# Comparative Analysis of Dual Source DC/DC converter Topologies for Improved Performance in Integration of Hybrid Energy Sources

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Abstract: Hybrid Energy Source is used to combine the multiple energy source, in order to use their characteristics at their best. A power electronic converter is needed to interface these hybrid energy source with a load. In traditional methods various single input DC-DC power electronic converters are used but it has drawbacks such as, complex design, huge cost and less efficiency. Therefore, it is important to identify the opportunities to cutdown the cost and to enhance the performance of the converter. One such possibility is to use dual source DC-DC converter that leads to reductions of filter size, cost and losses. Taking this into consideration, this study explores, the various topologies of dual source DC-DC converters and compares their performance for different operational conditions. The converter can work in buck, boost and bidirectional operating mode to achieve desired voltage level. Furthermore, various converter's performance is compared in terms of component counts, efficiency, output voltage vs duty ratio, average output power vs output resistance.

*Keywords:* Bidirectional power flow, DC-DC power converters, Hybrid energy source, Topologies, Performance comparison

## 1. INTRODUCTION

Hybrid Energy Sources (HES) is one of the emerging technologies to integrate the energy sources that has diverse V-I characteristics such as wind, solar PV, battery, super capacitor etc. As per typical methods, the energy sources are combined using multiple single input DC-DC converters to a common DC link. However, the specific use of energy is not taken in to account due to their extremely inconsistent nature. Therefore, by combining two-energy source is brought into practice which is called hybridization. This energy systems have earned more popularity because of its reliability and dynamic in operation when compared with single source. Hybrid Energy Sources primarily lean on power electronic converter to integrate energy sources. The power modulator used in the study is non isolated dual source DC/DC converter.

A unique multiple input DC/DC converter was introduced (Kumar and Jain, 2013). with bidirectional capabilities and small signal modelling; power management control is validated in simulation and through experimental results. A novel Bidirectional DC-DC Converter (BDC), Improved Bidirectional DC-DC Converter (IBDC) converters, dual input and modified dual input DC-DC converter - analysis, circuit diagrams, working description, control strategy followed by topological comparison with other converters is carried out both in hardware and software (Athikkal et al.,2017)-(Athikkal et al., and Sankar,2017).Simulation Vs experimental results comparison for three input DC-DC converter is carried out to check the performance and efficiency of the converter under different loading condition (Sivaprasad et al.,2015).

A detailed investigation on different configuration of multiple input DC-DC converter for hybrid electric vehicles is reported (Jyotheeswara Reddy and Natarajan,2018). Multiple Input Single Output boost converter is designed and their working modes, small signal modelling analysis is carried out. A prototype circuit is developed, and justified with simulation (Mudadla Dhananjaya,2019).

Proposed a converter which offers less components, compact structure and improved efficiency in contrast to existing converters followed by state space analysis along with simulation and experimental result (Kumaravel et al.,2018).A two input, two output DC-DC converter used to integrate different energy sources to provide a power to electric vehicle is verified with prototype (Kumaravel et al.,2019).Dual Input DC/DC converter and their architecture, conduction states of converter and its implementation in both software and hardware were presented (Kumar and Jain, 2012).

Simulation Vs experimental results comparison for three in-put DC-DC converter is carried out to check the performance and efficiency of the converter under different loading condition (Athikkal,2020).A novel topology is developed to overcome the demerits of huge size, complexity in design and increased cost in traditional converter with single source supply (Sathishkumar et al.,2017).Two different configuration of dual input single-output DC-DC converters are presented and a prototype of the converters is developed and it is correlated with simulation results(Athikkal et al., and Sankar,2018).Dual input DC-DC converter with slighter modification in arrangement is preferred, Software simulation is conducted and results are elaborated in detail. A standard prototype is built to match with the computer model (Athikkal et al., and Sankar,2017). A SEPIC configuration with dual input DC-DC converter topology is simulated and a hardware model is developed to check the converter capability (Yasin et al., and Peter,2019).

The proposed topology offers good accuracy, simple in control and durable in voltage source selection. An extensive comparison of the converter with current literature is presented and it simulated in MATLAB/ SIMULINK, further verified with digital controller (Thakur and Patel,2019). This study is carried to provide an investigation on multi-input DC-DC converters for electric vehicle systems (Affam et al.,2021). Different DC-DC converter topologies for electric vehicles is presented, analysed and compared in detail (Chakraborty et al.,2019). A dual input super boost DC-DC converter for electric vehicle application is designed and validated with simulation and hardware results (Kumar et al.,2019).

A step-up multi-input DC-DC converter, multi-input multi-output DC-DC boost converter and dual active bridge DC-DC converter for electric vehicle application is designed and verified with experimental results (Ahrabi et al.,2017)-(Karthikeyan and Gupta,2018).

A fast voltage loop's stability analysis and design of DC-DC converters based on the Popov criterion is discussed in detail. It interconnects the nonlinear system with linear system (Petru Dobra et al.,2007).

Type controllers were designed and implemented based on k-factor approach, and an optimization technique is used to improve the stability and performance of a closed loop DC-DC Switched Mode Boost Converter. The closed loop control system has been implemented on the dSPACE platform in real time and the performance of the converter is compared with conventional and optimised Type II/Type III controllers (Arnab Ghosh and Subrata Banerjee,2015).

A step-by-step procedure is followed to create a state feedback controller for an DC-DC buck converter circuit in order to track the output-voltage (Omer Saleem Bhatti, et al.,2018). The buck converters output voltage is regulated using Proportional-Integral-Derivative controller along with a Linear- Quadratic - Regulator (Omer Saleem Bhatti, et al.,2019).

Sliding Mode Controller is used for power factor correction in Bridgeless Interleaved Boost Converter is proposed (Subashini et al.,2019). Adaptive neuro-fuzzy inference system controller based on high Gain DC-DC converter is designed and developed for energy harvesting application (Marikkannan et al.,2019). The voltage source converter is controlled by using a super-twisting sliding mode predictive current control. The energy required for a micro-grid is supplied by using the battery, PV and wind energy (Ridha Benadli,2019).

Hybrid power system is controlled by using an Integral sliding mode controller and PI controller (Masoud Bahmanpour et al.,2019). A PI controller is used to control the quadratic boost converter with an energy source as battery and solar panel (Dhanaraj Amudhavalli.,2020). Chaos and Bifurcation analysis is carried out in Continuous input and output power boost converter using Average Current Mode (ACM) controller and General Pulse Width Modulation (GPWM) controller (Maheswari Ellappan et al.,2020).

## 2. GENERAL BLOCK DIAGRAM OF DUAL SOURCE DC-DC CONVERTER

A general form of two input DC/DC Converter is conceptually represented in Fig. 1.

The sources will provide energy depending upon the load demand. The power is transferred from one end to another end through DC-DC converter. By proper tuning of duty cycle, the converter will buck and boost the voltage level.

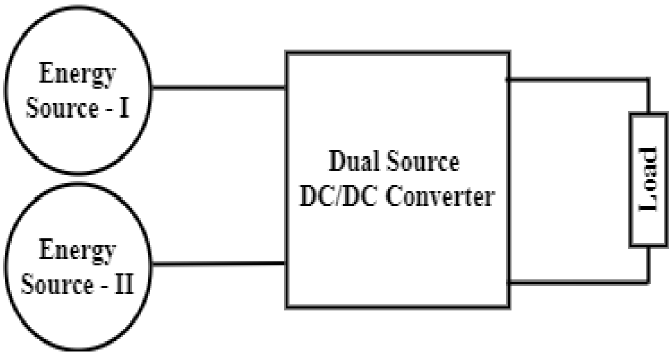


Fig. 1. Block diagram of dual source DC-DC converter

## 3. TOPOLOGICAL COMPARISON OF DIFFERENT DUAL INPUT CONVERTER

### *3.1. Multiple input non isolated DC/DC converter (Topology-I):*

Architecture of two input DC/DC converter is shown in Fig.2.

