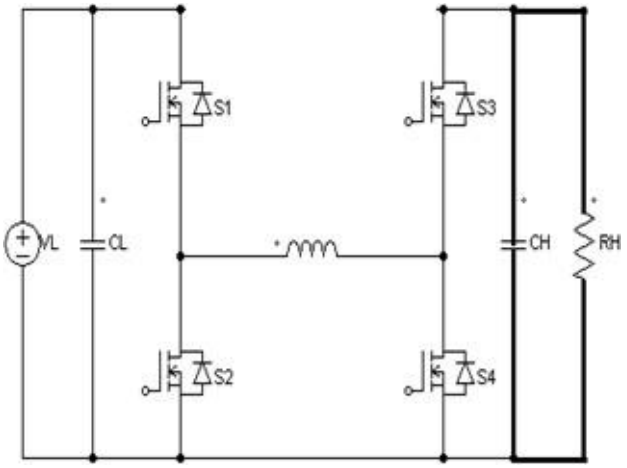



*Fig 13.Equivalent circuit of mode 3*

## III. STEPDOWN MODE

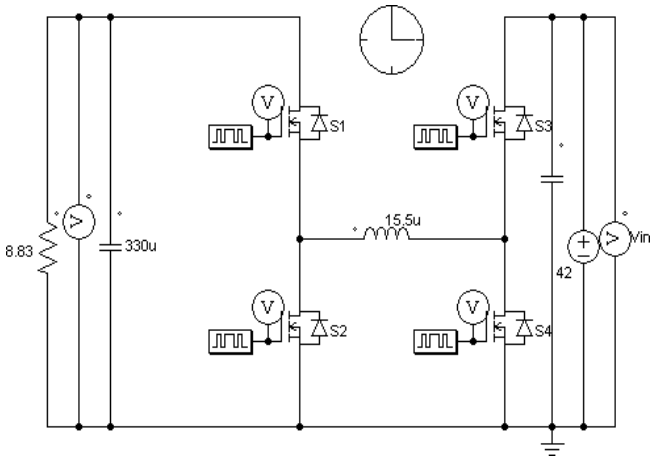



*Fig 14 Circuit diagram of step down converter*

### CONTINUOUS CONDUCTION MODE

**Mode 1:**. During this time interval [*t*0, *t*1], S2, *S*3 are turned

On and *S*1/*S*4are turned off. The current flow path is shown

In Fig 15. The energy of the high-voltage side *VH* is transferred to the inductor, the capacitor *CL*, and the load.

$$\frac{di_{L1}}{dt} = \frac{VH-VL}{L}$$

**Mode 2:** During this time interval [*t*1, *t*2], S2,*S*3 is turned Off and *S*1/*S*4are turned on. The current flow path is shown in Fig 16. The energy stored in the coupled inductor is released to the capacitor *CL* and the load.

$$\frac{di_{L1}}{dt} = \frac{-VL}{L}$$


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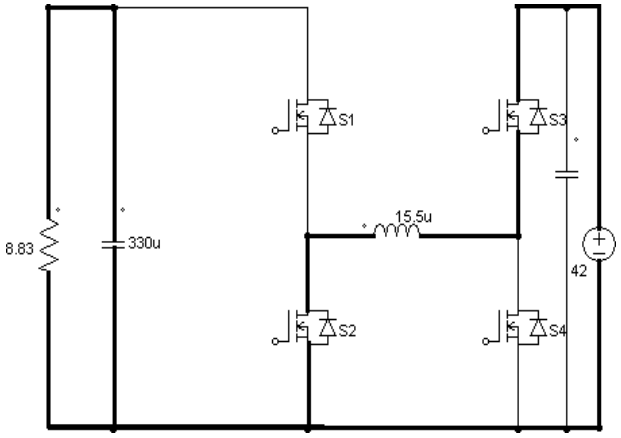



*Fig 15. When switch S2, S3 are turned ON*

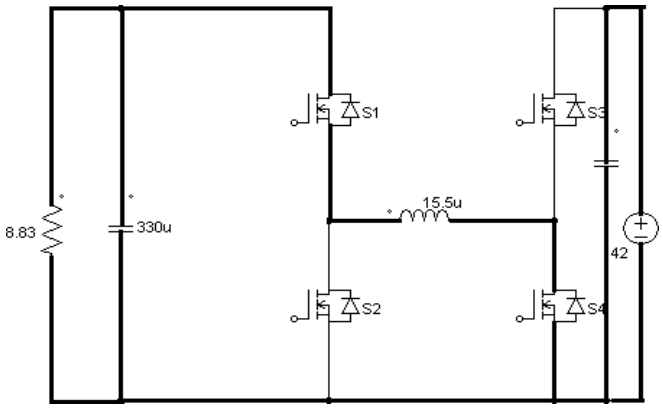



*Fig 16. When switch S1, S4 are Turned ON*

## 2. DISCONTINUOUS CONDUCTION MODE

**Mode 1:** During this time interval [t0, t1], S2, S3 are turned on and S1/S4are turned off. The current flow path is shown in Fig 17. The energy of the high-voltage side VH is transferred to the inductor, the capacitor CL, and the load.