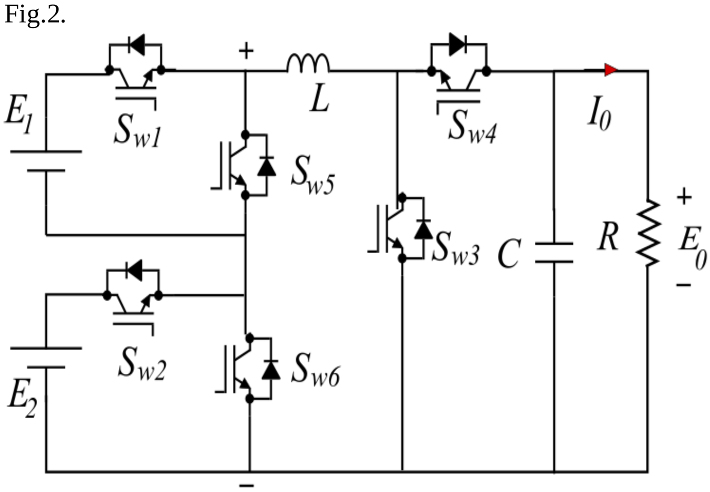


Fig. 2. Multiple input non-isolated DC-DC converter

The pulsating voltage source are represented with the $E_1$ and $E_2$, $S_{W1}$, $S_{W2}$, $S_{W3}$, $S_{W4}$, $S_{W5}$, $S_{W6}$ switches, followed by $D_1$, $D_2$, $D_3$, $D_4$, $D_5$ and $D_6$ diodes. The switch $S_{W1}$ and $S_{W2}$ determine the conduction and supply sources while the switches $S_{w3}$ decides the converter mode under buck, boost. $S_{W4}$, $S_{W5}$ and $S_{W6}$ decides the bidirectional mode [1].

Fundamental waveform of voltage and current through the inductor during various working state of the converter over one revolution (unidirectional mode) is shown in Fig.3. Converters waveform under bidirectional mode is given in Fig.4.

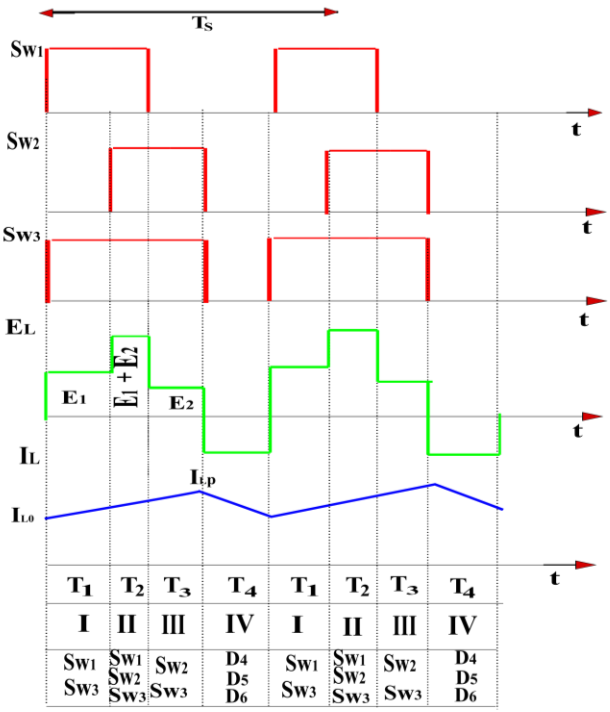


Fig. 3. Operating waveform - Source to Load (CCM)

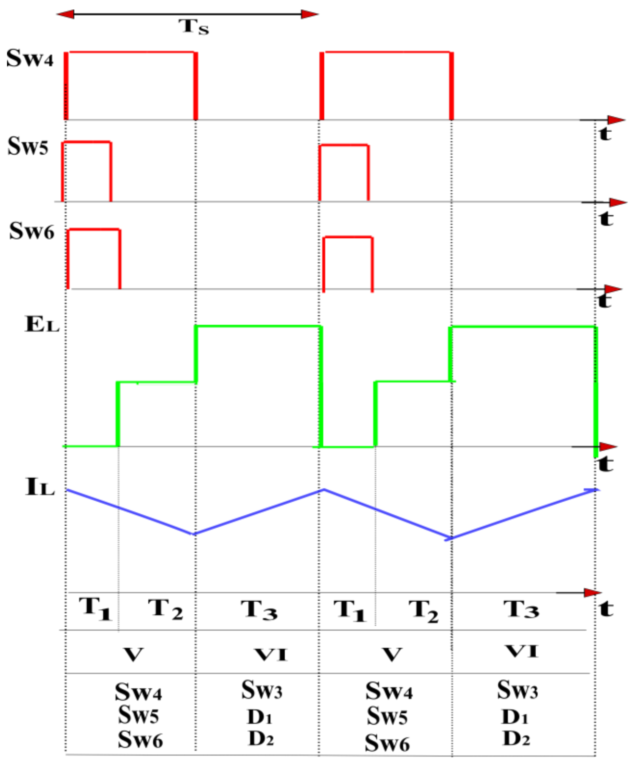


Fig. 4. Operating waveform - Load to Source (CCM)

Operating modes of multiple input non isolated DC/DC converter and their analytical waveforms as shown in Table 1.

Table 1. Various working modes of the converter

| Working modes (Unidirectional) | Supplying Source | ON state switch | Inductor voltage | Inductor status |
|---|---|---|---|---|
| Working mode-I | $E_1$ | $S_{W1}$, $S_{W3}$ | $E_1 - E_0$ | charging |
| Working mode-II | $E_1$+$E_2$ | $S_{W1}$, $S_{W2}$, $S_{W3}$ | $E_1$+$E_2$-$E_0$ | charging |
| Working mode-III | $E_2$ | $S_{W2}$, $S_{W3}$ | $E_2$-$E_0$ | charging |
| Working mode-IV | None | $D_4$, $D_5$, $D_6$ | -$E_0$ | discharging |
| **Working modes (Bidirectional)** | **Receiving Source** | **ON state switch** | **Inductor voltage** | **Inductor status** |
| Working mode-V | -$E_O$ | $S_{W4}$, $S_{W5}$, $S_{W6}$ | -$E_O$ | charging |
| Working mode-VI | $E_1$+$E_2$ | $S_{W3}$, $D_1$, $D_2$ | $E_1$+$E_2$ | discharging |

Simulation parameters considered for multiple input non isolated DC/DC converter are discussed in Table 2.

Table 2. Simulation parameter

| S. No | Parameters | Specification in Boost Mode | Specification in Buck Mode |
|---|---|---|---|
| 1 | Input Source voltage-($E_1$) | 24 V | |
| 2 | Input Source voltage-($E_2$) | 12 V | |
| 3 | Duty ratio($d_1$) | 60% | 40% |
| 4 | Duty ratio($d_3$) | 60% | 0% |
| 5 | Duty ratio($d_2$) | 60% | 40% |
| 6 | Inductor(L) | 14.4mH | |
| 7 | Capacitor(C) | 216µF | |
| 8 | Switching Frequency ($F_S$) | 10kHz | |
| 9 | load resistance(R) | 10Ω | |
| 10 | Output voltage ($E_O$) | 53.3 V | 13.7 V |

Output equation of buck mode converter is

$$E_o = E_1 d_1 + E_2 d_2 \tag{1}$$

Output equation of boost mode converter is

$$E_o = \frac{E_1 d_1 + E_2 d_2}{(1 - d_3)} \tag{2}$$

*3.2. Improved Bridge Type Dual Input DC-DC (IBDC) Converter (Topology-II):*

The converter consists of six switches ($S_{W1}$, $S_{W2}$, $S_{W3}$, $S_{W4}$, $S_{W5}$, $S_{W6}$) and their corresponding six diodes ($D_1$, $D_2$, $D_3$, $D_4$, $D_5$ and $D_6$) along with bidirectional capabilities as shown in Fig.5. The power will be delivered to the load from individual energy sources/simultaneous energy sources. And it has compact structure with good efficiency in loading condition [2-3].

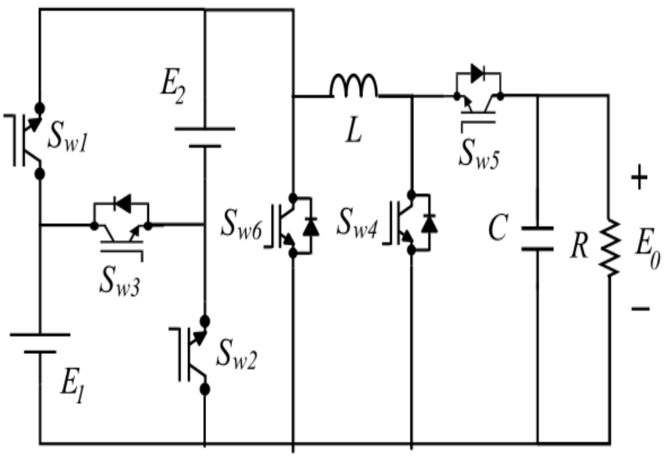


Fig. 5. Improved bridge type dual input DC-DC converter

Steady state waveforms of a converter under unidirectional state over a one cycle is shown in Fig.6. Switching signal of switches, inductor voltage and current waveform under bidirectional state is shown in Fig.7.

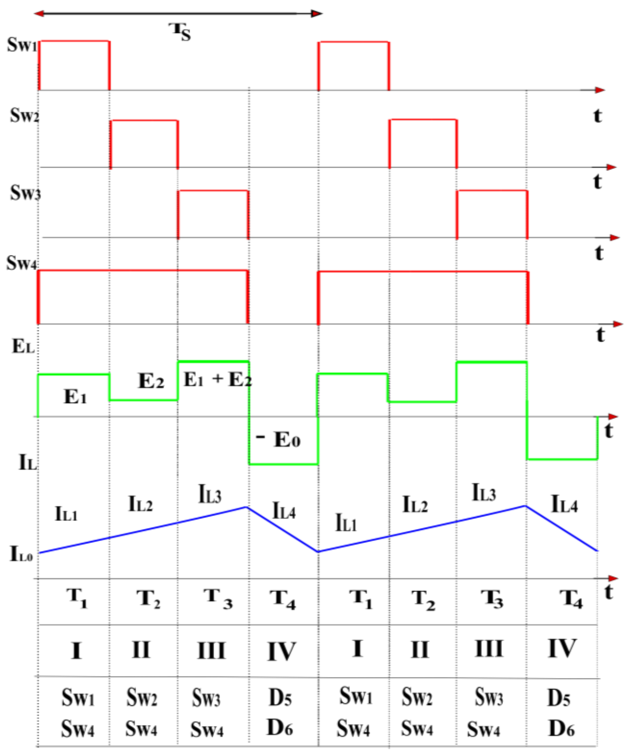


Fig. 6. Typical waveform- Source to load (CCM)

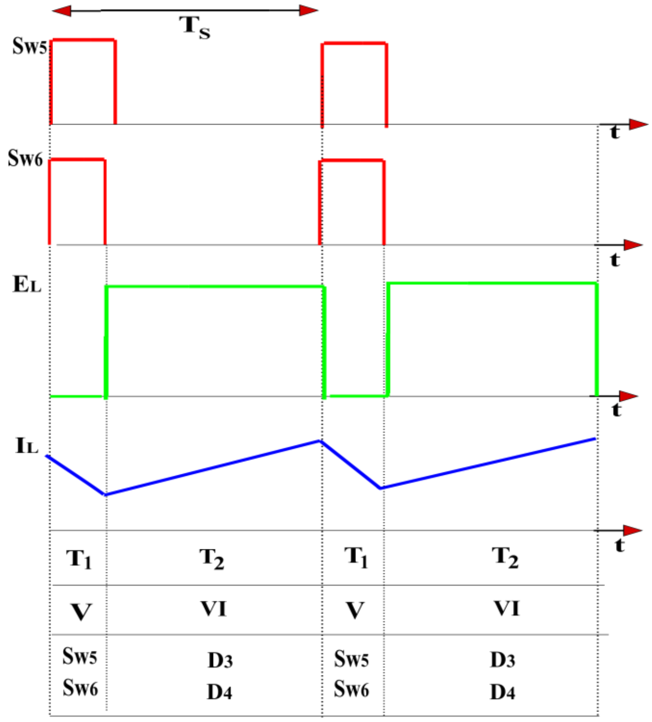


Fig. 7. Typical waveform- Load to Source (CCM)

Possible operating modes of improved bridge type dual input DC-DC (IBDC) converter as shown in Table 3.

Table 3. Different working modes of the converter

| Working modes (Unidirectional) | Supplying Source | ON state switch | Inductor voltage | Inductor status |
|---|---|---|---|---|
| Working mode-I | $E_1$ | $S_{W1}$, $S_{W4}$ | $E_1 - E_0$ | charging |
| Working mode-II | $E_2$ | $S_{W2}$, $S_{W4}$ | $E_2$-$E_0$ | charging |
| Working mode-III | $E_1$+$E_2$ | $S_{W3}$, $S_{W4}$ | $E_1$+$E_2$-$E_0$ | charging |
| Working mode-IV | None | $D_5$, $D_6$ | -$E_0$ | discharging |
| **Working modes (Bidirectional)** | **Receiving Source** | **ON state switch** | **Inductor voltage** | **Inductor status** |
| Working mode-V | -$E_O$ | $S_{W5}$, $S_{W6}$ | -$E_O$ | charging |
| Working mode-VI | $E_1$+$E_2$ | $D_3$, $D_4$ | $E_1$+$E_2$ | discharging |

After the various working modes of the converter, followed by the parameters considered for the simulation of improved bridge type dual input DC-DC (IBDC) converter as shown in Table 4

Table 4. Simulation parameter

| S. No | Parameters | Specification in Boost Mode | Specification in Buck Mode |
|---|---|---|---|
| 1 | Input Source voltage-($E_1$) | 50 V | |
| 2 | Input Source voltage-($E_2$) | 30 V | |
| 3 | Duty ratio($d_1$) | - | 15% |
| 4 | Duty ratio($d_3$) | Continuous on | 10% |
| 5 | Duty ratio($d_2$) | - | 15% |
| 6 | Duty ratio($d_4$) | 20% | - |
| 7 | Inductor(L) | 7mH | |
| 8 | Capacitor(C) | 470µF | |
| 9 | Switching Frequency ($F_S$) | 20kHz | |
| 10 | load resistance(R) | 10Ω | |
| 11 | Output voltage ($E_O$) | 100 V | 20 V |

Output equation of buck mode converter is

$$E_o = E_1 d_1 + E_2 d_2 + (E_1 + E_2) d_3 \tag{3}$$

Output equation of boost mode converter is

$$E_o = \frac{(E_1 + E_2)}{(1 - d_4)} \tag{4}$$

*3.3. Enhanced dual source DC-DC converter (Topology- III):*

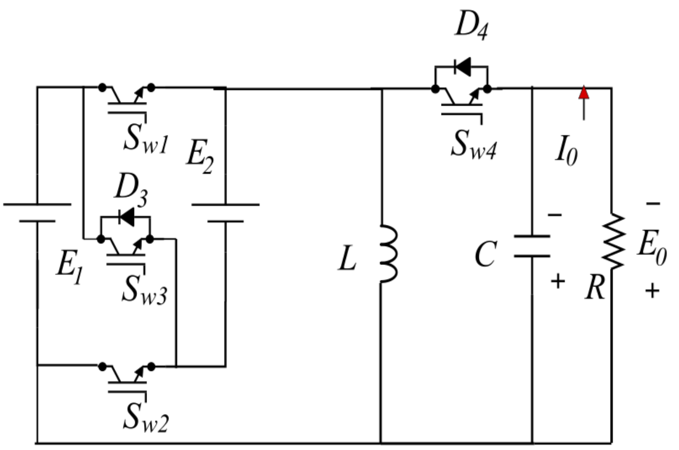


Fig. 8. Enhanced dual source DC/DC converter

The switches are operated in appropriate manner in order to send power as well as receive power as shown in Fig.8.Here, the common inductor shares the sources. Anyone of the switches $S_{W1}$ / $S_{W2}$ / $S_{W3}$ / diode $D_4$ will conduct at a time. By altering the duty cycle of semiconductor switches $S_{W1}$, $S_{W2}$, $S_{W3}$ and $S_{W4}$ the power continues to flow from / to source is controlled. The Dual source DC/DC converter is operated in (Modes 1- 4) under unidirectional mode. Similarly, it operates in two more modes (Modes 5 and 6) under bidirectional mode.

The waveforms of enhanced dual source DC-DC converter in stable condition under unidirectional mode are given in Fig.9.The waveforms of the converter under bi-directional mode over one cycle as shown in Fig.10.