**Mode 2:** During this time interval [t1, t2], S2,S3 is turned off and S1/S4 are turned on. The current flow path is shown in Fig. 18. The energy stored in the coupled inductor is released to the capacitor CL and the load.

**Mode 3:** During this time interval, S2,S3 is still turned off and S1, S4 are still turned on. The energy in the inductor is zero. The energy stored in the capacitor CL is discharged to load.


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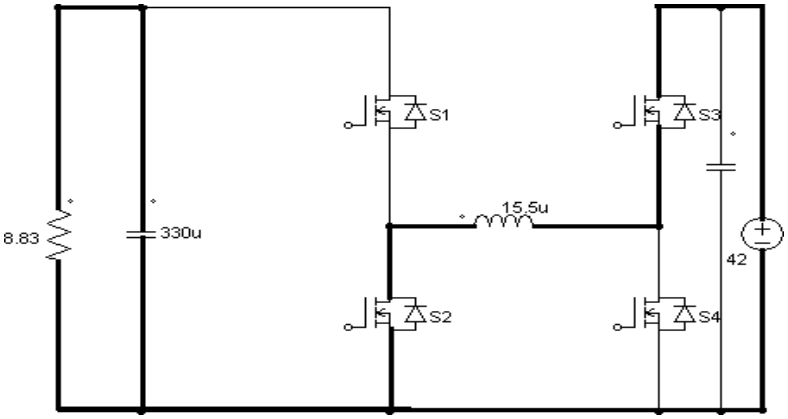



***Fig 17.When switch S2,S3 are turned ON***

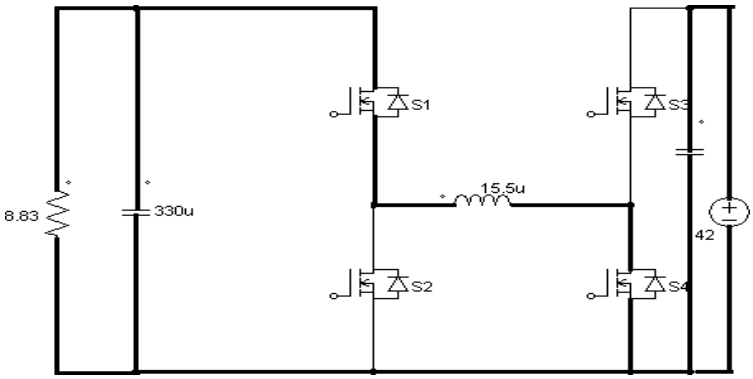



***Fig 18.When switch S1, S4 are turned ON***

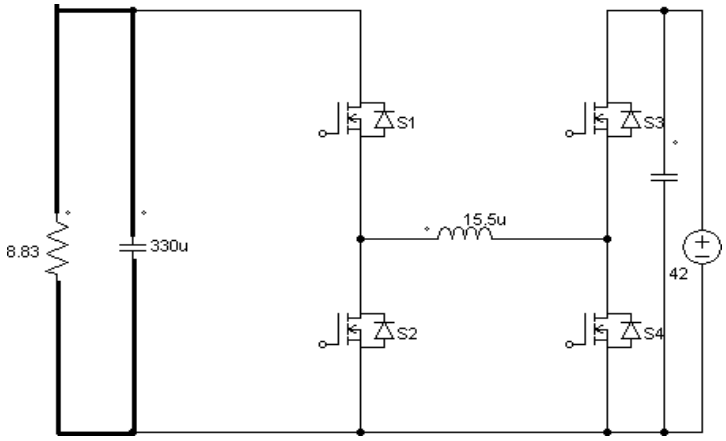



***Fig 19. Equivalent circuit of mode3***


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## IV. SIMULATION RESULTS

The various topologies of converter circuit are simulated using PSIM software for different voltage levels. Switching frequency of the converter is 50 KHz.