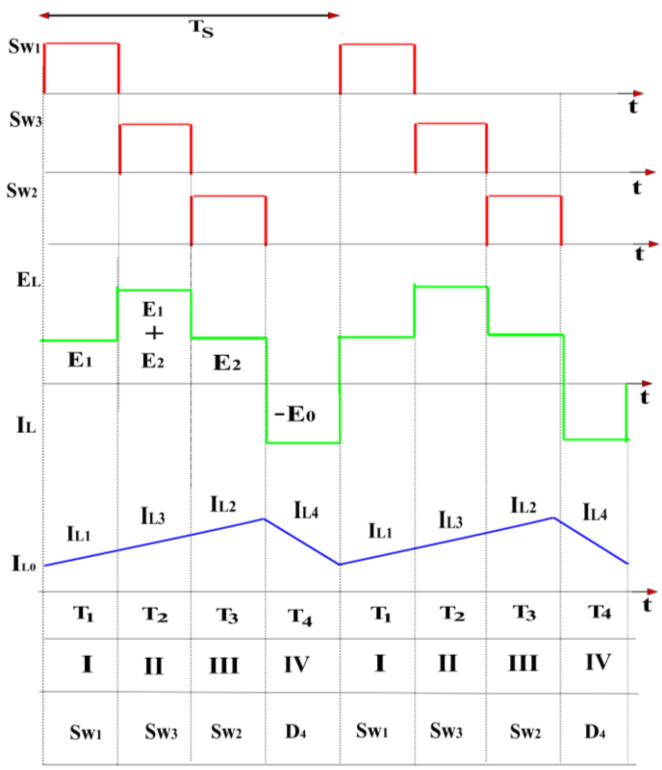


Fig. 9. Analytical waveform- Source to load (CCM)

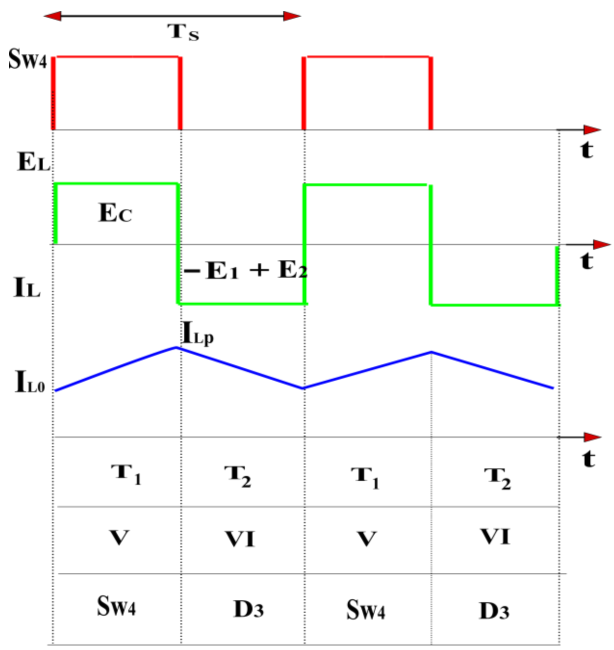


Fig. 10. Analytical waveform- Load to Source (CCM)

The unidirectional and bidirectional operating modes of enhanced dual source DC-DC converter as shown in Table 5. followed by the discussion about the simulation parameters.

Table 5. Different working modes of the converter

| Working modes (Unidirectional) | Supplying Source | ON state switch | Inductor voltage | Inductor status |
|---|---|---|---|---|
| Working mode-I | $E_1$ | $S_{W1}$ | $E_1 - E_0$ | charging |
| Working mode-II | $E_1$+$E_2$ | $S_{W3}$ | $E_1$+$E_2$-$E_0$ | charging |
| Working mode-III | $E_2$ | $S_{W2}$ | $E_2$-$E_0$ | charging |
| Working mode-IV | None | $D_4$ | -$E_O$ | discharging |
| **Working modes (Bidirectional)** | **Receiving Source** | **ON state switch** | **Inductor voltage** | **Inductor status** |
| Working mode-V | -$E_O$ | $S_{W4}$ | -$E_O$ | charging |
| Working mode-VI | $E_1$+$E_2$ | $D_3$ | $E_1$+$E_2$ | discharging |

Parameters considered for simulation of enhanced dual source DC-DC converter as shown in Table 6.

Table 6. Simulation parameter

| S. No | Parameters | Specification in Boost Mode | Specification in Buck Mode |
|---|---|---|---|
| 1 | Input Source voltage-($E_1$) | 48 V | |
| 2 | Input Source voltage-($E_2$) | 36 V | |
| 3 | Duty ratio($d_1$) | 20% | 15% |
| 4 | Duty ratio($d_3$) | 32.5% | 10% |
| 5 | Duty ratio($d_2$) | 20% | 15% |
| 6 | Inductor(L) | 6.5mH | |
| 7 | Capacitor(C) | 433µF | |
| 8 | Switching Frequency ($F_S$) | 10kHz | |
| 9 | load resistance(R) | 160Ω | |
| 10 | Output voltage ($E_O$) | -160 V | -35V |

Output equation of buck and boost mode converter is given by

$$E_o = -\left( \frac{E_1 d_1 + (E_1 + E_2) d_3 + E_2 d_2}{1 - (d_1 + d_2 + d_3)} \right) \quad (5)$$

## 4. SIMULATION RESULTS AND DISCUSSION

### *4.1. Simulation results of multiple input non isolated DC/DC converter (Topology-I)*

#### *4.1.1 Boost Mode:*

Input voltage and switching signals are given to switches $S_{W1}$, $S_{W2}$, $S_{W3}$ are represented in Table 2. followed by the initial voltage over the inductor is 12 V (viz. $E_1$ - $E_O$). Further, charged inductor has a voltage of ($E_1$ + $E_2$ - $E_O$), viz., 36 V and the voltage of inductor is discharged to 30 V ($E_O$) for the remaining duration is shown in Fig.11(a) and inductor current is charged to 13.18 A and discharged to 13.10 A as shown in Fig.11(b). The voltage across the resistor is of 52.06 V and output current is of 5.206 A and it is shown in Fig.11(c) and Fig.11(d).

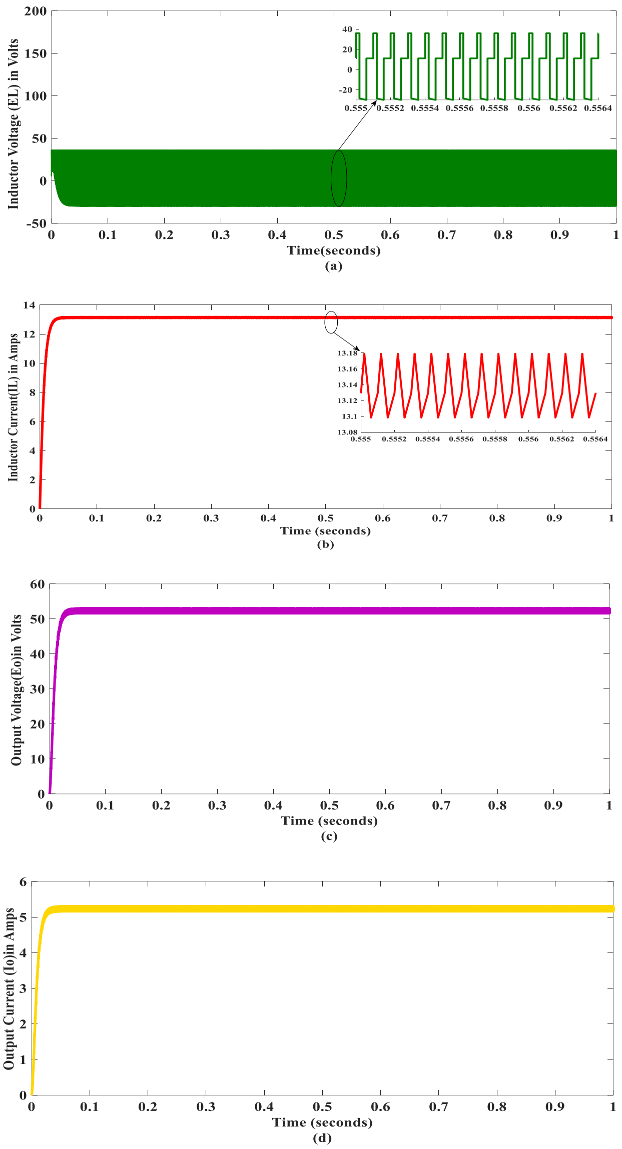


Fig.11. (a) Inductor voltage (b) Inductor current (c) Output voltage (d) Output current [$d_1$=0.6, $d_2$=0.6, $d_3$=0.6, $E_1$=24 V, $E_2$=12 V, $E_O$=52.06 V, $I_O$=5.206 A]

#### *4.1.2 Buck Mode:*

The input voltage and switching signals given to the switches $S_{W1}$, $S_{W2}$ is shown in Table 2. At time ($t_1$), inductor voltage is of 10 V (viz. $E_1$ - $E_O$). and for time ($t_2$), the inductor charges to a 22 V (viz. $E_1 + E_2$ - $E_O$), for time ($t_3$), inductor discharged to 2.5 V (viz. $E_1$ - $E_O$) while at time ($t_4$) further the inductor current is discharged to its initial position Fig.12(a) and inductor current is charged to 1.364 A and discharged to 1.32 A as shown in Fig. 12(b). By varying the dutycycles $d_1$ and $d_2$, the inductor current, load current and voltage at the output can be controlled. The output voltage is of 13.44 V and the output current is of 1.344 A as shown in Fig.12(c) and Fig.12(d).