The simulation diagram and waveform are given as follows and the designing parameter of the system values are tabulated. The electric specification of the converter circuit is tabulated below:

***Table 1: Design parameters of bidirectional dc-dc converter***

| S.NO | PARAMETERS | VALUES |
|---|---|---|
| 1. | Input voltage | 14V<br>24V |
| 2. | Switching frequency | 50KHz |
| 3. | Output voltage | 42 V |
| 4. | Inductance (L1,L2) | 370V |
| 5. | Capacitor ($C_H$) | 15.5 uH<br>330Uf |

### *1. Step Up Mode Of Operation*

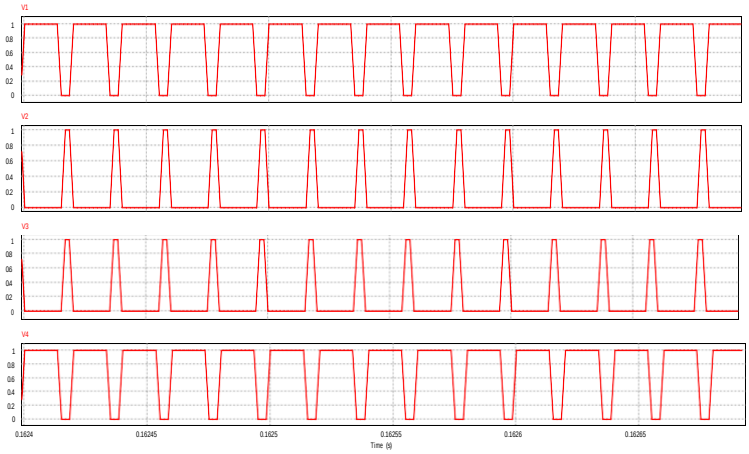


***Fig 20.Input pulses for switches***


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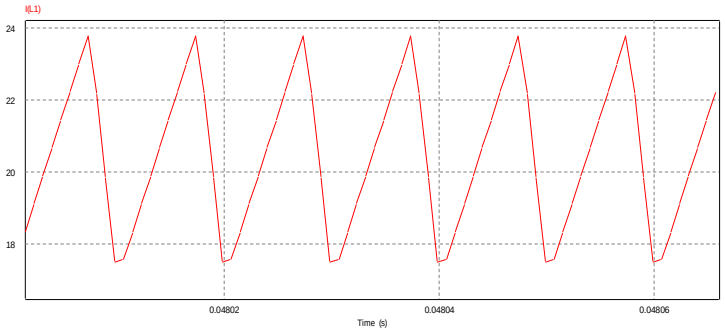



***Fig 21.Inductor current waveform***

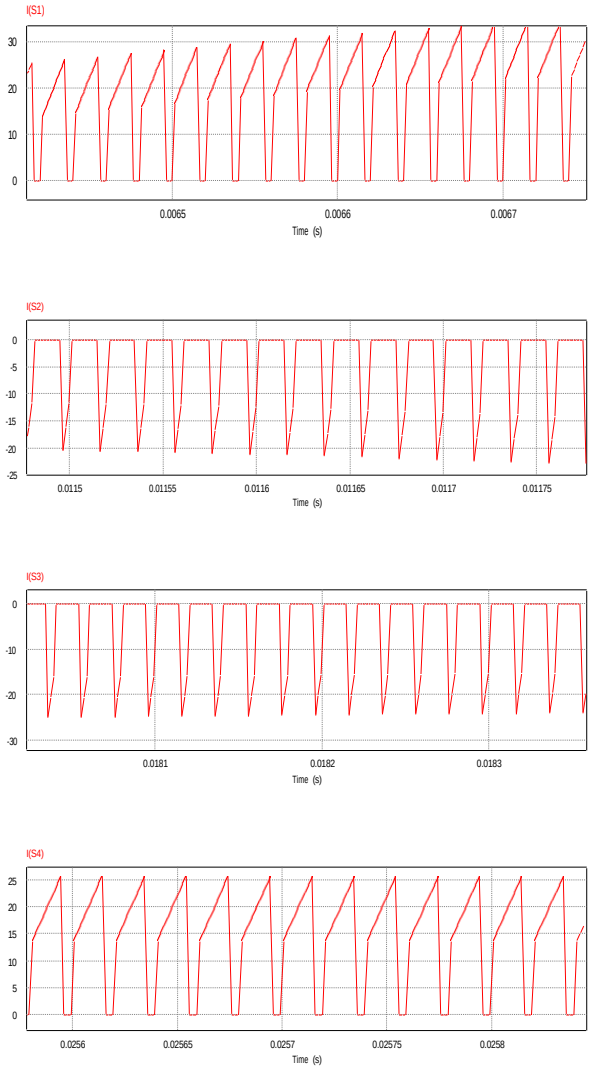



***Fig 22.Switching current waveform***


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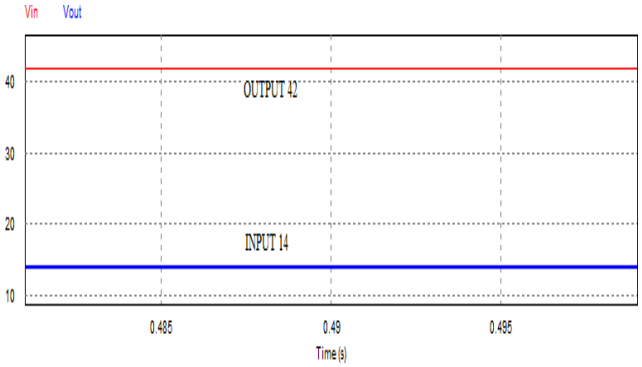