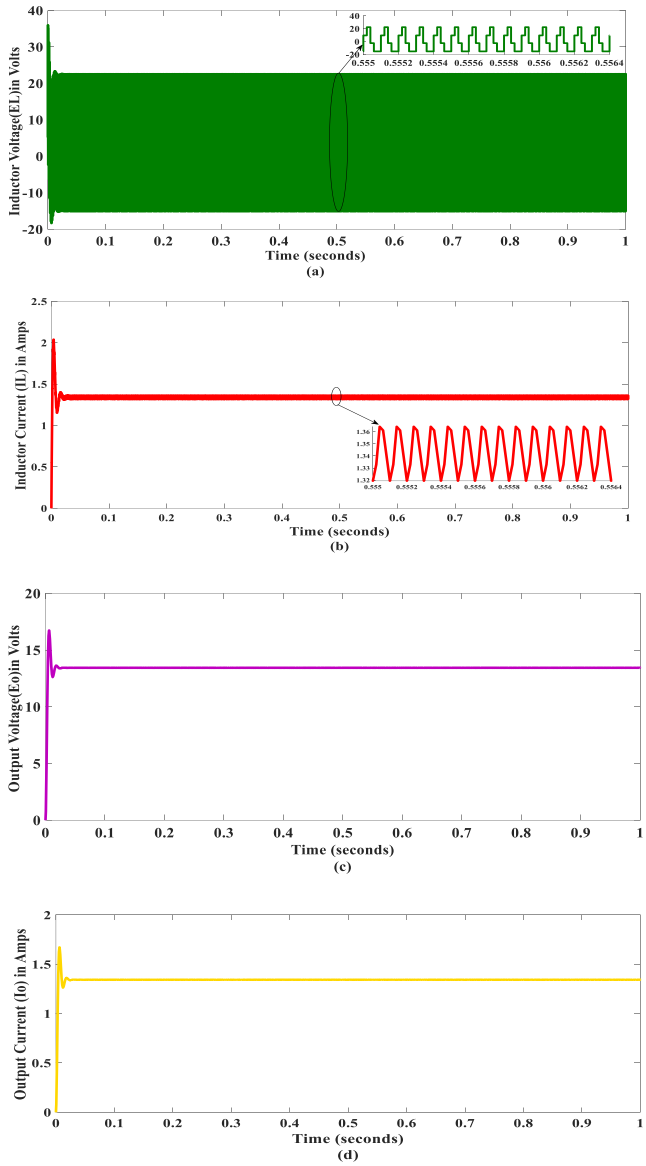


Fig.12.(a) Inductor voltage (b) Inductor current (c) Output voltage (d) Output current [$d_1$=0.4, $d_2$=0.4, $E_1$=24 V, $E_2$=12 V, $E_O$=13.44 V, $I_O$=1.344 A]

*4.1.3 Bidirectional Mode:*

The bidirectional operation of the converter is also justified, by considering an input voltage of $E_{in}$ =30 V. The switching signals are given to switches $S_{W4}$, $S_{W5}$, $S_{W6}$ with duty ratio $d_4$= 52% $d_5$=20% $d_6$=20% respectively. An inductor is charged to voltage of 20 V, initially it is discharged to -10 V and finally it is discharged to -30 V is shown in Fig.13(a) and an inductor current is charged to -2.15 A and discharged to -2.21 A as shown in Fig.13(b). The output voltage yielded by a converter is 19.14 V ($E_{O1}$+$E_{O2}$) as shown in Fig.13(c) and output current is 4.29 A is shown in Fig.13(d) as the converter works as single input multiple output converter.

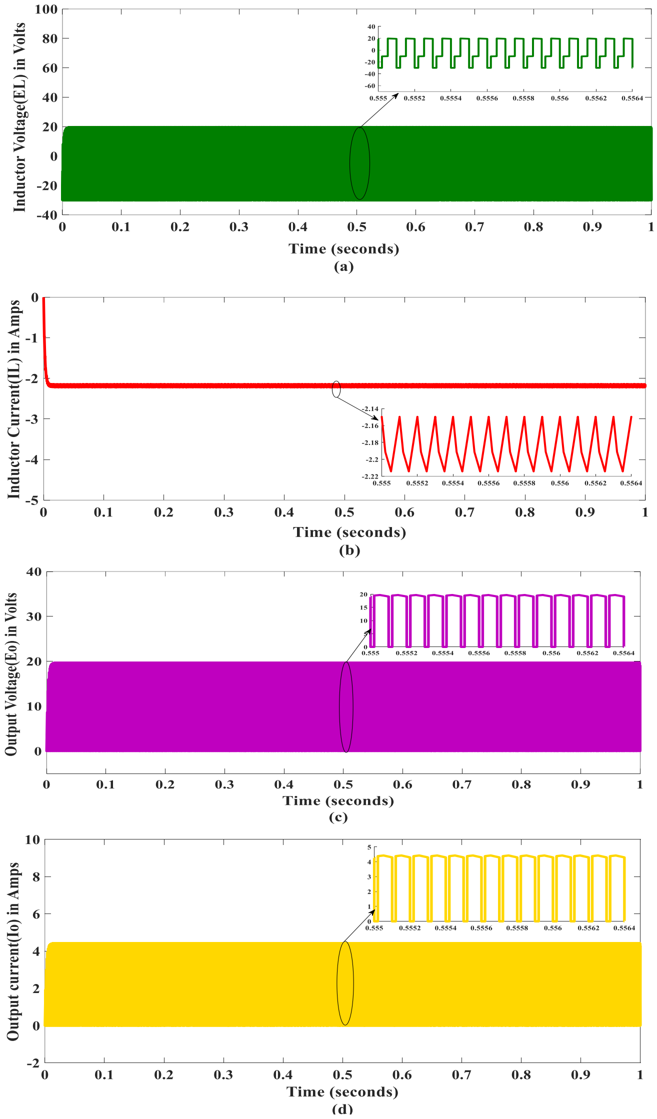


Fig.13.(a) Inductor voltage (b) Inductor current (c) Output voltage (d) Output current [$d_4$=0.52, $d_5$=0.2, $d_6$=0.2, $E_{in}$=30 V, $E_L$=19.13V, $I_L$=-2.15A, $E_{O1}$=10.75V, $E_{O2}$=8.38V, $E_{O1}$+$E_{O2}$=$E_O$ =19.14 V, $I_O$=4.29A]

*4.2. Simulation results of Improved Bridge type DC/DC converter (Topology-II)*

*4.2.1 Boost Mode:*

Input voltage and switching signal $S_{W3}$ and $S_{W4}$ is given to the converter as shown in Table 4. For simple operation consider series connection switch $S_{W3}$ between $E_1$ and $E_2$ and it is turned ON permanently, While $S_{W1}$ and $S_{W2}$ are turned off and $S_{W3}$ charges the inductor by two inputs together with a voltage of 80 V (viz., $E_1$ + $E_2$) is shown in Fig.14(a). Inductor current is charged to 12.54 A and discharged to 12.42 A as shown in Fig.14(b). Finally, the inductor is discharged to a voltage is -

20 V (viz., $E_1 + E_2 - E_O$). As shown in Fig.14(c) and Fig.14(d), the output voltage and output current across the resistor is 99.97 V and 9.997 A.