***Fig 23.Input and Output voltage waveform of boost converter***

## *2. Step Down Mode Of Operation*

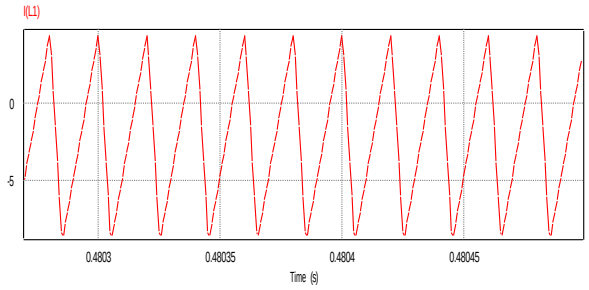
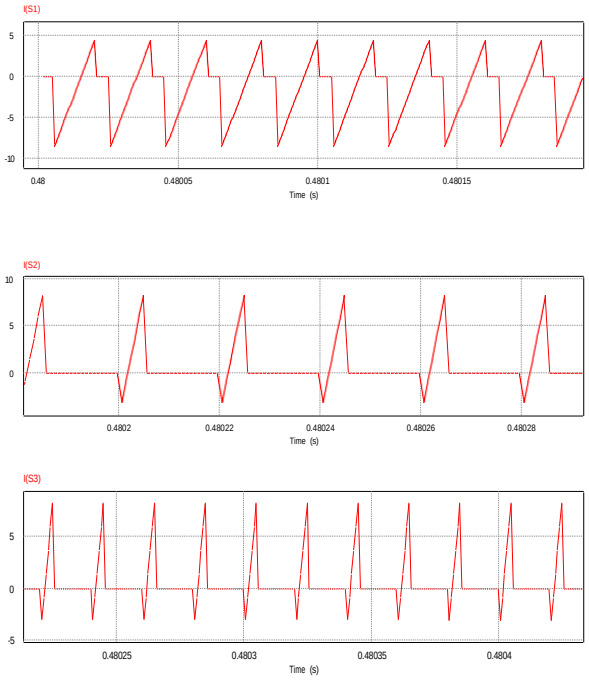



***Fig 24 Inductor current waveform***





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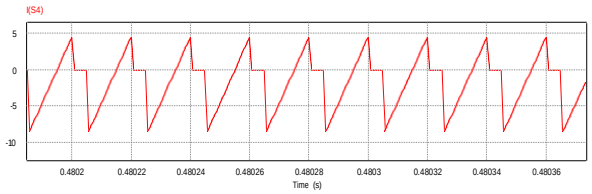



*Fig 25. switching current waveform*

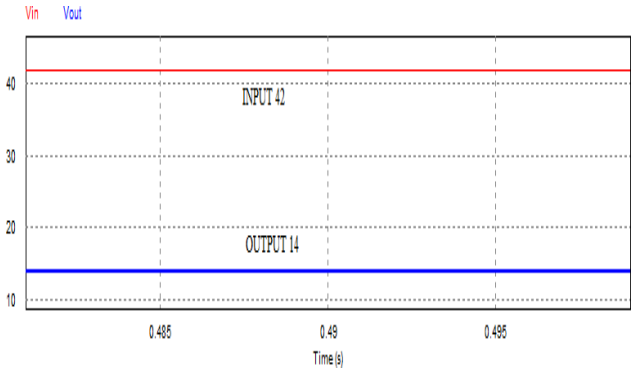



*Fig 26. Input and output voltage waveform of buck converter*

## V. CONCLUSION

This paper analysed various topologies of bidirectional DC-DC converter. Two converters are using coupled inductor and one converter using single inductor. Design considerations are discussed and the circuit is simulated for both continuous and discontinuous modes of buck and boost operation. The simulation results are given as waveforms. The average switch currentis 15A for one topology which is non-isolated bidirectional dc-dc converter and 10 A for other two topologies. When comparing with non-isolated bidirectional dc-dc converter, the other topologies are having lower average value of the switch current and hence the efficiency is to be increased and provides efficient conversion of various power sources.

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