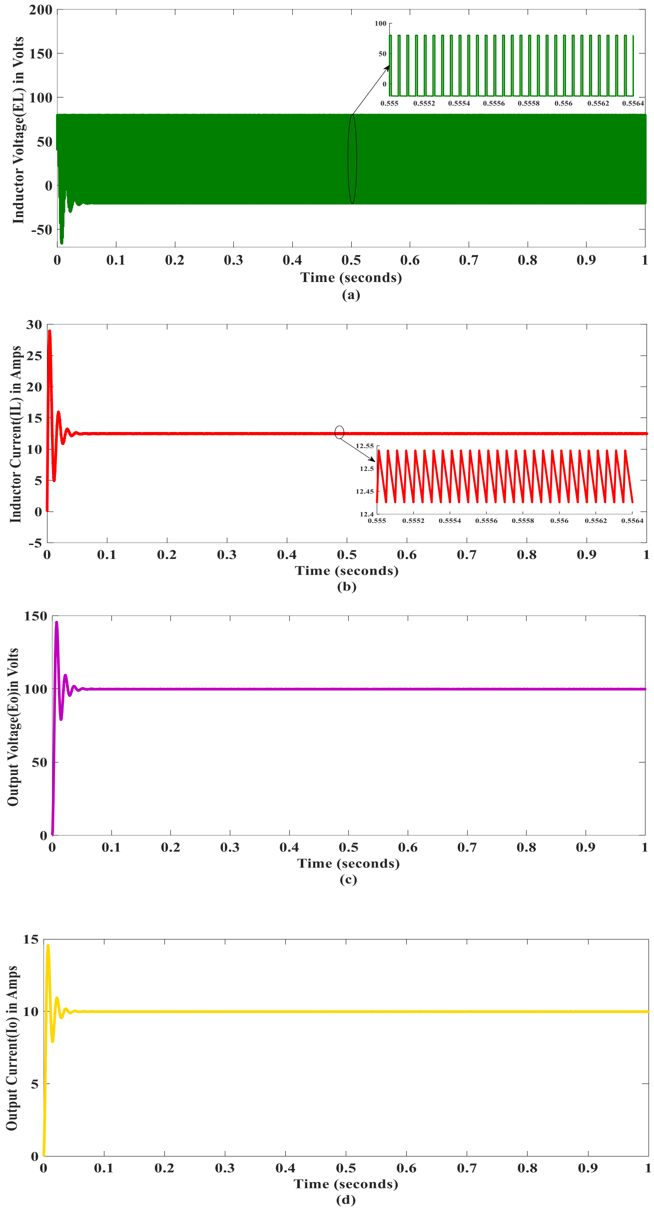


Fig.14. (a) Inductor voltage (b) Inductor current (c) Output voltage (d) Output current [$d_3$=Continuous 'on', $d_4$=0.2, $E_1$=50 V, $E_2$=30 V, $E_O$=99.97 V, $I_O$=9.997 A]

*4.2.2 Buck Mode:*

Input voltage and switching signal $S_{W1}$, $S_{W2}$, $S_{W3}$ is given to the converter as shown in Table 4. The inductor charges to 30 V (viz., $E_1$-$E_O$) for $d_1$ duty ratio, 10 V (viz., $E_2$-$E_O$) for $d_2$ duty ratio and 60 V (viz., $E_1 + E_2 - E_O$) for duty ratio $d_3$, at last, the inductor is discharging to a voltage of -19.54 V (viz., -$E_O$) is shown in Fig.15(a) and inductor current is charged to 1.99 A and discharged to 1.91 A for the remaining period as shown in Fig.15(b). The output voltage and output current are settled down to a value of 19.54 V and 1.91 A as shown in Fig.15(c) and 15 (d).

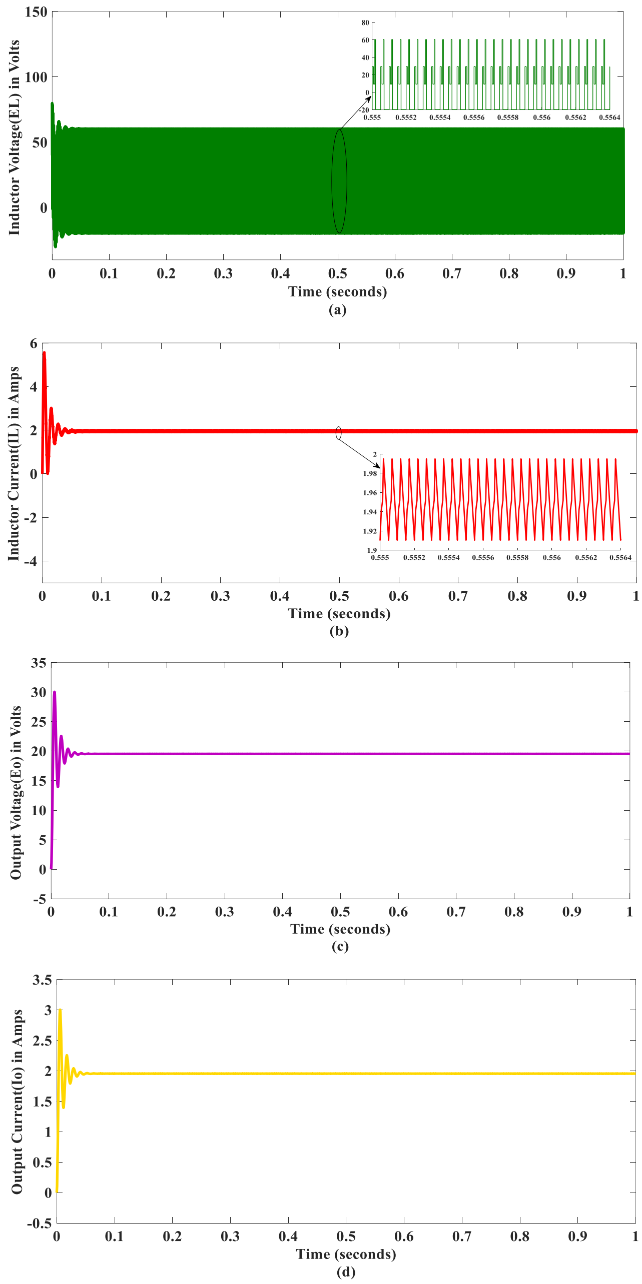


Fig.15.(a) Inductor voltage (b) Inductor current (c) Output voltage (d) Output current [$d_1$=0.15, $d_2$=0.15, $d_3$=0.1, $E_1$=50 V, $E_2$=30 V, $E_O$=19.54 V, $I_O$=1.91 A]

*4.2.3 Bidirectional Mode (Buck Mode):*

The bidirectional operation is verified with an input voltage of $E_{in}$ = 30 V. Switching signals are given to switches $S_{W5}$, $S_{W6}$ with duty ratio $d_5$= 20% and $d_6$= 20% The inductor charges to a 7.4 V and finally it is discharged to -30 V is shown in Fig.16(a) and inductor current is charged to -14.92 A and discharged to -14.96 A as shown in Fig.16(b). The converter gives an output voltage of 14.92 V ($E_{O1}$+$E_{O2}$) is shown in Fig.16(c) and output currentof 14.9 A is shown in Fig.16(d).

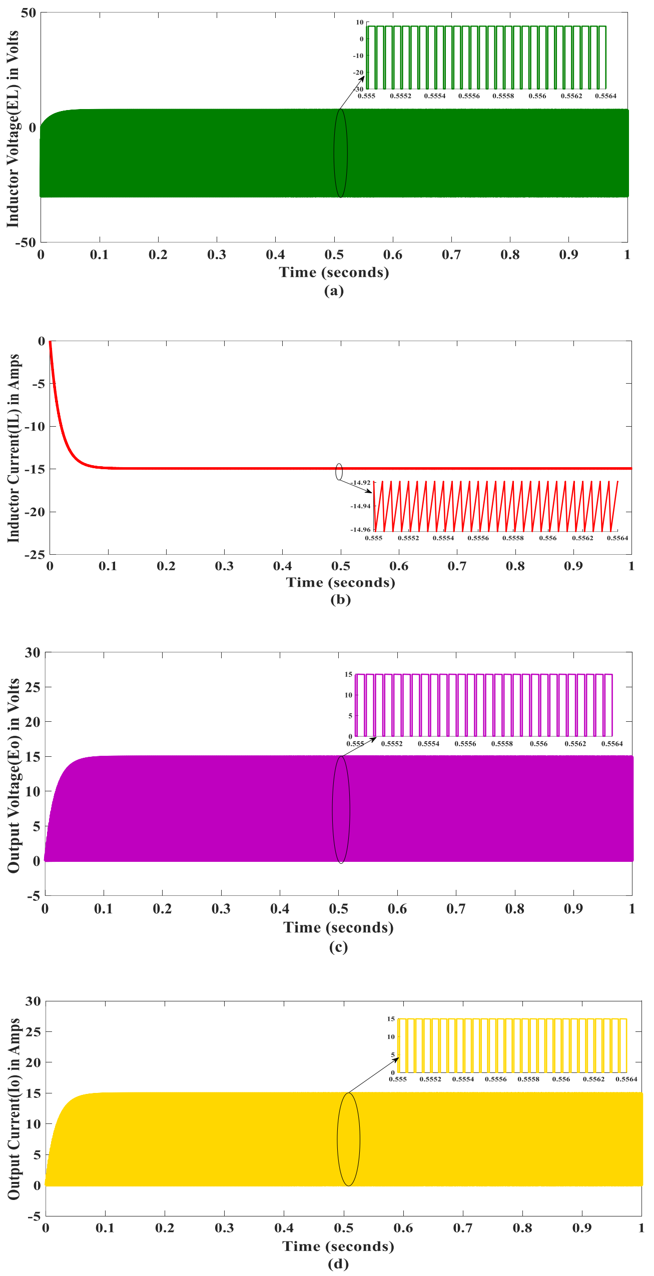


Fig.16. (a) Inductor voltage (b) Inductor current (c) Output voltage (d) Output current [$d_5$= 0.2, $d_6$=0.2, $E_{in}$=30 V, $E_L$=7.482 V, $I_L$=-14.92 A, $E_{O1}$=7.459 V, $E_{O2}$=7.459 V, $E_{O1}+E_{O2}$= $E_O$=14.92 V, $I_O$=14.9 A]

### *4.3. Simulation results of Enhanced Dual Source DC/DC converter (Topology-III)*

#### *4.3.1 Boost Mode:*

In boost mode input voltage and switching signal $S_{W1}$, $S_{W2}$, $S_{W3}$ is given to the converter as shown in Table 6. For $d_1$ the voltage over the inductor is 48 V (viz., $E_1$ - $E_O$), and the inductor charges to a voltage of ($E_1$ + $E_2$ - $E_O$), viz., 84 V for $d_3$. Further inductor discharges to a 36 V (viz., $E_2$ -$E_O$) for $d_2$ and it is finally discharged to a (-$E_O$) i.e., - 159 V, for the remaining time period is shown in Fig.17(a) and an inductor current is charged to 4.57 A and discharged to 3.9 A as shown in Fig.17(b). The output voltage is of - 159 V and output current is of - 0.9937 A is shown in Fig.17(c) and Fig.17(d).

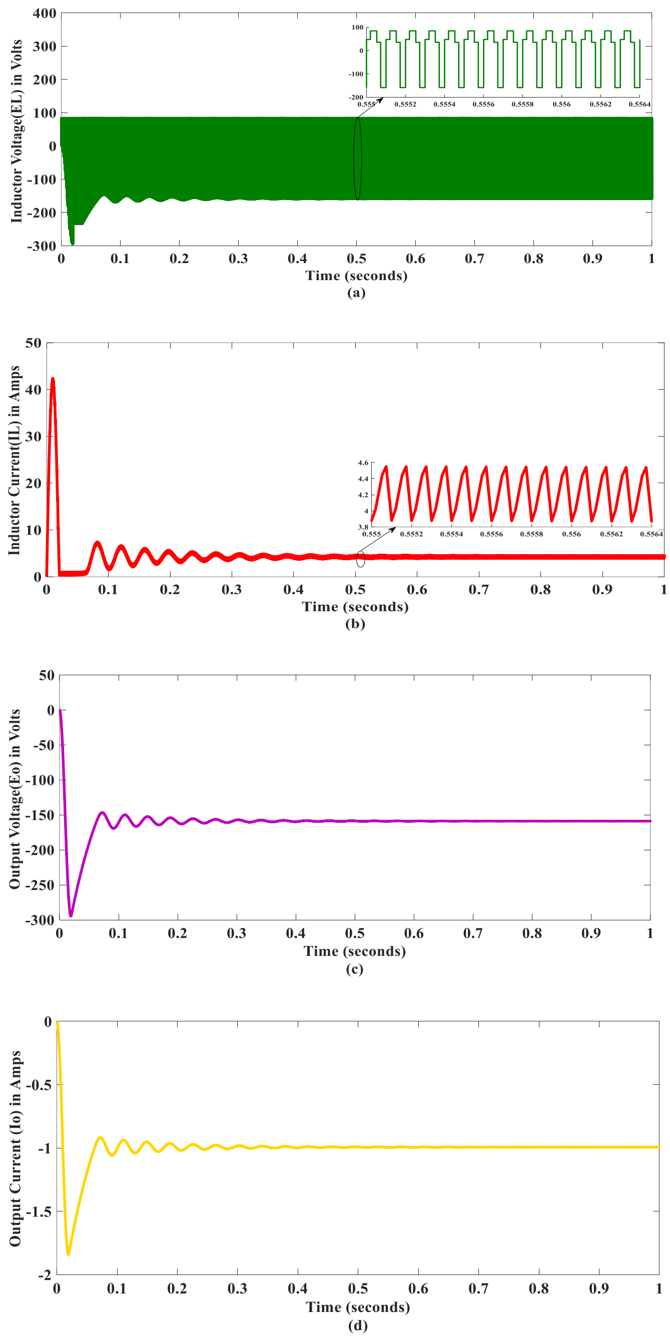


Fig.17.(a) Inductor voltage (b) Inductor current (c) Output voltage (d) Output current [d1=0.2, d2=0.2, d3=0.325, E1=48 V, E2=36 V, EO= -159 V, IO=-0.9937 A]

#### *4.3.2 Buck Mode:*

Input voltage and switching signal $S_{W1}$, $S_{W2}$, $S_{W3}$ is given to the converter as shown in Table 6. It is obvious that the inductor is charged to a 48 V (i.e., $E_1$-$E_O$) for $d_1$, 36 V (i.e., $E_2$-$E_O$) for $d_2$ and 84 V (i.e., $E_1$ + $E_2$ - $E_O$) for $d_3$. Finally, the inductor is discharged to a -34.52 V (i.e., - $E_O$) for the rest of the period is shown in Fig.18(a) and an inductor current is charged to 0.64 A and discharged to 0.33 A as shown in Fig.18(b). The output voltage and output current waveform reaches to a steady state value of -34.52 V and -0.2157 A is shown in Fig.18(c) and 18(d).

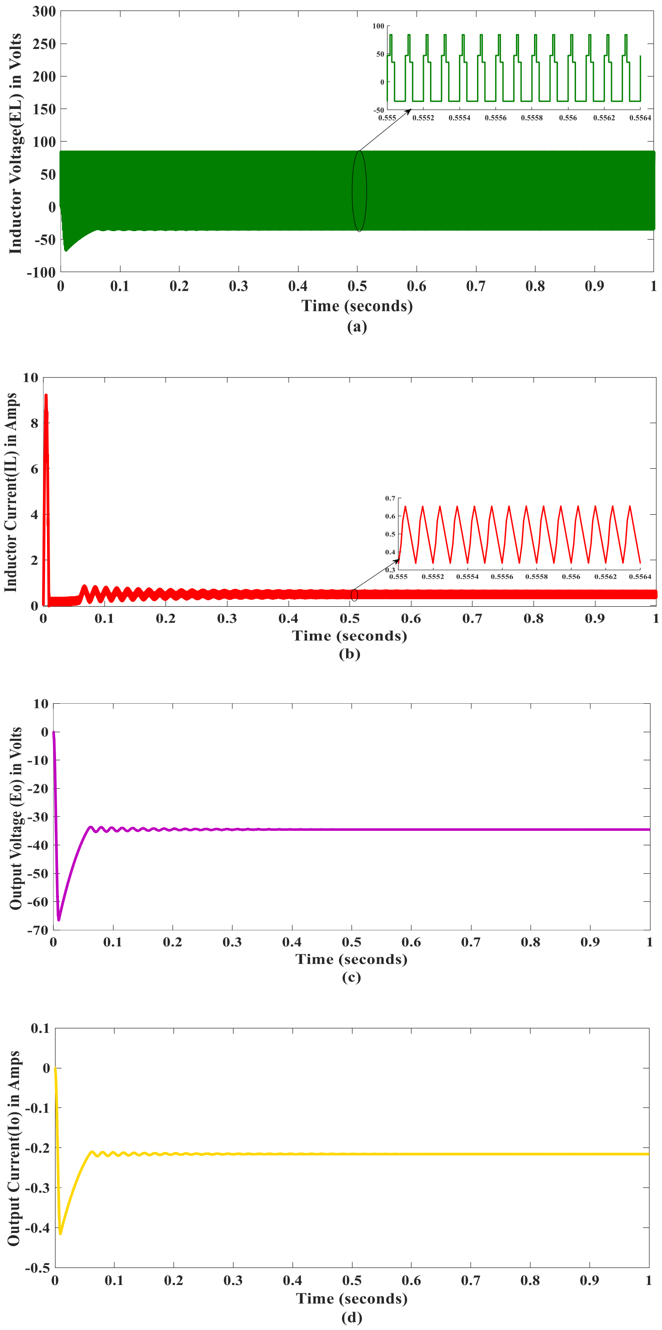


Fig.18. (a) Inductor voltage (b) Inductor current (c) Output voltage (d) Output current [$d_1$=0.15, $d_2$=0.15, $d_3$=0.1, $E_1$=48 V, $E_2$=36 V, $E_O$=-34.52 V, $I_O$=-0.2157 A]

*4.3.3 Bidirectional Mode:*

The bidirectional working of the converter is considered with an input voltage of $E_{in}$ =-160 V. Switching signals are given to switches $S_{W4}$ with duty ratio $d_4$=34%. The inductor charges to 81.65 V and finally it is discharged to -160 V is shown in Fig.19(a). Inductor current is charged to -41.7 A and discharged to -40.92 A as shown in Fig.19(b). The output voltage of 81.65 V is produced by the converter such as ($E_{O1}$+$E_{O2}$) is shown in Fig.19(c) and output current of 81.61 A is shown in Fig.19(d).

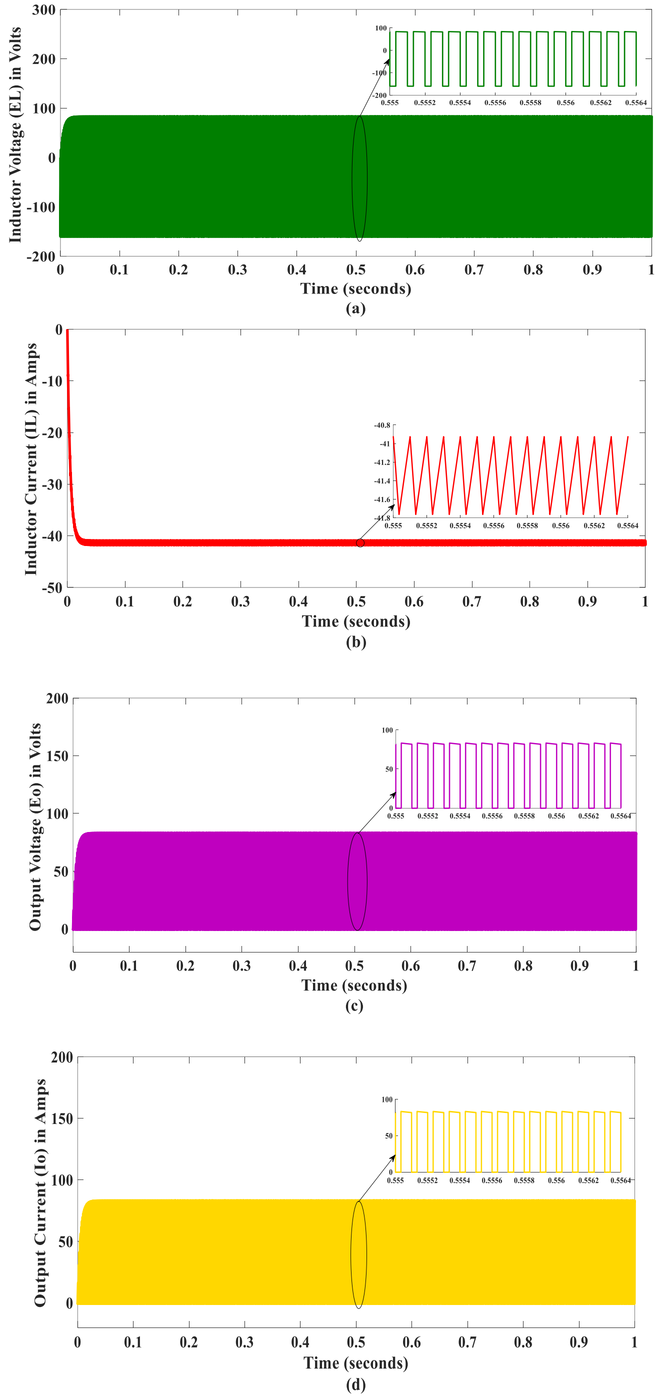


Fig.19. (a) Inductor voltage (b) Inductor current (c) Output voltage (d) Output current [$d_4$= 0.34, $E_{in}$= -160 V, $E_L$=81.65 V, $I_L$=-40.93 A, $E_{O1}$=40.8 V, $E_{O2}$=40.8 V, $E_{O1}$+$E_{O2}$= $E_O$=81.65 V12, $I_O$=81.61 A]

## 4. PERFORMANCE COMPARISON OF DIFFERENT TOPOLOGIES

The topographical comparison of dual input dc-dc converter in terms of efficiency, output voltage, average output power is discussed in detail below

Table 7. Performance comparison

| Parameter | Multi input non isolated DC-DC converter | Improved bridge type dual input DC-DC converter | Enhanced dual source DC-DC converter |
|---|---|---|---|
| Inductor | 1 | 1 | 1 |
| Capacitor | 1 | 1 | 1 |
| IGBT'S | 6 | 6 | 4 |
| %Efficiency | 82-91% | 84-93% | 84-96% |

It is inferred that enhanced dual source DC-DC converter gives a better efficiency with reduced no of switches compared with other topologies as discussed in Table 7.

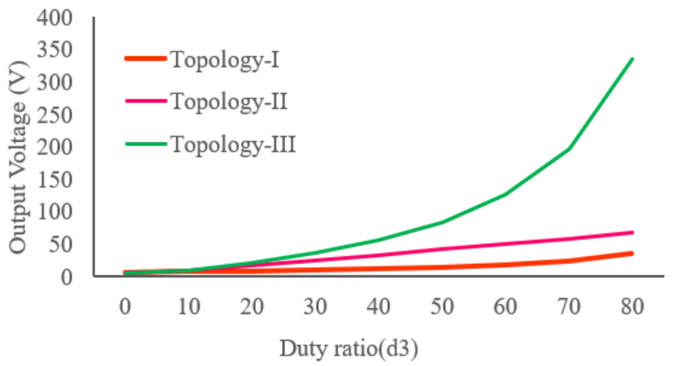


Fig.20. Output voltage Vs Duty ratio ($d_3$)

The output voltage is compared with duty ratio as shown in Fig.20. To calculate an output voltage, consider a $E_1$=48 V, $E_2$=36 V, R=160 Ω, $d_1$ = 10% $d_2$ = 10% and $d_3$ is varied from 0% to 80%. The comparison proves that the Topology III provides a high output voltage than Topology-I and Topology-II this is due to a switch $S_{W3}$ which operate the both input sources $E_1$ and $E_2$.

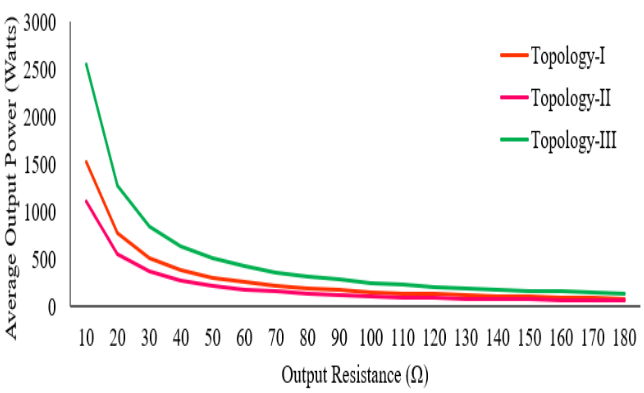


Fig.21. Output resistance Vs Average output power

The voltages of three different topologies are scaled down to $E_1$=48 V, $E_2$=36 V, and duty ratio for boost mode is taken for simulation from the simulation result topology-III produces more average output power for change in load resistance as shown in Fig.21.

## 4. CONCLUSION

A various type of non isolated DC–DC converter to incorporate different sources such as, battery, wind, supercapacitor, solar and fuel cell etc. are reported. A multi input non isolated DC/DC converter, An Improved bridge type dual input Dc-DC converter and an enhanced dual source DC-DC converter with their mode of operation, steady state waveform for both unidirectional/bidirectional mode, design parameters and output equation of different modes are elaborated.

Later, the simulation results of buck, boost and bidirectional modes for three different topologies of the converter are presented in sequential order.

Finally, a performance comparison table is presented for different converter topologies based on component count, efficiency, output voltage vs duty ratio and average output power vs output resistance. From the above results, the topology-I has a voltage gain of 34.82 V with an efficiency of 91% and the average output power produced by the converter is 1.5kW. The topology-II converter has a voltage gain of 67.08 V with an efficiency of 93% and the average output power is 1.1kW. The topology-III, produces a voltage gain of 336 V with an efficiency of 96%, Further the converter's average output power is 2.5 kW. It is concluded that the enhanced dual source dc-dc converter can operate in bidirectional mode with improved efficiency, and it gives high average output power, wide control range for output voltage along with reduced no of switches. Hence, it is suitable for applications including electric vehicle and renewable energy sources.

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